BULLETIN NO. 37 1947

STATE OF ILLINOIS

DWIGHT H. GREEN, *Governor*

THE CAUSES AND EFFECTS OF SEDIMENTATION IN LAKE DECATUR

CARL B. BROWN, J. B. STALL AND E. E. DETURK

ILLINOIS STATE WATER SURVEY, SOIL CONSERVATION SERVICE, UNITED STATES DEPARTMENT OF AGRICULTURE, AND ILLINOIS AGRICULTURAL EXPERIMENT STATION, COOPERATING

DEPARTMENT OF REGISTRATION AND EDUCATION

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SUMMARY

1. Lake Decatur, municipal water-supply reservoir of Decatur, Illinois, is located on the Sangamon River at the edge of the city. It has a drainage area of 906 square miles. When built in 1922, the reservoir had a surface area of 2,805 acres and a storage capacity of 19,738 acre-feet.

2. A sedimentation survey made in 1936 showed a capacity loss of 1.0 percent annually. A second survey made in 1946 showed a loss of 1.2 percent since 1936—a 20 percent increase. By 1946, the surface area of the lake had been reduced 201 acres and the capacity by 5,171 acre-feet, or 26.2 percent,

3. The consumption of lake water by the city and local industries has increased from an average of 340 million gallons per month in 1937 to an average of 428 million gallons per month in 1944. The future annual increase in the average monthly consumption is estimated to be at a rate of 8.7 million gallons.

4. In 36 years (1908-1945) there have been seven periods of six consecutive months in which the stream flow at Decatur has been less than the present or near-future demands on the lake (withdrawal for consumption plus estimated losses from evaporation and seepage). The lowest flow for six months, 3,573 acre-feet, which occurred in 1914-1915, is estimated to have a recurrence frequency of once in 35 years.

5. The increasing consumption and decreasing storage capacity of the lake will result in a water shortage by 1959 if a 6-months low flow equal to that of 1914-1915 should recur. The city, however, should guard against the probability of even smaller inflow. It is considered desirable to provide storage to offset a minimum flow of 2,500 acre-feet in six months, which is estimated to have a recurrence frequency of once in 50 to 100 years. To provide against this contingency will require additional storage by 1956. Thus, because of sedimentation, supplementary storage should be provided when the present lake is 34 years old. If no sedimentation had occurred, the present lake would have been adequate for 78 years.

6. The estimated average annual inflow to the lake from 1923 through 1935 was 68,000 acre-feet greater than that from 1936 through 1945. During the earlier period, stream flow exceeded 1,000 cubic feet per second for 44.6 days per year on an average; whereas during the later period, it exceeded this rate only 36.7 days per year. This indicates that hydrologic conditions were more favorable to erosion and sedimentation during the earlier period. Actually the sedimentation rate was 20 percent greater during the later period.

7. About three-quarters of the land in the drainage area above Lake Decatur has slopes of less than 2 percent. The remaining quarter, except for seven-tenths of 1 percent, has slopes ranging from 2 to 15 percent. The area is a broad, gently-rolling glacial drift plain in the heart of the Corn Belt. Its black prairie soils are intensively used for

agriculture. In a typical county—Piatt—in 1943, approximately 31 percent of the land was in corn; 331/2 percent in soybeans; 11 percent in small grain; 141/2 percent in hay and plowable pasture; 2 percent in woodland; and 8 percent in other uses. About 62 percent of the farms, embracing 72 percent of the land, are tenant-operated. Soil conservation practices had been planned on only 4.2 percent of the land to July 1, 1946, and only about one-half of the planned practices had been installed.

8. Turbidity and stream-flow records, analysis of lake sediments, and repeated observations and experiments on the land, show that the lake sediment is derived from all parts of the drainage area. It is estimated that at least 90 percent comes from sheet erosion, primarily from corn and soybean fields on slopes of 2 to 15 percent. Only 10 percent, or less, comes from gully, stream-channel, and shoreline erosion. Measurements in the lake show that shore-line erosion contributes between 1.6 and 6.6 percent of the total sediment.

9. From 1936 to 1946, 2,650,000 tons of sediment were deposited in the lake, while an estimated 750,000 tons passed over the spillway. This constitutes a loss of 3,400,000 tons of soil from farms of the drainage area during the 10 years. Although this is only part of the total soil loss, it is equivalent to complete removal of 7 inches—the plow depth—of fertile topsoil from 3,400 acres of land.

10. Analysis of plant nutrients in the reservoir sediment shows a loss from farmland during 24.3 years of 2,478,600 pounds of active nitrogen worth $223,560, and available organic phosphorus worth $85,050. Much larger losses are involved in some 12 million pounds of reserve nitrogen in organic matter and some 31/2 million pounds of total phosphorus included in the sediment inflow to the lake.

11. The 20-percent increase in the average rate of sedimentation during the 10 years, 1936-1946, as compared with the preceding 14.2 years, is attributed to progressive increase in the intensity of land use for intertilled row crops. In Piatt County, land in row crops increased from approximately 39 percent in 1924 to 641/2 percent in 1943. The increase was due mainly to soybeans. The present rate of sedimentation is estimated to be 30 percent above the average rate prior to 1936.

12. Possible remedial measures for maintaining the water supply and other values associated with Lake Decatur include (1) raising the present dam, (2) construction of several small reservoirs on tributary streams, (3) construction of one or more sizable reservoirs on the Sangamon River above Lake Decatur, and (4) soil conservation measures on the drainage area. Dredging is not considered economically feasible at present.

13. A complete program of soil conservation on the drainage area should include reduction in the acreage of land used for intertilled crops, crop rotations involving no more than two years in four of intertilled corn and soybeans, contour planting; and where required, terracing, diversions, grassed waterways, drainage and other practices. It is estimated that a complete conservation program would reduce sedimentation by 62 percent from its average rate during the 10-year

period, 1936-1946, or by 65 percent from the probable present rate. This conservation program would result in a higher level of farm income and maintain the soil resources of the area, as well as protect Lake Decatur. The Soil Conservation Districts organized in each of the six counties in the drainage area provide a means for accomplishing the needed soil conservation work.

14. It is estimated that past and future sedimentation will cause damage to Decatur's water storage facilities equivalent to $200 per acre-foot, or $47,200 annually at the 10-year average rate of 236 acre-feet of deposits. In addition, an estimated future loss of $4,375,000 in property values adjacent to the lake may result if the lake is permitted to become 80 percent filled with sediment. A further damage to the community estimated at $40,000 annually will result from loss of recreational facilities if the lake is allowed to become 80 percent silted. Probably the city would be justified in spending $100,000 annually over the next 100 years, or the equivalent present worth now, to effect a reduction of sedimentation to 38 percent of its 10-year average rate. Furthermore, the farmers of the area have a large stake in maintaining the industries and trading outlets in Decatur and can afford to protect their own soils in order to protect the water supply of the city.

15. This investigation, together with data on a few other reservoirs in Illinois, indicates that sedimentation is a critical problem in the utilization of impounding reservoirs. In 1944, 62 cities and towns in Illinois depended on impounding reservoirs subject to sedimentation. Widespread construction of additional municipal reservoirs appears probable.

THE CAUSES AND EFFECTS OF SEDIMENTATION IN LAKE DECATUR

BY

CARL B. BROWN,[1] J. B. STALL[2] AND E. E. DETURK[3]

INTRODUCTION

For more than a hundred years surface water has been impounded in reservoirs and purified for public and industrial uses in some sections of the United States. For that long, at least, sediment has been recognized as a major problem in utilizing surface water supplies. Chemists early found that minute sediment particles were the principal cause of turbidity—the cloudy or muddy quality that must be removed before water is acceptable on the dinner table, in the bath, or in the factory boiler. Moreover, engineers began to recognize some decades ago that sediment carried by flowing streams settles in impounding reservoirs built on these streams and, in some cases, rapidly reduces the capacity of the reservoirs to store water. As recently as 15 years ago, however, there was little quantitative data on the rates at which reservoirs were being filled with sediment. Moreover, there was little appreciation of the intimate relationship between the sources of sediment on the lands of the drainage basin and the increasing losses of reservoir capacity or the increased costs of water purification.

The need for more information on the effects of sediment on surface water supplies began to be recognized in Illinois as early as 1930. In 1931 and 1932 the State Water Survey Division undertook preliminary investigations of sedimentation in Lake Decatur in cooperation with the Decatur Water Supply Company, former owner of this municipal reservoir. Impetus was given to investigation of sedimentation problems with the spread of the movement to control soil erosion, which led to the creation of the Soil Conservation Service as a permanent agency of the U. S. Department of Agriculture in 1935. This agency undertook a systematic study of rates of reservoir sedimentation in all parts of the country in an effort to evaluate the effects of accelerated soil erosion on public water supply and other services rendered by storage reservoirs. Related studies were made of land use and erosion on the drainage areas. One of the early projects under this program was a survey of Lake Decatur and its watershed made in April-June, 1936, in cooperation with the State Water Survey Division, the State Agricultural Experiment Station, and the city of Decatur (See Figure 1).

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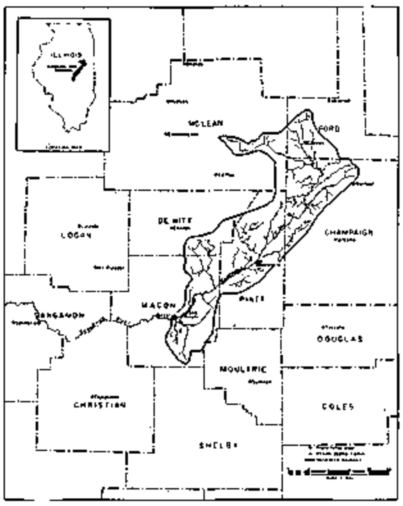

FIG. 1.—Index Map of Lake Decatur Watershed.

A second survey of Lake Decatur was made by these agencies in May and June, 1946. Additional investigations designed to cover all of the important relationships between reservoir capacity, water needs, effects of sediment on treatment problems, water supply from the Sangamon River, and effects of land use and agricultural practices in this drainage basin have been made during 1946. The results of these studies are reported in this publication. The findings have led to a prediction of the remaining useful life of Lake Decatur. They show the nature of the problem confronting the city. They give a basis for long-range planning for the protection and maintenance of the city's water supply. Furthermore, these investigations have shown for the first time in this section of the country the intimate relationship between public water supply and problems of the land. They give a measure of the effects of land use and treatment on the quality of water and the maintenance of storage reservoirs. The results are useful not only in solving the problem of the city of Decatur; they also indicate the general nature of the problems confronting other cities and towns in Illinois that now depend on surface water supplies and many more that will be developing surface supplies in the future as ground-water supplies become more and more fully developed or overdeveloped.

SCOPE OF INVESTIGATIONS

In the summer of 1930, F. L. Washburn, Engineer for Macon County, made an investigation for the Decatur Water Supply Company, former owner of Lake Decatur, to determine the extent of erosion around the shores of the lake and its effects on sedimentation on the lake bottom. He found that some shore lines had eroded back 25 to 35 feet since the reservoir was impounded in 1922. Several small bays and inlets had been filled with sediment. A resurvey of a line of levels taken in 1920 for the road across the south Sand Creek arm showed deposits of from 1 to 2 feet entirely across the valley below this road. Sounding along the line of a proposedfroad one-fourth mile south of Rhea's Bridge showed that the lake had filled from 1 to 2 feet across half the width of the lake basin. Soundings in the borrow pit near the Nelson Park Bridge showed deposits up to 4 feet thick.

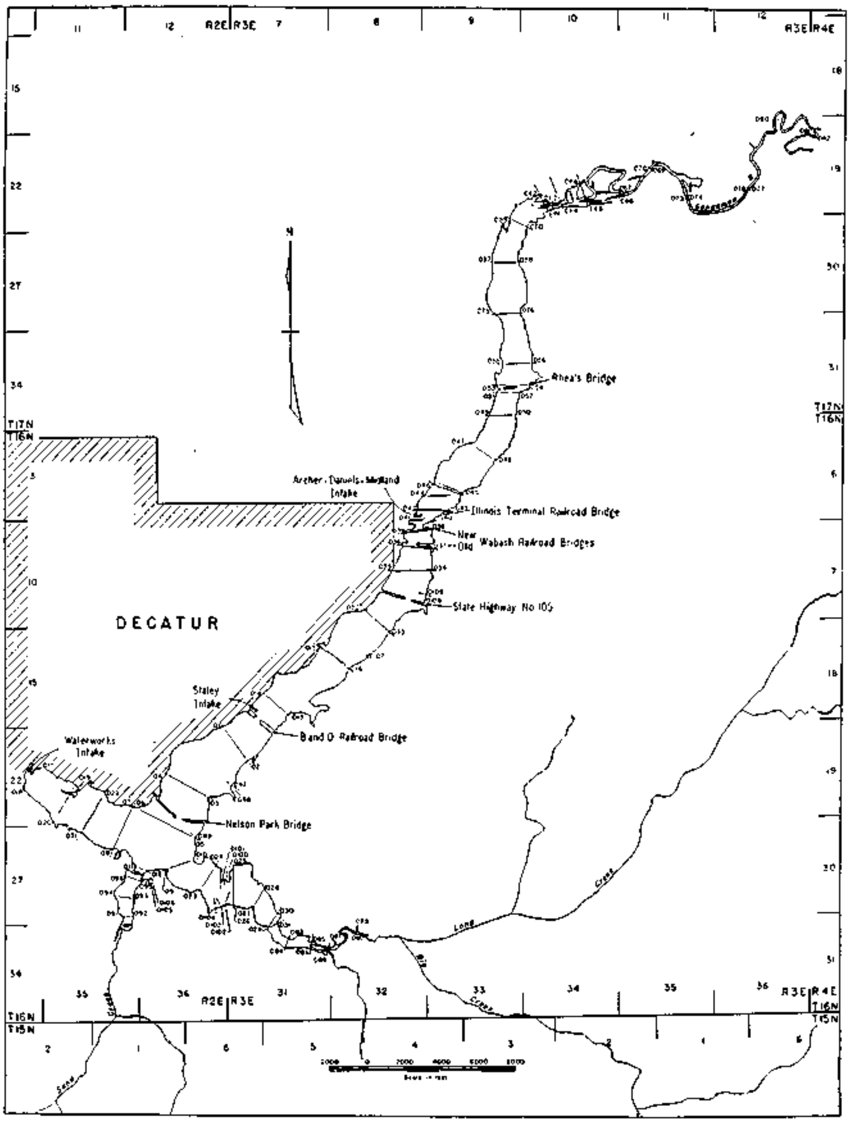

FIG. 2.—Map of Lake Decatur.

These findings by Mr. Washburn led the State Water Survey Division, in cooperation with the Decatur Water Supply Company, to establish a system of *55* ranges for sedimentation measurements throughout the reservoir between September, 1931 and January, 1932. The range ends were accurately located from transit traverses and elevations were determined by levels from convenient bench marks. Concrete monuments or iron pipes were placed to mark the range ends. The ranges were closely spaced near the principal bridges crossing the lake in order to determine the effects of these constrictions on sedimentation. Over the greater part of the lake, away from the bridges, ranges were spaced at intervals of ¾ to 1½ miles. Soundings were taken along these ranges, and profiles of the then-existing lake bottom were plotted. Sediment thicknesses were also determined along ranges in the upper part of the lake above State Highway No. 105 bridge and near the heads of the Sand Creek and Big Creek arms. No measurements were made in the lower part of the lake, and hence the total volume of sediment could not be computed. The survey was made for the primary purpose of establishing a basis for future measments of sedimentation.

A complete sedimentation survey of the reservoir was made between April 8 and July 3, 1936, by a field party of the Soil Conservation Service with the cooperation of the State Water Survey Division, the State Agricultural Experient Station, and the city of Decatur.[4] The methods used in making this survey are described in a subsequent section (See pp.000). From this survey the original capacity of the reservoir was redetermined, and the capacity and sediment volume of the lake on the date of the survey were computed. A second survey, based on the system of ranges used in 1936, was made between May 1 and June 12, 1946, by a party composed of personnel supplied by the Soil Conservation Service, the State Water Survey Division, and the city of Decatur. From this survey the additional loss of capacity in the reservoir was determined. The data permit comparison of the rate of sedimentation during the period 1922-1936 with the period 1936-1946.

In addition to determining the volume of sediment in the lake, ranges were established in 1936 for measuring the extent and rate of shore-line erosion due to wave action around the lake. These ranges were resurveyed in 1946. The resulting data make it possible to estimate within limits the volume of sediment contributed by wave erosion to the lake.

On May 4 and 6, 1936, following heavy rains, sets of water samples were taken by engineers of the State Water Survey Division as a basis for estimating the rate of movement of turbid water through the lake, and the characteristics of the sediment. After the survey of 1946, the State Water Survey Division undertook a detailed analysis of the turbidity records obtained by the city's filtration plant and similar records obtained by the A. E. Staley Manufacturing Company. Correlative studies were made of rainfall distribution over the drainage

[4]Glymph, L. M., Jr., and Jones. V. H. Advance Report on the Sedimentation Survey of Lake Decatur, Decatur, Illinois. U. S. Soil Conserv. Serv. SCS-SS-12. 23 pp., illus., processed. Washington, D. C, Apr., 1937.

basin and stream discharge into the lake during selected periods in which high turbidity occurred. These studies have given a further basis for estimating the rate of movement of turbid water out of the watershed, into and through the reservoir, and to indicate the sources of sediment which are responsible for loss of storage capacity and for increase in the costs of water purification.

During the 1936 survey, Dr. E. E. DeTurk of the State Agricultural Experiment Station collected and analyzed samples of sediment from various locations in the lake to determine the texture, colloidal content, volume-weight, and plant-food constituents. Another series of samples was collected for the same purpose during the 1946 survey. These data give significant indications of the sources of sediment deposited in the reservoir, the extent of soil and plant-food losses from the drainage area, and the average weight of sediment per unit volume of deposit.

Subsequent to the 1946 survey, the State Water Survey Division has made an analysis of trends in water consumption by the city of Decatur and the A. E. Staley Manufacturing Company as a means of predicting future water requirements. The history of use and drawdown of the lake since 1930 has been studied. An analysis has been made from stream-flow records of the average water yields, or runoff from the drainage area, the frequency and duration of flood flows of various magnitudes, and the low-water or drought expectancy. From the study of low-flow expectancy in relation to the expected trends in consumption and the measured rate of storage loss resulting from sedimentation, it has been possible to predict the dates at which Decatur may face a water shortage if low flows comparable to those experienced in the past as well as those theoretically possible are experienced.

In an effort to determine the causes of increase in the rate of sedimentation of the lake, the Soil Conservation Service with the cooperation of the State Agricultural Experiment Station has made a study of trends in land use, crop production, and application of conservation practices in the drainage area of Lake Decatur from the time it was built until 1946. These data, together with the analysis of hydrologic conditions made by the State Water Survey Division, have led to an interpretation of the cause of increased sedimentation, and to a forecast of what may be expected in the future under present or various possible future conditions of land use and agriculture.

A preliminary study of the effects of sediment, or turbidity, on the city water-treatment costs showed that the latter was influenced to a large extent by modernization and improved techniques which prevented any direct comparison. Consideration was also given to the economic effects of sedimentation on water supply, the recreational value of the lake for boating and fishing, and on the value of property adjacent to the lake.

ACKNOWLEDGMENT

Many individuals have contributed materially to the investigations reported in this publication. Credit is due in particular to the following local, State, and Federal officials and other persons who have

supplied data or cooperated in making possible the several surveys and investigations: Mr. Henry H. Bolz, Secretary of the Decatur Association of Commerce; Mr. John Rehfelt, Superintendent of the Municipal Water Department; Mr. L. A. Nalefski, former chemist, and Mr. Gerald Davis, present chemist, of the city; Mr. Earl Cooper formerly superintendent of the Lake Decatur Water Supply Company; and other officials of the city of Decatur who were instrumental in supplying boats, equipment, and various items of information pertaining to the reservoir; Dr. R. E. Greenfield, chemist of the A. E. Staley Manufacturing Company of Decatur; the directors of the soil conservation districts of Macon, Dewitt, Piatt, Champaign, Ford, and McLean Counties, who have urged the undertaking of the latter phases of these investigations; Mr. Harry R. Beeson, secretary of the Upper Sangamon Valley Association of the Soil Conservation Districts, and conservationist of the Upper Sangamon Valley Conservation Service, an organization supported by the city of Decatur; Mr. Pete E. Cooley, former secretary of the Association; Dr. Roger H. Bray of the Department of Agronomy, Dr. John E. Wills of the Department of Agricultural Economics, Mr. Ralph C. Hay, Associate Professor in Agricultural Engineering Extension of the University of Illinois and of the staff of the State Agricultural Experiment Station; Mr. Bruce Clark, State Conservationist, Mr. W. W. Russell, District Conservationist, of the Soil Conservation Service; Mr. Louis M. Glymph, Jr., and Dr. Victor H. Jones who were in charge of the sedimentation investigations made by the Soil Conservation Service in 1936; Mr. Gunnar M. Brune who was in charge of the SCS Survey in 1946; Mr. Louis C. Gottschalk of the Sedimentation Section, SCS; and members of the staff of the State Water Survey Division who have participated in these investigations, including Mr. W. D. Gerber, retired, Dr. Max Suter, Mr. C. O. Reinhardt, and Mr. H. F. Smith.

THE DAM AND RESERVOIR

Lake Decatur is located on the Sangamon River in Macon County, T. 16 and 17 N., R. 2 and 3E. The lake borders the city of Decatur on the south and east and extends about 8 miles upstream from the northeastern city limits. It is impounded on the main stem of the Sangamon River, and backwater extends into two principal tributaries, Sand Creek and Big Creek. The reservoir is used primarily for municipal and industrial water supply but has an important value for recreation, including boating, fishing, and swimming.

The reservoir is created by a dam which has a total length of approximately 1,900 feet, extending nearly north and south across the Sangamon River Valley (See Figure 2). The dam consists of three segments—the concrete-spillway segment in the middle, which is 480 feet long, 28 feet in height above the bottom of the original channel, 4 feet thick at the top, and 14 feet thick at the base; and two earth-fill sections on either end each having a length of about 675 feet and providing a freeboard of approximately 22 feet between its top and the crest of the spillway. The upstream faces of the end segments have

FIG. 3.—Lake Decatur Dam.

slopes of 2.5 to 1 and are faced with concrete slabs. The upstream face of the spillway section is vertical. Both end segments meet the spillway at oblique angles, giving the dam a zigzag pattern. The spillway-crest elevation is 610 feet above mean sea level (USGS datum). Provision was made in construction for 21/2-foot flash boards along the entire length of the spillway, but they have never been used. Two flood gates 9 feet high and 14 feet wide, with tops at spillway-crest level, adjoin the north end of the spillway segment. In addition, one 3 x 4 foot flushing conduit in the middle of the spillway provides an outlet at a depth of 15 feet below spillway crest.

When storage began on April 16, 1922, the surface area of the reservoir was 2,805 acres, and the storage capacity was 19,738 acre-feet, or approximately 6,432,000,000 gallons (as determined by the survey of 1936). The dam was constructed in 1921-1922 by the Decatur Water Supply Company, an Illinois corporation, which furnished water to the city for 10 years under contract. During this period an extensive program of shore-line stabilization by riprapping was carried out. In 1932, the control and administration of the lake was acquired by the city of Decatur. The cost of the Lake Decatur development, according to city officials, was as follows: Dam, $940,000; land, $547,897.13; clearing of land, $119,295.02; roads and bridges, $309,-091.97; riprapping, $97,555.81. The total original cost was $2,013,-839.93. Subsequent improvements, including the cost of the filtration plant, have brought the total investment to more than $2,500,000.

Lake Decatur occupies a relatively long, somewhat winding stretch of the Sangamon River Valley, through which the stream formerly followed a tortuous, meandering course over a well-developed floodplain. The floodplain is slightly less than one-half mile in width, on the average, and is bordered mainly by bluffs and steep slopes. The lake ranges in width from about 1/4 to 3/4 mile. Just upstream from the dam, the maximum depth of water over the original floodplain was 16 feet, and the maximum depth in the original channel was about 28 feet. The average gradient of the floodplain through the reservoir basin is about 1.5 feet per mile. Throughout the lake proper, the impounded water covers the entire floodplain and encroaches slightly upon the adjacent bluffs and slopes; thus, much of the lake shore is steep or even precipitous. The submerged channel ranges in width from 100 to 200 feet and in depth from 5 to 10 feet below the level of the floodplain. The only important tributary arms are Big Creek and Sand Creek which join the main lake about 2 miles above the dam.

SEDIMENTATION IN THE RESERVOIR

Methods of Survey

The record of sedimentation in Lake Decatur is based on the survey system established in 1936, which incorporated a substantial part of the range system laid out by the State Water Survey Division in 1931—1932 (See Figure 2). The 1936 survey was tied to a chained 2,000-foot base line across the lake along the south side of the Baltimore & Ohio Railway fill. From this line 72 triangulation stations were established by plane table and telescopic alidade. An auxiliary base line, also 2,000 feet in length, was chained across the lake along the north shoulder of State Highway 105 fill between triangulation stations 1038 and 1039. Using the triangulation stations as control points, the spillway-crest contour, elevation 610, was mapped on a scale of 500 feet to the inch around the entire reservoir, a distance of approximately 70 miles. In the delta areas of the main lake and tributary arms, both the original and 1936 crest lines were mapped.

To determine the capacity and sediment volume, 49 ranges crossing the lake and tributaries were established and tied into the triangulation net. Twenty-four of these ranges had been previously laid out and sounded by the State Water Survey Division in 1931-1932. The 1936 range system included most of the older ranges, except the closely-spaced ranges near Rhea's Bridge and the old and new Wabash Railroad bridges. Ranges had been concentrated in these areas in anticipation of an exceptionally large amount of sedimentation here. Preliminary spudding in 1936 indicated that this was not the case. Soundings were taken along the ranges at intervals of 25 feet or less, and spuddings at intervals of 100 feet or less. On most ranges the boat was kept on line by a signalman on shore, while the position of the sounding or spudding was cut in by intersection from a plane table located on an adjacent range end or suitably-located cut-in station. On several ranges, however, a marked cable was stretched from shore to shore, and the position of soundings was determined by this means.

In addition to the sedimentation ranges, 14 special shore-line ranges were established for future determination of the extent of wave erosion as a factor in reservoir silting. Furthermore, surveys of 14 end sections of regular ranges were extended for the same purpose. On these ranges and the range ends, levels were run from a point well back from the expected maximum limit of erosion down to the water's edge, and by closely-spaced soundings out into the lake to the limit of coarse, wave-erosion debris.

Soundings were taken with a bell-shaped, cast-aluminum sounding weight, approximately 5 inches in diameter at the base, and weighing about 5 pounds. Direct measurements of sediment thickness were obtained with a spud, which consists of a well-tempered steel rod, similar to axle shafting, into which encircling triangular grooves have been machined at intervals of 0.1 foot along its length. The spud, when dropped in the water, goes through the sediment deposits and into the underlying old soil. Each groove retains a sample of the deposit at the point at which it comes to rest. Clear distinctions could be made almost everywhere in Lake Decatur between sediment and old soil. That positive identifications were obtained was verified in the 1946 survey in which spuddings at the 1936 points of measurement, but through greater thickness of sediment, showed consistent elevations of the old soil, seldom differing from the 1936 measurements by more than 0.1 to 0.2 foot.

In the 1946 survey, both soundings and spuddings were repeated on a number of ranges. The results were so consistent that spudding was largely abandoned, except as an occasional check, and the larger number of ranges were simply sounded to obtain the surface of the sediment. Profiles on the shallow water ranges were obtained by leveling. In the 1946 survey, 39 of the 49 sedimentation ranges were resurveyed. The ranges not remeasured are those crossing the channel only in the extreme upper end of the lake and the tributary arms. Examination of these ranges indicated no significant change since 1936 because of the scouring action of stream inflow. All 28 wave-erosion ranges were resurveyed and the amount of erosion was determined.

In 1936, samples of bottom sediment were obtained from 39 selected sites by means of two types of sediment samplers. For the thinner deposits on the submerged floodplain, the iron tube sampler developed by the State Water Survey Division was used. The samples from the channel, where the sediment was more than 3 feet deep, were obtained with the spud. In 1946, samples were obtained with a pipe sampler to the end of which 2-inch nipples were attached below a check valve.

In both surveys the plotted cross-sections along the ranges were planimetered to determine the cross-sectional area of the range prior to sedimentation and in 1936 and 1946. The difference in cross-sectional area represented the area of sediment deposited to these dates. The surface area of each segment bounded by one, two or more ranges, and the intervening shore line was planimetered. From these data the capacity and sediment volume of the reservoir was determined by the SCS range survey formula.[5]

Rates of Sedimentation

The following is a summary of sedimentation data obtained from the surveys of Lake Decatur, together with data derived therefrom which are pertinent to the interpretation of the record.

[5]Eakin, H. M. Silting of Reservoirs. *V.* S. Dept. Agr. Tech. Bul. 524. Rev. by C. B. Brown, 168 pp., illus. Washington. U. S. Govt. Print. Off., 1939. Appendix.

SUMMARY OF SEDIMENTATION DATA ON LAKE DECATUR, DECATUR, ILL.

	Quantity	Unit
Age:[1]		
1922-1936	14.2	Years
1936-1946	10.0	Years
1922-1946	24.2	Years
Watershed:		
Total area:[2]	906	Square miles
Reservoir:		
Area at spillway stage:		
1922	2,805	Acres
1936	2,746	Acres
1946	2,604	Acres
Storage capacity at spillway level:		
1922	19,738	Acre-feet
1936	16,930	Acre-feet
1946	14,567	Acre-feet
Capacity per square mile of drainage area:		
1922	21.79	Acre-feet
1936	18.69	Acre-feet
1946	16.08	Acre-feet
Sedimentation:		
Total sediment:		
1922-1936	2,808	Acre-feet
1936-1946	2,363	Acre-feet
1922-1946	5,171	Acre-feet
Average annual accumulation:		
From entire drainage area:		
1922-1936	198	Acre-feet
1936-1946	236	Acre-feet
1922-1946	214	Acre-feet
Per 100 square miles of drainage area:[3]		
1922-1936	22.0	Acre-feet
1936-1946	26.2	Acre-feet
1922-1946	23.7	Acre-feet
Per acre of drainage area:[3]		
By volume:		
1922-1936	15.0	Cubic feet
1936-1946	17.8	Cubic feet
1922-1946	16.1	Cubic feet
By weight:[4]		
1922-1936	0.39	Tons
1936-1946	0.46	Tons
1922-1946	0.42	Tons
Depletion of Storage:		
Loss of original capacity:		
Per year:		
1922-1936	1.00	Percent
1936-1946	1.20	Percent
1922-1946	1.08	Percent
Total:		
1922-1936	14.23	Percent
1936-1946	11.97	Percent
1922-1946	26.20	Percent

[1]Storage began April 16, 1922. Date of first survey was April 8, 1936, to July 3, 1936. Date of second survey was May 1, 1946, to June 15, 1946.

[2]Including area of lake.

[3]Excluding area of lake.

[4]Average dry weight of 1 cubic foot of sediment is 51.7 pounds, based on weighted average of 21 samples.

The more significant findings shown by this summary are as follows:

1. The surface area of the lake has been reduced 201 acres in 24.2 years by deposits in the upper end of the lake and in the two principal tributary arms, Sand Creek and Big Creek.
2. The capacity of the reservoir for water storage has been decreased by 5,171 acre-feet, or 26.2 percent in the 24.2 years from the date of its completion in 1922 to the date of the 1946 survey.
3. The loss of original storage capacity has increased from an average of 1.0 percent annually during the period 1922-1936 to 1.2 percent annually during the succeeding 10 years, 1936-1946. For the entire period the average annual loss has been 1.08 percent.
4. The sediment accumulated in the lake represents an average annual loss of 16.1 cubic feet per acre from the drainage area of 577,000 acres (excluding the lake area). The rate of loss has increased, however, from 15.0 cubic feet per acre annually before 1936, to 17.8 cubic feet per acre annually since 1936.

Distribution of Sediment

An outstanding characteristic of sedimentation in Lake Decatur is the relative uniformity in thickness and in type of deposits over the lake basin. The average thickness of sediment in the main body of the lake increases gradually from slightly less than 2 feet near the dam to slightly more than 3 feet in the upper part of the reservoir. There is a notable absence of thick delta deposits near the head of the lake. This is interpreted as being due to the uniformly fine texture of the incoming sediment, which is carried in suspension to all parts of the reservoir.

Throughout the reservoir, the thickest deposits of sediment are in the submerged channel. Deposits in the channel increase from about 5 feet near the dam to about 9 feet near Range 55-56. Above this point they decrease until near the head of the lake the main channel is practically free of sediment as a result of scour by inflowing flood discharge. The most completely silted portions of the lake are above Range 57-58. In this area, deposits have been built up to above spillway level, and for a stretch of more than. one mile the original lake area now consists of swampy vegetation such as willows, cattails, and grasses, cut by meandering overflow channels (See Figure 4). Small areas of above-crest deposits have accumulated also at the heads of Sand Creek and Big Creek arms. On submerged valley slopes and other areas above the general level of the floodplain, little or no sediment has accumulated. Adjacent to the areas of wave erosion, however, there are comparatively narrow wave-built benches of coarser material, generally extending 20 to 100 feet from shore. In percentage, the greatest concentration of capacity loss occurs between Ranges 36-37 and 65-66.

FIG. 4.—Upper Section of Lake Decatur showing area almost completely filled by sediment.

Character of Sediment

The sediment in Lake Decatur consists chiefly of poorly compacted silt and clay, ranging in color from gray or bluish-gray in submerged areas, to brown or rust where recently exposed to the air. Coarse sand, grit, and gravel occur in narrow areas along several sections of the lake shore at the foot of wave-cut bluffs. No typical delta deposits have formed at the head of the main reservoir, but small deltas in the two major tributaries, Sand Creek and Big Creek, have filled the original stream channels for some distance. In the channel above the head of the open lake, the sediment differs little from that normally present in free-flowing streams in this region. The bulk of the channel sediment is silt and fine sand, with occasional gravel bars, all of which are subject to seasonal scour and fill.

Chemical and physical measurements were made on a number of samples of sediments from Lake Decatur in order to secure information that would aid in determining the volume-weight relations and in estimating the nature, amount, and value of the erosional losses from the land in the watershed.

Roughly 10 percent of the watershed land is covered by light-colored soils, formerly timbered, bordering the Sangamon River, as against 90 percent in dark-colored, grassland soils. The analyses, Tables 1 and 2, indicate that the lake sediment is similar to the surface soil (plowed depth) of this area. The content of organic carbon and nitrogen in the sediments is nearly twice as great as in the surface of the predominant timber soils and slightly lower than the prairie soils. The physical analysis further shows the similarity in proportion of the different particle sizes of a typical sample of sediment shown in

TABLE 1.—ANALYTICAL DATA ON SAMPLES OF SEDIMENT FROM MAIN BODY OF LAKE DECATUR TAKEN IN 1936 AND 1946

Range	Miles above dam	1936 Samples			1946 Samples			Water in air-dry Samples
		Thickness	Organic Carbon	Total Nitrogen	Thick-ness	Total Nitrogen	Apparent Vol. Wt.[1]	
		Feet	*Percent*	*Percent*	*Feet*	*Percent*		*Percent*
		0.5	2.69	0.230				
017-018	0.1	4.3c[4]	3.06c[4]	0.303c[4]				
		1.4	2.92	0.259				
		2.7	2.90	0.269		0.264c	0.64c	4.54c
06-05	1.8	2.3c	2.91c	0.261c		0.238c	0.70c	3.03c
		0.7	2.80	0.252		0.194	1.04	2.90
		0.6	2.53	0.214		N.S.	N.S.	N.S.
01-02	2.8	1.9c	2.68c	0.252c		0.141c	1.06c	3.12c
		0.4	2.67	0.237		0.188	0.95	2.27
013-014	3.4	3.1	2.67	0.261				
		0.7	2.82	0.253				
		1.8c	1.97c	0.174c		0.229c	0.74c	4.29
032-033	4.8	0.2	N.S.	N.S.		0.234	0.72	4.18
		1.2	2.64	0.256		N.S.	N.S.	N.S.
035-034	5.4	1.9[5]	2.23[5]	0.205[5]				
		3.1	2.87	0.269				
		0.7	2.79	0.243				
038-039	5.8	3.5c	2.85c	0.266c				
		0.6	2.35	0.206				
042-043	6.0					0.217	0.82	4.41
						0.272c	0.78c	4.57c
		1.1	2.85	0.258				
045-046	6.3	0.5	2.82	0.255				
		3.7c	2.88c	0.269c				
		5.2c	2.57c	0.241c				
049-050	7.3	0.6	2.74	0.240				
		1.6	2.59	0.234				
		1.3	2.57	0.232		N.S.[6]	N.S.[6]	
055-056	7.8	0.6	2.71	0.254		0.191	0.70	2.85
		6.3c	2.58c	0.252c		0.219c	0.67c	3.00c
		1.0	2.76	0.193				
057-058	8.7	0.4	2.37	0.204				
		6.0c	2.29c	0.198c				
						0.184[2]	1.20[2]	3.18[2]
065-066	10.0					0.283[3]	0.85[3]	3.65[3]
						0.197c	0.71c	2.31c
073-074	11.4		2.17c	0.180c				
Mean			2.65	0.239		0.218	0.827	3.45

[1]Apparent volume weight calculated as W=a/b where a is net dry weight of sample (gm) and b is volume (ml) of wet sample as packed into sampling cylinder in process of taking sample. Dry weight in pounds per cubic foot can be obtained by multiplying this value by 62.5.

[2]Delta samples, surface is 2.2 ft. above original crest line.

[3]Delta sample, surface 2.9 ft. above original crest line.

[4]The designation "c" represents samples taken from original river channel.

[5]Particle size distribution on this sample in Table 4.

[6]N.S. = No sample.

TABLE 2.—ANALYTICAL DATA ON SAMPLES OF SEDIMENT FROM SIDE ARMS OF LAKE DECATUR AND ON WAVE EROSION SEDIMENTS TAKEN IN 1936 AND 1946

1936 Samples

Range	Description	Thickness	Organic Carbon	Total Nitrogen
		Feet	*Percent*	*Percent*
		0.8	2.43	0.230
024–023	Big Creek arm at mouth	0.6	2.46	0.227
		0.7	2.01	0.187
		1.2	2.18	0.206
027–028	Big Creek arm 0.5 mile above mouth	...	2.26	0.193
		1.4c	2.20c	0.200c
		5.6	2.18	0.216
		4.1	2.35	0.219
095–096	Sand Creek arm 0.14 mile above mouth	1.8c	2.29c	0.210c
		2.0	2.35	0.223

1946 Samples

Range	Description	Total Nitrogen	Apparent Vol. Wt	Water in air-dry Samples
		Percent		*Percent*
093–094	Sand Creek arm 0.3 mile above mouth	0.181	1.06	2.46
		0.119	1.34	4.11
025–026	Big Creek arm 0.3 mile above mouth	0.200	1.04	3.42
		0.210	0.75	3.80
0109	Main lake, 5.2 miles above dam, 18 feet from S.E. shore	0.064	1.54	1.41
0102	Big Creek arm S. shore, 0.3 mile above dam	0.017	1.66	0.22
0104	Big Creek arm S. shore, 0.2 mile above dam	0.067	1.43	1.48

TABLE 3.—BASE EXCHANGE PROPERTIES OF LAKE DECATUR SEDIMENT, 1946 SELECTED SAMPLES

Range	Description	Base exchange capacity m.e.[1]	Total bases m.e.[1]	Base saturation percent	pH
06–05	1.8 mi. above dam, in channel	35.3	74.7	212	7.4
06–05	1.8 mi. above dam, S.E. of channel	26.4	28.3	107	6.9
032–033	4.8 mi. above dam, toward N.E. shore	35.8	56.8	159	7.3
032–033	4.8 mi. above dam, toward S.E. shore near or at channel	33.5	49.2	147	7.4
065–066	10.0 mi. above dam, delta, surface	32.1	39.0	121	7.5

[1]m.e. = milligram equivalents per 100 grams of soil.

TABLE 4.—PARTICLE SIZE DISTRIBUTION OF 1936 SAMPLE FROM FLAT ON RANGE 035-034 (TABLE 1) COMPARED TO SAMPLE OF HARTSBURG SILT LOAM SURFACE SOIL

Size Grade	Lake Sediment Separates percent	Lake Sediment Cumulative percent	Hartsburg Silt Loam Separates percent	Hartsburg Silt Loam Cumulative percent	
1/16 micron	10.8	10.8	12.3	12.3	Colloidal clay (1/16 micron to 1 micron); Clay (1/16 micron to 2 microns)
1/8 micron	2.5	13.3	2.6	14.9	
1/4 micron	4.6	17.9	1.9	16.8	
1/2 micron	10.0	27.9	2.5	19.3	
1 micron	4.4	32.3	4.8	24.1	
2 microns	8.4	40.7	3.0	27.1	
5 microns	14.5	55.2	6.5	33.6	Silt to 50 microns
10 microns	15.3	70.5	8.7	42.3	

comparison with one of the better prairie silt loam soils, Hartsburg silt loam (See Table 4). The analysis shows that the sediment contains less of the finest clay particles but more of the coarser material. This is understandable when it is considered that the finest material remains suspended in the water longer and is carried over the dam into the stream below, while the coarser particles form the lake sediments. The superfine material that passes out of the lake contains a larger proportion of organic matter and colloidal clay, both of which are very important in soil fertility and its durability.

Calculations from the turbidity records indicate that approximately 750,000 tons of suspended soil material passed over the dam in the 10 years from 1936 to 1946, and in the same period 2,650,000 tons were deposited in the lake. This 10-year loss from the farms of the watershed, amounting to 3,400,000 tons, is equivalent in amount and quality to the plow depth, or surface 7 inches, of 3,400 acres of land.

It has been found by the study of crop removal of plant nutrients from the soil that the plowed surface of soils similar to those in this watershed give up to crops, under average farm management, not less than 30 pounds of nitrogen per acre per year in addition to that which is obtained from the air through legumes. This nitrogen, which is actually deliverable to growing crops, is equal in value to that in fertilizers, which is valued at nine cents a pound. The minimum value of the active nitrogen loss is then 3400 X 30 = 102,000 pounds of nitrogen, worth $9,200 per year, or $92,000 for the 10-year period. By a similar calculation, it is found that the part of the soil phosphorus which would have been delivered to crops during the 10 years, much of which is organic phosphorus, has a value of $3,500 a year. If these nitrogen and phosphorus losses alone are projected back to 1922 when the reservoir was constructed, the total value of the available forms of these two plant-food elements lost from the watershed is almost one-third of a million dollars for the 24 years.

These estimates are conservative, because they place a value on only that part of the nitrogen and phosphorus that was actually deliverable into growing crops as shown by plant-food removals by crops growing in similar soils. They do not include the 12 million pounds of reserve nitrogen in the organic matter of the suspended soil material which entered the lake, nor do they include the 31/2 million pounds of total phosphorus, nearly half of which is in the organic matter and subject to release as the organic matter decays. Another portion of this phosphorus is absorbed by the clay and also subject to release to growing crops.

The above evaluation of the plant-nutrient losses does not include the mineral nutrients such as potassium, calcium and magnesium. The loss of these elements by erosion, although serious, is less critical than that of nitrogen and phosphorus, whose presence in organic forms is confined to the thin mantle of organic matter within one to about three feet of the surface. These nutrients, of course, are not renewable from below.

On the other hand, as subsoil gradually comes into the surface zone as a result of erosion, it brings fresh supplies of potassium, calcium, magnesium and other mineral elements into the zone of usefulness for crop growth. No nitrogen renewal can occur by this process and the phosphorus, though renewed, is all mineral phosphorus, which is of lower crop-supplying value than the organic forms produced in the surface soil during the long period under native vegetation.

The rate of devaluation of the land in the watershed, which by a very rough approximation may be estimated at around one-half of one percent annually, is, obviously, much slower than the rate of destruction of the reservoir. The soil loss also is irregular in its distribution throughout the watershed. The similarity of organic content and mechanical composition of the sediment to the dark-colored prairie soils of the flatter slopes indicates that these are the primary source of the lake sediment rather than the surface soils of the rougher land adjacent to the streams and the morainal slopes. The soils of the rougher and steeper areas are much lower in organic content and nitrogen. Although they have a higher erosion potential, they do not appear to be a principal source of sediment, probably for two reasons. First, they cover only about 10 percent of the entire watershed, and second, they have a much higher percentage of permanent cover of grass and trees.

There is the further possibility that selective removal of surface soil during erosion may occur. That is, the finer particles and the organic matter, both of which should be more susceptible to removal by water than the coarser material, may be removed more rapidly with resultant concentration of these materials in the eroded material as compared to the material left in place.

Trap Efficiency

A rough approximation of the trap efficiency of Lake Decatur was obtained from analyses of stream-flow records at Monticello, turbidity records of the A. E. Staley Manufacturing Company, and determination of the coefficient of fineness. The outflow from the reservoir was assumed to equal the inflow, which was computed from the Monticello stream-flow records on the basis of an equivalent run-off per unit area. In this calculation of trap efficiency evaporation from the lake surface was neglected as a minor correction and a refinement of analysis inconsistent with the limits of error of turbidity determinations.

From gravimetric determinations of the sediment content of a number of water samples on which turbidity readings were taken, the average coefficient of fineness, or ratio of suspended solids in parts per million to turbidity in parts per million, was estimated. These analyses are contained in an unpublished report by Dr. Max Suter.[6] Using this coefficient, the Staley turbidity records for the period 1936-1946 were converted to sediment content in outflow (in percent) from which the sediment loss was computed to be approximately 750,000 tons. As the sediment deposited in the lake during this period was approximately 2,650,000 tons, the total sediment inflow is estimated to have been 3,400,000 tons. This indicates that 78 percent of the incoming sediment was deposited, whereas 22 percent remained in suspension and passed over the spillway.

Wave Erosion

The ranges established in 1936 for wave-erosion measurements were selected to represent as nearly as possible the variations in conditions of shore-line erosion with respect to height and slope of bank, character of material, and current and wind direction.

In 1946 a study was made in the field and from aerial photographs to classify the shore line around the lake. Wave erosion was designated as very severe, severe, moderate, or slight, or as areas of fill, and the percentage of shore line in each class was estimated (See Figure 5). The results of the resurveys of wave-erosion ranges, computed as

FIG. 5.—Wave erosion on north shore of Big Creek arm.

cross-sectional areas of scour or fill, were then applied to each condition for which the ranges were representative. The results of this study are shown in Table 5.

TABLE 5.—VOLUME OF SEDIMENT DERIVED FROM WAVE EROSION, 1936-1946

Degree of wave erosion	Average erosion or fill on range	Estimated shore line		Estimated total erosion or fill
	Square Feet	*Feet*	*Percent*	*Acre-Feet*
Very Severe (Ranges 020,026, 0102, and 0103)	−311	4,440	2	−31.7
Severe (Ranges 05,0105, 0106, 0107, 0108, and 0109)	−140	11,100	5	−35.7
Moderate (Ranges 012,054, 093,097 and 098)	−60	33,300	15	−45.9
Slight (Ranges 08,022,027, 039,095,0100, 0101B, and 0104)	−16	117,660	53	−43.2
Fill (Ranges 045,053,057,099, and 0101A)	+95	55,500	25	+121.0
Total	−7	222,000	100	−35.5

This study disclosed that there has been a gross erosion of 156.5 acre-feet of soil in 10 years from the 52.5 miles of shore line that have undergone some degree of wave erosion. On the remaining 25 percent of the shore line net fill has occurred. Part of this fill is from erosion of adjacent higher slopes and part from sedimentation in the lake. It has not been possible to determine what percentage is from each source. The actual contribution of sediment by wave erosion is, therefore, estimated to be between 35.5 acre-feet, the indicated net erosion, and 156.5 acre-feet, the indicated gross erosion. These amounts are respectively 1.5 percent and 6.6 percent of the sediment deposited in the reservoir during the 10-year period. It is believed that the amount actually derived from wave erosion is much closer to the lower than to the higher value.

In addition to its effect on sedimentation, wave erosion is a serious problem along certain stretches of the shore because of its detrimental influence on property and esthetic values. Wave erosion undoubtedly has been retarded by the riprapping of approximately two-thirds of the shore line in the lower part of the reservoir before 1936. The riprap consisted of large angular rocks, placed at a total cost of more than $97,000, according to city officials. Additional treatment and some maintenance is needed to assure adequate protection in the future. Some areas are still being damaged by wave action.

TURBIDITY AND SEDIMENT MOVEMENT

The rate of movement of sediment into and through the lake was estimated by analysis of turbidity records of the lake water and of stream-flow data. Daily turbidities of the raw lake water at the dam were available from the Decatur waterworks for the period 1934-1946. Daily readings of the lake level at the dam were available for the period 1927-1946. Daily turbidities of raw lake water for the period 1934-1946 were also available from the A. E. Staley Manufacturing Company, which has an intake about three miles above the dam, as shown in Figure 2.

Turbidity is an approximation of the suspended matter present in water determined by optical methods.[7] A turbidity value expressed in parts per million is not equivalent to the suspended matter content, also expressed in parts per million, but the two often have a sufficiently constant relationship that turbidity values can be used as a rough approximation of suspended-sediment content.

A Jackson candle turbidimeter was used for all determinations at Staley's except for very low values. The city waterworks uses the same type of instrument for values above 100 parts per million, and a Hellige turbidimeter for values below 100. Staley's values represent the turbidity of a 24-hour composite sample prepared from intake samples collected every two hours. At the waterworks the turbidity measurements are made on one sample daily taken between 8 A.M. **and** 10 A.M.

The relation between turbidity fluctuations and the movement of sediment-laden water through the lake was investigated after heavy rains in early May, 1936, by Dr. Max Suter of the State Water Survey Division[6]. In order to compare the suspended matter actually present with recorded turbidity, a series of water samples covering the entire length of the lake was collected on May 4 and again on May 6. Filtration of these samples showed the suspended solids present at each point throughout the length of the lake on these two days. These data showed that the suspended sediment load maintained a rather sharp front during its movement down the lake; definite turbidity peaks substantiate this interpretation. This study showed that from May 4 to May 6 the turbid inflow moved nearly 3½ miles, from a point about 9.6 miles to a point about 6.2 miles above the dam. On May 7 and 8 a turbidity peak occurred at the dam. During this period the lake level remained practically constant at 0.70 foot above spillway crest.

As part of this study, numerous gravimetric determinations of sediment content were made by the Gooch filter method on samples from which turbidity readings had been previously taken. These data give a basis for estimating the average coefficient of fineness or ratio of turbidity readings to gravimetric determination of sediment content in the water. This correlation of suspended-sediment content

[6]Suter, Max. Report on Sedimentation Studies of Lake Decatur, Decatur, Illinois. Illinois State Water Survey (1936). (Unpublished)

[7]Standard Methods for the Examination of Water and Sewage. American Public Health Association and American Water Works Association, Ninth Edition, (1946).

with rises in turbidity at Staley's and at the dam showed that a turbidity peak at either point could be considered evidence that a mass of sediment-laden water was moving through that portion of the lake.

Because turbidity records were incomplete for the period prior to the 1936 sedimentation survey, a comparison of turbidity during the two periods before and after this date was not possible.

In order to study general trends in turbidity changes, yearly charts were drawn to show daily turbidities at Staley's and at the waterworks, daily lake levels, and precipitation at Decatur. These charts revealed that turbidity changes could not be directly correlated with precipitation at Decatur. Certain short periods were then selected for more detailed study of the effects of precipitation and run off over the entire watershed. The criteria used in selection of these periods were as follows:

1. Periods in which isolated showers occurred after a comparatively dry period during which the turbidity and lake level reached reasonably stable conditions. Subsequent turbidity changes could thus be directly attributed to the shower.
2. Periods between two very heavy rains. The large turbidity rises could be definitely attributed to the two heavy rains, so the lesser turbidity changes occurring during the intervening period between major turbidity peaks could be directly attributed to smaller rains occurring during this period.
3. a. Rains affecting turbidity only at the waterworks.
   b. Rains affecting turbidity only at Staley's.
4. Uniform precipitation over the entire watershed.
5. Precipitation on only a specific portion of the watershed.

For each period chosen for study, isohyetal (rainfall-contour) maps were drawn for every rain in excess of 0.25 inch falling on the watershed during the period. The isohyetals were drawn from daily precipitation records from. 17 rain gages in this section of Illinois (See Figure 1). Three of the gages, at Decatur, Monticello, and Gibson City, were within the watershed. From these maps the spread of each rainfall over the watershed could be observed.

Daily flow records for the period 1922-1946 were available from the gaging station of the U. S. Geological Survey located on the Sangamon River near Monticello.

The time of concentration of runoff on this watershed and hence the rate of travel of the suspended sediment load was estimated on the basis of unpublished investigations now being made by the U. S. Geological Survey in the adjacent Kaskaskia River and Salt Creek watersheds. Following uniform rainfall on only the upper half of the watershed, the time of increased sediment concentration at the head of the lake was found not to exceed 56 hours; for uniform rainfall from a major storm occurring over the entire watershed the time of concentration of peak runoff at the head of the lake was estimated to be about 48 hours. The rate of travel of sediment-laden water through the lake was found by Dr. Suter[6] in 1936 to be of the order of two miles per day.

Analysis of periods of uniform precipitation over the entire drainage area showed that Big and Sand Creeks in the lower part of the watershed brought down sediment loads rather quickly and sometimes caused turbidity rises comparable to those caused by the Sangamon River inflow. The large sediment deposits near the outlets of those creeks, however, comprise only a small percentage of the total volume of sediment in the lake.

Precipitation occurring only on the upper sections of the watershed was found to cause a definite rise in turbidity in the lake several days later. This indicates that sediment is brought into the lake from even the most distant parts of the drainage area. Following general rains, sediment coming into the lake is derived in rather uniform proportions from all parts of the drainage area, as shown by consistently turbid stream flow on all tributaries, by the time of concentration of peak turbidity at the reservoir, and by the records of suspended sediment movement through the lake.

RUNOFF AND INFLOW

Water Yield

The annual inflow into Lake Decatur has been estimated from stream flow data obtained at the Monticello gaging station. The drainage area above this station is 550 square miles. The drainage area above Lake Decatur is 906 square miles. As all available information indicates that precipitation, topography, land use, and other factors affecting runoff are comparable over the entire watershed, the inflow at the lake was computed by multiplying the flow at Monticello by the ratio of these two areas (1.65). Table 6 shows the annual inflow to Lake Decatur thus computed (to the nearest 1,000 acre-feet) for the two periods 1923-1935 and 1936-1945.

TABLE 6.—ESTIMATED ANNUAL INFLOW TO LAKE DECATUR

Water year (Ends Sept. 30)	Inflow Acre-Feet	Water year (Ends Sept. 30)	Inflow Acre-Feet
1923	415,000	1936	311,000
1924	866,000	1937	549,000
1925	320,000	1938	576,000
1926	686,000	1939	582,000
1927	1,302,000	1940	159,000
1928	713,000	1941	170,000
1929	816,000	1942	755,000
1930	460,000	1943	845,000
1931	89,900	1944	479,000
1932	215,000	1945	285,000
1933	512,000		
1934	81,200		
1935	530,000		
Average	539,000	Average	471,000
Average 1923-1945			509,000

The maximum inflow of 1,302,000 acre-feet occurred during the water year 1927, and a minimum flow of 81,200 acre-feet occurred in 1934. The average annual inflow during the entire period has been 509,000 acre-feet. The average for the period 1923-1935 was 68,000 acre-feet greater than for the period 1936-1945, although sedimentation was greater during the second period.

Frequency and Duration of High Flows

In order to determine whether the increase in rate of sedimentation during the period 1936-1946 might have been caused by a greater number of high inflows, an analysis was made of the frequency of such flows during the life of the lake. This study also was based on the flow records from the Monticello gaging station. For each of the two periods, 1922-1935 and 1936-1946, a count was made of the total number of days that the mean flow exceeded 1,000 cubic feet per second at Monticello. This showed that during the earlier period flow exceeded this amount an average of 44.6 days per year, and during the later period, 36.7 days per year. Although flows above 1,000 c.f.s. occur on only about 10 percent of the total number of days each year, turbidity records and studies in other drainage basins indicate that the highest 10 percent of the discharge transports the great bulk of the total sediment load.

The analysis was further extended by counting the number of days in which the mean flow fell within each increment of 1,000 c.f.s. above a minimum of 1,000 c.f.s. and below the maximum recorded flow of 15,400 c.f.s.

The number of days that flow exceeded 2,000, 3,000, 4,000 . . . 15,000 c.f.s. during each period of sedimentation record was then expressed as a percent of the total number of days during which flow exceeded 1,000 c.f.s. This percentage was plotted as a cumulative curve against the rate of flow. Frequency-duration curves of flow were thus derived for each period of sedimentation. These two curves are virtually identical, as shown in Figure 6.

The fact that the frequency of occurrence of these high discharges has been practically identical for each of the two periods of sedimentation, and that the total inflow was greater during the first period, leads to the conclusion that the higher rate of silting during the later period must be due to reasons other than the difference in the volume of flow or the frequency and duration of high flows.

Frequency and Duration of Low Flows

Records of the daily levels of Lake Decatur, which are available from 1927 to 1946, are shown in Figure 7. It is obvious that when the lake level is receding below spillway crest more water is being taken from the lake (for consumptive use and by evaporation and other losses) than is flowing into it. Since the purpose of an impounding reservoir is to store water during periods of high stream flow for use during periods of low flow, the reservoir is actually needed only when this "reserve" must be used to supplement the inflow. When this condition exists

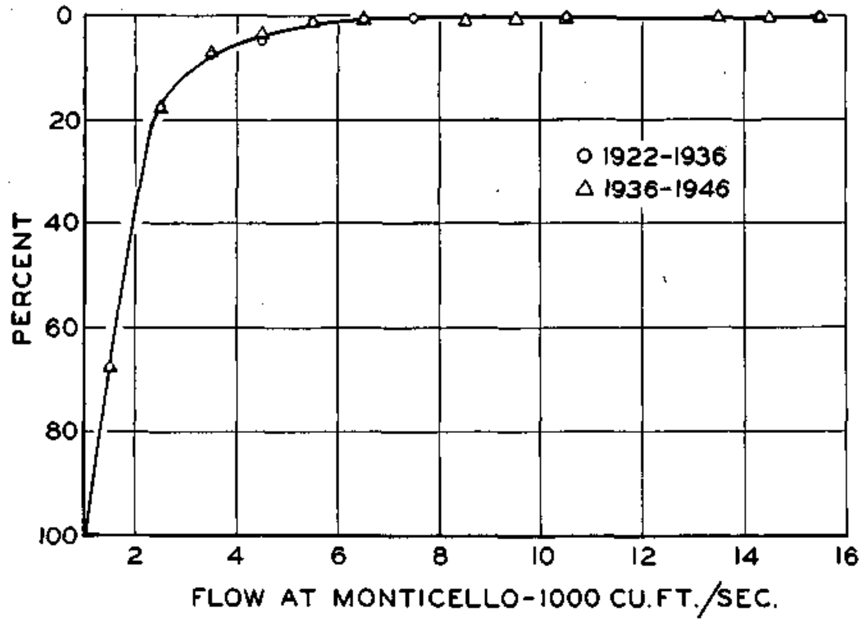

FIG. 6.—Flow - Duration curve for Sangamon River at Monticello, Illinois.

the lake level is below spillway crest and is falling. A water deficiency will occur if the reservoir lacks sufficient capacity to supply all requirements during the entire period until inflow again exceeds use, evaporation and other losses. During the period when inflow exactly equals the average demand, the hourly variation in water consumption could cause a water shortage to exist were the reservoir not present to equalize the supply, so this period is also included in the critical period of reservoir usage.

It is during periods of reservoir draw-down that the volume of sediment in the lake causes, or will ultimately cause, a deficiency of water supply by occupying space that would otherwise be filled with water. That portion of the original capacity of the reservoir which is filled with sediment would have been available for storage of an equivalent volume of water during high-flow periods, but, instead, this water has been lost over the spillway.

Figure 7 shows that the two most prolonged low-flow periods since 1927 occurred in 1940-1941 and in 1944-1945. These are the only periods when the lake level receded more than two feet below spillway crest. The next most pronounced periods of draw-down were in 1930-1931 and 1936 when the level receded 1.6 feet. To determine the length of these critical periods a count was made of the number of days the reservoir was actually needed, as defined above, and also of the number of days that inflow was equal to use plus losses, or that the lake level remained constant at or below spillway crest. The sum of

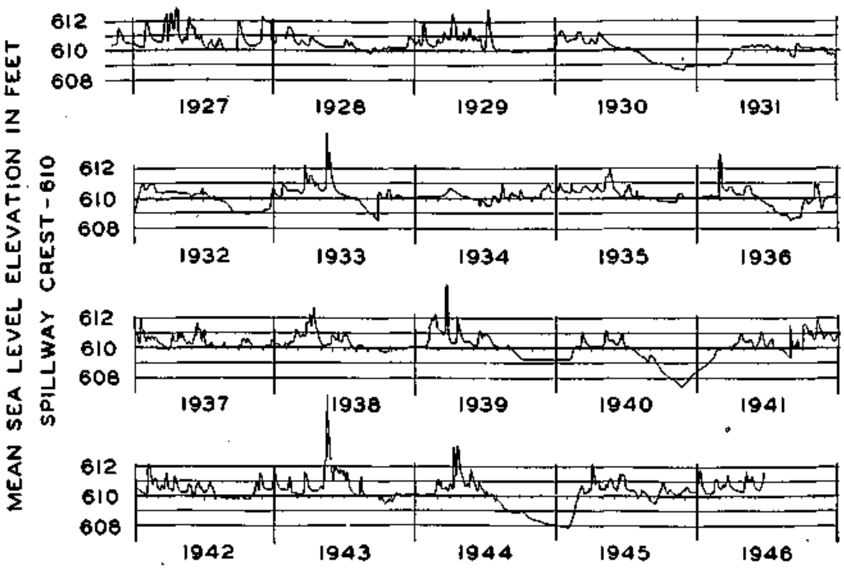

FIG. 7.—Water levels in Lake Decatur.

these two gave the length of the critical period of reservoir usage for each year in days. The length of the critical period was found to be 183 days in 1944 and 195 days in 1940, or slightly more than six months in each case.

Analysis of the stream flow records from the Monticello gaging station shows that there have been seven periods since 1908 of six consecutive months in which the total stream flow at Decatur was materially' less than the predicted water use and losses from Lake Decatur as of 1955. In four periods the low flow lasted for seven consecutive months and in one period for eight months. As shown in Table 7, the six-month low-flow periods ranked from most severe to least severe occurred in 1914-1915, 1930-1931, 1944-1945, 1908-1909, 1940-1941, 1916-1917 and 1920. As the period of record covers approximately 36 years it might be assumed that the 1914-1915 low flow has a statistical frequency or recurrence interval of once in 36 years, whereas the 1920 flow has a frequency of approximately once in 5 years, having been equaled or exceeded seven times in 36 years. In such a scale, based only on the record available, the 1940-1941 flow has a frequency of about once in 7 years, the 1944-1945 flow once in 12 years and the 1930-1931 flow once in 18 years; The probable explanation of the smaller draw-down of the lake in 1930-1931 lies in the smaller consumption of this year, possibly in combination with smaller evaporation, which is known to vary widely from year to year with fortuitous climatic events.

TABLE 7.—FLOW OF SANGAMON RIVER AT DECATUR, ILLINOIS[1]

	1908–09	1914–15	1916–17	1920	1930–31	1940–41	1944–45
	Ac.-ft.	*Ac.-ft.*	*Ac.-ft.*	*Ac.-ft.*	*Ac.-ft.*	*Ac.-ft.*	*Ac.-ft.*
July		807		4,362		3,054	
August	1,339	363	1,248	1,025	362	1,329	1,268
September	651	641	746	1,060	353	242	1,119
October	740	446	1,177	782	561	342	953
November	1,266	540	1,482	1,227	855	1,001	1,129
December	1,441	812	1,593	1,786	1,178	1,836	1,065
January	1,704	771	1,887		887	3,084	1,025
February			1,869		916		
March					1,983		
Total 6 months[2]	7,141 (4)	3,573 (1)	8,133 (6)	10,242 (7)	4,197 (2)	7,804 (5)	6,559 (3)
Total 7 months		4,380 (1)	10,002 (3)		5,113 (2)	10,888 (4)	
Total 8 months					7,096 (1)		

[1]U. S. Geological Survey stream flow records from Sangamon River at Monticello, Illinois, in mean c.f.s. for each month converted to monthly flow at Decatui in acre-feet on the basis of proportional watershed areas (x 1.65).

[2]Number in parenthesis shows rank in series.

USE OF THE RESERVOIR

The two chief consumers of water from Lake Decatur are the city, which has an intake at the dam, and the A. E. Staley Manufacturing Company, which has an intake about three miles above the dam. Water is also withdrawn by the Archer-Daniels-Midland Company, which has an intake about nine miles above the dam, but it is used only for condenser cooling and is all returned to the lake.

Records from meters of the city waterworks show the amount of water taken from the lake monthly for the period 1933-1946. Monthly records of the A. E. Staley Company for the period 1936-1946 are based partly on meter measurements and partly on estimates. The records show, however, the amount of water returned to the lake as well as the total raw water pumped from the lake, so they represent essentially the amount of water consumed.

The Archer-Daniels-Midland Company pumps about 85 million gallons per month. This pumpage has remained substantially the same from its beginning in 1939 to 1946. Although this usage does not represent a net loss of water and is not included in the total consumption figure for this report, operations dependent on this pumpage would not be possible if the lake were completely drawn down while inflow was negligible. This is also true of that part of the water returned by the A. E. Staley Manufacturing Company.

Figure 8 shows the upward trends in water consumption by the city and by the Staley Company, as well as the combined consumption or the total draft on the lake by months. A 3-year running average has been plotted to show the trends of these records. For the 7-year period for which the running average is shown, the total consumption of lake water has increased from 340 million gallons per month during 1937 to 428 M.G.M. during 1944. This is an average annual rate of increase of 12.5 M.G.M. This period includes, however, the industrial expansion at the beginning of World War II. The major increase in

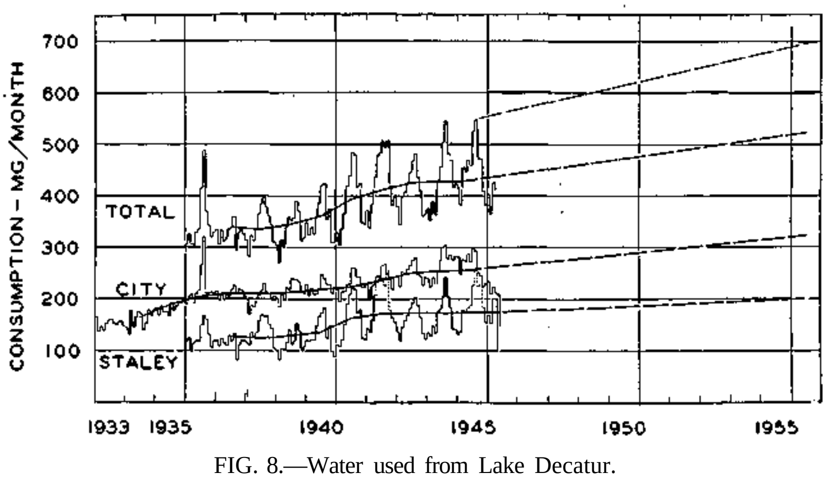

FIG. 8.—Water used from Lake Decatur.

consumption by the city occurred during 1942 and 1943 at an annual rate of 14 M.G.M., whereas the large increase in Staley's consumption, amounting to 26.5 M.G.M., occurred during the year 1941.

Prediction of Future Needs

In order to estimate the future rate of increase in water demand, the curves in Figure 8 were, extended to cover the next ten years. The city's consumption curve was extrapolated at the same rate as the average for the seven years, 1937-1944, which is an annual increase of about 6.2 M.G.M. This curve shows a rather uniform rise over the last seven years, and, so far as can be foreseen, this extrapolation should give a fair and possibly conservative representation of the future consumption of the progressive city of Decatur.

At the Staley plant the average annual rate of increase for the period 1937-1944 was 6.6 M.G.M. There was, however, an increase in consumption of 26.5 M.G.M. during the single year 1941. From that year until 1946 there was. practically no increase, the consumption having remained nearly constant, at an average of 175 M.G.M. In consideration of this fact and of lack of information on future plans of the company, the monthly consumption curve for Staley's was extrapolated at an annual increase of 2.5 M.G.M.

The composite curve shows an annual increase in total water consumption from the lake of approximately 8.7 M.G.M. This estimate, which is substantially lower than the 12.5 M.G.M. average rate of rise from 1937 to 1944, eliminates, in effect, the results of industrial expansion during World War IT. It is a forecast, therefore, of what is believed to be a normal rate of population and industrial growth comparable to that experienced in the late 1930's.

Figure 8 also shows that the monthly consumption varies considerably throughout each year. During the summer months more water is consumed both by city users and by the Staley Company. The chart shows also that the seasonal variation is greater at Staley's than at the city waterworks and that the difference between maximum and minimum monthly use is increasing slightly.

In 1941 the deviation of the maximum total monthly consumption from the 3-year running average was 22.8 percent, but in 1945 it had increased to 28.1 percent. The three years before 1945 were war years, however. It is thought that the deviation will not increase more than another 5 percent in the ten years for which the curves are extrapolated. This would mean a 33-percent deviation in 1955. With an estimated mean monthly consumption of 520 million gallons in 1955 and 33-percent deviation of the maximum from this value, it can be reasonably expected that the maximum monthly draft on Lake Decatur will reach 690 M.G.M. in 1955. A line has been drawn in Figure 8 from the 1945 maximum to this 1955 maximum to show this rise.

EFFECTS OF SEDIMENTATION ON THE USEFUL LIFE OF THE RESERVOIR

An increasing demand for water and a decreasing storage capacity, resulting from sedimentation, will some day result in a deficiency of water supply to meet all requirements. This deficiency will occur after months of low stream flow when the lake has been drawn down to the fullest extent possible to maintain the normal water supply. Figure 9 shows the predicted future effects of increasing water consumption and decreasing storage capacity with the recurrence of low-flow periods comparable to those of 1914-1915, 1930-1931, and 1944-1945, as well as an estimated minimum inflow against which it would seem prudent to provide a storage "reserve."

The uppermost horizontal line is at the level of the original reservoir capacity, 19,738 acre-feet. The volume of sediment line, based dn the surveys previously described, shows that 2,808 acre-feet of sediment had been deposited in 1936 and 5,171 acre-feet in 1946. The sediment curve is extended on the assumption of a continuing rate of storage loss of 1.2 percent annually.

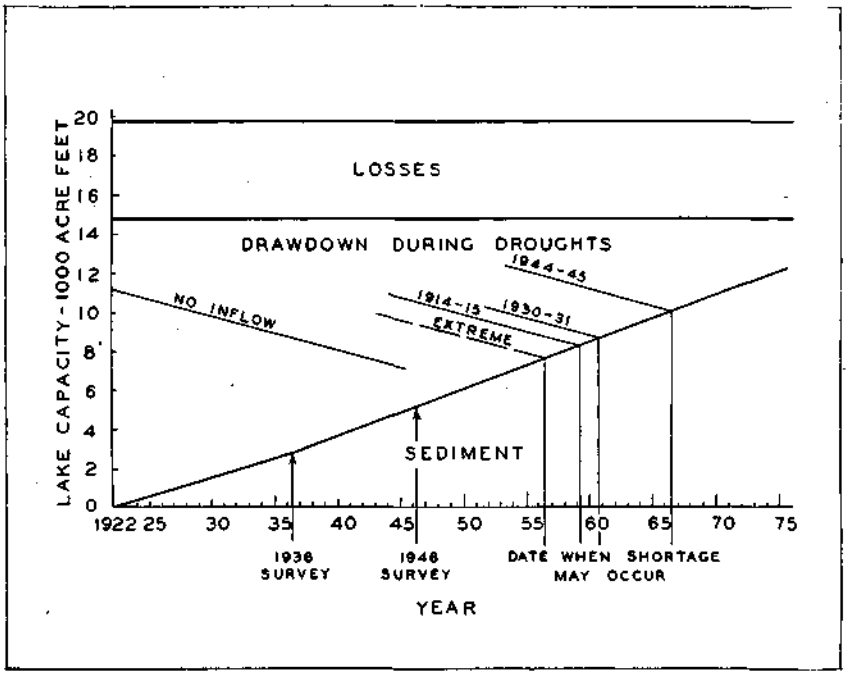

FIG. 9.—Effect of sedimentation on the useful life of the reservoir.

From records of stream flow, water use from the lake and draw-down the unaccounted water losses by evaporation and seepage were computed to be approximately 7,500 acre-feet and 3,200 acre-feet, respectively, for the 6-month low-flow periods in 1940-1941 and 1944-1945. Based on these data, a near-average value of 5,000 acre-feet was chosen for the purpose of this analysis as the average unaccounted loss during a

6-month dry period. This 5,000 acre-feet has been plotted to scale in Figure 9 as a deduction from the original 19,738 acre-feet. Thus, 14,738 acre-feet might be considered the net usable original capacity during a 6-month dry period.

The total consumption curve, extrapolated at the same rate of change as shown in Figure 8, is plotted in Figure 9 as a descending curve below the usable capacity. The distance between the consumption curve, at any point, and the original capacity represents the total demand (use plus losses) or the extent to which the lake would be drawn down during a 6-month dry period in any year, *provided* there were no inflow during this period. Inflow, however, does occur. The lowest flow recorded in 36 years for a 6-month period was during the dry season of 1914-1915 (See Table 7). In this drought season the estimated total flow at Decatur was only 3,573 acre-feet; the total flow of the second most deficient period, 1930-1931, was 4,197 acre-feet; and that of the third, 1944-1945, was 6,559 acre-feet. As the period of record covers only 36 years, however, it is statistically probable that inflow will be even less. On the assumption that the city would choose to guard against even smaller inflow than has been experienced, 2,500 acre-feet has been chosen by a rough extrapolation according to probability methods as a "minimum" expected inflow for a 6-month period. This drought probably would have a recurrence interval of once in 50 to 100 years. These low inflows have been plotted in Figure 9 above and parallel to the consumption curve as inflow represents a decrease in the volume of water that must be withdrawn from the reservoir to satisfy all requirements.

Figure 9 thus shows that if the estimated "minimum" inflow of 2,500 acre-feet should occur in any year after 1956, the reservoir would be called upon during this extreme drought to furnish more water than would be in storage. Similar calculations based on actual records of the 1914-1915, 1930-1931 and 1944-1945 seasons show that the reservoir would lack adequate capacity after 1959, 1960 and 1966, respectively.

This does not mean that the reservoir would be entirely useless in 1956 to 1966. It would, however, lack sufficient capacity to meet all estimated needs during such a prolonged dry period. To assure the continuity of an adequate water supply, it would appear that additional storage should be provided before 1956.

Expressed in other terms, the estimated increase in consumption is 180 acre-feet annually for the 6-month minimum flow period. The 10-year average annual rate of sedimentation is 236 acre-feet. *If* both rates continue, the storage requirements of the city will increase 416 acre-feet annually to offset the present storage loss and to meet new storage needs.

If no capacity had been lost by silting and the estimated rate of increase in consumption continued, the original 19,738 acre-feet of storage would have been sufficient to furnish the entire water-supply needs with the "minimum" 6-month inflow until the year 2000. This means that the reservoir could have been used for 78 years instead of 34 years, 1922-1956, before supplementary storage should be provided.

Moreover, even after 78 years the lake could have been continued in permanent use in connection with other storage.

It is believed that all assumptions made in the preceding analysis are conservative. Several factors could result in a water shortage at an even earlier date. These are (1) increased water demand due to a rate of industrial and population growth in Decatur greater than has been estimated, (2) continuance of the estimated present rate of storage loss (1.3 percent annually) or acceleration of the rate as a result of agricultural trends in the watershed, (3) even less inflow than 2,500 acre-feet during a 6-month period, or (4) unaccounted losses of more than 5,000 acre-feet. Furthermore, it is well known that evaporation losses are especially large in dry years, having a tendency to occur simultaneously with low inflows. The reverse operation of any of these factors would, of course, tend to extend the period during which the water supply would be adequate.

It should be understood that Lake Decatur will not be useless when it can no longer meet the full water demands on it. The remaining storage can always be used to meet water requirements up to the point of its exhaustion. But supplementary storage or other sources of water supply will be required to assure the continuity of full service. No progressive industrial city can long tolerate conditions under which its water supply may be inadequate every few years. Although there is no universally accepted standard for adequate water supply it would appear to be economically sound for industrialized urban areas dependent on surface water to aim at providing against deficiency during low flows that may be expected to occur more often than once in 50 to 100 years.

In estimating dates at which the reservoir capacity would be inadequate, it is not implied that the city can afford to wait for this danger point to start remedial measures. These dates were calculated from purely hydrologic considerations. In order to preserve the valuable recreational and esthetic values alone, it is important to seek measures for prolonging the life of the present lake. These measures should not only afford protection against an intolerable water shortage; but they should also preserve the esthetic values located at the doorstep of the city by reducing the rate of sedimentation in the lake and the consequent effects of more drastic lowering of the water level during dry periods.

Immediate substantial reduction of sedimentation in the present lake could be obtained only by constructing another reservoir upstream on the Sangamon River. A reservoir in such a location would, by increasing the low-water flow through regulated release, eliminate the need for heavy draw-down on Lake Decatur. Heavy draw-down is very detrimental to the recreational use and esthetic value of the lake. The only provident solution to the sedimentation problem, however, as shown in the section on Remedial Measures, is the control of soil erosion on the agricultural land of the drainage area.

ECONOMIC LOSSES FROM SEDIMENTATION

Sedimentation in Lake Decatur is causing three types of direct damage. These are: (1) premature loss of the reservoir's capacity to provide adequate water supply; (2) potential reduction in property values surrounding the lake; and (3) gradual reduction in recreational value for boating, fishing, etc. In the absence of corrective measures, other indirect losses will occur, such as loss of business and higher costs of production to industry in the city and to the agriculture of the surrounding trading zone.

The city can maintain its water supply by developing additional reservoir storage and by reducing the rate of loss of the present or future storage through assistance in the soil conservation program on the watershed area. There appear to be three economically feasible alternatives for developing additional storage (See pp. 52): (1) raising the present dam; (2) building several small reservoirs on tributaries to the present lake; and (3) building one or more larger reservoirs on the Sangamon River above Lake Decatur. If the 1936-1946 average rate of sediment production from the watershed continues, all three alternatives probably will have to be used within the next 100 years. Only a detailed engineering investigation of potential dam sites and a study of the financial aspects of future storage developments could determine the sequence in which these alternatives should be used.

Certain economic considerations should be recognized at this time. First, the construction of a sizable reservoir upstream from the present lake would be effective in shutting off probably 80 percent of the sediment now coming into Lake Decatur. Smaller reservoirs on the tributaries would shut off only 20 percent or less of the total sediment inflow. On the other hand, a complete soil conservation program on the watershed would reduce sedimentation by an estimated 62 percent (Seepp. 57). Because of the nature of the conservation job, however, probably 10 years of aggressive effort would be required to complete the application of conservation practices and needed conversions in land use and farm economy. As additional storage should be provided by 1956, before a conservation program could be fully effective, the protection of the present lake by an upstream reservoir should be given proper weight in considering the over-all practicability of the three alternatives for providing additional storage.

A second important consideration is the advancing cost of construction. Louis R. Howson has recently shown[8] that permanently higher construction costs may be expected. He presents construction-cost indices that show permanently higher costs result after every major war. For example, following the Civil War, construction costs never receded to less than 40 percent above those prevailing in 1860. Following the first World War, construction costs never receded to as much as 50 percent above those of 1913. Except for slightly more than a year, about 1922, and for a little more than 4 years, between 1930

[8]Howson, L. R. Permanently Higher Costs Here—Rate Increase Necessary. Water Works Engineering, Vol. 99, No. 12, pp. 684-687, 704-708, 1946.

and 1935, during the worst depression of record, construction costs were more than double those of 1913. As of April 1946, the construction-cost index stood at more than 330, compared with 100 in 1913. Between 1922, when Lake Decatur was built, and the early part of 1946, construction costs had increased 65 percent. This indicates that if Lake Decatur had to be replaced in 1946 it would have cost $168 per acre-foot instead of $102 per acre-foot of storage. Mr. Howson predicts that construction costs during the next decade will average 60 to 75 percent above those of 1939, and that even in time of a future depression will not recede to within 40 to 50 percent above the cost prevailing in 1939.

Lake Decatur was built during a short depression in 1922. Since that date costs have been lower for only a short period at the bottom of the major depression, in 1932-1933. Although the cost-index curve has had its advances and recessions throughout our history, the long-time trend has been one of constant increase. During the life of Lake Decatur to the date of the 1946 survey, the cost-index curve has had a straight-line increase equivalent to $2.75 per acre-foot per year. If this average straight-line increase continues, replacement of storage would cost $185 per acre-foot in 1956. If price trends follow past history, continued increases over a long-term period may be expected. Costs in any given year, however, are quite unpredictable. For the purpose of economic analyses, therefore, it has been assumed that all future replacement costs will average $200 per acre-foot, or approximately double the cost when Lake Decatur was built.

It should be recognized that in addition to increased construction costs future reservoirs may also cost more per acre-foot because of additional facilities required, and added operation and maintenance charges. For example, Lake Decatur is the most favorable site for the water-supply reservoir of the city. To get the same amount of water at the filter plant from more remote sites may require more capital outlay per acre-foot of storage. Certainly the cost of operating and maintaining two or more reservoirs instead of the present one will entail additional costs.. Therefore, it is believed conservative to evaluate future storage needed by the city at an average cost of $200 per acre-foot.

Several economic analyses have been made to estimate the expense that silting may cause the Decatur water supply during the century ending 2046. The present rate of storage loss due to sedimentation and the present rate of increase in consumption were assumed to remain constant. The rate of storage depletion for the ten years, 1936-1946, has been 236 acre-feet per year. At $200 per acre-foot replacement cost, this would amount to a loss of $47,200 per year for the next 100 years.

Replacement of storage would not be made year by year but would take the form of a series of remedial measures. For example, the city might first build a new reservoir similar to Lake Decatur upstream from the present lake. When, due to increased needs of the city and decreased storage due to sedimentation, this reservoir and the present Lake Decatur combined were no longer adequate, the present dam might be raised to provide more storage. As needs continue to rise and sedimentation continues to rob storage space, smaller reservoirs or tributary areas could be built. Still later a second upstream reservoir might be built.

Various replacement schedules were evaluated by converting the cost of each successive project into the amount of money that would need to be set aside now at 31/2 percent interest to accumulate an amount that would pay for construction when it is needed. This is the "present worth" of the project. The sum of these figures for projects in any schedule is the total present worth of that particular schedule.

The present worth of storage needed to take care of Decatur's growth was figured: (1) with sedimentation continuing at the present rate, and (2) with sedimentation eliminated. The second value is much smaller than the first because, without sedimentation, construction jobs are few and far between. The difference in the present values of these two schedules represents the cost of sedimentation to the city.

Lake Decatur is losing $47,200 worth of storage space each year. The city would have to invest $1,305,336 at 31/2 percent interest to provide $47,200 per year. It was found that this sum is less than the extra construction costs caused by sedimentation. The straight-line depreciation, $47,200 per year, is therefore a conservative measure of the annual damage to the water-supply use of Lake Decatur.

An estimate was also made of the monetary benefits from a practicable reduction in sedimentation through a soil conservation program. Sediment production cannot be stopped completely by conservation measures. It seems reasonable to assume that soil conservation measures can reduce the average rate of sediment accumulation from 236 acre-feet during the period 1936-1946 to 90 acre-feet per year by 1956, a reduction of 62 percent, and that sedimentation could be held constant at that figure for the succeeding 90 years. If such measures were applied, the annual silting damage to the lake would be reduced. This damage would average $32,600 during the first 10 years, and $18,000 during the succeeding 90 years. On a present worth basis, this reduction in sedimentation would save the city $27,400 annually for 100 years. Put another way, such a reduction in damage would justify an expenditure of two-thirds of a million dollars for soil conservation work now to preserve the water supply storage.

Silting is not only rapidly reducing the usefulness of the present lake to provide adequate water supply, but it is causing even more obvious effects by reducing the surface area of water, reducing the average depth of water, and increasing the amount of draw-down required during drought periods, thereby exposing unsightly marshes and mudflats. Although measures must be taken during the next 10 years to insure safety of the water supply, positive action should be taken even sooner to preserve the esthetic aspects of the present lake. The unsightliness of near-shore sediment deposits, the shoaling and swamping, the decreased accessibility from shore to deeper water, and the large area of the water too shallow for boating are all consequences of an advanced stage of reservoir sedimentation.

It is estimated that property values in the developed portion of the present lake-front area, which includes 15.4 miles of the shore line and contains about 2,000 acres, would decline 50 percent were the lake to lose its scenic and recreational attractions. With an estimated present value of $3,500 per acre, this loss would amount to $3,500,000. It has been further estimated that there are about 2,000 acres of partially-developed property not actually bordering the lake, but in the immediate vicinity, that would decline 25 percent in value. With an estimated value of $1,750 per acre, this would represent an additional loss of $875,000. Thus, the total depreciation of property values would amount to an estimated $4,375,000 when sedimentation in the lake has so advanced that the lake would be considered "undesirable" as a scenic and recreational area. If no reservoir is built upstream and no reduction of sediment production is achieved by conservation measures on the watershed, this condition would exist when, or before the lake had lost 80 percent of its capacity, that is, by the year 1990. For the 44-year period, 1946-1990, this loss would amount to an average of $99,432 per year. This depreciation may not actually be felt in this form, as many other conditions affect property values, but it is well-recognized that the value of lake-front property is enhanced by scenic and recreational considerations. It is presumed that these values would decline to equal or lower amounts if these considerations were eliminated.

The potential loss in property values should be considered in relation to its effect on the future tax base of the city. While it does not seem practicable to make monetary estimates at this time, it should be recognized that the city may be fully justified in taking remedial measures now, not only to protect its water supply, but to protect its tax base many years hence. Lake-front property, unlike some other locations, has a permanently enhanced site value if the lake is maintained, even though homes and other structures built on it may depreciate and be replaced.

Lake Decatur also has a recreational value to the community as a whole. This value is largely intangible, just as the value of a public park is intangible. While it is true that there is some revenue from recreational use of the lake, this serves mainly to cover operation and maintenance of recreational facilities. It is believed that it would be conservative to estimate, on the basis of the use now being made of the lake, that the city would be warranted in expending $40,000 per year to maintain the lake for recreation.

Although maintenance of property values and recreational use of the lake can be most rapidly achieved by construction of an upstream reservoir, this upstream reservoir must be protected against premature loss by sedimentation in order to protect the present lake. Whereas an upstream reservoir may trap 80 percent of the incoming sediment initially, as it becomes filled with sediment, more and more of the sediment load would pass over the dam and would settle in the present lake. It is estimated, therefore, that in addition to the $27,740 that the city is justified in spending annually on soil conservation measures to maintain its water supply, it is justified in spending $40,000 annually to maintain the recreational value, and a sizable additional sum to maintain property values and the tax base that they represent. Probably the sum total of justifiable expenditures would equal at least $100,000 annually to reduce sedimentation to 38 percent of its 10-year average, 1936-1946. The present value of such an annual expenditure over a 100-year period would be $2,765,543 at 31/2 percent discount. Since more funds are needed initially to establish conservation measures on the watershed and less in the future to maintain them, the city would be warranted in making larger appropriations for this purpose now and smaller appropriations in the future, in view of the benefits to be derived.

]t should be emphasized that not only the city residents have a stake in the maintenance of Lake Decatur, but that the farmers of the tributary area likewise have a large stake in maintaining a prosperous and growing city. The farmers over much of the watershed are dependent on the industries of the city as an outlet for their produce. Much of the soybeans and corn produced in the area are processed in Decatur. If such processing plants should be forced to move to other areas because of failure of water supply, greater shipping costs and other factors would result in a smaller net yield to the farmers. Furthermore, a growing city offers an outlet certainly not yet fully tapped by local farmers for meat and dairy products. Local markets alone offer opportunity for profitable conversion of land from row crops to pasture and for establishment of proper rotations. Although it can be shown (See pp. 22) that the adoption of conservation measures is profitable to the farmer without considering any indirect benefits, the farmers and landowners, many of whom are numbered among the city's population, should recognize that the indirect benefits resulting from protection of the city's water supply would warrant an added expenditure on the part of the farmer to maintain his markets and consumers.

CHARACTER OF THE WATERSHED

Topography and Geology

The Sangamon River drainage area above Lake Decatur covers a broad, gently undulating to rolling, glacial drift plain. In Piatt County, where topography is rather typical of the watershed as a whole, 73.9 percent of the land is nearly level (less than 2 percent slopes); 25.4 percent has slopes ranging from 2 to 15 percent; and only 0.7 percent has slopes greater than 15 percent. The headwaters of the Sangamon River rise upon the southern slopes of a low ridge, the Bloomington Moraine, which stands about 100 feet above the surrounding plain but because of the low regional relief is a relatively conspicuous topographic feature.

From its point of origin near the small town of Ellsworth, east of Bloomington, the Sangamon River flows southeastward about 25 miles air line and then makes a nearly right-angle bend to flow southwestward about 50 miles to the vicinity of Decatur. The gradient is low, and the stream course meanders. At Decatur the valley has reached a mature stage of development. It has an average width of nearly one-half mile, and the floodplain lies 50 to 90 feet below the level of the upland. A belt of more rolling topography one to one and one-half miles wide on each side of the Sangamon River floodplain in Piatt County contains only 38.9 percent nearly level land; whereas 18.5 percent of the land has 2 to 5 percent slopes, 35.9 percent has 5 to 15 percent slopes, and 6.7 percent has slopes of more than 15 percent.

Geologically,[9,10] the drainage area is comparatively uniform and homogeneous. It is almost entirely covered by the Shelbyville till, a glacial formation that resulted from the advance of the southwestern salient of the Michigan glacial lobe in early Wisconsin (Pleistocene) time. Nearly everywhere the till is covered by wind-deposited loess, which attains thicknesses of as much as 4 feet in this area. Beneath the Wisconsin till are deposits of two earlier glacial periods, but their surface outcrop is limited. The Iowan-Peorian loess zone and the Sangamon gumbotil outcrop around the lake, and the older Illinoian till is exposed in steep banks near the State Highway 105 bridge and near the Decatur Country Club. No outcrops of still older formations are known in the watershed. Some fluvio-glacial sands and gravels in the form of valley-train and terrace deposits occur along the Sangamon River Valley.

Soils and Erosion

Erosion as related to soils has not been mapped over the entire drainage area of Lake Decatur. The Soil Conservation Service has mapped much of Piatt County, however, and this is believed to give a good representation of conditions in the watershed as a whole. Piatt County is about one-half as large as the drainage area above Lake Decatur. Although only about 58 percent of the county is within the drainage area, physical land conditions in the rest of the county are typical of the watershed, of which about 27 percent is within Piatt County (See Figure 1).

Soil conservation survey maps have been prepared on more than 100,000 acres in Piatt County. These maps give a physical inventory, showing soil types, percent of slope, degree of erosion, and present land use. Maps representing 15 percent of the entire county were selected at random from each of the so-called problem areas of the county, and the acreage of the various Land-Capability Classes was tabulated. This information was then projected to the entire county and is summarized in Table 8. This table shows that nearly three-quarters of the entire county consists of nearly level, highly productive soils, requiring no special erosion-control practices to maintain the soil for general agricultural purposes. Although these soils are not considered a problem for general farming in so far as erosion is concerned, it is probable that the relatively small loss per acre of soil removed in runoff and drainage water is an important part of the total sediment production of the drainage area. More than one-fourth of the land is in Classes II, **III,** and IV, on slopes ranging from 2 to 15 percent. Here a major sheet-

[9] Leighton, M. M. The Glacial History of the Sangamon River Valley at Decatur and its Bearing on the Reservoir Project: Illinois State Acad. Sci. Trans., Vol. 14, pp. 213-218, 1922.

[10] Leighton, M. M. and Ekblaw, G. E. The Glaciology of the Decatur Region (abstract): Illinois Acad. Sci. Trans., Vol. 27, No. 2, p. 111, 1934.

erosion problem exists. Land in these classes is widely distributed, and it probably produces most of the sediment reaching Lake Decatur.

TABLE 8.—CLASSES OF LAND IN PIATT COUNTY

Land-Capability Classes	Entire County	Rolling Area adjacent to Sangamon River
	percent	*percent*
Class I Land		
Nearly level, less than 2% slope; dark colored, highly productive soil. Land suitable for cultivation, requiring no erosion-control practices to maintain soil for general agricultural purposes.	73.9	38.9
Class II Land		
Gently sloping, less than 5%; productive soil. Good land that can be cultivated safely with easily applied practices.	19.4	18.5
Class III Land		
Sloping, less than 10%; moderately productive soil. Moderately good land that can be cultivated safely with such intensive treatments as terracing and strip cropping.	4.8	29.1
Class IV Land		
Strongly sloping or eroded land. Slopes up to 15%. Best suited to hay or pasture, but can be cultivated occasionally, usually not more than 1 year in 6.	1.2	6.8
Class VI Land		
Steep or eroded land, not recommended for cultivation. Best suited for permanent pasture land.	0.5	3.8
Class VII Land		
Very steep or eroded land. Suited for woodland or pasture with major restrictions in use; needs extreme care to prevent erosion.	0.2	2.9
Total	100.0	100.0

A separate analysis was made of the more rolling part of Piatt County, which occurs in a belt about one to one and one-half miles wide adjacent to the Sangamon River (See Table 8). In this belt slightly less than two-fifths of the land is nearly level, whereas three-fifths is on slopes of 2 to 15 percent and is eroding moderately to severely.

Land Use and Conservation

The Sangamon River watershed lies in a rich and productive agricultural area in the heart of the Corn Belt. Except for urban areas, roads, railroad rights-of-way, etc., practically all of the land in the drainage area is in farms, and a high proportion of farm land is in cultivated crops. In Piatt County in 1943, 30.9 percent of the land was planted to corn; 33.5 percent to soybeans; 10.9 percent to small grain, mostly oats and wheat; and 14.6 percent was in hay and plowable pasture, 2.0 percent in woodland, and 8.1 percent in other uses including urban areas, farmsteads, roads, idle land, etc. In the six counties, Champaign, DeWitt, Ford, Macon, McLean, and Piatt, to which the Sangamon River drainage area above Lake Decatur is wholly confined, 60 percent of all the land was planted to corn and soybeans in 1945.

In the entire drainage area there are 3,270 farms, of which 62 percent, embracing 72 percent of the land, are operated by tenants.

A number of agencies have been active during the past 15 years in promoting the control of soil erosion and the conservation of soil and water resources in the Sangamon River drainage basin. The history and present status of these efforts is summarized on pp. 00. The war, with the consequent need for heavy crop production, attended by manpower and material shortages, slowed the tempo of conservation work that might otherwise have been accomplished in the watershed. The records show that as of July 1, 1946, complete conservation plans had been prepared for 307 farms, embracing 24,343 acres, or 4.2 percent of the drainage area. About one-half of the conservation work planned on these farms has been established on the land. The practices and amounts established to that date are as follows:

(1) Contour planting 14,512 acres; (2) Strip cropping 495 acres; (3) Terracing 440 acres; (4) Pasture improvement 4,044 acres; (5) Tree planting 20 acres; (6) Woodland protection 265 acres; (7) Dams 50; (8) Waterways 649,808 linear feet; (9) Diversions 1,730 linear feet; (10) Tile 180,323 linear feet; (11) Open ditches 19,344 linear feet; (12) Farm ponds 6.

Sources of Sediment

Analysis of turbidity and stream-flow records has shown that sediment comes rather uniformly from all parts of the drainage area, even those parts most remote from the lake (See pp. 28). This fact has been confirmed by repeated observations of many experienced conservationists. Observations in the watershed on June 13, 1946, are illustrative.

On the night of June 11, 1946, after several days of hot sultry weather, a severe thunderstorm struck the area. The downpour began at Decatur about 9:30 P.M., and rain fell intermittently throughout the night. A rain gage at Monticello near the middle of the area registered 0.95 inch. The following day was clear, but during the night of June 12 another electrical storm occurred. At the Monticello gage 0.73 inch of rain was recorded in 20 minutes. Soils everywhere in the watershed, already wet to saturated near the surface from the previous night's rain, were severely eroded, even on relatively gentle slopes. Sheet erosion was evident in almost every cultivated field. As much as 4 inches of soil was eroded from some field drainageways (See Figure 10). Deposits of soil behind fences at the lower edges of many fields amounted to several feet (See Figure 11).

FIG. 10.—Sheet erosion in cornfield near Monticello, Illinois. June 13, 1946.

FIG. 11.—Sheet erosion and deposition above fence near Parnell, Illinois. June 13, 1946.

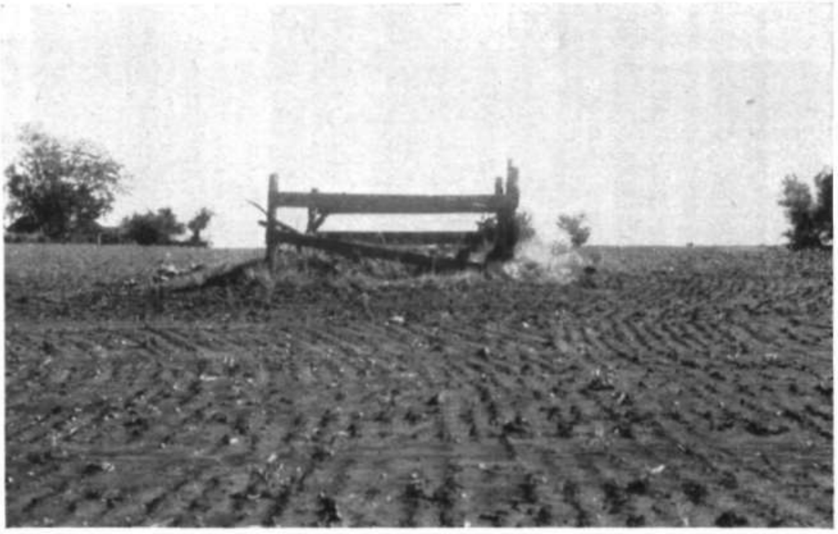

FIG. 12.—Sheet erosion in field surrounding abandoned well showing depth of soil removal near LeRoy, Illinois. June 13, 1946.

FIG. 13.—Gully erosion on strongly rolling land near Sangamon River.

Water in the main stream and its tributaries to their extreme headwaters was highly turbid. Even the water flowing from the tile drainage outlet one-half mile north of Ellsworth, which is the beginning of the Sangamon River, was very muddy, doubtless because of surface flow into broken tile lines in the field above.

Marked contrasts between the black soil on the flatter land and the light-brown soil on the steeper slopes of the fields are evidence of widespread sheet erosion throughout the watershed. Figure 12 shows the extent of topsoil loss in a gently sloping corn field surrounding an abandoned well near Leroy. The grass sod around the well has maintained the soil at its original level while one-half to one foot of soil has been washed from the surrounding field. Conservation surveys on scattered farms throughout the watershed have fully confirmed these observations.

Gully and channel erosion is locally conspicuous, though not particularly widespread, in the belt of rolling land bordering the Sangamon River Valley and the principal tributaries. Many of these gullies have raw steep banks, and erosion appears to be active. However, study in 1946 of severely gullied fields that were examined and photographed in 1936, revealed that the volume of soil lost during ten years was not large (See Figure 13). Considering the extent of soil loss in the areas studied and the relatively limited extent of gully erosion in the watershed, it is concluded that this type of erosion furnishes only a small percentage of the annual sediment production from the drainage area.

Stream-bank erosion is negligible. It has been estimated (pp. 25) that wave erosion along the shores of Lake Decatur furnishes between 1.5 percent and 6.6 percent of the total lake deposits, but probably nearer to the lower value.

The similarity in organic content and mechanical composition of the lake sediments and black prairie soils of the flatter land (see pp. 23) gives further confirmation that sheet erosion on clean-tilled fields is the principal source of reservoir sediment.

In the light of all available evidence, therefore, it is concluded that at least 90 percent, and probably more, of the sediment originates from sheet erosion on cultivated land, mainly corn and soybean fields on slopes of 2 to 15 percent. Such land is widely distributed throughout the drainage area. Gully and channel erosion, stream-bank erosion and wave erosion on the lake shores account for 10 percent or less of the total sediment.

CAUSE OF INCREASE IN THE RATE OF SEDIMENTATION

The rate of sediment production from the Sangamon River drainage basin, as determined by the Lake Decatur surveys, should be classed as moderate in a scale of rates determined from all sections of the country. After addition of the estimated 22-percent sediment loss over the dam, a total sediment production of 28 acre-feet per 100 square miles per year for the period 1922-1936, and 33 acre-feet for the period 1936-1946, is indicated. Drainage areas of equal or larger size have been found to produce sediment at rates (expressed in acre-feet per 100 square miles per year) ranging from less than 10 A.F. in well-forested regions of New England and the Upper Mississippi Valley to 25-30 A.F. in the Ozark Mountain area of Missouri and Oklahoma, 40-50 A.F. in the Southern Piedmont, 45-90 A.F. in the prairies and plains of Texas, and 200-300 A.F. or more in the arid areas of the Rio Grande and Colorado River basins of the Southwest.

With comparable land use, rates of sediment production are generally higher in smaller drainage areas, in areas of steeper topography and in the regions south of Illinois because of the longer season without snow and frost during which the soil is subjected to erosion. Watersheds of a few square miles in the Blacklands of Texas, for example, have produced sediment at rates equivalent to more than 500 acre-feet per 100 square miles annually during long periods.

The moderate rate of sediment production from the Sangamon River drainage area should not be confused with the high rate of storage loss by sedimentation in Lake Decatur. The annual loss of storage (in percent of original capacity) depends not only on the rate of sediment production from the watershed but also on the capacity of the reservoir. Obviously, if Lake Decatur had been built twice as large, its capacity would have been reduced at only half the present rate. For example, during the period 1922-1936 the annual sediment inflow was 198 acre-feet, which reduced the original capacity of 19,738 acre-feet by 1.00 percent annually. If the original capacity had been twice as great, however, the annual loss would have been only 0.50 percent.

With this interpretation of the significance of measured rates of sediment production and of capacity loss in the reservoir, it is pertinent to consider the cause or causes of the 20-percent increase in the average rate of sedimentation for the 10-year period, 1936-1946 as compared with the 14.2 year period, 1922-1936. Analysis of streamflow data indicated that the increase could not be attributed to climatic differences (See pp. 29). The average annual flow and the average number of days of flow exceeding 1,000 c.f.s. were slightly larger during the earlier period. The flow-duration curves for the two periods are virtually identical.

On the other hand, a study of land use changes in the drainage basin, in conjunction with experimental data[1] on the effects of various land uses on erosion, leads to a logical and apparently conclusive explanation of the increased sedimentation. Figure 14 shows the trend in land use in Piatt County, which is considered typical of the drainage area as a whole. The heavy line separates the intertilled, erosion-producing crops, corn and soybeans, from the erosion-resisting small grains, pasture and other uses. In 1924 only 39 percent of the area of the county was devoted to intertilled crops; in 1943 64.4 percent was in these crops. The marked increase in acreage of intertilled crops after 1934 was due mainly to expansion in production of soybeans. This spectacular increase in intensity of land use for erosion-producing, cash crops is the only apparent cause of the increased rate of sedimentation in Lake Decatur.

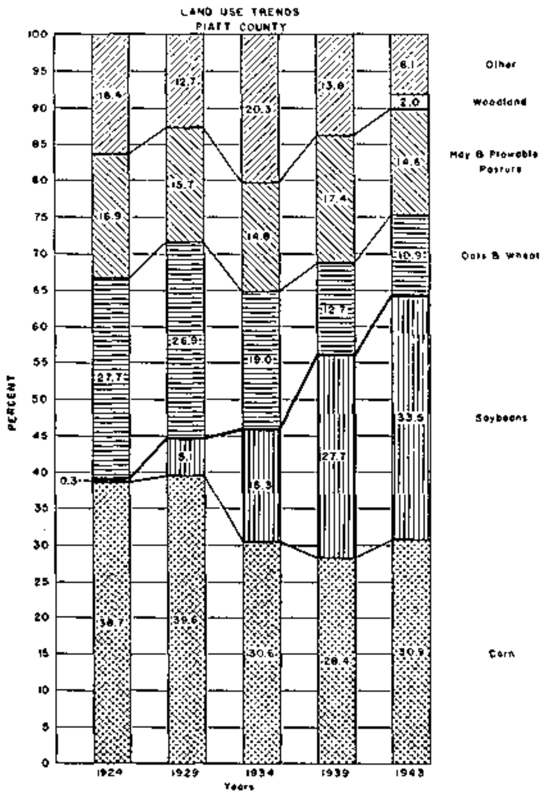

FIG. 14.—Land use trends in Piatt County.

Land use data for each of the six counties in which the watershed lies show the same trend. The acreage planted to corn and soybeans in these counties has increased from 41 percent of their combined area in 1922 to 60 percent of their area in 1945. In every county the increase has been due to expansion of acreage in soybeans. In 1922 only 30,365 acres in all six counties was planted in this crop; in 1945, 614,700 acres was in soybeans, a net gain of 584,335 acres. Corn acreage declined from 1,043,800 acres in 1922 to 951,800 acres in 1945, a net loss of 92,000 acres. If it is assumed that all of the net loss in corn acreage was replaced by soybeans, there remains 492,335 acres now in soybeans (19 percent of the total land area in the six counties) which was used in 1922 for small grain, hay, pasture, and other purposes engendering far less soil erosion.

Although only meager experimental data on soil erosion are available for this area, the results of plot studies at the University of Illinois are indicative of the effects of land use.[11] Four plots on a 2-percent

[11] Van Doren, C. A., and Stauffer, R. S. Summary of Contour Farming Study. Ill. Agr. Exp. Sta. and Soil Conserv. Serv. June 1946 (mimeographed).

slope were established in 1940 on the Agronomy Farm at Urbana by the Illinois Agricultural Experiment Station and Soil Conservation Service to study soil and water losses. During the period 1941-1945 one of these plots planted in corn up and down the slope—the prevailing practice in the Sangamon River area—lost 7,290 pounds of soil per acre annually. The loss ranged from 13,771 pounds in 1941 to 2,922 pounds in 1943. An adjacent plot in oats lost 1,699 pounds of soil annually during the same years. In 1945 an additional plot planted in soybeans lost 4,042 pounds of soil. While no measurements were made on grass-sod plots, observations here and data from other experiment stations indicate losses of only a few pounds per acre per year from land in good sod cover. These data,, although fragmentary, are indicative of the erosion hazard resulting from major shifts in land use from pasture and small grain to intertilled corn and soybeans.

It should also be noted in Figure 14 that the rate of increase in intertilled-crop acreage has risen sharply since 1934. This trend is confirmed by data on all six counties. The rate of sedimentation most recently measured in Lake Decatur is an average for the period 1936-1946. It is probable that this rate actually has been increasing in proportion to the increased use of land for intertilled crops. The present rate of storage loss for a normal runoff year may be approximately 1.3 percent annually. The rate in future years will depend (1) on the trend in land use, that is, whether intertilled-crop acreage further increases, levels off or declines, and (2) on the speed of application of soil conservation practices.

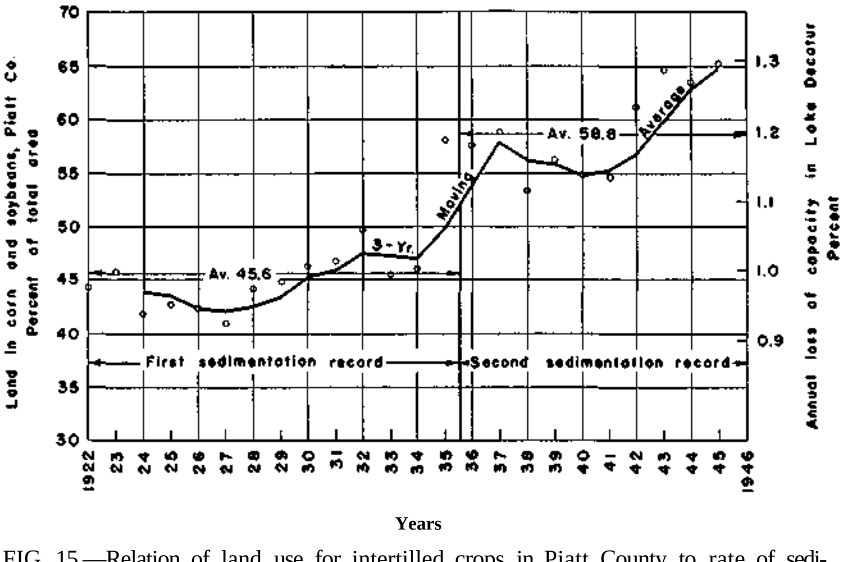

FIG. 15.—Relation of land use for intertilled crops in Piatt County to rate of sedimentation in Lake Decatur.

The extent of soil conservation measures and practices thus far applied on the land in the drainage area (see pp. 45) is not enough to have any significant effect on the rate of sediment production. As of July 1, 1946, conservation measures had been planned on farms embracing only about 4.2 percent of the total area of the watershed, but only about one-half of the planned work had been accomplished on the land. Even if these practices completely controlled erosion where applied, their limited areal extent would have resulted in a net effect so small that it could not be detected by reservoir surveys.

REMEDIAL MEASURES

Dredging

Removal of sediment from Lake Decatur by dredging does not appear to be economically feasible at present as a means of maintaining storage for water supply. It is obvious that removal of one cubic yard of sediment from the lake by dredging will provide only one additional cubic yard of storage capacity. The movement of a cubic yard of earth, however, for raising the present dam or building another dam, might be expected to furnish as much as 50 cubic yards of additional storage. The overall costs of the two operations may not be much different. Therefore, dredging compares very unfavorably with the cost of new reservoir construction. On the other hand, at some later date the esthetic and recreational value of the lake, because of its location at the edge of the city, may warrant a certain amount of dredging for maintenance of values other than water supply.

Dredging also creates the problem of disposal of the dredged material. A considerable area of land would be required for dumping any quantity of dredged material. Flat lands on which such materials could be deposited without extensive dyking are not available at reasonable price near the reservoir because of its proximity to the city. Long haulage or pumpage of this material would be very expensive. Furthermore, it is doubtful if any of the land on which such material could be deposited would be much, if any, improved in fertility by the addition of the lake sediment. Deposition of dredged material in locations where it might wash back into the lake would represent a waste of effort and funds.

Raising the Dam

It is estimated that if the present spillway were raised two feet, the storage capacity of Lake Decatur would be increased by approximately 5,400 acre-feet. Such a permanent rise in lake level would, of course, necessitate considerable modification or reconstruction of existing installations near the present water line. It would require also an extended program of new riprapping to protect lake shores from erosion at the new level. It is uncertain as to whether the spillway could be raised more than two feet owing to extensive improvements around the lake, land ownership, flowage rights, and other factors.

All costs involved in raising the spillway should be determined and evaluated in the light of expected benefits and in comparison with alternative methods of maintaining the water supply. At the average rate of sedimentation during the period 1936-1946, 5,400 acre-feet of storage will be lost in slightly less than 23 years. Actually, however, because of the increasing rate of consumption this much added storage in Lake Decatur would prolong the period of safe storage "reserve" against the estimated "minimum" 6-month inflow by only 13 years (from 1956 to 1969). This can be tested in Figure 9 by raising the "extreme" inflow curve 5,400 acre-feet and observing its point of intersection with the volume of sediment curve.

Thus, raising the spillway two feet would be, in reality, only a temporary measure, a "breathing spell" of 13 additional years until a more permanent solution of the problem could be worked out.

New Reservoirs

Preliminary investigations of possible reservoir sites on the creeks emptying into the lower end of Lake Decatur have shown three sites where small reservoirs might be built.

On Finley Creek, approximately 4,700 acre-feet of water could be impounded. The expected runoff from a drainage area of 29.5 square miles would be large enough to fill the reservoir about three times per year.

On Sand Creek, approximately 3,700 acre-feet could be impounded and the expected runoff from a drainage area of 12.1 square miles would fill the lake about twice per year.

On Big Creek, approximately 2,700 acre feet could be impounded, and the reservoir would be filled about three times per year from a drainage area of 25.4 square miles.

Further investigation of these sites is probably warranted from the standpoint of developing supplementary storage to augment the present lake. The sedimentation surveys of Lake Decatur have shown, however, that considerable sediment is carried by these small creeks. The amount of sediment accumulated in the arms of Lake Decatur, which extend up these creeks, is equivalent to about 50 acre-feet per 100 square miles annually during the entire period of record. This is almost double the average rate for the entire drainage area of Lake Decatur. Even so, the rate of capacity loss in these smaller reservoirs would be much less than in Lake Decatur because of the larger ratio of capacity to watershed area.

The estimated total storage that could be developed if all three reservoirs were built amounts to only 11,100 acre-feet. The estimated increase in water consumption is now at the rate of about 2,000 acre-feet in 10 years (See Figure 9), whereas the storage loss in Lake Decatur was 2,363 acre-feet during the 10 years, 1936-1946. Thus, it is apparent that these three reservoirs combined could only prolong the period of "safe" water supply by a few years. It is estimated that before 1951 the city will need more than 11,000 acre-feet of storage to meet its full water requirements if the "minimum expected" inflow during a 6-

month "extreme" drought, period should be experienced. By 1970 the city will need about 14,500 acre-feet under the same conditions. At that date Lake Decatur could supply only 4,000 acre-feet after deducting losses. Thus, the combined storage of the three small reservoirs and of Lake Decatur would barely cover the estimated water-storage requirements.

Several possible reservoir sites exist on the Sangamon River above Lake Decatur. A feasible site may exist just above the present lake, but no investigation of this site has been made. A reservoir at this location would have the same general characteristics as Lake Decatur. Several sites farther up the Sangamon River were investigated in 1934[12] in connection with possible additional water supply for Champaign, Urbana and the University of Illinois. Feasible storage capacities at these sites range from less than half the original capacity of Lake Decatur to more than one and one-half times its capacity. A site in Section 15, T.20 N, R. 7 E., Champaign County, where the largest amount of storage could be developed, was found, however, to be geologically unfavorable.

Reservoirs at any of the upstream sites would be broad, shallow lakes similar to Lake Decatur. They would have large water losses from evaporation. Their rate of silting under present watershed conditions probably would range from about one-third to about equal that of Lake Decatur, depending on the ratio of capacity to watershed area. Upstream reservoirs would decrease the rate of silting in Lake Decatur but would themselves be subject to fairly rapid depletion of storage. Thus, in effect, sedimentation would be reduced in the present lake where it has proved to be very costly, and would be partially transferred to another site where, presumably, the expense to water-supply, property, and recreation would not be so great.

Soil Conservation

In preceding sections it has been pointed out that the city's water storage may be increased by raising the present dam or by constructing one or more additional reservoirs in the drainage basin above the present reservoir. This additional storage will be necessary some 44 years earlier than if no sedimentation had occurred in the present reservoir. Even though it will alleviate the threat of deficient water supply for a few decades, this storage too will be rapidly lost by sedimentation unless measures are taken on the land to control and reduce the rate of soil erosion. The ultimate solution of the water supply problem can be achieved only by proper coordination of the needs of the city and the needs of the land, that is, by planning the use, treatment and management of the land in such a way as to achieve lasting agricultural prosperity with the minimum of soil erosion. Already enough is known of the science of soil conservation to point the direction toward what can be and must be done to maintain the soil resources of this great agricultural area as well as the water resources of its streams.

[12]Preliminary Data on Surface Water Supplies. Illinois State Water Survey Division Bull. No. 31, 157 pp., 1937.

Reduction in the rate of sediment production will require both the correction of minor maladjustments in land use and the widespread adoption of crop rotations and other soil conserving practices. A small amount of land should be converted from row-crop use to a permanent cover of grass or trees. In Piatt County at present, 52.5 percent of the Class IV land (as classified in Table 8), 7.0 percent of the Class VI land, and 5.9 percent of the Class VII land are being cultivated. Although these classes of land together comprise only 1.9 percent of the total area of the county, they are undoubtedly areas of exceptionally large sediment production. All land in Classes VI and VII should be retired from cultivation, and land in Class IV generally should not be cultivated more often than about one year in six. In the rolling area along the Sangamon River, 10.2 percent of the Class VI land and 6 percent of the Class VII land is being farmed, whereas the recommended uses for these classes of land are permanent pasture or woodland.

In the watershed as a whole, however, the major problem in land use is not one of conversion, but rather one of reducing the intensity of land use for clean-tilled crops. The Soil Conservation Service found in 1946 that 82 percent of the cropland in Piatt County was being used for row crops, while 13 percent was in small grain, and 5 percent was in hay and plowable pasture. Agricultural experts recommend that no more than 50 percent of the land should be in intertilled crops in any one year, while 25 percent should be used for small grains and 25 percent for hay (largely legumes) and pastures. They recommend further that cropland (in general, Class I and II land) should be used in rotation involving two years of intertilled crops, one year of small grains, and one year of hay. The University of Illinois College of Agriculture recommends that the hay land should always include deep-rooted legumes. The establishment of such rotations will require the liberal application of limestone and fertilizer.

Besides these measures, additional supporting soil conservation practices should be established on the land in order to maintain permanently the soil productivity of the area and to reduce to a minimum erosion losses- which cause damage to downstream reservoirs and other resources. From its study of sample farms in Piatt County the Soil Conservation Service, with the assistance of the Board of Directors of the Piatt County Soil Conservation District, the County Farm Advisor and the Production Credit Supervisor, has estimated the extent of practices of various types required to complete the job of soil and water conservation and to achieve optimum erosion control in this area. This estimate is shown in the table on page 56.

Existing data do not permit a close estimate of the maximum reduction in sedimentation that might be expected from a complete soil and water conservation program covering the entire drainage area. Nevertheless, some speculation on the basis of findings in this investigation seems justified.

The average annual sediment production was 20 percent greater during the 10 years 1936-1946 than during the 14.2 years 1922-1936. It has been concluded that this rise resulted from progressive increase in the use of land for intertilled crops. Figure 15 shows the percentage

QUANTITY OF CONSERVATION PRACTICES NEEDED
PIATT COUNTY SOIL CONSERVATION DISTRICT

Practice	Unit	Amount	Practice	Unit	Amount
Cropland			*Pastureland*		
Contour planting	Acres	57,000	Terraces	Miles	77
Terraces	Miles	2,160	Diversions	Miles	49
Diversions	Miles	160	Ponds	No.	58
Grassed waterways	Miles	480	Concrete dams		
Concrete dams			(all kinds)	No.	71
(all kinds)	No.	350	Pasture improvement	Acres	21,170
Farm drainage			Liming	Acres	18,700
Tile	Acres	117,100	Fertilizing	Acres	20,700
Liming	Acres	151,200	Seeding	Acres	18,700
Fertilizing	Acres	173,000	Mowing	Acres	21,170
			Regulated		
Woodland			grazing	Acres	21,170
Tree planting	Acres	120	Brush control	Acres	1,900
Protection from			Farm drainage		
grazing	Acres	2,900	Tile	Acres	6,400

of land in Piatt County used for intertilled crops during the period of sedimentation record. The average use during the first period was 45.6 percent and during the second period 58.8 percent. The difference of 13.2 percent was responsible for an increase of 0.2 percent in the annual rate of storage loss in Lake Decatur. As the 1945 land use for row crops was 6.2 percent above the 10-year average, it is probable that storage loss in Lake Decatur is now occurring at the rate of about 1.3 percent annually. If much of the land converted in the last several years to row crops is on the steeper slopes and more erodible soils, as may well be the case, the rate may actually be somewhat higher. From data available, however, only a straight-line relationship can be assumed. If the recommended rotation systems were adopted, only about 116,000 acres, or 41.6 percent of the land in Piatt County, would be in intertilled crops in any year. This would reduce the intensity of land use for row crops to approximately the level of the years 1924-1927. Based on the assumptions involved in Figure 15, this change alone should reduce the sedimentation rate to about 0.92 percent annually.

Actually, as shown by experimental data from several sections of the Corn Belt, the recommended rotations may be expected to further materially decrease the erosion losses during the years of row-crop use. It has been found, in general, that a four-year rotation consisting of two years of corn followed by one year of small grain and one year of hay has the effect of reducing soil losses from corn in the first year following hay to about 50 percent of the loss experienced under continuous corn, whereas in the second year the loss is about 75 percent of that under continuous corn. The effect of the year of hay is essentially lost after two years; that is, soil loss from third-year corn following hay is practically the same as the soil loss under continuous corn. In a four-year rotation consisting of one year of corn, one year of soybeans, one year of small grain, and one year of hay, the soil losses from corn and soybeans are both about 50 percent of average soil losses of either of the row crops under continuous cultivation, particularly if soybeans are drilled in 7- or 8-inch rows instead of planted in rows and cultivated. The reduction in soil loss resulting from the use of proper rotations is in addition to the reduction obtained from decrease in the total acreage of land used for row crops.

Still further reduction in soil losses may be expected from applying additional supporting conservation practices, of which contour farming is very important. Experimental data from the plot studies at Urbana are indicative.[11] Two of these plots are farmed on the contour, and two are tilled up and down the slope. For the four years, 1941-1944, soil losses were almost twice as great from the corn and oats plots farmed up and down the slopes as from adjacent plots farmed on the contour. The corn plots showed an average annual soil loss of 7,290 pounds per acre from up-and-downhill cultivation as against a loss of **4,181** pounds from contour cultivation. The oats plots showed 1,699 pounds lost from up-and-downhill cultivation, and 1,015 pounds from contour cultivation. A record for 1945 only is available on the soybean plots, and this was a year of relatively low erosion. This record showed 4,042 pounds lost from the up-and-downhill cultivation, against 502 pounds lost from contour cultivation. More data are needed before valid comparisons can be made of the long-term differences between these two methods of cultivation, but the results thus far appear indicative of the large savings that would result from this simple change in farming practice.

The 57,000 acres of land recommended for contour planting in Piatt County is about equal to the acreage of land that would be in row crops on slopes of more than 2 percent in any one year. In addition, terraces and diversions, grassed waterways and soil-saving dams would aid materially in reducing the soil loss from fields and preventing erosional debris from reaching the main stream courses through which it could be transported to Lake Decatur. All of these measures have the effect of slowing down the movement of water and causing deposition of the soil before it reaches stream channels, as well as inhibiting the initial detachment of soil particles.

Although the indicated effect of recommended rotations is a reduction in soil losses of 37.5 percent to 50 percent, and the effect of contour cultivation is a reduction of 40 to 50 percent, these reductions are not wholly additive. On the basis of available evidence, however, it does seem conservative to predict that proper rotations, plus contour farming on all land for which it is recommended, plus terraces, grassed waterways and soil-saving dams as required, would reduce the soil losses by at least 50 percent in addition to the reduction obtained from decrease in the acreage of land devoted to row crops. This addititional 50 percent reduction in soil loss should reduce the rate of sedimentation in Lake Decatur to about 0.46 percent annually. This would represent a decrease to 35 percent of the probable present rate of 1.3 percent annually, or to 38 percent of the average rate of 1.2 percent annually during the 10-year perjod, 1936-1946.

Farm management studies in the Corn Belt have indicated a higher level of farm income with the recommended rotation system than with continuous cultivation of row crops. Over a long-term period it is probable that the total production of corn and soybeans grown for two years in a four-year rotation would be as great as under prevailing nearly continuous cultivation. On the whole, however, the recommended rotation system would require more livestock to utilize the added forage production, and therefore, some shift in the general farm economy.

Soil Conservation Districts. The means for achieving soil and water conservation on the Sangamon River drainage area are already at hand in the Soil Conservation Districts. A forerunner of these districts was the Erosion Control Demonstration Project established in 1933 in McLean County by the Soil Conservation Service in cooperation with the University of Illinois. This project was located at the head of the Sangamon River and was successful in demonstrating effective methods of controlling soil erosion on gently sloping Corn Belt land.

During the fall of 1941, meetings of representatives of farm groups were held throughout the watershed. At these meetings it was decided that the best long-range conservation program could be achieved through the organization of soil conservation districts in each of the counties of the watershed. By July 1, 1943, all six of the counties (Macon, Dewitt, Piatt, Champaign, Ford, and McLean) had organized districts through the democratic process of local petitions, followed by local elections of District directors in each county to manage the affairs of the District. At present 504,360 acres, or 87 percent of the watershed, including a much larger percentage of the agricultural land, is within organized Districts. These Districts have solicited and are receiving aid from the Soil Conservation Service, U. S. Department of Agriculture, and the cooperative Extension Services of the State and Federal Governments.

Through the efforts and cooperation of the Upper Sangamon Valley Conservation Service described later, the University of Illinois, county farm advisers, and Soil Conservation District Directors, the Upper Sangamon Valley Association was organized in the latter part of 1941. The Association consists of one district director and a farm adviser from each county in the watershed. Conservationists of the Upper Sangamon Valley Conservation Service act as executive secretaries to the Association. The Association meets every two months to interchange ideas and discuss problems and subjects of mutual interest.

The published objectives of the Association are (1) to promote the general welfare and security of families in the Upper Sangamon Valley (2) to promote an all-out effort to get conservation on the land by interesting all rural and urban people in taking cooperative action for conservation of soil and water, (3) to effect an interchange of ideas, methods, and suggestions among these counties, (4) to promote a clear understanding of problems common to both rural and urban people, (5) to assist in coordinating an educational program that will make both rural and urban people aware of proper land use and related problems and desirous of solving them, and (6) to enlist the assistance of all local, State, and Federal agencies which may be helpful in carrying out this program.

Upper Sangamon Valley Conservation Service. As a result of the findings of the 1936 investigation of sedimentation in Lake Decatur, the Decatur City Council came to recognize that a long-range farm-city program of conservation of natural resources in the Upper Sangamon Valley could benefit all of the people in the watershed and at the same time prolong the usefulness of Lake Decatur for water supply.

In June 1941 the city council employed two conservationists and established the Upper Sangamon Valley Conservation Service in the city's Public Property Department. The purpose of this service is to determine what the problems are, to assist farmers and land-owners to establish conservation on their farms, and to secure the assistance and cooperation of local, State, and Federal agencies to work with districts in carrying out a land use and conservation program in the watershed.

The city has been providing funds for advancing this program to the extent of approximately $12,000 a year.

The main assistance at first was helping all the counties to organize Soil Conservation Districts. After the counties had organized Districts, the Upper Sangamon Valley Conservation Service entered into co-operative agreements with each of the Soil Conservation District boards, under which the Service furnishes (1) assistance in preparation of district programs and work plans, (2) assistance with educational meetings, tours, publicity, and demonstrations, (3) assistance in making available educational materials which will help farm people to solve their erosion problems, and (4) assistance in helping farmers lay out conservation practices.

RELATION OF FINDINGS TO SURFACE WATER SUPPLY IN ILLINOIS

Out of 249 treated public water supplies in Illinois in 1940,[13] 107 were surface water supplies and 142 were ground water supplies. Of the 2,581,253 persons[14] in Illinois that rely on sources other than Lake Michigan, nearly half depend on surface water. The increasing need for use of impounding reservoirs for public water supply is shown by the 15-percent growth in number of these reservoirs from 1937 to 1944. In addition, a large number of surface water supplies are used by rail-roads and industries. As of 1944,[14] 62 cities and towns had impounding reservoirs. Most towns dependent on surface water supplies that are not located on Lake Michigan or the largest rivers, such as the Ohio, Mississippi, or Illinois, have found it necessary to provide storage for use during recurrent periods of low stream flow or drought.

It has been recognized for some years in Illinois and throughout the North Central States that ground water supplies were being rapidly developed to the limits of their capacity. The decline of ground water levels over a long period of years has been a common experience in many industrial areas from Ohio westward into Iowa. Investigations of several areas with declining water tables have pointed to over-

[13]Weibel, S. R. A Summary of Census Data on Water Treatment Plants in the United States. U. S. Public Health Service Public Health Reports, Vol. 57, No. 45, pp. 1679-1694. Nov. 6, 1942.

"Data on Illinois Public Water Supplies. Illinois Department of Public Health, Division of Sanitary Engineering, June, 1944.

development and over-draft as the principal cause. The further growth of some industrial areas dependent on ground water is already being impeded by lack of adequate supplies. It seems probable, therefore, that the next several decades will witness an increasing use of surface water supplies, which are still available and incompletely developed in most parts of the state. Generally, their development will require construction of impounding reservoirs. Increased use of surface supplies obviously will increase the importance of the sedimentation problem and will magnify the aggregate damages resulting from the annual loss of storage capacity.

The few investigations of reservoir sedimentation that have been made in Illinois all point to the seriousness of the sedimentation problem. A survey of Lake Calhoun,[15] owned by the Galva Country Club, located on Fitch Creek in Knox County, showed a storage loss of 4.38 percent annually during the period 1924-1936. This reservoir had lost 52.1 percent of its original capacity of 286 acre-feet during this period and is now (1946) practically full of sediment. Its drainage area is 13.03 square miles, and its capacity watershed ratio, abbreviated as C/W ratio, was 22 acre-feet per square mile, the same as that of Lake Decatur. The indicated rate of sediment production is equivalent to 96 acre-feet per 100 square miles, but allowing for significant sediment losses over the spillway, the total sediment production may be in the order of 120 ac.-ft./100 sq. mi.

A survey made by the Soil Conservation Service of the Pittsfield Reservoir located on the south fork of Panther Creek in Pike County showed an anual storage loss of 1.71 percent from 1925 to 1946. This reservoir of 367 acre-feet original capacity had an indicated sediment production equivalent to 354 acre-feet per 100 square miles from 1.8 square miles of drainage area. The C/W ratio was 199 acre-feet per square mile, which indicates that practically all of the incoming sediment was trapped. The sediment production from this small watershed is about twelve times that from the Lake Decatur watershed during virtually the same period of years.

A survey of Lake Bracken,[16] owned by the Chicago, Burlington and Quincy Railroad, located on Brush Creek near Galesburg in Knox County, and used for recreation as well as railroad water supply, showed a storage loss of 0.60 percent annually from .1923 to 1936. This reservoir had an original capacity of 2,881 acre feet and a drainage area of 8.62 square miles, giving it a very large C/W ratio, 334 ac.-ft./sq. mi., which means that practically all the incoming sediment was trapped. A large C/W ratio, however, also results in a relatively small rate of capacity loss. (It is obvious that for a given amount of sediment inflow, the larger the storage capacity of the reservoir the smaller will be the percentage of annual storage loss.)[17] Actually, the indicated rate

[15] Glymph, L. M., Jr., and Jones, V. H. Advance Report on the Sedimentation Survey of Lake Calhoun, Galva, Illinois. U. S. Soil Conserv. Serv. SCS-SS-16. 9 pp., illus., processed. Washington, D. C., May, 1937.

[16] Jones, V. H. Advance Report on the Sedimentation Survey of Lake Bracken, Galesburg, Illinois. U. S. Soil Conserv. Serv. SCS-SS-14. 10 pp., illus., processed. Washington, D. C, May, 1937.

[17] Brown, C. B. Aspects of Protecting Storage Reservoirs by Soil Conservation. Jour. Soil and Water Conserv. Vol. I, No. 1, pp. 15-20, 43-45, July, 1946.

of sediment production from the drainage area was equivalent to 200 ac.-ft./l00 sq. mi., as compared with 22 ac.-ft./l00 sq. mi. during the same period from the area above Lake Decatur.

A survey of West Frankfort Municipal Reservoir[18] located on Tilley Creek in Franklin County showed an annual storage loss of 0.81 percent from 1926 to 1936. This reservoir had an original capacity of 1,175 acre-feet and a drainage area of 3.54 square miles, which gives it a large C/W ratio of 332 ac.-ft./sq. mi. Its indicated rate of sediment production, however, is equivalent to 268 ac.-ft./lOO sq. mi. of drainage area, or twelve times as great as that of the Lake Decatur watershed.

In the development of surface water supplies, engineers commonly select the most favorable natural site for an impounding reservoir. The choice is usually dependent on proximity to the city, desirable geological conditions, adequate water yield from the drainage area and lowest cost per acre-foot of storage for development. Almost never in the past has the factor of sedimentation been given weight in either the selection of a site or the design of a reservoir. Yet, this factor may overweigh various other factors in the long-term economics of the project. Failure to consider sedimentation has been due largely to lack of quantitative information on its effects. More studies of the general type reported herein are urgently needed as a guide to sound planning for the most economical and efficient utilization of surface water supplies.

In planning new reservoir developments, three factors relating to sedimentation should be considered in addition to the usual site and water-supply factors. These factors are: (1) the ratio of the capacity of the proposed reservoir to the size of the drainage area, not only with respect to adequacy of water yield to meet all demands but also with regard to rate of capacity loss in the light of estimated sediment inflow; (2) the possibilities of protecting the reservoir through watershed treatment and soil conservation measures; and (3) the possible applicability of other measures of sedimentation control such as venting density currents.[19]

The data cited above indicate that reservoirs with relatively low C/VV ratios in agricultural sections of Illinois will have high rates of storage depletion. The smaller the total drainage area, the higher will be the rate of storage loss for a given C/W ratio, other factors being equal. The rate of sediment production from drainage areas of a few square miles may be six to twelve times as high as from drainage areas of a few hundred square miles, as shown by comparison of the measurements in Lake Bracken, Lake Calhoun, West Frankfort and Pittsfield Reservoirs with the data from Lake Decatur.

Under prevailing land use and agricultural practices, it would appear, on the basis of present information, that reservoirs with large drainage areas must have an original storage capacity of not less than 50 ac.-ft./sq.mi., and reservoirs with small drainage areas must have a storage capacity of several hundred acre-feet per square mile in order

[18]Jones, V. H. Advance Report on the Sedimentation Survey of West Frankfort Reservoir, West Frankfort, Illinois. U. S. Soil Conserv. Serv. SCS-SS-15. 9 pp., illus., processed. Washington, D. C., May, 1937.

[19]Brown, C. B. The Control of Reservoir Silting. U. S. Dept. Agr. Misc. Pub. 521. 166 pp., illus. Washington, U. S. Govt. Print. Off., 1943.

to assure a reasonably long and economic life.[17] With sedimentation surveys of a considerable number of additional reservoirs in the state, it would be possible to set up a definite scale of values as a guide to reservoir planning and design.

On the other hand, it should be recognized that the provision of a large amount of excess storage, over and above that needed to meet anticipated demands on the reservoir during its period of amortization, is a form of insurance against premature loss by sedimentation. It may be that this excess investment could be better spent in another way, namely, in reducing the rate of sediment production from the drainage area through aid to the soil conservation program.-[0] Expenditures for furthering soil conservation rather than for large excess storage capacity would have the double value of assuring much greater longevity of the water supply, and at the same time maintaining the agricultural productivity of the surrounding area on which the urban population is dependent in many ways.

Furthermore, expenditures for conservation of watershed lands tend to increase the purity and stability of water supply, enhance the esthetic appeal and protect property values of the lake area, and maintain the usefulness of the lake for recreational purposes by reducing the turbidity and deposition of silt bars which interfere with swimming, boating and fishing. To the fullest extent possible, therefore, the control of erosion on watershed areas should be planned and promoted by water users in this state in lieu of developing a great excess of storage.

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[20]Brown, C. B. Erosion Control on Watershed Lands. Jour. Amer. Water Works Assoc, Vol. 38, No. 10, pp. 1127-1137. October, 1946.