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AN IMPROVED METHODOLOGY FOR ESTIMATING FUTURE RESERVOIR STORAGE CAPACITIES: APPLICATION TO SURFACE WATER SUPPLY RESERVOIRS IN ILLINOIS

by
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INTRODUCTION

Intrastate rivers arc one of the main sources of surface water supply in Illinois. With the exception of the Illinois and Fox Rivers, intrastate rivers usually have very low flows during dry years. To ensure an adequate and dependable water supply, one of the following means is used: in-channel dams, which create storage reservoirs; low-channel dams (which create enough storage to meet a few weeks' demand during very low streamflow conditions) on rivers with relatively sustained flows; side-channel reservoirs to which water is pumped from rivers during moderate or high-flow conditions; and sometimes auxiliary or standby ground-water wells.

Currently there are more than 90 public water supply systems in central and southern Illinois that have generally poor ground-water resources and that rely partially or totally on intrastate rivers for water supply. A list of these public water supply systems is given by Singh *et al.* (1988). There are more than 80 in-stream impounding reservoirs that supply water to these water supply systems. The adequacy and reliability of these water supplies are therefore largely dependent upon the ability of these reservoirs to provide sufficient water storage during the critical dry periods. However, these surface water reservoirs face many problems that may result in the decrease of their safe yield and thus in an inadequacy to supply sufficient water in the next 10-40 years. Some of these problems are: a) increases in water demand because of increases in population, industry, or per capita water use; b) gradual loss of reservoir capacity and yield because of sedimentation in the reservoirs; and c) emerging recreational demands and demands for mandatory low-flow releases from the reservoirs for maintaining streamwater quality, ecology, and aquatic habitats.

To evaluate the future reliability of public water supply systems using intrastate rivers as their main source of supply, an inventory of the systems using intrastate rivers was done by Singh *et al.* (1988). Also determined in this study were the future water demands of investigated water supply systems based on population projections, historical water use, and anticipated trends in future water needs. What is needed therefore is an evaluation of current reservoir capacities and projections of future capacities in the next 10-40 years on the basis of historical data and reservoir sedimentation modeling. Only after that can we estimate the years when each water supply system may become inadequate under various drought scenarios. Then the systems which appear to be at high risk can be selected and further investigated to determine mitigative measures.

The purpose of this study was to develop an improved methodology for determining the future capacities of the water supply reservoirs for the next 10-40 years, based on the available data from reservoir sedimentation surveys. The results have also been used for capacity projections for the non-surveyed reservoirs that are being used for water supply.

Acknowledgments

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BACKGROUND INFORMATION

The sediment inflow rate into a particular reservoir is, in general, a function of the watershed characteristics such as drainage area, average land and channel slope, soil type, land management and use, and hydrology. The rate of storage reduction in a reservoir due to sedimentation usually depends on the rate of sediment inflow; type of sediment material (sand, silt, clay); consolidation rate of the existing sediment deposits; type of dam outlet structures; and operation of the dam.

Most small- and medium-sized in-stream reservoirs with overflow spillways are designed to impound 5-15% of the average annual streamflow, but about 75-90% of the incoming sediment is entrapped during the process. This is because the sediment concentrations are significantly higher towards the bottom of the lake, and when the floodwater flows over an overflow spillway, cleaner water is skimmed from the top of the lake. The ratio of the volume of trapped sediment in a reservoir to the volume of incoming sediment to a reservoir is usually referred to as the reservoir's trap efficiency. Several factors may affect the trap efficiency of a reservoir, including 1) capacity-inflow (C/I) ratio = acre-feet capacity per acre-foot of annual flow, since as the capacity of the reservoir gets larger less water is released downstream and a higher percentage of incoming sediment is trapped; and 2) compaction of the sediment deposits due to different reservoir operations. Normally ponded reservoirs with sediment deposits that are always submerged will have a smaller compaction rate than desilting basins and reservoirs with periodic drawdowns. If a reservoir is periodically lowered for maintenance or other purposes, then the sediment deposits are compacted faster than the natural compaction rate.

The sedimentation process is a very complicated phenomenon governed by several hydraulic and hydrologic variables. Unfortunately there is no analytical relation that can be used directly for estimating the rate of deposition or capacity loss in a reservoir, given all the relevant parameters. Because of that, reservoir sedimentation rates are based primarily on empirical relations, which are then calibrated by using field measurements. Therefore a reservoir sediment model and a computerized methodology were needed for analyzing the available data from reservoir sediment surveys in order to calibrate the empirical relations, and for estimating the future storage capacities of the water supply reservoirs based on the empirical relations. This study has two major parts. The first part involves determining a statewide pattern of reservoir sedimentation, based on the extensive reservoir sediment survey data collected in Illinois. The second part uses the results obtained from the first part of the study to estimate the sedimentation rates of the non-surveyed water supply reservoirs, and derives the future storage capacities of these reservoirs.

The models developed here for estimating the reservoir sedimentation and future capacity projections are based upon equations for storage continuity and stream sediment yield.

RESERVOIR SEDIMENTATION MODEL

Reservoir sedimentation surveys have been conducted for more than 100 reservoirs across the state of Illinois. This extensive data base was used to establish a pattern of reservoir sedimentation in Illinois by using the methodology explained subsequently. The sedimentation pattern was then used for estimating the sedimentation rate or relevant parameters used in the method, and finally for estimating the future- storage capacities of the non-surveyed water supply rescrvoirs. In order to perform any of the above tasks we use a storage balance (or continuity) equation. The storage continuity equation used in the development of the methodology is given by

$$C_0 = S \cdot \Delta T + C_T \quad (1)$$

where

C_0 = initial storage, or the design capacity of the reservoir at time T_0
S = annual reservoir capacity loss rate due to sedimentation
ΔT = time elapsed ($T - T_0$) in years
C_T = available reservoir capacity at time $t = T$

For the surveyed reservoirs the C_0 value is usually available. If C_0 is not available for a surveyed reservoir, the capacity estimate from the earliest sedimentation survey can be used for C_0, and T_O is taken as the year that survey was made. For the non-surveyed water supply reservoirs, C_0 values had to be estimated from several sources. S-ΔT gives the total capacity loss in ΔT years due to sediment deposition. S is not a constant value but changes from year to year due to fluctuations in the inflow and to changes in trap efficiency and sediment density. C_T values are usually estimated by the reservoir sediment surveys, and are used with C_0 to calculate the S values. For water supply reservoirs C_T usually indicates the projected capacity in year T, and it is estimated by using sufficiently small values of ΔT successively in equation 1. Through this procedure, all the parameters affecting S can be updated after each ΔT increment.

Reservoir Capacity Loss **Rate**

Reservoir capacity loss rate, S, is usually derived from stream sediment yields. One method of predicting stream sediment yields is by combining intermittent sediment concentration data with continuous discharge data in the form of a rating curve. The total sediment of the stream can then be estimated by convoluting the rating curve by the flow-duration curve of the stream. This method is applicable only if sediment concentration and discharge data are available for a particular location. The method used in this study for evaluating the stream sediment yield is a modified version of the

Upper Mississippi River Basin Commission (UMRBC, 1970) approach. The UMRBC approach describes the sediment yield of a stream as

$$Y = K \cdot A^{-0.12} \tag{2}$$

where

Y = sediment yield in tons per year per square mile of watershed area
K = a regional constant
A = watershed area in square miles

The reservoir capacity loss rate, S, in acre-feet per year can then be obtained as

$$S = \frac{Y \cdot A \cdot TE}{2178 \cdot \delta} \tag{3}$$

and by substituting equation 2 in equation 3, we get

$$S = \frac{K \cdot A^{0.88} \cdot TE}{2178 \cdot \delta} \tag{4}$$

where

TE = trap efficiency of the reservoir in percent
2178 = a conversion constant
δ = density of sediment in pounds per cubic feet

Regional constant K: The general distribution of the regional constant K over Illinois is given by Terstriep *et al.* (1982). K values represent the degree of severity of sediment deposition in a reservoir. The land resource areas (LRA) and their K values for Illinois are shown in Figure 1. However, preliminary investigations done in this study by using the reservoir sedimentation survey data, as well as equations 1 and 4, revealed that the variation of K values within a particular LRA may be quite significant compared to the values given in the figure. Therefore, the K values of all the reservoirs for which sediment surveys had been done were calculated by using the procedure explained in the following sections, and were taken as the basis for estimating the future storage capacities of the non-surveyed water supply reservoirs.

Trap efficiency: The trap efficiency (TE), given as a percentage of the volume of stream sediment retained in the reservoir, can be estimated by using Brune's curve (Brune, 1953). Brune's curve, as shown in Figure 2, correlates the trap efficiency of a reservoir to its capacity-inflow (C/I) ratio. If the C/I ratio is high, then less water and subsequently less sediment will be released from the reservoir, and the trap efficiency will be high. Brune's curve should be used for reservoirs operated with overflow spillways under submerged conditions. The trap efficiency of a reservoir

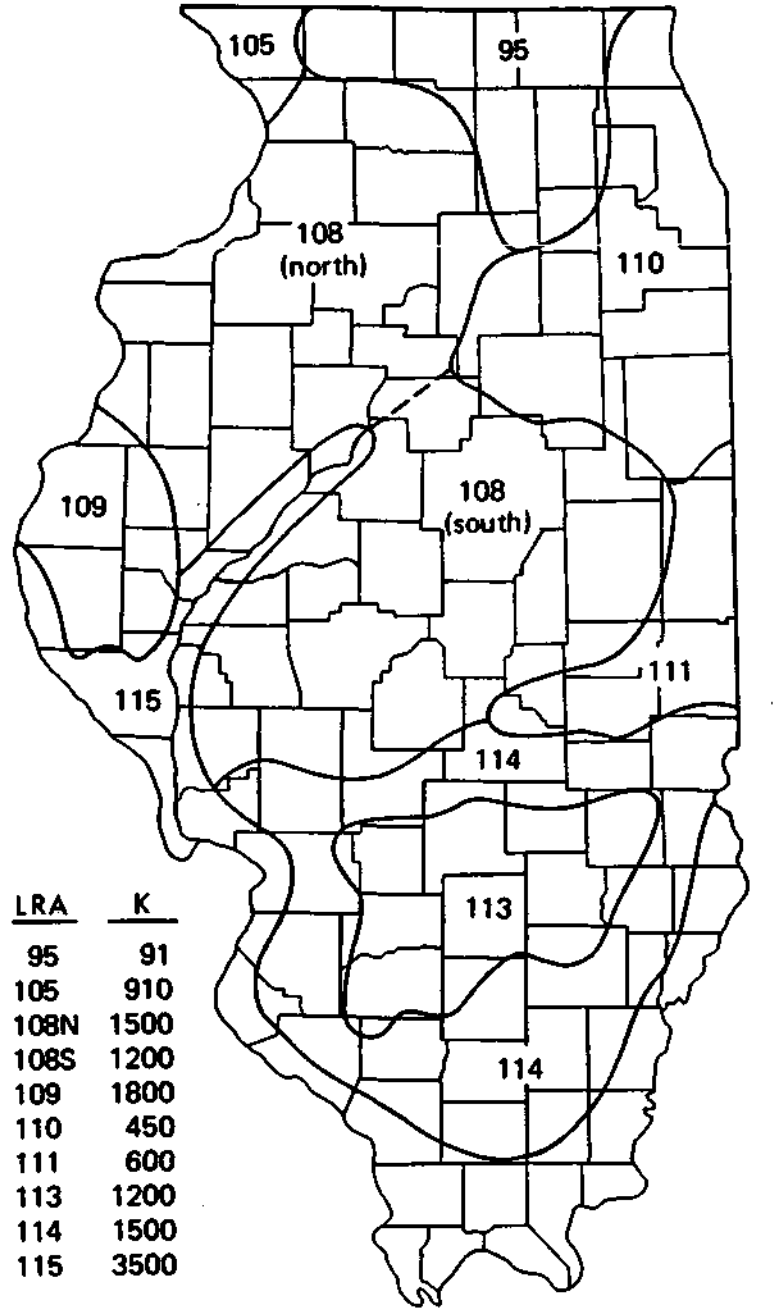

Figure 1. Land resource areas in Illinois, and regional factors (K)
(from Terstriep et al., 1982)

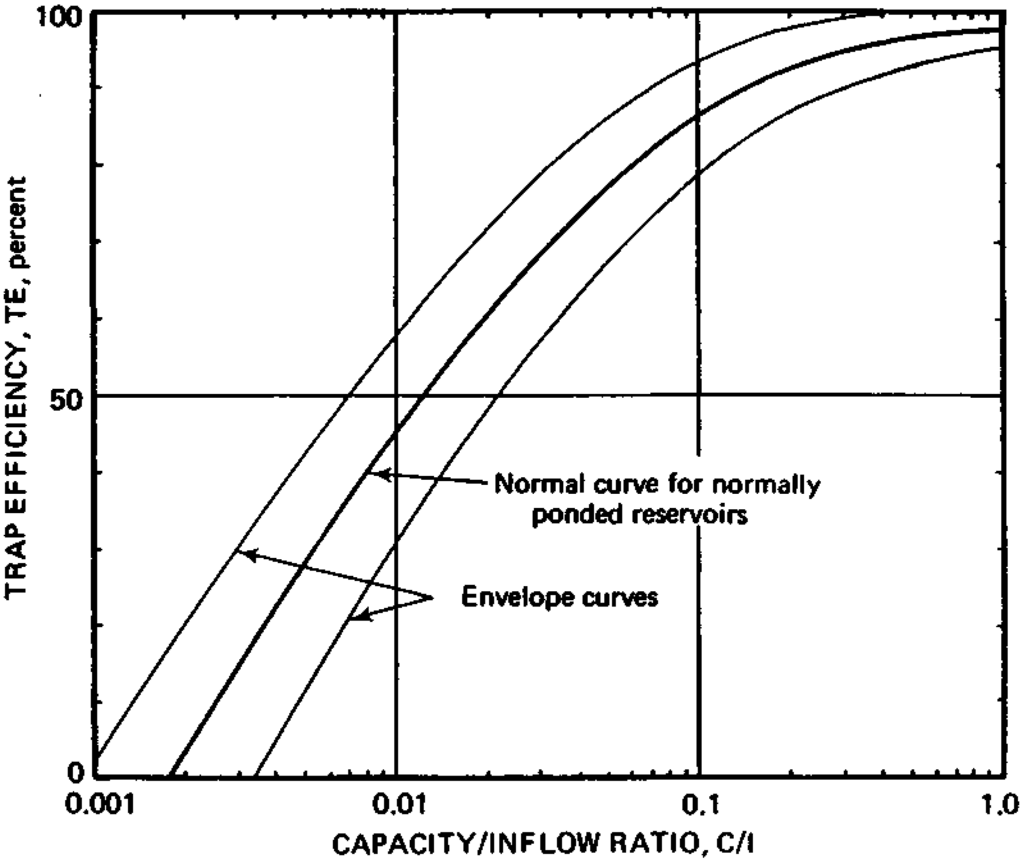

Figure 2. Brune's curve (from Brune, 1953)

gradually decreases during its useful life, because the C/I ratio diminishes due to sediment deposition.

Density of sediment: The density δ of the sediment deposits also varies with time due to compaction. The rate of compaction of the deposits depends on the content of the sediment material (percentage of sand, silt, and clay), and whether or not the deposits are exposed to drying due to drawdown. Lane and Koelzer (1943) presented the following empirical equation, based on the age and grain-size distribution of the sediment, for estimating the density:

$$\delta_T = \delta_1 + M \cdot \log T \tag{5}$$

where

δ_T = density of sediment after T years of compaction
δ_1 = density at the end of first year
M = an adjustment constant for compaction

The values of δ_1 and M for different sediment types and reservoir operation conditions are given in Table 1.

Table 1. Values of δ_1 and M Used for Estimating Average Density of the Compacted Sediment Deposits*

Reservoir operation	Sand		Silt		Clay	
	δ_1	M	δ_1	M	δ_1	M
Reservoir always or nearly always submerged	93	0	65	5.7	30	16.0
Normally moderate reservoir drawdown	93	0	74	2.7	46	10.7
Normally considerable drawdown	93	0	79	1.0	60	6.0
Reservoir normally empty	93	0	82	0.0	78	0.0

*After Lane and Koelzer (1943).

Equation 5 gives the density of the first year's deposits after T years of consolidation. The average density $\bar{\delta}_T$, which includes the subsequent years' deposits, can be obtained by integrating equation 5 over T years as

$$\bar{\delta}_T = \delta_1 + \frac{M}{T}\sum_{t=1}^{T}\log t \tag{6}$$

If the sediment deposits consist of a mixture of materials, then the weighted average $\bar{\delta}_T$ can be obtained with the following equation, by using the percent weight distribution P of the sediment materials:

$$\bar{\delta}_T = \frac{1}{100}\sum_{i=1}^{3} P_i\left[\delta_{i,1} + \frac{M_i}{T}\sum_{t=1}^{T}\log t\right] \tag{7}$$

where the index i = 1, 2, and 3 represents sand, silt and clay, respectively.

Another form of the density function can be obtained by integrating the capacity loss rate S, given by equation 4, to obtain an average capacity loss rate $\bar{S}$ for a period of T years.

$$\bar{S} = \frac{K\cdot A^{0.88}\cdot TE}{2178\cdot\bar{\delta}_T} = \frac{1}{T}\sum_{t=1}^{T}\left[\frac{K\cdot A^{0.88}\cdot TE}{2178\cdot\delta_t}\right] \tag{8}$$

By substituting equation 5 in equation 8, and cancelling identical terms (assuming that TE values do not change significantly), we get

$$\frac{1}{\bar{\delta}_T} = \frac{1}{T}\sum_{t=1}^{T}\left[\frac{1}{\delta_1 + M\cdot\log t}\right] \tag{9}$$

and, similarly, for sediment deposits composed of sand, silt, and clay equation 9 becomes

$$\frac{1}{\bar{\delta}_T} = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{100}\sum_{i=1}^{3}\left[\frac{P_i}{\delta_{i,1} + M_i\cdot\log t}\right] \tag{10}$$

Equation 7 may be more desirable for simple hand calculations; however, more accurate results may be obtained by using equation 10 in a computer program.

Combining equation 1 with equation 4, replacing δ with $\bar{\delta}_T$, and dividing both sides by the annual inflow I, we get a new form of the continuity equation:

$$\frac{C_0}{I} = \frac{C_T}{I} + \frac{K\cdot A^{0.88}\cdot TE}{2178\cdot I\cdot\bar{\delta}_T}\Delta T \tag{11}$$

Annual flow I is incorporated into the continuity equation, so that it is easier to use Brune's curve for calculating TE in the algorithm. If the initial conditions and all other parameters are determined (or estimated), then the future reservoir capacity C_T can be estimated by using equation 11 successively with any selected ΔT value over the period T_0 to T.

DATA USED IN THE STUDY

The main volume of data used in this study came from the reservoir sedimentation surveys in Illinois. More than 100 reservoirs have been surveyed, covering most of the state with the exception of some northeastern counties. The names and code numbers of the counties where surveys have been conducted and water supply reservoirs are located are given in Table 2. The reservoir sedimentation surveys provide valuable information about the drainage area, initial storage, construction year, and capacities of the reservoirs during years in which subsequent surveys were conducted. Any changes regarding the storage capacities of the reservoirs are also available in the State Water Survey files. Average annual inflow values are taken from the Upper Mississippi River Basin Commission report (UMRBC, 1970) (see Figure 3).

Table 2. Code Numbers and Names of the Counties Used in the Reservoir Sedimentation Analysis

County Code	County Name	County Code	County Name
001	Adams	058	Macon
003	Bond	059	Macoupin
005	Brown	060	Madison
009	Cass	061	Marion
011	Christian	065	Menard
012	Clark	066	Mercer
013	Clay	068	Montgomery
014	Clinton	069	Morgan
015	Coles	072	Peoria
018	Cumberland	073	Perry
023	Edgar	075	Pike
024	Edwards	079	Randolph
025	Effingham	080	Richland
026	Fayette	083	Saline
028	Franklin	084	Sangamon
029	Fulton	087	Shelby
030	Gallatin	088	Stark
031	Greene	089	Stephenson
034	Hancock	091	Union
037	Henry	092	Vermilion
039	Jackson	095	Washington
041	Jefferson	096	Wayne
044	Johnson	097	White
048	Knox	098	Whiteside
055	McDonough	100	Williamson
057	McLean	102	Woodford

More than 20 of the reservoir surveys in Illinois included particle size analysis for determining the granulometric distribution of sediment deposits. On the basis of these data, sediment materials were classified under 3 groups with respect to their average particle diameter D, as follows:

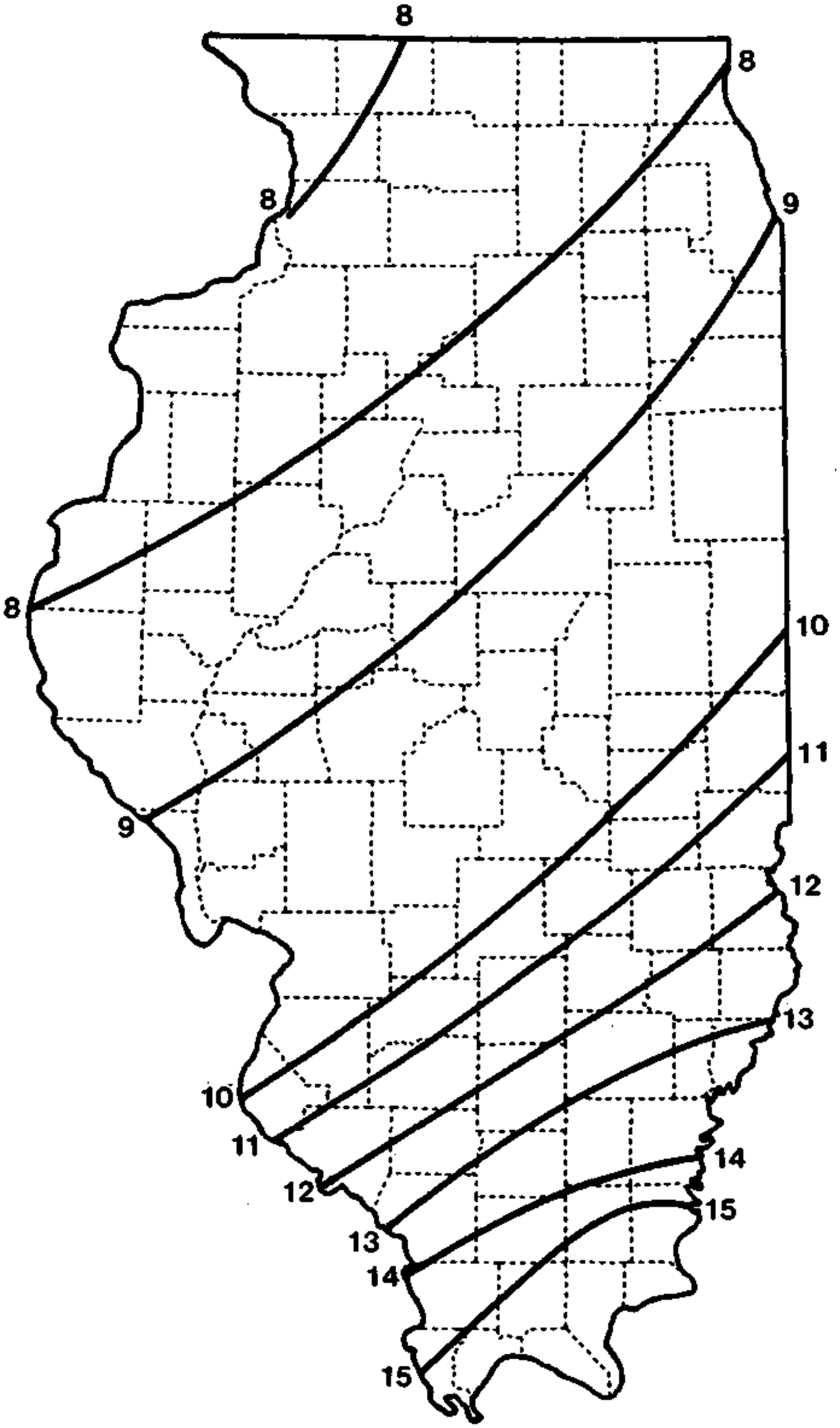

Figure 3. Average annual runoff for Illinois in inches per square mile (from UMRBC, 1970)

$D \leq 0.004$ mm Clay

$0.004 \text{ mm} < D \leq 0.062$ mm Silt

$0.062 \text{ mm} < D \leq 2.0$ mm Sand

The locations of the reservoirs for which particle size distribution analyses were done, and their percentages of sand, silt, and clay, are shown in Figures 4, 5, and 6. From these data, contour maps were generated to determine a pattern of particle size distribution of sediment deposits in Illinois. These maps were then used for estimating the sand, silt, and clay percentages of the sediment deposits of the reservoirs for which particle size distribution analysis was not done. The particle size data for sand, silt, and clay for the surveyed reservoirs were generated from these maps and are given in Table 3.

All the available and estimated data for the surveyed reservoirs, including the annual inflow and the dam coordinates, are also given in Table 3. The storage capacities listed in Table 3 in most cases show decreases with time. However, if the reservoir was dredged or the spillway crest was raised at any time, this condition is indicated by an increase in the storage. For example, the spillway of Mt. Sterling Reservoir was raised by 1 foot in 1954, resulting in a storage increase of 62 acre-feet (295.2 minus 233.3). The K values given in Table 3 for the surveyed reservoirs were calculated by the algorithm that is explained in detail in the next section. The locations of the surveyed reservoirs are shown in Figure 7.

The data for the non-surveyed water supply reservoirs were collected from personal communication with the municipalities and water treatment plants, from Corps of Engineers dam safety reports, and from Illinois Environmental Protection Agency records and publications (Illinois Environmental Protection Agency, 1978a, 1978b). Drainage areas were usually verified from topographical maps. Particle size distributions were estimated from Figures 4, 5, and 6, as mentioned earlier. The data used in the analysis of the non-surveyed water supply reservoirs are listed in Table 4. The locations of the water supply reservoirs are shown in Figure 8.

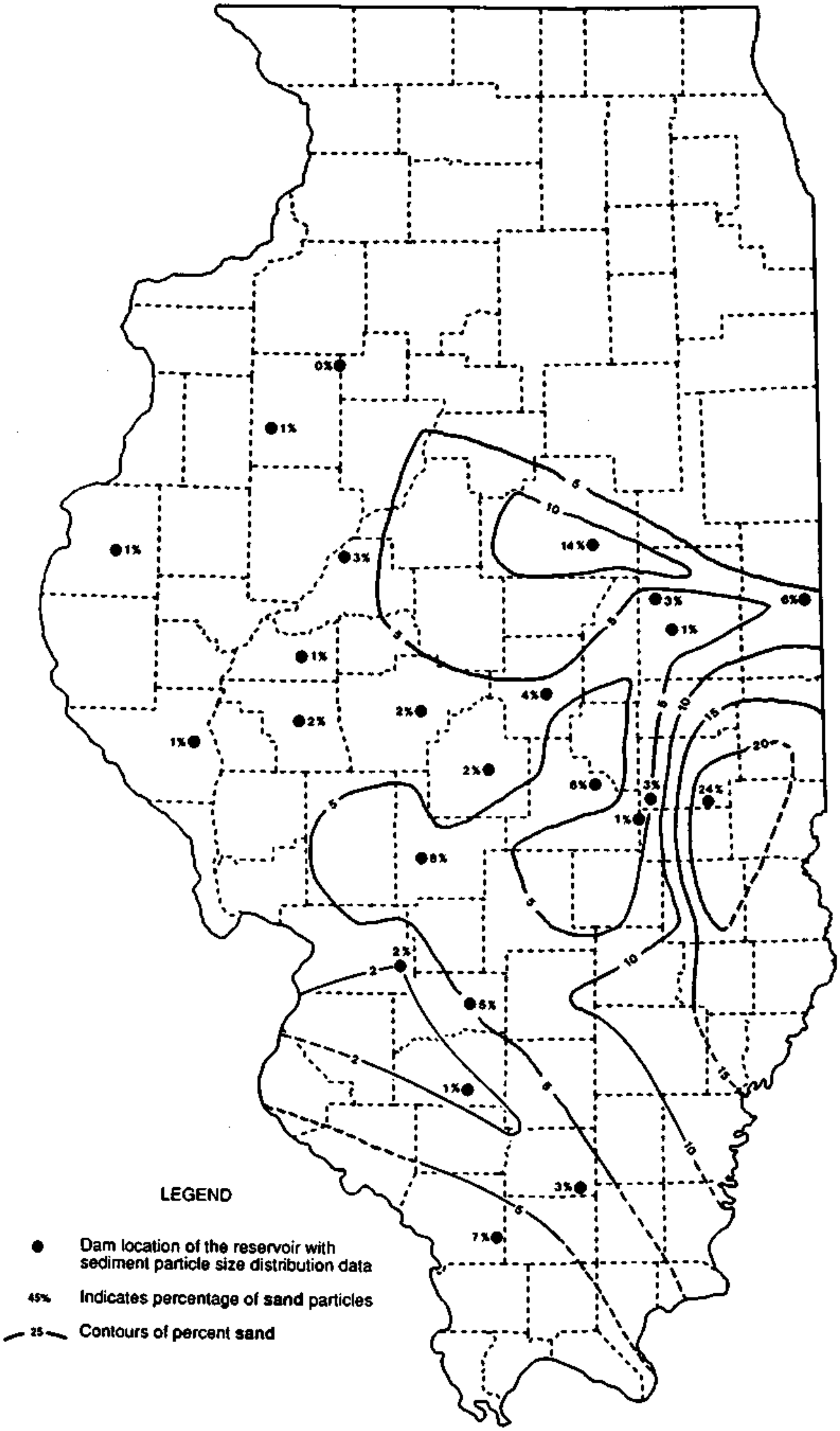

Figure 4. Locations of reservoirs for which sediment particle size analysis has been conducted, and contour map for percent sand distribution

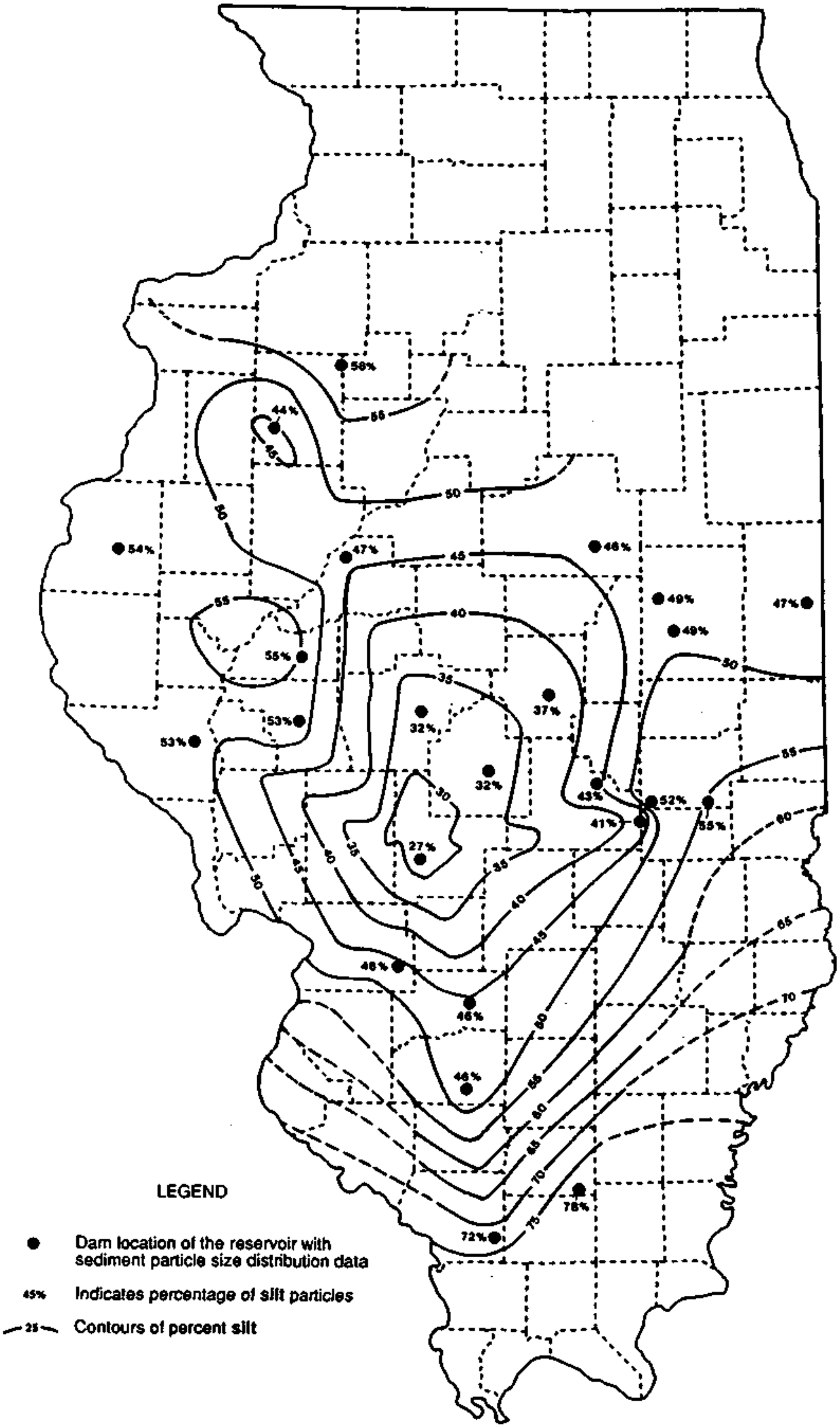

Figure 5. Locations of reservoirs for which sediment particle size analysis has been conducted, and contour map for percent silt distribution

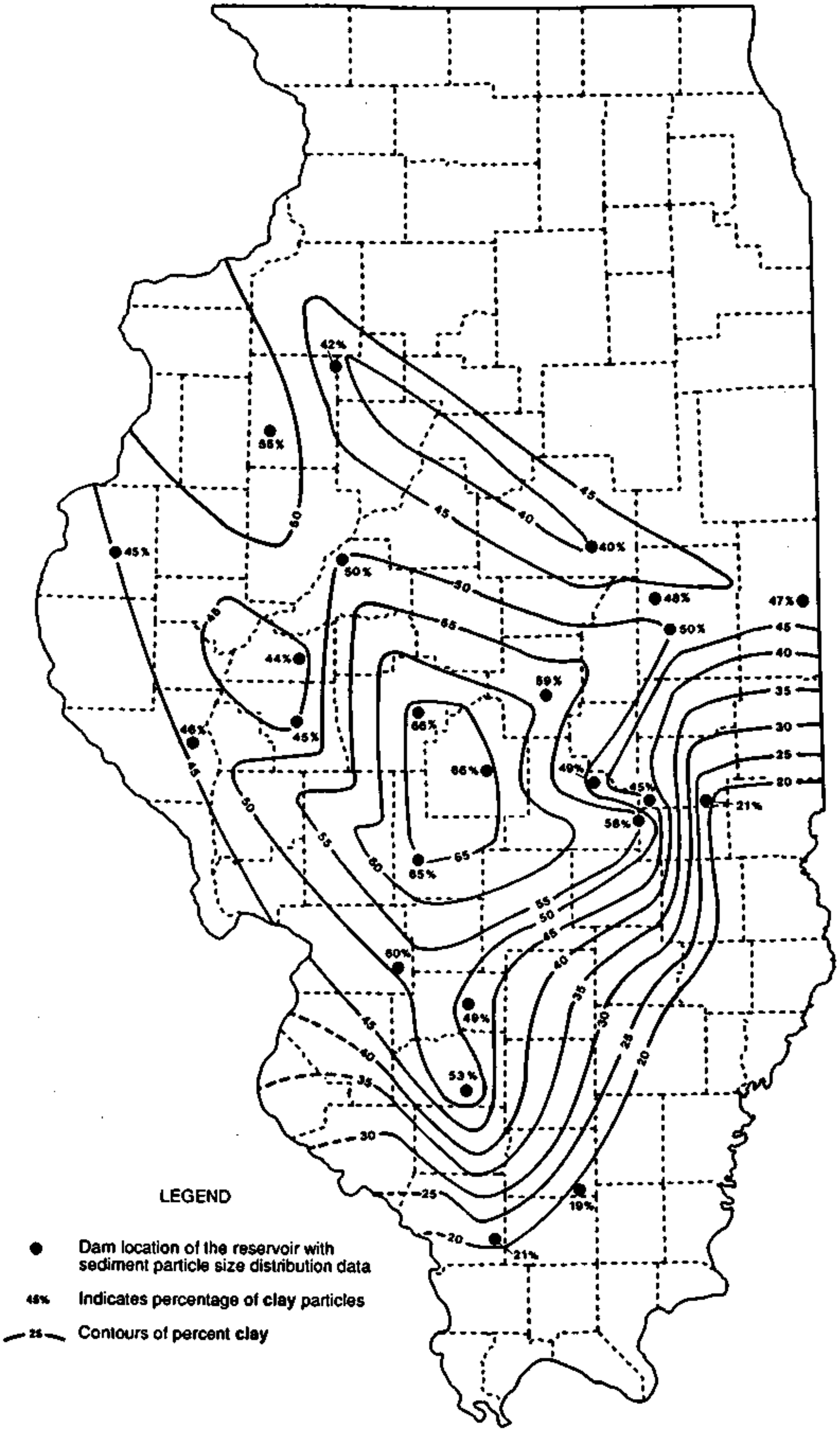

Figure 6. Locations of reservoirs for which sediment particle size analysis has been conducted, and contour map for percent clay distribution

Table 3. Surveyed Reservoirs and Available Data

County & Reservoir Codes[†]	Reservoir Name	Annual Inflow (in.)	Drainage Area (mi^2)	Particle Size Distribution (%)			K	Surveys		Township Range & Section
				Sand	Silt	Clay		Year	Capacity (acre-ft)	
1 - 1	CBQ Reservoir	8.40	2.13	1.0	54.0	45.0	1167	1875 1962	140.6 23.3	01N 06W 35
1 - 2	Clayton Reservoir	8.40	3.17	1.0	54.0	45.0	1363	1943 1962	225.3 172.1	01S 05W 2
1 - 3	Saukenauk Lake	8.40	1.54	1.0	53.0	46.0	3083	1953 1962	453.6 418.3	02N 08W 9
3 - 1	Ayer's Reservoir	9.80	1.90	6.1	35.7	58.2	756	1906 1958	200.0 150.0	06N 03W 21
5 - 1	Mt. Sterling Reservoir	8.50	1.80	1.0	54.5	44.6	3052	1935 1951 1954 1954 1962	306.0 248.3 233.2 295.2 262.5	01S 03W 4
5 - 2	Hambaugh-Martin #1	8.50	2.09	1.0	53.9	45.1	2914	1961 1972	426.6 375.3	02S 02W 33
9 - 1*	Virginia Reservoir	8.80	0.83	1.0	55.0	44.0	3426	1933 1950 1964 1982	154.0 116.0 217.0 179.0	18N 10W 34
11 - 1*	Lake Taylorville	9.50	131.30	2.0	32.0	66.0	1631	1962 1977	9406.0 7914.0	13N 02W 36
12 - 1	Craig & Davidson Lake	11.50	0.67	19.0	61.0	20.0	2159	1947 1959	187.8 175.2	09N 12W 8
12 - 2	Stevenson's Lake	11.50	0.37	21.0	59.0	20.0	2189	1950 1959	52.1 46.5	11N 13W 32
13 - 1	Brown Park Lake	11.60	1.47	12.4	58.8	28.9	673	1938 1959	49.1 37.8	03N 06E 33
13 - 2	Greendale Lake	11.60	9.50	11.3	55.7	33.0	802	1927 1940	306.0 260.1	03N 05E 31
13 - 3	Patterson Lake	11.60	1.27	5.2	53.1	41.7	1191	1926 1959	316.8 281.1	05N 05E 17
14 - 1*	Carlyle Lake @445	10.50	2719.00	5.0	46.0	49.0	720	1971 1976	220269.0 217008.0	02N 02W 18
15 - 1	Lake Charleston	10.20	811.00	21.8	53.5	24.8	1517	1947 1960 1974	2128.7 1290.5 864.6	12N 09E 25
15 - 2	Ridge Lake	10.20	1.41	24.0	55.0	21.0	2724	1941 1947	187.4 171.9	11N 09E 13
15 - 3*	Lake Paradise	10.20	18.10	3.0	52.0	45.0	1037	1908 1979	2042.0 1407.0	11N 07E 8
15 - 4*	Oakland Lake	10.00	14.31	17.8	52.5	29.7	397	1937 1954 1954 1972 1973	94.0 68.0 91.0 70.0 115.0	14N 11E 18
18 - 1	Vevay Park Lake	11.00	0.25	24.3	56.3	19.4	1322	1906 1959	67.4 54.5	10N 10E 26
26 - 1	Farina Lake	11.00	0.35	5.3	52.6	42.1	405	1928 1958	16.4 13.3	05N 04E 25
26 - 2	Etcheson's Lake	9.80	0.17	5.8	38.8	55.3	1428	1943 1958	19.7 16.0	07N 01E 31
28 - 1	Christopher City Reservoir	13.00	0.93	2.9	62.7	34.3	1275	1925 1960	383.9 353.6	06S 01E 16

Table 3. Continued

County & Reservoir Codes†	Reservoir Name	Annual Inflow (in.)	Drainage Area (mi^2)	Particle Size Distribution (%)			K	Surveys		Township Range & Section
				Sand	Silt	Clay		Year	Capacity (acre-ft)	
28 - 2	ICRR Reservoir, Thompsonville	13.60	1.80	4.0	76.2	19.8	1383	1926 1960	352.4 300.6	07S 04E 3
28 - 3	Valier Outing Club Reservoir	13.00	2.47	2.0	62.0	36.0	901	1922 1957	369.0 320.0	05S 01E 36
28 - 4	West Frankfort Reservoir (New)	13.80	7.62	3.0	78.0	19.0	4183	1945 1960	2654.7 2390.8	07S 04E 18
28 - 5	West Franklin Reservoir (Old)	13.80	4.03	3.0	78.0	19.0	3755	1926 1936	1608.0 1515.0	07S 04E 19
28 - 6*	Rend Lake @405	13.50	488.00	3.0	67.0	30.0	4270	1970 1980	184700.0 177000.0	06S 02E 3
29 - 1	Astoria Reservoir	8.40	0.42	2.0	52.0	46.1	2625	1924 1962	67.2 33.1	03N 01E 15
29 - 2	Avon Residential Lake	8.10	3.09	1.0	47.0	52.0	820	1906 1962	192.8 109.1	08N 01E 20
29 - 3*	Canton Lake	8.40	15.00	2.0	50.0	48.0	2688	1939 1960	3513.0 3023.0	07N 05E 30
31 - 1	Greenfield Pond	9.20	0.23	4.0	42.0	54.0	1708	1924 1952	67.2 56.7	10N 10W 10
31 - 2	Roodhouse Park District	9.20	0.45	3.0	44.0	53.0	585	1917 1952	61.6 53.9	12N 11W 19
31 - 3*	Whitehall Lake	9.20	0.97	2.0	45.5	52.5	1264	1897 1952	459.3 407.7	12N 12W 36
31 - 4	Woodbine Country Club Lake	9.20	0.33	3.1	41.8	55.1	1940	1926 1952	58.5 43.4	11N 10W 16
34 - 1*	Carthage Reservoir	8.00	3.07	1.0	54.0	45.0	1828	1926 1949 1955 1955 1962	406.3 308.4 293.4 373.4 276.6	05N 07W 13
37 - 1	Johnson Sauk Trail Lake	8.00	1.37	0.9	56.6	42.5	3006	1958 1981	543.8 471.5	16N 05E 35
39 - 1*	Little Cedar Lake	13.80	6.53	7.0	73.0	20.0	4022	1969 1976	757.4 655.8	10S 02W 35
39 - 2*	Carbondale Reservoir	13.60	3.30	7.0	72.0	21.0	4421	1926 1948	1386.0 1193.0	09S 01W 33
41 - 1	ICRR Reservoir, Bluford	12.50	3.35	2.0	57.0	41.0	850	1926 1960	670.7 609.7	02S 04E 35
41 - 2	Packerwood Lake (Farrell Lake)	12.00	0.52	6.1	56.1	37.8	1399	1945 1960	35.6 27.4	02S 02E 11
41 - 3*	Miller Lake	12.00	4.65	7.1	57.1	35.7	3120	1944 1953	1746.4 1658.8	01S 03E 32
41 - 4*	Jaycee Lake (Mt. Vernon Reservoir)	12.00	2.61	6.1	58.2	35.7	2096	1908 1924 1925 1959	600.2 545.3 1201.2 1084.4	02S 03E 8
48 - 1	Lake Bracken	8.00	8.91	1.0	44.0	55.0	2922	1923 1936 1949 1962	2881.0 2660.0 2452.0 2266.0	10N 10E 14
48 - 2	Lake Calhoun	8.00	13.10	0.0	58.0	42.0	2427	1924 1936 1936 1947	285.6 136.7 273.1 112.4	13N 04E 23

Table 3. Continued

County & Reservoir Codes†	Reservoir Name	Annual Inflow (in.)	Drainage Area (mi^2)	Particle Size Distribution (%)			K	Surveys		Township Range & Section
				Sand	Silt	Clay		Year	Capacity (acre-ft)	
48 - 3	Lake Storey	8.00	7.07	0.0	49.0	51.0	1134	1928 1962	2089.7 1920.0	12N 01E 32
48 - 4	CB&Q Reservoir, Rio	8.00	0.40	0.0	50.5	49.5	666	1888 1962	22.4 8.5	13N 01E 20
55 - 1	Argyle Lake	8.10	6.56	1.0	51.0	48.0	2769	1950 1962	1979.9 1830.8	05N 03W 6
55 - 2*	Spring Lake	8.00	20.20	1.0	50.5	48.5	1613	1927 1951 1951 1968 1968	503.6 184.0 372.4 172.0 2880.0	06N 03W 15
55 - 3*	Lake Vermont	8.30	2.30	2.0	51.5	46.5	2449	1942 1962 1980	366.0 292.0 223.0	04N 01W 25
57 - 1*	Lake Bloomington	8.90	61.00	7.1	50.5	42.4	1113	1929 1948 1952 1955	6654.0 6062.0 5905.0 5863.0	25N 02E 1
57 - 2	Dawson Lake	9.10	4.50	14.0	46.0	40.0	2291	1964 1986	1619.0 1475.0	23N 04E 35
58 - 1*	Lake Decatur	9.50	906.00	4.0	37.0	59.0	649	1922 1936 1946 1956 1956 1966 1983	19738.0 16930.0 14567.0 14077.0 22200.0 20800.0 18800.0	16N 02E 22
59 - 1	Arctic Lake	9.50	0.53	6.0	33.0	61.0	1568	1922 1949 1954 1961	175.6 159.5 152.2 147.6	09N 07W 11
59 - 2	Bunker Hill Reservoir	9.50	7.19	5.1	42.4	52.5	1901	1937 1954	133.0 36.0	07N 08W 16
59 - 3*	Lake Carlinville	9.50	25.40	6.0	33.0	61.0	994	1929 1949 1954 1959 1986	2350.0 2110.0 2050.0 1950.0 1650.0	09N 07W 10
59 - 4	Edwards Lake	9.50	0.70	6.9	33.7	59.4	1066	1949 1958	74.2 68.0	08N 06W 17
59 - 5*	Old Gillespie Lake	9.50	5.73	5.9	34.7	59.4	886	1922 1954	799.0 696.0	08N 07W 10
59 - 6	King's Lake	9.50	0.38	6.4	31.8	61.8	1494	1921 1958	158.6 139.5	07N 06W 16
59 - 7*	Mt. Olive Lake	9.50	5.21	7.0	34.0	59.0	1378	1938 1958 1981	464.8 346.4 282.4	08N 06W 28
59 - 8	Rinaker Lake	9.50	0.49	6.0	34.0	60.0	1117	1904 1958	160.5 135.8	09N 07W 6
59 - 9*	Lake Staunton	9.50	3.68	6.1	36.4	57.6	1588	1926 1954 1978	1248.0 1140.0 1049.0	07N 06W 20
59 -10	Wilsonville, Mine Pond #4	9.50	5.29	6.1	38.4	55.6	1276	1916 1958	296.1 141.6	07N 07W 10

Table 3. Continued

County & Reservoir Codes†	Reservoir Name	Annual Inflow (in.)	Drainage Area (mi^2)	Particle Size Distribution (%)			K	Surveys		Township Range & Section
				Sand	Silt	Clay		Year	Capacity (acre-ft)	
59 -11*	Old Mt. Olive Reservoir	9.50	0.70	6.9	33.7	59.4	1503	1896	452.0	07N 06W 3
								1981	382.0	
60 - 1*	Highland Silver Lake	9.80	49.30	2.0	48.0	50.0	2107	1962	7340.0	04N 05W 30
								1981	6350.0	
								1984	6220.0	
60 - 2	Schaefer Lake	9.80	0.09	2.8	42.5	54.7	2080	1937	20.2	05N 07W 30
								1949	17.6	
61 - 1*	ICRR Reservoir, Kinmundy	11.00	0.55	9.3	49.5	41.2	1055	1902	174.1	04N 03E 28
								1959	149.1	
61 - 2*	Raccoon Lake	11.30	48.40	5.7	45.3	49.1	1097	1943	5650.0	01N 01E 8
								1959	5230.0	
61 - 3*	Salem Reservoir	11.20	4.02	8.3	51.0	40.6	585	1912	597.1	02N 02E 2
								1960	530.9	
65 - 1	GM&O Lake, Tallula	9.00	0.85	2.0	45.0	53.0	610	1902	31.7	17N 08W 12
								1952	15.4	
66 - 1	Matherville Lake	8.00	0.33	0.0	52.8	47.2	2325	1925	137.6	15N 02W 28
								1962	112.4	
66 - 2	Nelson Lake	8.00	0.50	0.0	52.8	47.2	1526	1938	66.7	15N 04W 15
								1962	51.3	
68 - 1	Panama Lake	9.60	0.85	6.0	33.0	61.0	1240	1928	177.8	07N 04W 22
								1958	151.9	
68 - 2	Walton Park Lake	9.60	2.04	7.0	30.0	63.0	1472	1862	376.3	08N 05W 9
								1959	187.2	
68 - 3*	Lake Lou Yaeger	9.60	115.00	8.0	27.0	65.0	2786	1965	15837.0	09N 05W 35
								1977	13906.0	
69 - 1	Anderson Pond	8.90	0.63	1.0	54.5	44.4	1521	1909	266.6	16N 11W 28
								1952	233.7	
69 - 2	Conlee Pond	9.00	0.39	3.0	51.5	45.5	591	1944	8.9	14N 09W 5
								1952	7.5	
69 - 3	Elliot State Bank Pond	9.00	0.31	2.0	51.5	46.5	865	1900	47.1	14N 10W 9
								1952	35.6	
69 - 4	Franklin Outing Club Lake	9.00	0.45	3.0	45.5	51.5	1514	1905	328.3	14N 08W 31
								1952	300.7	
69 - 5*	Lake Jacksonville	9.00	10.80	2.0	51.5	46.5	2971	1940	6680.0	14N 10W 9
								1952	6460.0	
								1986	5830.0	
69 - 6	Langdon Pond	9.00	0.36	2.9	47.1	50.0	890	1907	56.8	14N 09W 31
								1952	44.8	
69 - 7	Morgan Lake	9.00	2.75	2.0	51.5	46.5	665	1900	126.0	15N 10W 33
								1952	73.0	
69 - 8*	Mauvaiseterre Lake	9.00	32.60	2.0	53.0	45.0	1161	1921	1504.6	15N 10W 28
								1952	1015.2	
								1979	627.9	
69 - 9*	Waverly Lake	9.10	9.24	3.0	45.5	51.5	1049	1939	308.3	13N 08W 5
								1952	238.6	
								1971	159.4	
73 - 1	Lake Duquoin	12.50	10.73	2.9	56.9	40.2	1199	1939	2003.0	05S 01W 29
								1957	1870.0	
75 - 1	Old Pittsfield Lake	8.75	1.64	1.0	53.1	45.9	1853	1925	333.3	05S 04W 13
								1962	254.1	

Table 3. Continued

County & Reservoir Codes†	Reservoir Name	Annual Inflow (in.)	Drainage Area (mi^2)	Particle Size Distribution (%)			K	Surveys		Township Range & Section
				Sand	Silt	Clay		Year	Capacity (acre-ft)	
75 - 2*	Lake Pittsfield	8.75	11.10	1.0	53.0	46.0	5210	1961	3580.0	05S 03W 16
	(New-Big Blue Lake)							1974	3010.0	
								1979	2870.0	
								1985	2760.0	
79 - 1*	Coulterville Reservoir	11.75	1.22	3.1	58.2	38.8	874	1939	200.0	04S 05W 11
								1954	188.0	
80 - 1*	Borah Lake	12.30	3.36	16.7	63.7	19.6	2954	1954	1555.3	04N 10E 22
	(New Olney Reservoir)							1960	1517.4	
83 - 1*	Eldorado Reservoir	15.00	2.23	5.9	79.2	14.9	3063	1920	844.4	08S 06E 13
								1949	726.0	
83 - 2	Dering Co. Coal Pond	15.00	0.22	5.9	79.2	14.9	3129	1919	89.3	08S 06E 13
								1949	73.0	
84 - 1	Aschauer Pond	9.20	0.53	4.0	34.7	61.4	1655	1939	18.3	17N 03W 31
								1952	9.4	
84 - 2	Davis, Hose & Davis Farms	9.10	0.21	2.0	40.0	58.0	1369	1942	35.8	16N 07W 1
								1952	32.7	
84 - 3	Lake George	9.10	0.13	4.0	35.6	60.4	1303	1936	3.8	17N 05W 12
								1952	1.5	
84 - 4	Schmidt Pond	9.30	1.31	3.0	36.0	61.0	653	1943	6.0	14N 06W 14
								1952	3.4	
84 - 5*	Lake Springfield	9.30	265.00	2.0	32.0	66.0	1437	1934	59900.0	15N 05W 12
								1948	57300.0	
								1965	55000.0	
								1977	53300.0	
								1984	52200.0	
87 - 1*	Lake Mattoon	10.00	39.70	1.0	41.0	58.0	3176	1958	13160.0	10N 06E 1
								1980	11660.0	
87 - 2	Lake Shelbyville @599.7	10.20	1054.00	8.0	43.0	49.0	2071	1970	208000.0	11N 04E 8
								1980	200000.0	
88 - 1	Armstrong Pond	8.00	0.45	0.0	59.4	40.6	490	1950	40.6	13N 06E 4
								1962	38.3	
88 - 2	Ewan Pond	8.00	1.25	0.0	59.2	40.8	942	1935	61.6	14N 06E 29
								1962	40.6	
89 - 1	Lake Le-Aqua-Na	8.00	3.67	0.0	55.0	45.0	1462	1955	578.7	28N 06E 17
								1981	487.2	
91 - 1*	Alto Pass Reservoir	14.00	0.62	5.8	75.0	19.2	4807	1967	128.1	11S 02W 10
								1976	108.0	
91 - 2	Anna State Hospital	14.50	0.97	4.8	76.2	19.0	994	1914	81.0	12S 02W 14
								1936	71.0	
								1936	287.0	
								1953	273.0	
91 - 3*	Dongola City Reservoir	15.00	3.55	3.8	76.9	19.2	4617	1970	666.0	13S 01W 25
								1981	558.0	
92 - 1*	Lake Vermilion	9.80	298.00	5.5	42.7	51.8	883	1925	8514.0	20N 11W 31
								1963	5318.0	
								1976	4641.0	
95 - 1*	Ashley Lake	11.80	1.21	1.0	46.0	53.0	1308	1940	174.0	02S 01W 14
								1954	162.0	
								1985	123.0	
95 - 2*	Nashville Reservoir	11.50	1.39	2.0	45.5	52.5	1497	1935	320.0	02S 02W 19
								1954	289.0	
96 - 1	Steiner Lake	12.90	0.31	11.7	68.9	19.4	1410	1945	53.7	01S 08E 33
								1960	48.6	

Table 3. Concluded

County & Reservoir Codes†	Reservoir Name	Annual Inflow (in.)	Drainage Area (mi^2)	Particle Size Distribution (%)			K	Surveys		Township Range & Section
				Sand	Silt	Clay		Year	Capacity (acre-ft)	
97 - 1	Norris City Reservoir	14.00	0.83	8.8	76.5	14.7	1305	1936 1954	140.0 127.0	06S 08E 27
98 - 1	Lake Carlton	8.00	2.31	0.0	45.0	55.0	1983	1969 1975	846.0 822.0	21N 05E 6
100 - 1	Baker's Lake	14.50	0.26	5.8	75.0	19.2	835	1937 1951	24.0 21.7	10S 02E 14
100 - 2	Crab Orchard Lake	14.50	196.00	5.9	72.3	21.8	4455	1940 1951 1963	74400.0 71100.0 67000.0	09S 01E 19
100 - 3	Fluck's Lake	14.20	0.34	4.9	75.5	19.6	1402	1919 1951	58.1 46.8	09S 02E 22
100 - 4	Herrin Reservoir #1	14.50	1.78	5.0	73.3	21.8	531	1913 1951	199.0 178.0	09S 02E 6
100 - 5	Herrin Reservoir #2	14.40	3.13	5.9	76.5	17.6	5769	1927 1936	804.0 704.0	10S 02E 20
100 - 6	Johnston City Reservoir	14.00	3.85	4.0	78.0	18.0	1073	1922 1957	471.0 394.0	08S 03E 27
100 - 7	Knights Of Pythias Lake	14.50	0.26	4.9	77.5	17.6	1868	1925 1951	74.6 64.7	09S 03E 33
100 - 8	Little Grassy Lake	14.50	15.10	5.9	76.5	17.6	5122	1942 1951	26116.0 25740.0	10S 01E 30
100 - 9*	Marion Reservoir	14.40	6.48	5.9	76.5	17.6	1196	1921 1951	705.0 590.0	10S 02E 2

† See Table 2 for county names.

* Indicates that the reservoir is used for water supply.

K is the regional constant.

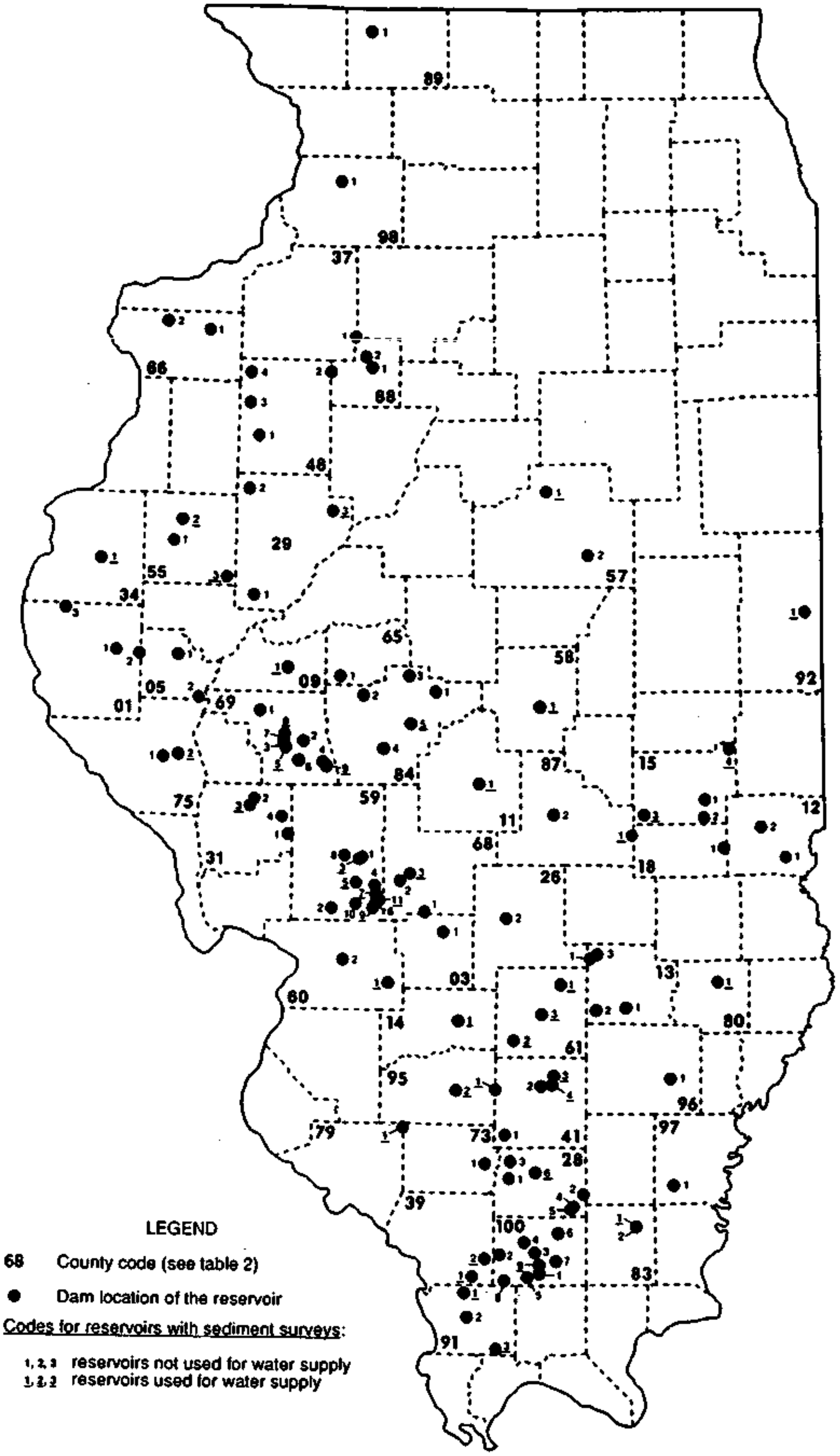

Figure 7. Locations of surveyed reservoirs

Table 4. Water Supply Reservoirs and Available Data

County & Reservoir Codes†	Reservoir Name	Annual Inflow (in.)	Drainage Area (mi^2)	Particle Size Distribution (%)			Township Range & Section	USGS Topographical Quad Map
				Sand	Silt	Clay		
3 - 2	Governor Bond Lake	9.90	35.10	3.1	37.5	59.4	06N 03W 35	Greenville
3 - 3	Sorento Reservoir	9.75	0.55	5.1	34.7	60.2	06N 04W 9	Sorento South
9 - 1*	Virginia Reservoir	8.80	0.83	1.0	55.0	44.0	18N 10W 34	Virginia
11 - 1*	Lake Taylorville	9.50	131.30	2.0	32.0	66.0	13N 02W 36	Taylorville
11 - 2	Lake Kincaid	9.40	2.50	2.0	31.4	66.7	13N 03W 13	Kincaid
11 - 3	Sangchris Lake	9.40	73.00	2.0	31.7	66.3	14N 04W 24	Edinburgh
11 - 4	Lake Pana	9.80	8.50	7.6	34.9	57.5	11N 02E 30	Oconee
14 - 1*	Carlyle Lake @445	10.50	2719.00	5.0	46.0	49.0	02N 02W 18	Carlyle
15 - 3*	Lake Paradise	10.20	18.10	3.0	52.0	45.0	11N 07E 8	Mattoon West
15 - 4*	Oakland Lake	10.00	14.31	17.8	52.5	29.7	14N 11E 18	Oakland
23 - 1	Twin Lake (Old, or West)	10.70	17.70	18.9	54.2	26.9	14N 12W 25	Paris North
23 - 1	Twin Lake (New, or Third)	10.70	12.85	18.9	54.2	26.9	14N 12W 25	Paris North
24 - 1	West Salem New Res	12.80	0.74	17.5	72.2	10.3	01N 14W 7	West Salem
24 - 2	West Salem Old Res	12.80	1.20	17.5	72.2	10.3	01N 14W 7	West Salem
25 - 1	Altamont New Res	10.40	1.07	3.0	45.0	52.0	07N 04E 23	Altamont East
25 - 2	CIPS Lake	10.50	0.84	3.1	48.0	49.0	08N 05E 25	Effingham South
25 - 3	Lake Sara	10.25	11.80	2.0	45.0	53.0	08N 05E 22	Effingham North
26 - 3	Lake Nellie (St. Elmo New Res.)	10.20	2.45	3.0	43.0	54.0	07N 03E 15	Altamont West
26 - 4	Vandalia Lake	9.90	26.00	4.0	39.0	57.0	07N 01E 32	Vera
28 - 6*	Rend Lake @405	13.50	488.00	3.0	67.0	30.0	06S 02E 3	Rend Lake Dam
29 - 3*	Canton Lake	8.40	15.00	2.0	50.0	48.0	07N 05E 30	Banner
30 - 1	Omaha Reservoir	14.60	0.24	8.6	86.0	5.4	07N 08E 28	Norris City
31 - 3*	Whitehall Lake	9.20	0.97	2.0	45.5	52.5	12N 12W 36	Roodhouse West
31 - 5	Greenfield Lake	9.30	1.11	4.0	42.0	54.0	10N 10W 3	Greenfield
34 - 1*	Carthage Reservoir	8.00	3.07	1.0	54.0	45.0	05N 07W 13	Carthage West
39 - 1*	Little Cedar Lake	13.80	6.53	7.0	73.0	20.0	10S 02W 35	Cobden
39 - 2*	Carbondale Reservoir	13.60	3.30	7.0	72.0	21.0	09S 01W 33	Carbondale
39 - 3	Cedar Lake	13.80	30.20	7.0	73.0	20.0	10S 02W 12	Pomona
39 - 4	Kinkaid Lake	13.00	62.30	6.1	69.4	24.5	09S 01W 33	Oraville
41 - 3*	Miller Lake	12.00	4.65	7.1	57.1	35.7	01S 03E 32	Kell
41 - 4*	Jaycee Lake (Mt. Vernon Res.)	12.00	2.61	6.1	58.2	35.7	02S 03E 8	Mt. Vernon
41 - 5	L & N Reservoir	12.40	0.55	5.2	58.8	36.1	02S 03E 30	Mt. Vernon
44 - 1	Bloomfield Lake (Vienna City R.)	15.50	1.16	6.9	88.2	4.9	13S 03E 3	Bloomfield
55 - 2*	Spring Lake	8.00	20.20	1.0	50.5	48.5	06N 03W 15	Good Hope
55 - 3*	Vermont Lake	8.30	2.30	2.0	51.5	46.5	04N 01W 25	Vermont
57 - 1*	Lake Bloomington	8.90	61.00	7.1	50.5	42.4	25N 02E 1	Gridley
58 - 1*	Lake Decatur	9.50	906.00	4.0	37.0	59.0	16N 02E 22	Decatur
59 - 3*	Lake Carlinville	9.50	25.40	6.0	33.0	61.0	09N 07W 10	Gillespie North
59 - 5*	Old Gillespie Lake	9.50	5.73	5.9	34.7	59.4	08N 07W 10	Gillespie North
59 - 7*	Mt. Olive Lake	9.50	5.21	7.0	34.0	59.0	08N 06W 28	Gillespie South
59 - 9*	Lake Staunton	9.50	3.68	6.1	36.4	57.6	07N 06W 20	Gillespie South
59 -11*	Old Mt. Olive Reservoir	9.50	0.70	6.9	33.7	59.4	07N 06W 3	Mt. Olive
59 -12	Otter Lake	9.30	20.20	5.0	38.0	57.0	11N 07W 7	Palmyra
59 -13	New Gillespie Lake	9.50	12.25	6.1	36.4	57.6	08N 07W 8	Shipman
59 -14	Fresson Lake (Bunn Lake)	9.30	4.23	5.0	39.0	56.0	11N 09W 25	Hettick
59 -15	Palmyra-Modesto Lake	9.30	1.70	4.9	40.6	54.5	12N 08W 35	Palmyra
59 -16	Shipman Reservoir	9.50	0.46	5.1	42.4	52.5	08N 09W 24	Shipman

Table 4. Concluded

County & Reservoir Codes†	Reservoir Name	Annual Inflow (in.)	Drainage Area (sq^2)	Particle Size Distribution (%)			Township Range & Section	USGS Topographical Quad Map
				Sand	Silt	Clay		
60 - 1*	Highland Silver Lake	9.80	49.30	2.0	48.0	50.0	04N 05W 30	Grantfork
60 - 3	Holiday Lake	9.65	6.33	4.1	44.3	51.5	05N 08W 1	Prairietown
61 - 1*	ICRR Reservoir, Kinmundy	11.00	0.55	9.3	49.5	41.2	04N 03E 28	Kinmundy
61 - 2*	Raccoon Lake	11.30	48.40	5.7	45.3	49.1	01N 01E 8	Centralia East
61 - 3*	Salem Reservoir	11.20	4.02	8.3	51.0	40.6	02N 02E 2	Salem North
61 - 4	Centralia Lake	11.30	7.00	7.3	51.0	41.7	01N 02E 5	Centralia East
68 - 3*	Lake Lou Yaeger	9.60	115.00	8.0	27.0	65.0	09N 05W 35	Butler
68 - 4	Lake Hillsboro	9.70	7.44	3.1	29.2	67.7	09N 04W 36	Hillsboro
68 - 5	Lake Glenn Shoals	9.65	80.00	3.1	28.1	68.8	09N 04W 36	Hillsboro
69 - 5*	Lake Jacksonville	9.00	10.80	2.0	51.5	46.5	14N 10W 9	Jacksonville
69 - 8*	Mauvaisseterre Lake	9.00	32.60	2.0	53.0	45.0	15N 10W 28	Jacksonville
69 - 9*	Waverly Lake	9.10	9.24	3.0	45.5	51.5	13N 08W 5	Waverly
69 -11	Reservoir #2	9.00	0.26	2.0	49.0	49.0	16N 09W 2	Prentice
72 - 1	Lake Camelot	8.40	1.50	4.9	50.0	45.1	08N 07E 31	Hanna City
73 - 2	Pinckneyville Reservoir	12.20	6.51	3.0	54.0	43.0	05S 03W 14	Pinckneyville
75 - 2*	Lake Pittsfield (New-Big Blue)	8.75	11.10	1.0	53.0	46.0	05S 03W 16	Griggsville
79 - 1*	Coulterville Reservoir	11.75	1.22	3.1	58.2	38.8	04S 05W 11	Coulterville
79 - 2	Sparta Old Reservoir	11.75	1.20	4.1	65.3	30.6	05S 05W 7	Steeleville
79 - 3	Sparta New (North) Reservoir	11.75	3.60	4.1	63.3	32.7	05S 05W 6	Tilden
80 - 1*	Borah Lake (New Olney Res.)	12.30	3.36	16.7	63.7	19.6	04N 10E 22	Dundas
80 - 2	East Fork Lake	12.20	10.40	17.2	65.7	17.2	04N 10E 22	Dundas
80 - 3	Vernor Lake	12.05	0.47	17.5	67.0	15.5	04N 10E 21	Dundas
83 - 1*	Eldorado Reservoir	15.00	2.23	5.9	79.2	14.9	08S 06E 13	Eldorado
83 - 3	Doc Mac Strip Pit	15.20	0.52	3.0	94.1	3.0	09S 05E 34	Carrier Mills
83 - 4	Peabody Strip Pit	15.20	1.09	3.9	93.1	2.9	09S 05E 32	Carrier Mills
84 - 5*	Lake Springfield	9.30	265.00	2.0	32.0	66.0	15N 05W 12	Springfield East
87 - 1*	Lake Mattoon	10.00	56.00	1.0	41.0	58.0	10N 06E 1	Neoga
91 - 1*	Alto Pass Reservoir	14.00	0.62	5.8	75.0	19.2	11S 02W 10	Cobden
91 - 3*	Dongola City Reservoir	15.00	3.55	3.8	76.9	19.2	13S 01W 25	Dongola
92 - 1*	Lake Vermilion	9.80	298.00	5.4	42.7	51.8	20N 11W 31	Georgetown
95 - 1*	Ashley Lake	11.80	1.21	1.0	46.0	53.0	02S 01W 14	Ashley
95 - 2*	Nashville Reservoir	11.50	1.39	2.0	45.5	52.5	02S 02W 19	Beacoup
100 - 9*	Marion Reservoir	14.40	6.48	5.9	76.5	17.6	10S 02E 2	Marion
100 -10	Lake of Egypt	15.00	33.34	6.7	78.8	14.4	10S 02E 25	Goreville
102 - 1	Lake Eureka	8.60	2.70	7.5	54.8	37.6	26N 02W 13	Eureka

† See Table 2 for county names.

* Indicates that the reservoir has been surveyed.

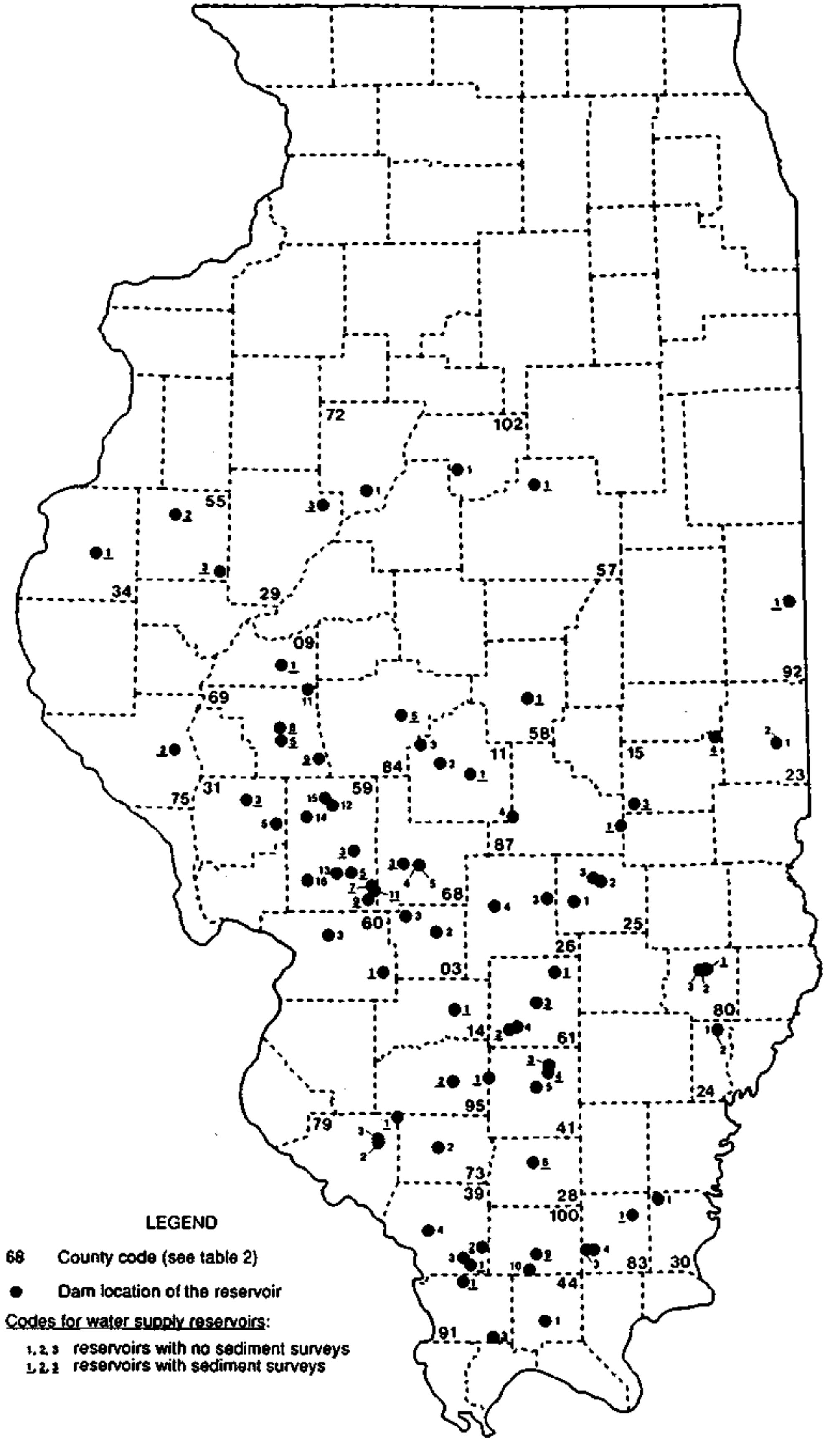

Figure 8. Locations of water supply reservoirs

CALCULATION OF FUTURE RESERVOIR STORAGE CAPACITIES

The future reservoir storage capacities C_T can be estimated by using equation 11 if all the required parameters are known. Some of the parameters, such as TE and $\bar{\delta}_T$, are time dependent and need to be changed at certain time intervals. Other parameters such as C_0, inflow, drainage area, and K are assumed to be constants, and may be estimated easily from physiographic properties of the reservoir. However, selection of the value for K may require additional care, since a preliminary investigation of the results of reservoir sedimentation surveys indicated that the K values given by UMRBC (see Figure 1) differ significantly from the K values calculated by using equation 11. This indicated a need to calculate the K values of the surveyed reservoirs by using the reservoir sedimentation surveys and equation 11. Therefore one of the purposes of developing this methodology was to estimate K values of the surveyed reservoirs by using the data from the reservoir sedimentation surveys.

The distribution of the calculated K values could then be used for estimating the unknown K values of the non-surveyed water supply reservoirs. If the surveyed reservoir is also used for a water supply reservoir, its future capacity could be projected by using the calculated K value. If a water supply reservoir had not had a sediment survey performed for it, then its K value was estimated by using the distribution of K values of the surveyed reservoirs.

The following algorithm was developed to perform the tasks required to estimate the future reservoir storage capacities of the water supply reservoirs. It summarizes the step-by-step procedure used in the methodology and can be used for the following purposes: 1) calculating the average K values by using the data from the reservoir sedimentation surveys, and 2) estimating the future capacity by inputting C_0, T_0, and K values. If a surveyed reservoir is also used as a water survey reservoir, both steps can be performed at once by the algorithm.

Algorithm

1. Input:

    I = inflow (inches/year)
    A = drainage area (square miles)
    P_i = percent sand, silt, or clay; $i = 1, 2$, or 3
    $t(j)$ and C_j = years and capacity estimates of each survey ($j = 0, \ldots, N$)
    ($j = 0$ indicates initial conditions and N is the actual number of surveys)

2. Set $j = 0$.

   If $N = 0$, then input K (no surveys), and go to step 9 (do not estimate K).

   If $j = N$, go to step 8.

   Otherwise $\Delta t_j = t(j+1) - t(j)$.

3. Estimate an average capacity-inflow ratio CIR and trap efficiency by using the surveys j and **j+1.**

$$\mathrm{CIR} = \frac{C_j + C_{j+1}}{2I}$$

$$\mathrm{TE}(\mathrm{CIR}) = f(\mathrm{CIR})$$

   where TE(CIR) is a function of CIR and is estimated from Brune's curve.

4. Calculate average sediment density, $\bar{\delta}$, for At_j years (equation 7 or 10).

5. Calculate an initial average estimate of K from equation 11:

$$\bar{K}_j = \frac{(C_j - C_{j+1}) \cdot \bar{\delta} \cdot 2178}{A^{0.88} \cdot \mathrm{TE}(\mathrm{CIR}) \cdot \Delta t_j}$$

6. Calculate an estimate of capacity C^*_{j+1} by using $\bar{K}_j$ and equation 11, with Δt^* year increments **($At^* \leq \Delta t_j$):**

$$C^*_n = C^*_{n-1} - \frac{\bar{K}_j \cdot A^{0.88} \cdot \mathrm{TE}(C^*_{n-1}) \cdot \Delta t^*}{2178 \cdot \bar{\delta}_n} \quad \text{for} \quad n = t_j + \Delta t^*, \ldots, t_{j+1}$$

   where C^*_n is a capacity estimate at the intermediate year, n, between two successive surveys, and TE(C^*_{n-1}) is the trap efficiency of the intermediate storage C^*_{n-1}, obtained from Brune's curve. The estimated capacity C^*_{j+1} should match the surveyed capacity C_{j+1}. In this study, At^* was taken as 1 year.

7. If $|C^*_{j+1} - C_{j+1}| \leq \varepsilon C_{j+1}$, then

$$K_j = \bar{K}_j$$

$$j = j+1 \qquad \text{Go to step 2.}$$

   Otherwise, change $\bar{K}_j$ by

$$\Delta K = C^*_{j+1} - C_{j+1}$$

$$\bar{K}_j = \bar{K}_j + \Delta K \qquad \text{Go to step 6.}$$

   In this study, e has been taken as 0.001.

8. Compute the weighted average K for the entire survey period, or just input K if the algorithm is to be used for estimating capacity projections (for N = 0):

$$K = \frac{\sum_{j=0}^{N-1} K_j \cdot \Delta t_j}{\sum_{j=0}^{N-1} \Delta t_j}$$

9. Estimate capacity projections by using equation 11, K, $\bar{\delta}_j$, and t(j) for t(j) > t(N):

$$\frac{C_{j+1}}{I} = \frac{C_j}{I} + \frac{K \cdot A^{0.88} \cdot TE(C_j) \cdot (t_{j+1} - t_j)}{2178 \cdot \bar{\delta}_{j+1}}$$

A computer program was written to execute the algorithm explained above. For calculating K and the capacity projections, all the steps in the algorithm must be performed. However, if a water supply reservoir has had no surveys and its K value is estimated from the results of reservoir sedimentation surveys, then only steps 1, 2, and 9 need to be performed.

Brune's curve was used for calculating TE, by expressing it in an analytical form of piecewise equations. The TE value used in step 6 was recalculated for each C* value. It has been found that, for reliable results, the time increment At* used in step 6 should be less than 5 years or Atj, whichever is smaller. The reliability of K_j depends highly on the accuracy of the survey results and Atj. Another factor that may affect the weighted average K values is the time difference between two successive surveys. If At is very large $C_j - C_{j+1}$ will be large, and then the average TE value calculated in step 3 will be very rough. In such a case Δt*, used in step 6, should be taken in as small an increment as 1 year to compensate for the error introduced in step 5.

The algorithm can handle situations where the reservoir capacity is increased by dredging or construction. Additional data needed to incorporate these situations are the capacity estimates for just before and after any changes were made, and the corresponding years of these changes. This is a very useful feature of the algorithm since some of the reservoirs in Illinois have their capacities changed either by increases in the spillway elevation or by periodic dredging. Another major feature of this methodology is the use of time-varying sediment density and trap efficiency. The average density of the sediment deposits containing an average of 50% clay and 50% silt may increase by 10 pounds per cubic foot during the first 20 years. Another 5-pound increase will take place in the next 40 years. Therefore, the difference between using a general average density or a time-varying density can be very significant over the early life of a reservoir. If the C/I ratio of a reservoir reduces from 0.10 to 0.01 over its useful life, then the trap efficiency will reduce by about 40%.

RESULTS

The results of this study are presented under two main subsections. The first section includes the analysis of surveyed reservoirs to establish statewide patterns of reservoir sedimentation and the distribution of sediment materials. These results may also serve as a basis for determining the causes of apparent local deviations in the sedimentation patterns in Illinois. The second section is basically an extension and application of the results of the sedimentation surveys to the water supply reservoirs for the estimation of future reservoir storage capacities. This information can be used to determine the safe yields of the water supply reservoirs in the future for various drought recurrence intervals, and can be combined with the results of a parallel study (Singh *et al.,* 1988), which is oriented toward estimating the future demands of the water supply systems. Then it will be possible to determine when a reservoir will become inadequate, and the type of mitigative measures that can extend the adequacy of the reservoirs for a number of years into the future.

Analysis of Surveyed Reservoirs

Reservoirs for which sedimentation surveys had been conducted were analyzed in order to develop more reliable sedimentation patterns in Illinois and to update the K values to be used in the sediment deposition model that was developed. K values represent the degree of severity of sediment deposition in a reservoir, and using inaccurate values may yield serious errors in storage capacity projections. The K values given by the UMRBC (see Figure 1) were not used in this methodology since they did not reflect the large regional deviations indicated by the reservoir sedimentation surveys. Rather than using the K values given in Figure 1, a new pattern of K values was developed by calculating the K values from the surveyed reservoirs (by using the developed model). This pattern was then used for projections of future storage capacity of the water supply reservoirs.

This task was achieved by analyzing 118 reservoirs for which sedimentation surveys had been conducted. A list of these reservoirs is given in Table 3, together with the data needed for calculating the K values. These surveyed reservoirs cover most of the state (except for the northeastern part) as shown in Figure 7. Forty-one of the surveyed reservoirs are also being used as water supply reservoirs; they are identified by asterisks following the reservoir codes in Table 3 and by underlines below the reservoir codes in Figure 7. The K values of the surveyed reservoirs were obtained by using a computer program developed to perform the procedure given by the algorithm. Changes in trap efficiency and in the density of sediments due to compaction over time have been incorporated in the model. The K values calculated from the reservoir sedimentation surveys are listed in Table

3, and these values are shown in Figure 9 to illustrate the statewide variation of K. Underlined K values in Figure 9 indicate surveyed water supply reservoirs.

Every attempt was made to simulate the actual reservoir conditions. For example, any increases in the storage capacities of the reservoirs due to construction or dredging were considered in the method. Streams that had multiple reservoirs in series (such as Lake Mattoon and Lake Paradise on the Little Wabash River, and Carlyle Lake and Lake Shelbyville on the Kaskaskia River) were treated differently, because the upstream reservoirs trap part of the sediment coming from the drainage areas upstream of the reservoirs. In such cases, the effective drainage areas of the downstream reservoirs were estimated by considering the drainage area below the upstream reservoirs and the trap efficiency of the upstream reservoirs.

For some large or multi-purpose reservoirs like Carlyle Lake and Rend Lake, storage capacities were taken at normal pool elevations, although the levels may rise above these levels during flood conditions. For Carlyle Lake normal pool elevation was taken as 445 feet (summer pool), and for Rend Lake the main spillway crest elevation at 405 feet was considered as the normal pool.

Variation in K values: The distribution of K values in Figure 9 exhibits a great deal of spatial variability. Although the general trend follows the pattern given by Figure 1, in some cases the variation of K values in a particular land resource area may be more than 100%. For example, in Franklin County (Code No. 28) the K values range from K = 901 for Valier Outing Club Reservoir (Reservoir Code No. 3) to K = 4270 for Rend Lake (Reservoir Code No. 6). The K value for Franklin County is given as K = 1500 in Figure 1. Also, in Sangamon County (Code No. 84) K = 653 for Schmidt Pond (Reservoir Code No. 4), and K = 1655 for Aschauer Pond (Reservoir Code No. 1). The K value for Sangamon County is given as K = 1200 in Figure 1.

Several factors may affect the variation of K. Analysis of the surveyed reservoir sites on topographic maps indicated that most of the variation in K can be explained by variation of land slope and watershed size. If the watershed is small, there is a greater chance that the average land slope of the reservoir drainage area will not be representative of the overall slope of the land resource area used for defining K values.

Duration of the survey records is also important. Reservoirs with relatively short records (less than 10 years, for example) may also show significant deviations since the hydrologic variables, like inflow, used in the calculations represent long-term averages and may not reflect the conditions that occur in a relatively short period. Therefore, it is suggested that careful consideration should be given to estimating K values, especially in regions where there is considerable variation in sedimentation patterns.

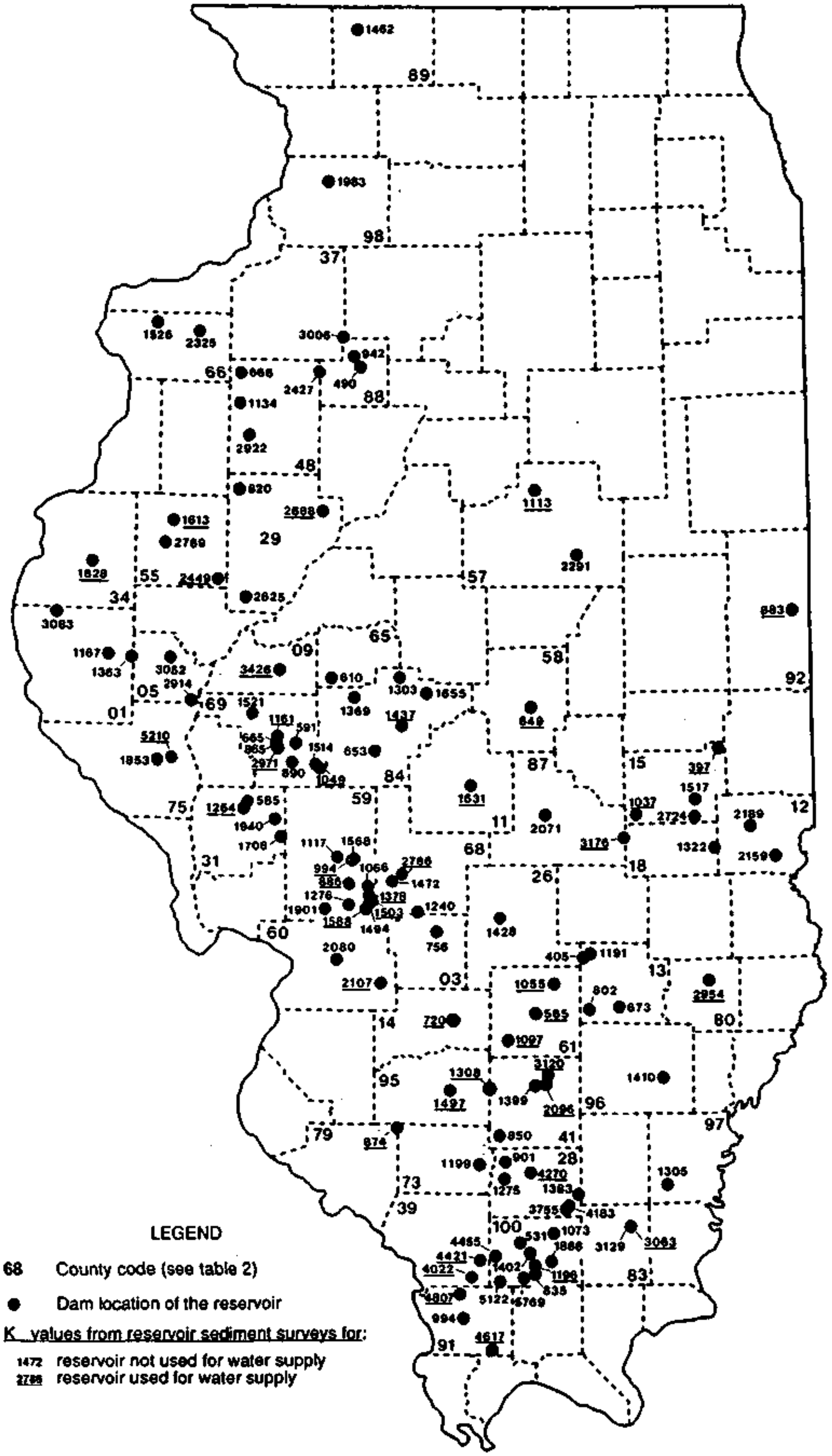

Figure 9. Calculated K values for the surveyed reservoirs

Analysis of Water Supply Reservoirs

In this study future storage capacities of 82 water supply reservoirs were estimated by using the developed methodology. Forty-two of the water supply reservoirs investigated here had also had reservoir sedimentation surveys conducted, and thus their K values were calculated by using data from the sediment surveys. The average K values of the remaining non-surveyed water supply reservoirs were estimated on the basis of the distribution of the K values calculated from the sediment surveys (Figure 9).

Several factors that were found to contribute to the regional variability of the K values were also considered in the estimation of K. For example, land slope, watershed size, and land use of the surrounding surveyed reservoirs were examined before selecting the K values of the non-surveyed water supply reservoirs. The estimated and calculated K values of all the water supply reservoirs are given in Table 5 and are also shown in Figure 10. The surveyed water supply reservoirs are indicated by asterisks in Table 5, and by underlined K values in Figure 10.

The projected future storage capacities of the water supply reservoirs up to the year 2030 are given in Table 5 for 10-year increments. These storage projections reflect an extension of the past sedimentation patterns of the reservoirs. Utmost care has been given in estimating the K values used in the capacity projections, by trying to use the local variations of the parameters believed to affect the sedimentation process in reservoirs. It should be kept in mind that all the storage capacity projections made here are based on the normal reservoir operations, and on hydrological conditions based on data for fairly long durations. Persistent deviations from normal conditions, such as changes in the operation policy of the reservoirs, or long periods of very wet or dry spells, would obviously affect the physiographic and hydrologic parameters used in the model.

Table 5. Estimated Future Capacities of the Water Supply Reservoirs

County & Reservoir Codes[†]	Reservoir Name	K	Latest Capacity Measurement (ac-ft)		Estimated Future Reservoir Capacities (ac-ft)				
			Year	Capacity	1990	2000	2010	2020	2030
3 - 2	Governor Bond Lake	1200	1969	9900.0	9413.3	9210.6	9014.4	8822.7	8634.6
3 - 3	Sorento Reservoir	900	1980	101.0	96.2	92.1	88.2	84.5	80.9
9 - 1*	Virginia Reservoir	3426	1982	179.0	163.3	143.9	125.0	106.4	88.1
11 - 1*	Lake Taylorville	1631	1977	7914.0	6829.3	6045.2	5296.9	4580.3	3893.3
11 - 2	Lake Kincaid	500	1980	263.9	253.6	244.9	236.8	228.9	221.3
11 - 3	Sangchris Lake	700	1967	35002.0	34382.0	34148.0	33921.0	33699.0	33481.0
11 - 4	Lake Pana	1500	1980	3297.0	3207.3	3130.4	3057.5	2987.0	2918.1
14 - 1*	Carlyle Lake @445	720	1976	217008.0	209420.0	204380.0	199510.0	194750.0	190090.0
15 - 3*	Lake Paradise	1037	1979	1407.0	1319.4	1241.1	1163.9	1087.8	1012.7
15 - 4*	Oakland Lake	397	1973	115.0	91.1	78.6	67.2	57.0	48.1
23 - 1	Twin Lake (Old, or West)	800	1983	150.0	121.5	89.5	64.3	45.5	32.8
23 - 1	Twin Lake (New, or Third)	800	1983	1400.0	1361.7	1312.8	1266.0	1220.6	1176.0
24 - 1	West Salem New Reservoir	1500	1968	138.0	122.3	115.5	108.9	102.3	95.8
24 - 2	West Salem Old Reservoir	1500	1968	36.8	18.8	12.2	7.0	3.5	2.0
25 - 1	Altamont New Reservoir	1000	1980	950.0	940.3	931.9	923.9	916.1	908.5
25 - 2	CIPS Lake	1000	1934	282.3	246.9	241.2	235.6	230.0	224.5
25 - 3	Lake Sara	1500	1957	13808.0	13453.0	13357.0	13263.0	13171.0	13079.0
26 - 3	Lake Nellie (St. Elmo New Res.)	1200	1964	828.5	772.9	753.9	735.5	717.4	699.6
26 - 4	Vandalia Lake	1200	1965	6750.5	6320.3	6168.7	6021.3	5876.9	5734.9
28 - 6*	Rend Lake @405	4270	1980	177000.0	170100.0	163470.0	157000.0	150630.0	144370.0
29 - 3*	Canton Lake	2688	1960	3023.0	2421.0	2229.2	2040.5	1854.5	1671.0
30 - 1	Omaha Reservoir	1500	1965	154.0	147.1	144.5	142.0	139.4	136.9
31 - 3*	Whitehall Lake	1264	1952	407.7	376.2	368.1	360.1	352.2	344.3
31 - 5	Greenfield Lake	1750	1980	564.0	546.5	531.5	517.3	503.4	489.9
34 - 1*	Carthage Reservoir	1828	1962	276.6	188.9	159.3	130.6	102.9	76.7
39 - 1*	Little Cedar Lake	4022	1976	655.8	477.0	358.9	248.8	149.1	66.3
39 - 2*	Carbondale Reservoir	4421	1948	1193.0	862.5	786.6	711.5	637.2	563.7
39 - 3	Cedar Lake	4000	1978	28365.0	27652.0	27107.0	26577.0	26056.0	25543.0
39 - 4	Kinkaid Lake	4000	1976	79000.0	77388.0	76336.0	75312.0	74306.0	73314.0
41 - 3*	Miller Lake	3120	1953	1658.8	1355.5	1278.1	1201.7	1126.4	1051.8
41 - 4*	Jaycee Lake (Mt. Vernon Res.)	2096	1959	1084.4	987.5	956.8	926.5	896.3	866.4
41 - 5	L & N Reservoir	1400	1978	182.0	174.2	168.4	162.8	157.3	152.0
44 - 1	Bloomfield Lake (Vienna City R.)	3000	1979	1472.8	1447.4	1425.4	1403.8	1382.6	1361.5
55 - 2*	Spring Lake	1613	1968	2880.0	2542.3	2393.4	2246.9	2102.2	1959.3
55 - 3*	Vermont Lake	2449	1980	223.0	189.6	157.3	126.1	96.1	67.6
57 - 1*	Lake Bloomington	1113	1955	5863.0	4936.4	4683.3	4434.2	4188.8	3946.7
58 - 1*	Lake Decatur	649	1983	18800.0	17859.0	16552.0	15285.0	14057.0	12868.0
59 - 3*	Lake Carlinville	994	1986	1650.0	1607.0	1501.1	1397.3	1295.4	1195.5
59 - 5*	Old Gillespie Lake	886	1954	696.0	596.6	570.1	544.0	518.2	492.8
59 - 7*	Mt. Olive Lake	1378	1981	282.4	249.5	214.4	180.6	148.2	117.4
59 - 9*	Lake Staunton	1588	1978	1049.0	1008.2	974.8	941.8	909.1	876.8
59 -11*	Old Mt. Olive Reservoir	1503	1981	382.0	375.3	368.0	360.7	353.5	346.4
59 -12	Otter Lake	1300	1969	16520.0	16188.0	16049.0	15914.0	15782.0	15652.0
59 -13	New Gillespie Lake	900	1980	2324.9	2252.4	2190.3	2131.3	2074.3	2018.6
59 -14	Fresson Lake (Bunn Lake)	1200	1985	1110.0	1089.4	1055.1	1023.3	992.7	963.0
59 -15	Palmyra-Modesto Lake	1150	1965	533.9	496.6	483.5	470.6	458.1	445.7
59 -16	Shipman Reservoir	1200	1980	114.0	108.7	104.1	99.8	95.6	91.4

Table 5. Concluded

County & Reservoir Codes†	Reservoir Name	K	Latest Capacity Measurement (ac-ft)		Estimated Future Reservoir Capacities (ac-ft)				
			Year	Capacity	1990	2000	2010	2020	2030
60 - 1*	Highland Silver Lake	2107	1984	6215.2	5947.2	5504.5	5073.1	4652.1	4240.9
60 - 3	Holiday Lake	2000	1978	4605.0	4496.4	4417.7	4342.4	4269.3	4197.6
61 - 1*	ICRR Reservoir, Kinmundy	1055	1959	149.1	136.9	133.0	129.1	125.3	121.6
61 - 2*	Raccoon Lake	1097	1959	5230.0	4543.0	4334.0	4128.0	3926.0	3727.0
61 - 3*	Salem Reservoir	585	1960	530.9	493.7	481.6	469.6	457.7	445.9
61 - 4	Centralia Lake	1000	1976	2772.0	2709.4	2669.8	2631.5	2594.1	2557.4
68 - 3*	Lake Lou Yaeger	2786	1977	13906.0	12142.0	10863.0	9634.2	8447.6	7298.4
68 - 4	Lake Hillsboro	1500	1982	1017.8	951.0	881.3	816.1	753.6	693.2
68 - 5	Lake Glenn Shoals	1500	1979	13203.0	12479.0	11922.0	11395.0	10887.0	10392.0
69 - 5*	Lake Jacksonville	2971	1986	5830.0	5763.0	5598.0	5435.0	5273.0	5114.0
69 - 8*	Mauvaisseterre Lake	1161	1979	627.9	495.0	383.2	281.2	193.5	123.9
69 - 9*	Waverly Lake	1049	1971	159.4	92.1	62.8	39.4	23.0	13.9
69 -11	Reservoir #2	1000	1978	159.3	156.0	153.7	151.4	149.2	147.1
72 - 1	Lake Camelot	2250	1969	699.6	645.1	622.0	599.6	577.6	556.0
73 - 2	Pinckneyville Reservoir	2000	1978	2870.0	2766.3	2690.1	2617.0	2545.8	2476.0
75 - 2*	Lake Pittsfield (New-Big Blue)	5210	1985	2760.0	2606.5	2307.0	2015.2	1729.7	1449.9
79 - 1*	Coulterville Reservoir	874	1954	188.0	163.3	156.7	150.2	143.9	137.6
79 - 2	Sparta Old Reservoir	1300	1915	322.2	246.3	237.0	227.8	218.6	209.5
79 - 3	Sparta New (North) Reservoir	1200	1954	184.1	104.8	86.1	68.6	52.5	37.9
80 - 1*	Borah Lake (New Olney Res.)	2954	1960	1517.4	1351.4	1298.5	1246.2	1194.6	1143.4
80 - 2	East Fork Lake	1500	1978	12460.0	12359.0	12281.0	12205.0	12130.0	12056.0
80 - 3	Vernor Lake	1500	1934	767.0	738.8	734.1	729.4	724.7	720.0
83 - 1*	Eldorado Reservoir	3063	1949	726.0	572.5	536.1	499.9	464.1	428.5
83 - 3	Doc Mac Strip Pit	1000	1980	144.2	140.6	137.2	133.8	130.5	127.2
83 - 4	Peabody Strip Pit	1000	1980	889.8	882.7	875.8	869.1	862.5	855.9
84 - 5*	Lake Springfield	1437	1984	52200.0	51387.0	50050.0	48732.0	47432.0	46147.0
87 - 1*	Lake Mattoon	3176	1980	11660.0	11063.0	10486.0	9921.5	9368.3	8824.0
91 - 1*	Alto Pass Reservoir	4807	1976	108.0	79.9	61.0	43.0	26.3	11.6
91 - 3*	Dongola City Reservoir	4617	1981	558.0	477.7	392.5	310.7	232.5	159.0
92 - 1*	Lake Vermilion	883	1976	4641.0	3785.2	3214.0	2681.0	2196.6	1764.3
95 - 1*	Ashley Lake	1308	1985	123.0	118.0	108.2	98.6	89.2	80.0
95 - 2*	Nashville Reservoir	1497	1954	289.0	239.3	226.2	213.3	200.5	187.9
100 - 9*	Marion Reservoir	1196	1951	590.0	455.6	422.7	390.4	358.6	327.5
100 -10	Lake of Egypt	5000	1961	41497.0	39319.0	38613.0	37915.0	37225.0	36539.0
102 - 1	Lake Eureka	1500	1986	291.5	279.4	253.4	229.3	206.1	183.8

† See Table 2 for county names.

* Indicates that the reservoir has been surveyed.

K is the regional constant.

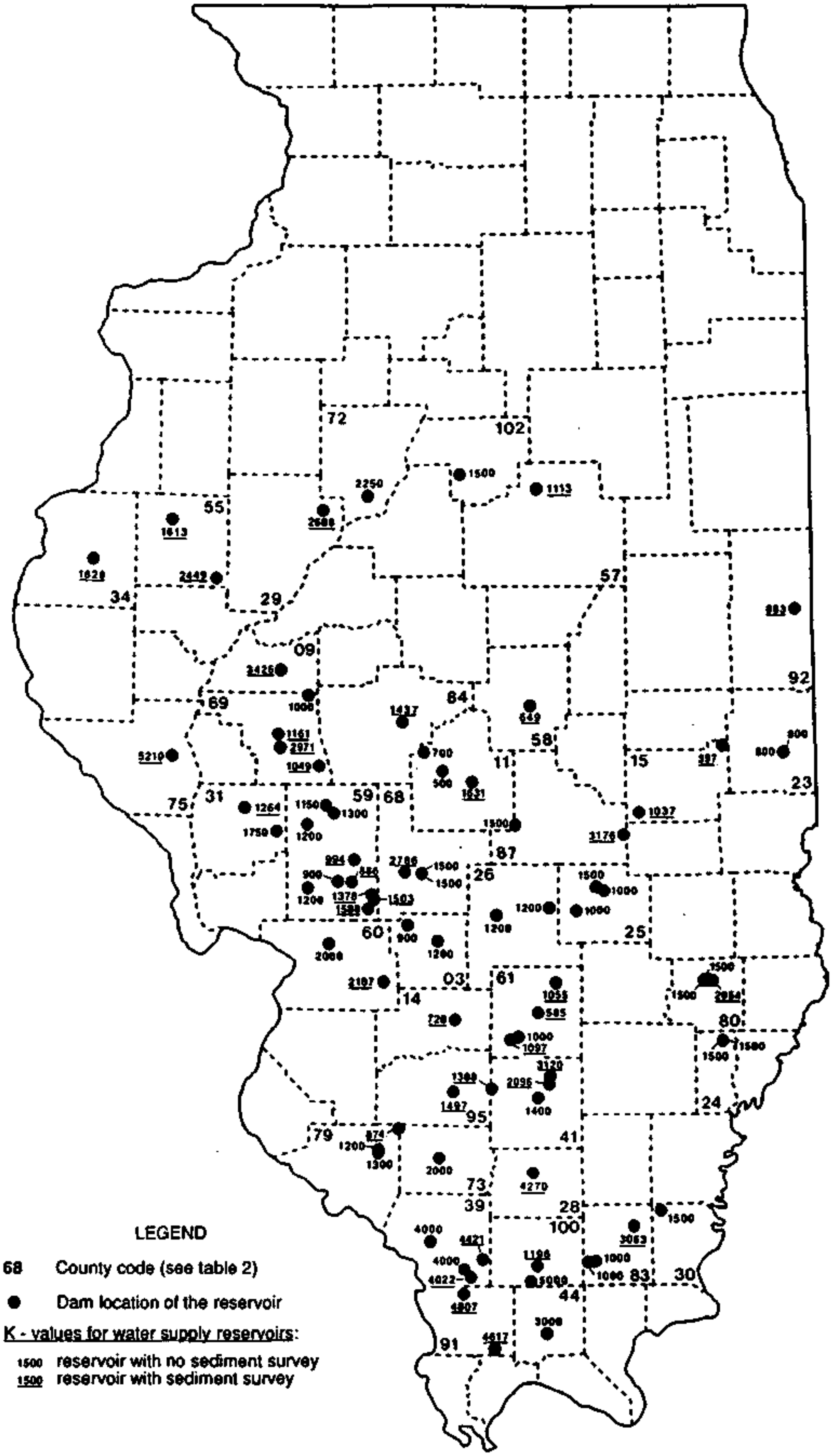

Figure 10. K values used for storage capacity projections for the water supply reservoirs

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Note: Various State Water Survey (SWS) personnel have been conducting lake sediment surveys for the last 50 years. The formal and informal reports, relevant files, contract reports, and reprints of technical papers were reviewed to compile and verify the data used in this report. The SWS professionals who contributed largely to the sediment surveys are John B. Stall, William C. Bogner, Nani G. Bhowmik, and William P. Fitzpatrick. Others include A. A. Klingebeil, S. W. Melsted, E. L. Sauer, L. C. Gottschalk, J. R. Adams, M. Demissie, M. T. Lee, and P. B. Makowski. However, this is not an exhaustive list.

Robin B. King compiled the information on percent sediment constituents from the Water Survey files and reports. His contribution to the project is greatly appreciated.

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