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A NEW METHOD FOR ESTIMATING FUTURE RESERVOIR STORAGE CAPACITIES[1]

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ABSTRACT: A new method has been developed for estimating future reservoir storage capacities, allowing for sediment deposition and compaction. Reservoir sedimentation surveys for 117 reservoirs, conducted by the Illinois State Water Survey over the past 60 years, were used to determine regional constants K to represent the severity of sediment deposition in the reservoirs. More than half of the 82 water supply reservoirs investigated had records of reservoir sedimentation surveys, and their K values were calculated by using data from those sediment surveys. The average K values of the remaining non-surveyed water supply reservoirs were estimated from the regional distribution of the K values. Other important factors considered in the estimation of future reservoir storage capacities are the trap efficiency of the reservoirs and the variation of density of sediment deposits due to compaction. The model can also be used for analyzing the economics of alternative sites and of design features that can be incorporated in dams for reducing reservoir sedimentation.

(KEY TERMS: reservoir sedimentation; water supply reservoirs; trap efficiency; sediment compaction; capacity estimation.)

INTRODUCTION

Intrastate rivers are one of the main sources of surface water supply. 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 into which water is pumped from rivers during moderate or high-flow conditions; and sometimes auxiliary or standby ground-water wells.

The adequacy and reliability of the water supplies from surface water resources are 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 yields and thus in an inadequacy to supply sufficient water in the next 10 to 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 demands for recreation and for mandatory low-flow releases from the reservoirs for maintaining stream-water quality, ecology, and aquatic habitats.

An inventory of Illinois water supply reservoirs that use intrastate rivers was carried out by Singh et al. (1988). An evaluation of current reservoir capacities and projections of future capacities in the next 10 to 40 years on the basis of historical data and reservoir sedimentation modeling is needed. Only after that can one estimate the years when each water supply system may become inadequate under various drought scenarios. Then the systems that appear to be at high risk can be selected and further investigated to determine mitigative measures.

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 to 15% of the average annual streamflow, while 75 to 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

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spillway, cleaner water is skimmed from the top of the lake. The ratio of the volume of sediment trapped in a reservoir to the volume of incoming sediment is usually referred to as the reservoir's trap efficiency. Several factors may affect the trap efficiency of a reservoir, including (1) the capacity-inflow (C/I) ratio or acre-feet capacity per acre-foot of annual flow (the larger the C/I, the smaller the amount of water released downstream and the higher the percentage of incoming sediment trapped); and (2) the compaction of the sediment deposits as a result of 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.

RESERVOIR SEDIMENTATION MODELING

The sedimentation process is a very complicated phenomenon governed by several hydraulic and hydrologic variables. Unfortunately, no analytical relation 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 on the basis of the empirical relations.

Reservoir sedimentation surveys have been conducted for more than 100 reservoirs across the state of Illinois over the last 60 years by personnel of the Illinois State Water Survey. This extensive data base was used to establish a pattern of reservoir sedimentation in Illinois by using the method 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 non-surveyed water supply reservoirs. The method developed here for estimating reservoir sedimentation and future capacity projections is based upon equations for storage continuity and stream sediment yield. The storage continuity equation used in the development of the method is given by

$$S = \frac{C_0 - C_T}{\Delta T} \quad \text{or} \quad C_0 = S \bullet \Delta T + C_T \qquad (1)$$

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 $t = T$.

Another form of Eq. 1 will be developed by substituting S with an empirical relation that uses parameters which represent the physical characteristics of a watershed. 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_0 is taken as the year that survey was made. For the non-surveyed water supply reservoirs, C_0 values had to be estimated through personal communications with the water supply districts, and from the Illinois Environmental Protection Agency (Illinois Environmental Protection Agency, 1978). $S \bullet \Delta T$ gives the total capacity loss in ΔT years due to sediment deposition. S is not a constant value but changes from year to year as a result of fluctuations in the inflow and changes in trap efficiency and sediment density. Historical C_T values are usually estimated by the reservoir sediment surveys, and are used with C_0 to calculate the historical 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 Eq. 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 Comprehensive Basin Study (UMRCBS, 1970) approach. The empirical UMRCBS approach describes the sediment yield of a stream as

$$Y = K \bullet A^{-0.12} \qquad (2)$$

where

- Y = sediment yield in tons per year per square mile of watershed area
- K = an empirical regional constant with dimensions [tons/year/mile$^{1.76}$]
- A = watershed area in square miles

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

$$S = \frac{Y \bullet A \bullet TE}{2178 \bullet \delta} = \frac{C_0 - C_T}{\Delta T} \tag{3}$$

and by substituting Eq. 2 into Eq. 3, we get

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

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 average K values given by Terstriep et al. (1982) cover large areas varying between 2000 to 10,000 square miles. However, preliminary investigations made in this study by using the reservoir sedimentation survey data, as well as Eqs. 1 and 4, revealed that the variation of K values within a particular region may be quite significant. 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), which is 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 relates the trap efficiency of a reservoir to its capacity-inflow (C/I) ratio. Its use in calculating sediment retained in the reservoirs is well established. 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 sediment conditions. The trap efficiency of a reservoir gradually decreases during its useful life, because the C_T/I ratio diminishes as a result of 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:

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

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 inTable 1.

TABLE 1. Values of δ_1 and M Used for Estimating Average Density of the Compacted Sediment Deposits (Lane and Koelzer, 1943).

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

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 Eq. 5 over T years as

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

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:

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

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

Equation 1 can be rewritten by substituting S by Eq. 4, and replacing δ with $\bar{\delta}_T$ to get a new form of the continuity equation:

$$C_0 = C_T + \frac{K \bullet A^{0.88} \bullet TE}{2178 \bullet \bar{\delta}_T} \Delta T \qquad (8)$$

If the initial conditions and all other parameters are determined (or estimated), then the current reservoir capacity C_T can be estimated by using Eq. 8 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 conducted by the Illinois State Water Survey over the last 60 years, Illinois Environmental Protection Agency (Illinois Environmental Protection Agency, 1978), and personal communications. A complete list of the data used in this study is given by Singh and Durgunoğlu (1988). 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. Contours of average annual runoff in inches were taken from the Upper Mississippi River Comprehensive Basin Study (UMRCBS, 1970). These contours are about the same as developed in recent unpublished studies.

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 three groups with respect to their average particle diameter D, as follows:

$$D \le 0.004 \text{ mm} \quad \text{Clay}$$
$$0.004 \text{ mm} < D \le 0.062 \text{ mm} \quad \text{Silt}$$
$$0.062 \text{ mm} < D \le 2.0 \text{ mm} \quad \text{Sand}$$

Contour maps showing distribution of percent clay, silt, and sand were generated to obtain the average percentages of these constituents in sediment deposited in a reservoir. These maps were then used for estimating the sand, silt, and clay percentages of the sediment deposits in the reservoirs for which particle size analyses were not available.

Available and estimated data for some surveyed reservoirs are given in Table 2. The storage capacities listed in Table 2 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 233.2). Spring Lake was dredged in 1951 to provide an additional 188.4 acre-feet of storage. Also in 1968 a new dam was built just downstream of the existing dam, which increased the storage capacity of Spring Lake to 2880 acre-feet. The K values given in Table 2 for the surveyed reservoirs were calculated with an algorithm specifically prepared for this purpose. The locations of the surveyed reservoirs are shown in Figure 1.

The data for the non-surveyed water supply reservoirs were collected from personal communications 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, 1978). Drainage areas were usually verified from topographical maps. Particle size distributions were estimated as mentioned earlier. The locations of the water supply reservoirs are shown in Figure 2.

CALCULATION OF FUTURE RESERVOIR STORAGE CAPACITIES

The future reservoir storage capacities C_T can be estimated by using Eq. 8 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

TABLE 2. Sample of Surveyed Reservoirs in Illinois and Available Data.

County & Reservoir Codes†	Reservoir Name	Annual Inflow (inches)	Drainage Area (mi^2)	Particle Size Distribution (%)			K	Surveys	
				Sand	Silt	Clay		Year	Capacity (acre-ft)
5 - 1	Mt. Sterling Reservoir	8.50	1.80	1.0	54.5	44.6	3052	1935	306.0
								1951	248.3
								1954	233.2
								1954	295.2
								1962	262.5
28 - 3	Valier Outing Club Reservoir	13.00	2.47	2.0	62.0	36.0	901	1922	369.0
								1957	320.0
28 - 6*	Rend Lake @ 405 ft.	13.50	488.0	3.0	67.0	30.0	4270	1970	184700.0
								1980	177000.0
55 - 2*	Spring Lake	8.00	20.20	1.0	50.5	48.5	1613	1927	503.6
								1951	184.0
								1951	372.4
								1968	172.0
								1968	2880.0
59 - 1	Arctic Lake	9.50	0.53	6.0	33.0	61.0	1568	1922	175.6
								1949	159.5
								1954	152.2
								1961	147.6
61 - 3*	Salem Reservoir	11.20	4.02	8.3	51.0	40.6	585	1912	597.1
								1960	530.9
69 - 5*	Lake Jacksonville	9.00	10.80	2.0	51.5	46.5	2971	1940	6680.0
								1952	6460.0
								1986	5830.0
91 - 3*	Dongola City Reservoir	15.00	3.55	3.8	76.9	19.2	4617	1970	666.0
								1981	558.0
92 - 1*	Lake Vermilion	9.80	298.00	5.5	42.7	51.8	883	1925	8514.0
								1963	5318.0
								1976	4641.0
100 - 6	Johnston City Reservoir	14.00	3.85	4.0	78.0	18.0	1073	1922	471.0
								1957	394.0

† See Figure 1 for county and reservoir codes.
* Indicates that the reservoir is used for water supply.
K is the regional constant (see Figure 3).

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. The K values of the surveyed reservoirs were calculated by using the reservoir sedimentation surveys and Eq. 8. 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, allowing for the effects of drainage area size, overland slopes, and drainage density.

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

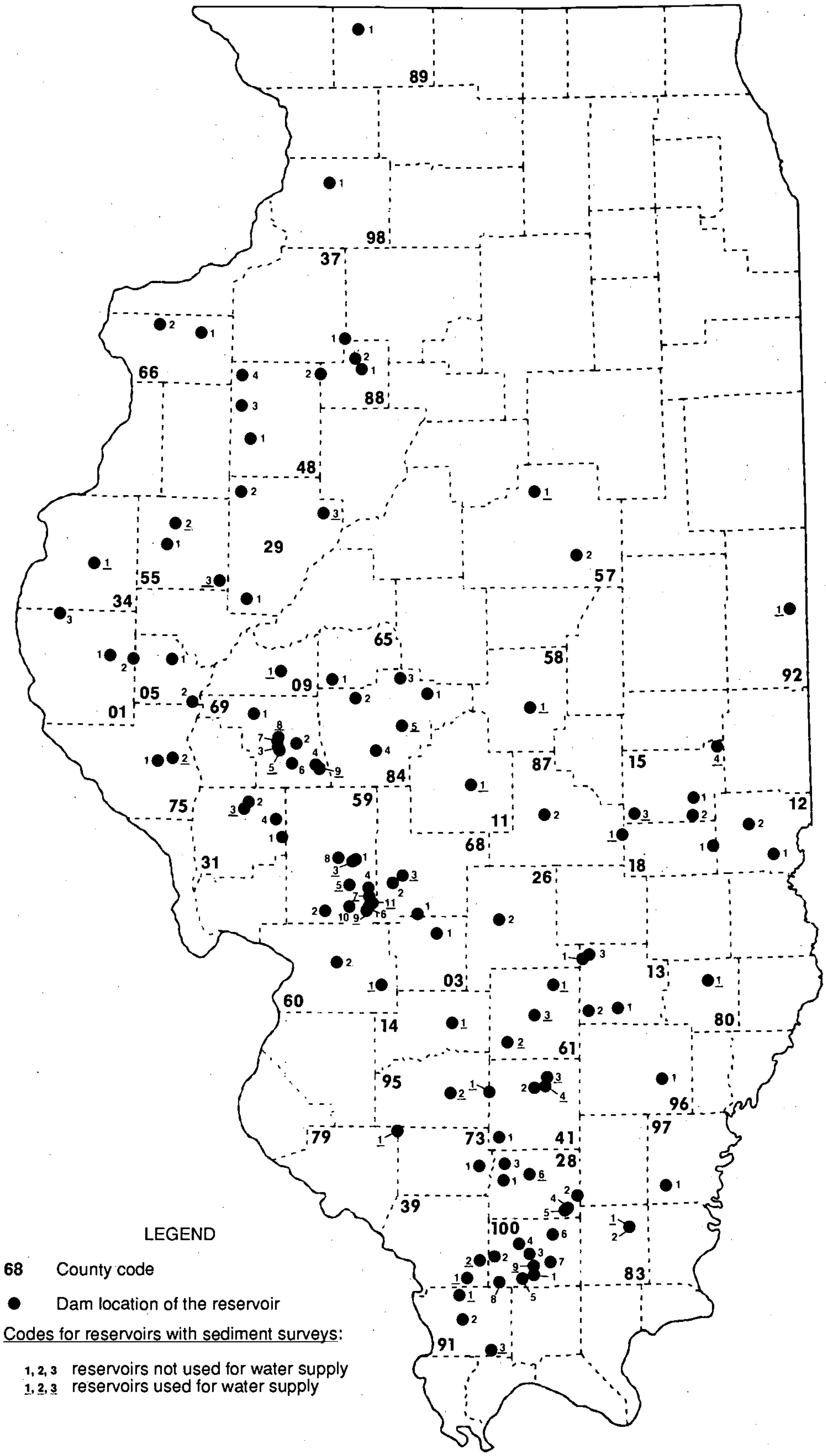

Figure 1. Locations of Surveyed Reservoirs in Illinois.

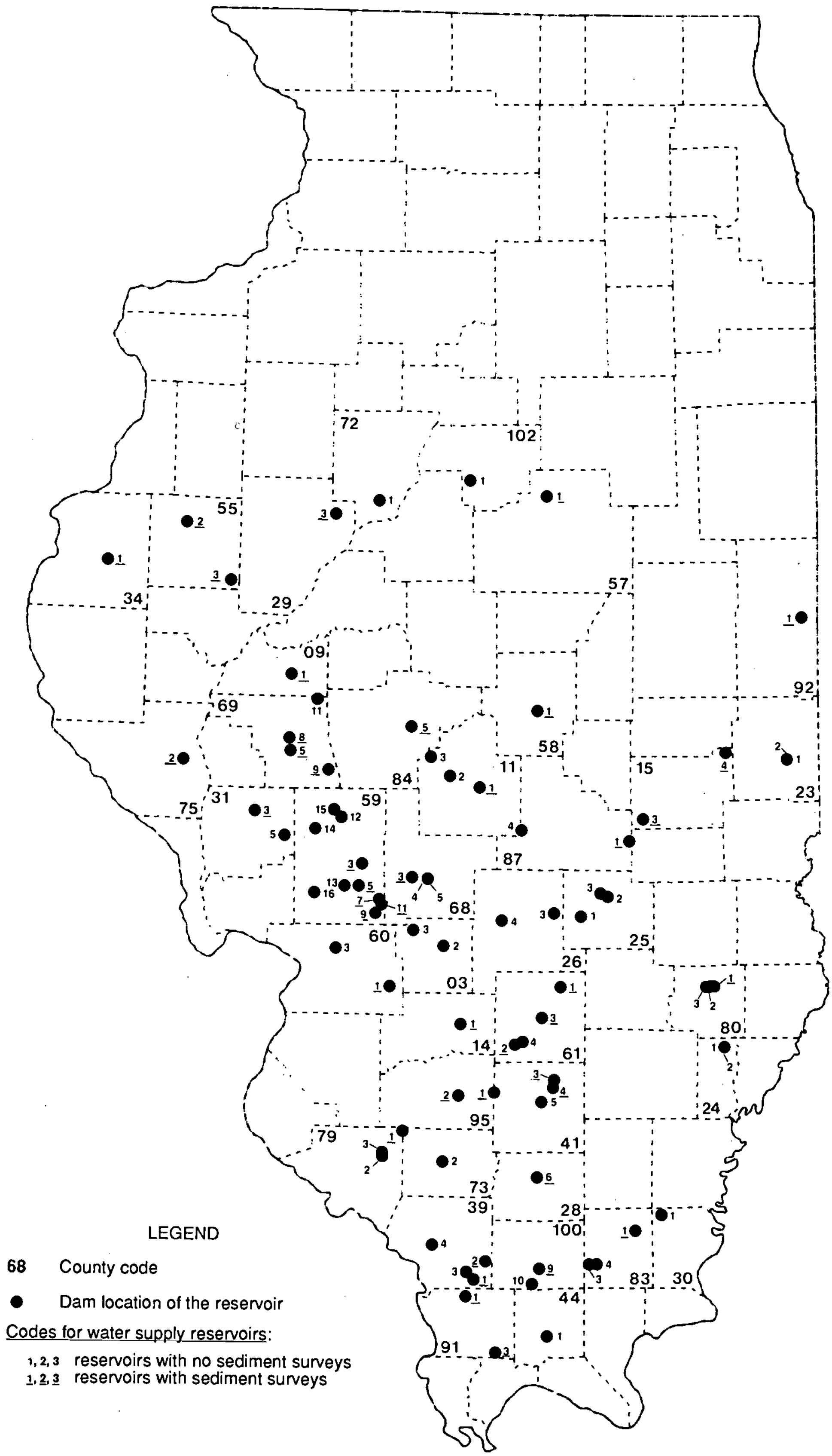

Figure 2. Locations of Water Supply Reservoirs in Illinois.

supply 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 storage capacity estimates from each survey (j = 0, ... , 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.

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

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

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

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

5. Calculate an initial average estimate of K from Eq. 8:

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

6. Calculate an estimate of capacity C^*_{j+1} by using $\bar{K}_j$ and Eq. 8, with Δt^* year increments ($\Delta t^* \leq \Delta t_j$):

$$C^*_n = C^*_{n-1} - \frac{\bar{K}_j \bullet A^{0.88} \bullet \mathrm{TE}(C^*_{n-1}) \bullet \Delta t^*}{2178 \bullet \bar{\delta}_n}$$

$$\text{for } n = t_j + \Delta t^*, \ldots , t_{j+1}$$

   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, Δt^* was taken as 1 year.

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

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

9. Estimate capacity projections by using Eq. 8, K, $\bar{\delta}_j$, and t(j) for t(j) > t(N):

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

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 Δt^* used in step 6 should be less than 5 years or Δt_j, whichever is smaller. The reliability of K_j depends highly on the accuracy of the survey results and Δt_j. Another factor that may affect the weighted average K values is the time difference between two successive surveys. If Δt 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%.

A sensitivity analysis was performed to test the effect of ±10% variation in reservoir inflow values which are used to calculate C_T/I. The C_T/I values were then used in estimating the trap efficiencies, and consequently the future reservoir storage capacities. Three reservoirs were selected to cover C/I values ranging from 0.06 to 0.55. The selected reservoirs are Rend Lake (C_0/I = 0.55), Salem Reservoir (C_0/I = 0.25), and Spring Lake (C_0/I = 0.06). The effect of ±10% variation in inflow on storage capacity projections (C_{25}), and trap efficiencies corresponding to C_{25} are presented in Table 3. The results of the sensitivity analysis indicate that the only noticeable change in the storage projections occur at the lower C/I value. With ±10% variation in inflow the C_{25} projections vary by less than 5% at C_0/I = 0.06. Therefore, using approximate inflow values for C/I is not expected to cause significant deviations in the storage capacity projections.

ANALYSIS OF RESERVOIR SEDIMENTATION SURVEYS

Reservoir sedimentation surveys 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 developed model was used to determine the distribution of the K values of the surveyed reservoirs. This distribution and other regional physical properties were then used for obtaining storage capacity projections of the water supply reservoirs.

This task was achieved by analyzing 118 reservoirs for which sedimentation surveys had been conducted by the Illinois State Water Survey. A sample list of these reservoirs is given in Table 2, 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 1. 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 2 and by underlines below the reservoir codes in Figure 1. The K values for the surveyed reservoirs were obtained by using a computer program developed to perform the procedure given by the algorithm. Land use and land cover conditions in Central and Southern Illinois have not changed significantly over the last 50 years, therefore, estimates of K values were assumed to be static. 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 2, and these values are shown in Figure 3 to illustrate the statewide variation

TABLE 3. Variation of C_{25} and TE Estimates with ±10% Variation in Inflow.

	Rend Lake (C_0/I = 0.55)			Salem Reservoir (C_0/I = 0.25)			Spring Lake (C_0/I = 0.06)		
	90% Inflow	100% Inflow	110% Inflow	90% Inflow	100% Inflow	110% Inflow	90% Inflow	100% Inflow	110% Inflow
C_{25} (acre-feet)	166,660	166,730	166,790	560.4	560.6	560.7	162.3	169.3	175.8
TE (percent)	96.3	96.0	95.6	93.6	93.3	92.9	62.1	60.0	59.5

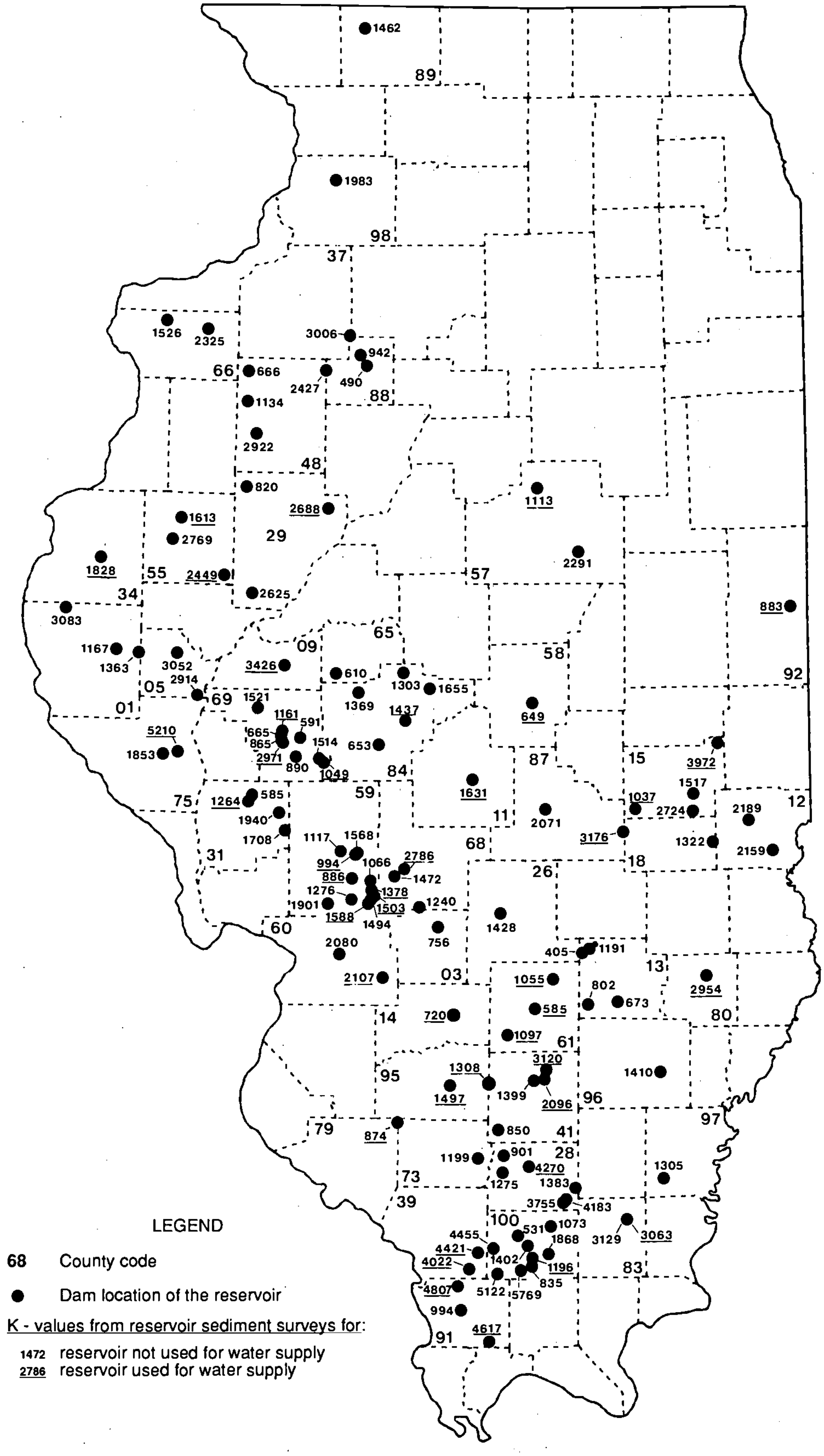

Figure 3. Calculated K Values for the Surveyed Reservoirs.

of K. Underlined K values in Figure 3 indicate surveyed water supply reservoirs. Several factors may affect the variation of K. Qualitative analysis of the surveyed reservoir sites on topographic maps indicated that most of the variation in K can be attributed to variation of land slope, watershed size, and drainage density.

The 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 be given to estimating K values, especially in regions where there is considerable variation in sedimentation patterns.

ANALYSIS OF WATER SUPPLY RESERVOIRS

Storage capacities of 82 water supply reservoirs were estimated by using the developed method. Forty-two of the water supply reservoirs investigated had records of previous sedimentation surveys, and thus their K values were calculated by using data from those 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 survey data (Figure 3). A complete list of the data used in the analysis is given by Singh and Durgunoğlu (1988).

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 the K values for the non-surveyed water supply reservoirs were selected. The estimated and calculated K values for some of the water supply reservoirs are given in Table 4. The surveyed water supply reservoirs are indicated by asterisks in Table 4.

The projected future storage capacities of the water supply reservoirs up to the year 2030 are given in Table 4 for 10-year increments. These storage projections reflect an extension of the past sedimentation patterns for 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 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 4. Estimated Future Capacities of Some Water Supply Reservoirs in Illinois.

County & Reservoir Codes†	Reservoir Name	K	Estimated Future Reservoir Capacities (ac-ft) 1990	2000	2010	2020	2030
11-3	Sangchris Lake	700	34382.0	34148.0	33921.0	33699.0	33481.0
25-3	Lake Sara	1500	13453.0	13357.0	13263.0	13171.0	13079.0
28-6*	Rend Lake @405 ft.	4270	170100.0	163470.0	157000.0	150630.0	144370.0
55-2*	Spring Lake	1613	2542.3	2393.4	2246.9	2102.2	1959.3
59-15	Palmyra-Modesto Lake	1150	496.6	483.5	470.6	458.1	445.7
61-3*	Salem Reservoir	585	493.7	481.6	469.6	457.7	445.9
69-5*	Lake Jacksonville	2971	5763.0	5598.0	5435.0	5273.0	5114.0
79-2	Sparta Old Reservoir	1300	246.3	237.0	227.8	218.6	209.5
91-3*	Dongola City Reservoir	4617	477.7	392.5	310.7	232.5	159.0
92-1*	Lake Vermilion	883	3785.2	3214.0	2681.0	2196.6	1764.3
100-10	Lake of Egypt	5000	39319.0	38613.0	37915.0	37225.0	36539.0
102-1	Lake Eureka	1500	279.4	253.4	229.3	206.1	183.8

† See Figure 2 for county and reservoir codes.
* Indicates that the reservoir has been surveyed.
K is the regional constant.

SUMMARY AND CONCLUSIONS

A new method was developed for estimating the future storage capacities of instream water supply reservoirs. The method was applied in Illinois for estimating future storage capacities up to the year 2030. Other than using the physical and hydrological properties of the watershed as inputs, the method incorporates the increase in the density of sediment deposits in time due to compaction, and the reduction of the trap efficiency of the reservoir as a result of diminishing capacity-inflow ratio. The results of the reservoir sedimentation surveys conducted by the Illinois State Water Survey were also used in establishing a sedimentation pattern and in estimating the future storage capacities of the water supply reservoirs in Illinois.

The method presented in this paper not only offers a tool for analyzing the remaining useful life of an existing water supply reservoir, but also offers a method for determining the economic viability of incorporating alternative design measures and for selecting sites for prospective reservoirs. This can be achieved by using the model for analyzing alternative reservoirs at different locations, and with design structures that can be used to control the trap efficiency at a desired level.

Further research is underway to explain the variability of K within a region in terms of drainage area, land slope, land cover and use, drainage density, soil type, etc. This study is expected to be completed within the next two years.

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