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# *Cost of Reservoirs in Illinois*

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## SUMMARY

The determination of reservoir cost is essential to the analysis of alternative costs in the development, use, and management of water resources. An analysis of single and multipurpose reservoir costs has produced a relationship allowing rapid determination of the cost of stored water. The empirical expression for project cost of single or multipurpose reservoirs includes construction cost, engineering services, contingencies, and land costs. The project cost expression is

$$P_c = 9161\ S^{0.54} + 0.49\ S^{0.87}\ k$$

where $P_c$ is the total project cost in dollars, $S$ is the reservoir storage capacity in acre-feet, and $k$ is the land cost expressed in dollars per acre.

A complete development of the expression and a graphical solution are presented in this circular. The estimating of project costs of reservoirs is necessary to the examination of alternatives in water resource development, but this type of estimating does not take the place of detailed engineering studies and can be used only for screening alternatives.

## INTRODUCTION

A recently completed report *Water for Illinois, a Plan for Action*[1] was the first step toward detailed planning for water resource development, use, and management in Illinois. This report compared the total potential resource available with projected demands for the next 50 years. It showed a general adequacy of the potential resource to meet future demands, but highlighted the needs for better management of both land and water resources for flood damage control, for recreational uses, for water quality control, and for industrial use and development.

It is now apparent that a need exists for a series of water resource development and management models. This series of models would assist in defining and analyzing water resource problems, investigating alternative solutions, and comparing the economic and technical aspects of those alternatives studied. The models will spell out the types of inputs and outputs necessary and how each will relate to the other. In general, the components in a water supply system are source, storage for unfinished and finished water, transmission facilities, pumps, treatment plant, and distribution system. In the water supply model the objective is to meet the demand with available supplies by the best economic, physical, and social scheme. The one common denominator for all the alternatives is that they satisfy the same objectives.

Parallel studies have been made or are currently under way at the Illinois State Water Survey on the cost of various elements of water resources development. The results have thus far been published briefly as technical letters, the five issued covering subjects as follows: Technical Letter 7, Water Transmission Costs, October 1967; Technical Letter 8, Cost of Reservoirs in Illinois, April 1968; Technical Letter 9, Cost of Pumping Water, July 1968; Technical Letter 10, Costs of Wells and Pumps, July 1968; Technical Letter 11, Cost of Water Treatment in Illinois, October 1968. Other studies in progress include cost of reconditioning water, sewage treatment, and waste disposal.

This circular provides more detailed information concerning one of the elements used in the water resource development model, the cost of storing water in a man-made reservoir, which was presented in brief form in Technical Letter 8. The objective of this circular is to develop a means for estimating the total project cost of a reservoir storing a given amount of water.

This circular is limited to the use of those variables that have the most direct bearing on the variation of the cost, namely, capacity and physical size. Since the applicability of this study is limited to the state of Illinois, the data have been gathered from within the state. This eliminates the variability that exists in other studies that treat the nation as a homogeneous unit. Two such studies were performed on a nationwide scale by Black and Veatch and Koenig[3] under the sponsorship of the Office of Saline Water.

This report is not a handbook on estimating cost of reservoirs. It will not take the place of the detailed estimates prepared by engineers for any specific site. It is intended that it be used as a basis for comparisons between alternatives, and its results will have the same degree of certainty as incorporated in the basic cost data.

## DATA COLLECTION

To reflect the conditions found in Illinois, cost information was collected only from reservoirs constructed in Illinois from 1946 through 1967. This minimized the variation in cost due to changes in technology, construction methods, and differences in material, labor, and equipment efficiency.

As used in this report, the *project cost* of a reservoir includes construction cost, land acquisition, engineering and legal services, and contingencies. The term *construction cost* encompasses land clearing, dam and spillway construction, and relocations.

The data on project cost or construction cost were collected from the State Water Survey files, consulting engineers, private and municipal water utilities, and state and federal agencies. The construction cost data existed as final or constructed costs, bid costs, or engineering estimates. The cost as discussed in this report is intended to be representative of final cost. Since some of the data were in the form of estimates or bids, ratios of final cost to bid costs were established for recreation lakes and municipal water supply reservoirs. Some examples of ratios were 1.21, 1.08, 1.13, 1.14, 1.15, and 1.19. Accordingly, bid costs were increased by an addition of 15 percent to account for change orders. The project or construction cost data in most cases were broken down into quantities and unit prices.

The results of this study are given without reference to specific projects since the data supplied are considered privileged and therefore are not identified nor illustrated.

## DATA ANALYSIS

Construction or project costs change with time as a result of change in essential and environmental factors, both physical and economic. In order to make comparisons, all dollar values in this report have been adjusted to the 1964 level by use of the Handy-Whitman cost index.[4] This index lists semiannual index numbers by regions representing construction cost of reservoirs.

Factors in the derivation of a method to estimate the project cost of a reservoir are the cost of construction, land cost, engineering services, and contingencies. Construction cost, previously defined, was adjusted as described to represent final cost. The amount of land necessary to make full utilization of the reservoir was determined from past experience to be 50 percent greater than the pool surface area indicated by the function of pool surface area to storage. From past experience, the engineering and legal services have been 15 percent of the construction cost on reservoirs of the size that can be built on the topography found in Illinois. Contingencies have been 10 percent of the construction cost. These have been combined into a constant $C_1 = 1.25$.

In this analysis the dispersion of the data will be considered to contain the variation due to differences in topography, detail of reservoir design, location within the state, and the contractor's desire to win a contract. When the data were plotted in functional relationships on rectangular coordinates, a curve resulted. The logarithms of the data, however, were normally distributed and produced a plot on which a computed regression line fit with normal looking dispersion. The dispersion in this case is a measure of the accuracy of any predicted value.

The measure of dispersion used here is the standard deviation. The original regression line denotes the average value of the dependent variable, and since the data were normally distributed around the average, the regression line also represents the median. A line one standard deviation from the regression line encloses 34 percent of the data. On log-log plots, lines one standard deviation above and below the regression line enclose 68 percent of the data. In using such a graph, probabilities can be assigned corresponding to the regression line and to a line one standard deviation above and below. The probabilities of being below these lines are 0.50, 0.84, and 0.16 respectively. For the purpose of making estimates of project cost, we have selected the line one standard deviation above the regression line. This implies that on the average we would expect to have actual values in excess of the estimated value only 16 percent of the time.

In Illinois reservoir capacity and physical size have had the most effect on the variation of project costs and were therefore used in the development of three mathematical relationships, construction cost versus reservoir storage capacity, surface lake area versus reservoir storage capacity, and construction cost versus earth embankment volume.

## CONSTRUCTION COST VERSUS RESERVOIR STORAGE CAPACITY

Reservoirs forming the basis of this study ranged in size from 70 to 40,000 acre-feet of storage capacity. The relationship between construction cost and storage capacity is presented here in terms of unit cost. The analysis resulted in the following equation for the average cost:

$$C/S = 4287\, S^{-0.4556}$$

where

$C$ = construction cost in dollars

$S$ = storage capacity in acre-feet

The function is shown in figure 1. The measure of dispersion is given by the standard deviation, shown on the figure as broken lines 71 percent above and 41.5 percent below the regression line.

At some size of reservoir it must be expected that construction cost per unit volume of storage becomes less dependent on storage. Intuitively this can be seen in figure 1 since unit cost cannot decrease indefinitely. The topography and land costs in Illinois indicate that economies of scale are available up to approximately 40,000 acre-feet. Beyond that limit the incremental cost increases.

### Physiographic Influences

Refinements in the above analysis were attempted without conclusive results. The data points were recognized according to their geographical location in one of the seven physiographic divisions of the state.[5] The premise was that the physiographic divisions were determined by topography and surficial geologic conditions, both having direct influence on design and therefore on cost of reservoirs. The amount of available data was unfortunately too small to indicate if cost varied because of location by physiographic division.

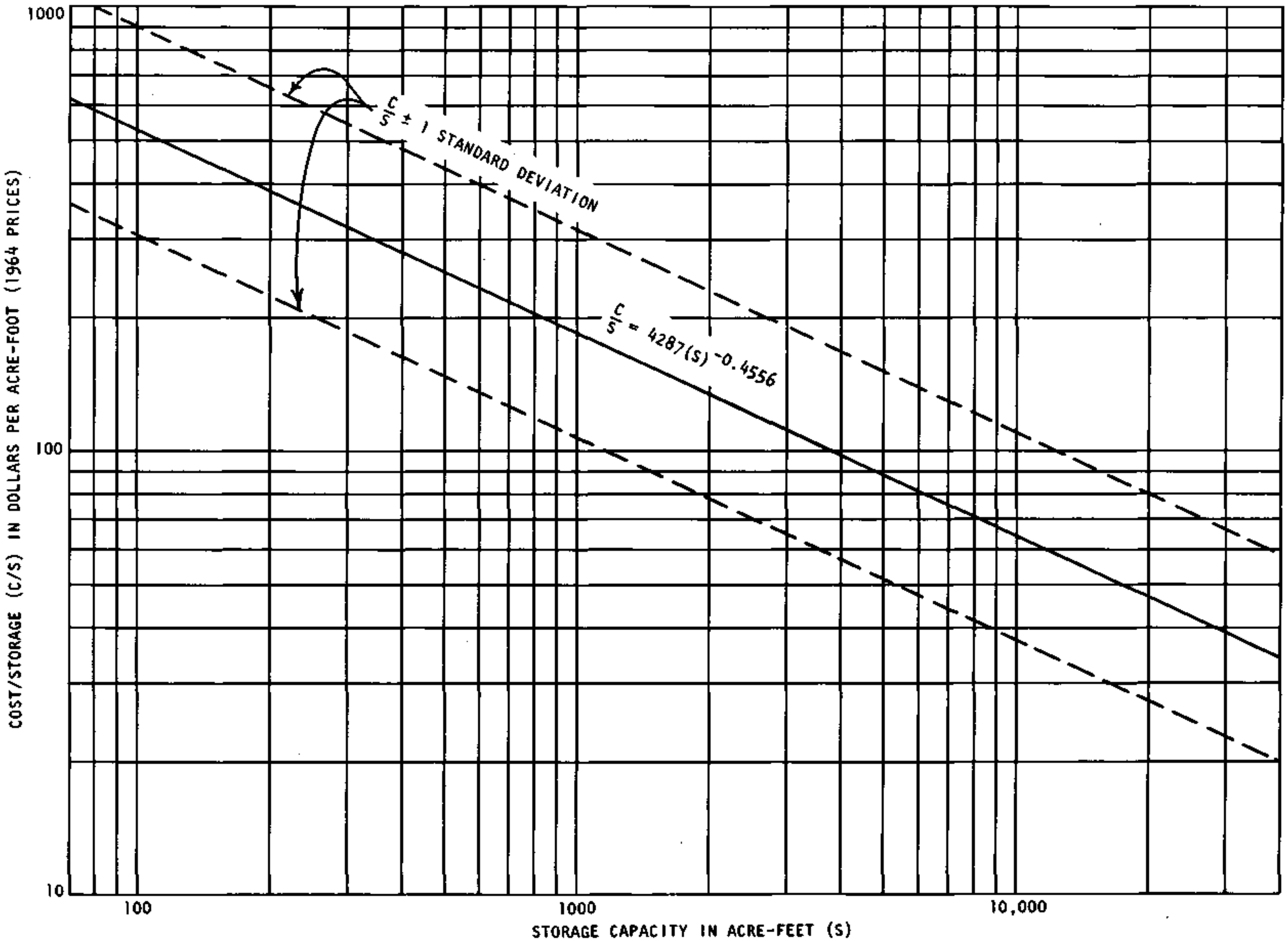



*Figure 1. Unit construction cost for reservoirs, 1964 dollars*

### Type of Reservoir Influence

The reservoir costs were classified as one of three general types: recreation, water supply, and flood control. The latter included those reservoirs built with federal assistance under Public Law 566. Some of the reservoirs were multipurpose with one primary and one secondary purpose. Since the dam design depends on the reservoir type, it was expected that such a classification would account for some of the variability in the data. No conclusion could be drawn about any difference in cost for reservoirs of the three types.

### Relocations

The cost of relocations can adversely influence the construction cost. The relocation costs for a large flood control reservoir, such as Carlyle,[6] is an example. For this reason data from large flood control projects were not included in this analysis. Cost of relocations as a percent of total construction cost varies a great deal over the whole range of data. Much of the uncertainty given by the standard deviation in figure 1 can be attributed to the cost of relocations.

## LAKE SURFACE AREA VERSUS STORAGE CAPACITY

The Illinois State Water Survey has completed a study on potential reservoir sites in Illinois.[7-10] The acres of lake surface area of a reservoir can be estimated from the storage capacity by the following equation:

$$L_a = 0.23\, S^{0.87}$$

where

$L_a$ = lake surface area in acres

$S$ = storage capacity in acre-feet

The uncertainty in this is given by the standard deviation, shown on figure 2 as broken lines 39 percent above and 28 percent below the regression line.

Before this equation can be used to estimate cost of land acquisition for a reservoir, two determinants must be provided. The first determinant is how much total acreage must be acquired to construct and utilize the reservoir and

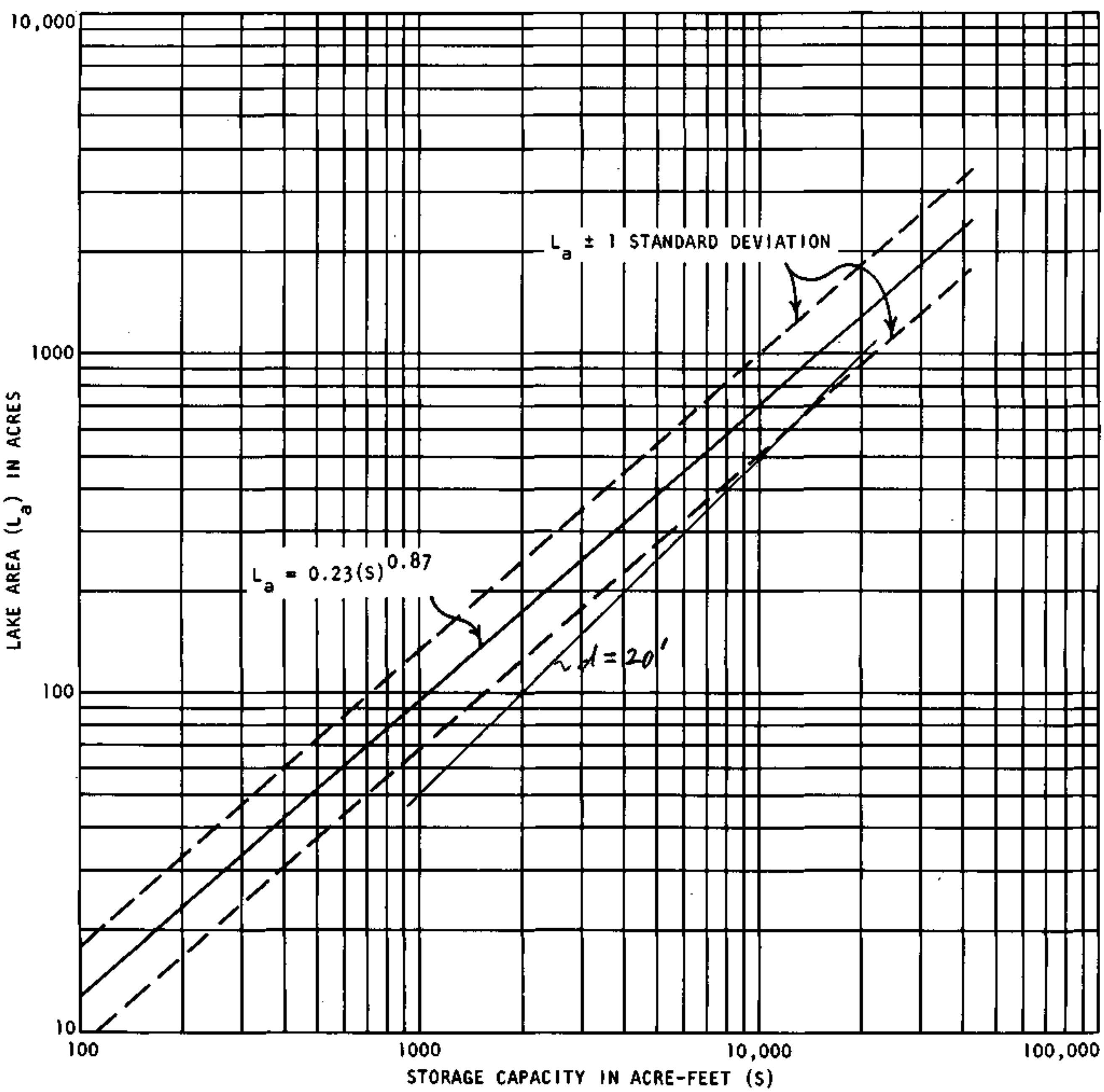



*Figure 2. Lake area versus storage*

surrounding area to meet project objectives. One can assume a constant, $C_2$, greater than 1, such that $C_2L_a$ denotes the total required area. The amount of data on the magnitude of $C_2$ was small and provided little evidence that $C_2$ is at all constant; however, experience warrants the assumption that the acquired land must be 50 percent more than the normal pool surface area. Therefore $C_2 = 1.50$.

The second determinant is land value. Land cost varies both regionally and locally as a result of soil fertility, topography, agricultural development, and other uses. With at least a 10-fold cost variation within the state it appears unrealistic to assign a specific value to land. This parameter must be left open so that the unit cost of land that applies in each specific case can be incorporated. If the price of land is $k$ (in dollars per acre), the estimated cost of land acquisition is $C_2\ L_a\ k$.

## PROJECT COST

Project cost can now be estimated as the sum of construction cost, engineering and legal services, contingencies, and land cost. The reservoir project cost in dollars is now

$$P_c = C_1\ C + C_2\ L_a\ k$$

Substituting expressions for $C$, $L_a$, $C_1$, and $C_2$ gives:

$$P_c = (1.25)\ 4287\ S^{0.5444} + (1.5)(0.23252)\ S^{0.8699}\ k$$

Introducing one standard deviation above the regression line gives:

$$P_c = (1.70922)(1.25)(4287)\ S^{0.5444} + (1.39046)(1.50)(0.23252)\ S^{0.8699}\ k$$

$$P_c = 9161\ S^{0.54} + 0.49\ S^{0.87}\ k$$

This equation was solved on the computer for $S$ values of 100, 1000, 10,000, 100,000, and 1,000,000 while $k$ had values of 100, 200, 300, 400, 500, 600, 700, 800, 1000, and 2000. These calculated values of project cost $P_c$ were plotted on log-log graph paper for each unit value of land cost $k$ (figures 3a-3j). For storage capacity in the range of 200 to 100,000 acre-feet a straight line fits the calculated data very well and simplifies the prediction equations. The equation of the straight line appears on the figures. In most cases, below a

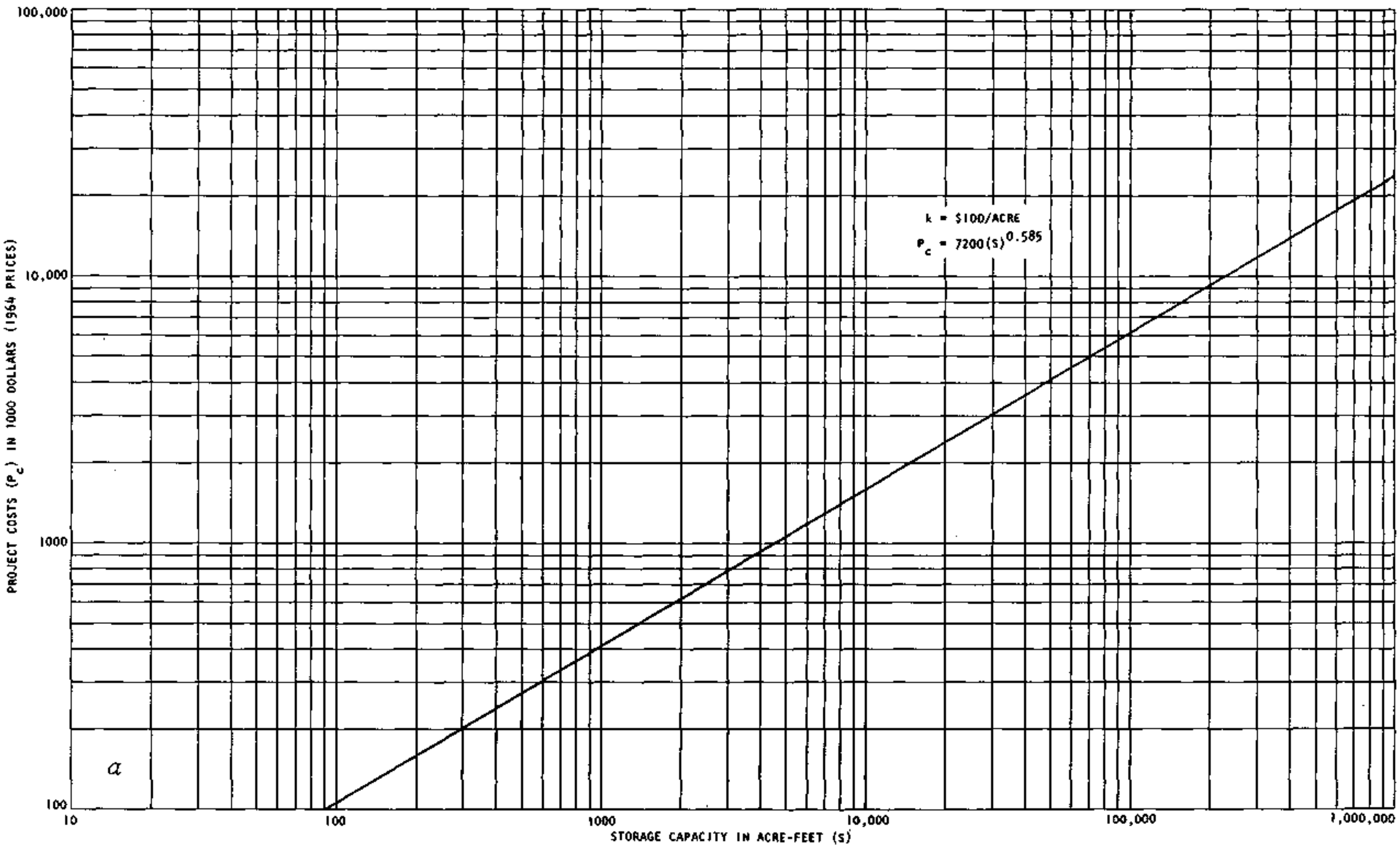



*Figure 3a-j. Project cost versus storage capacity in Illinois for varying land values*

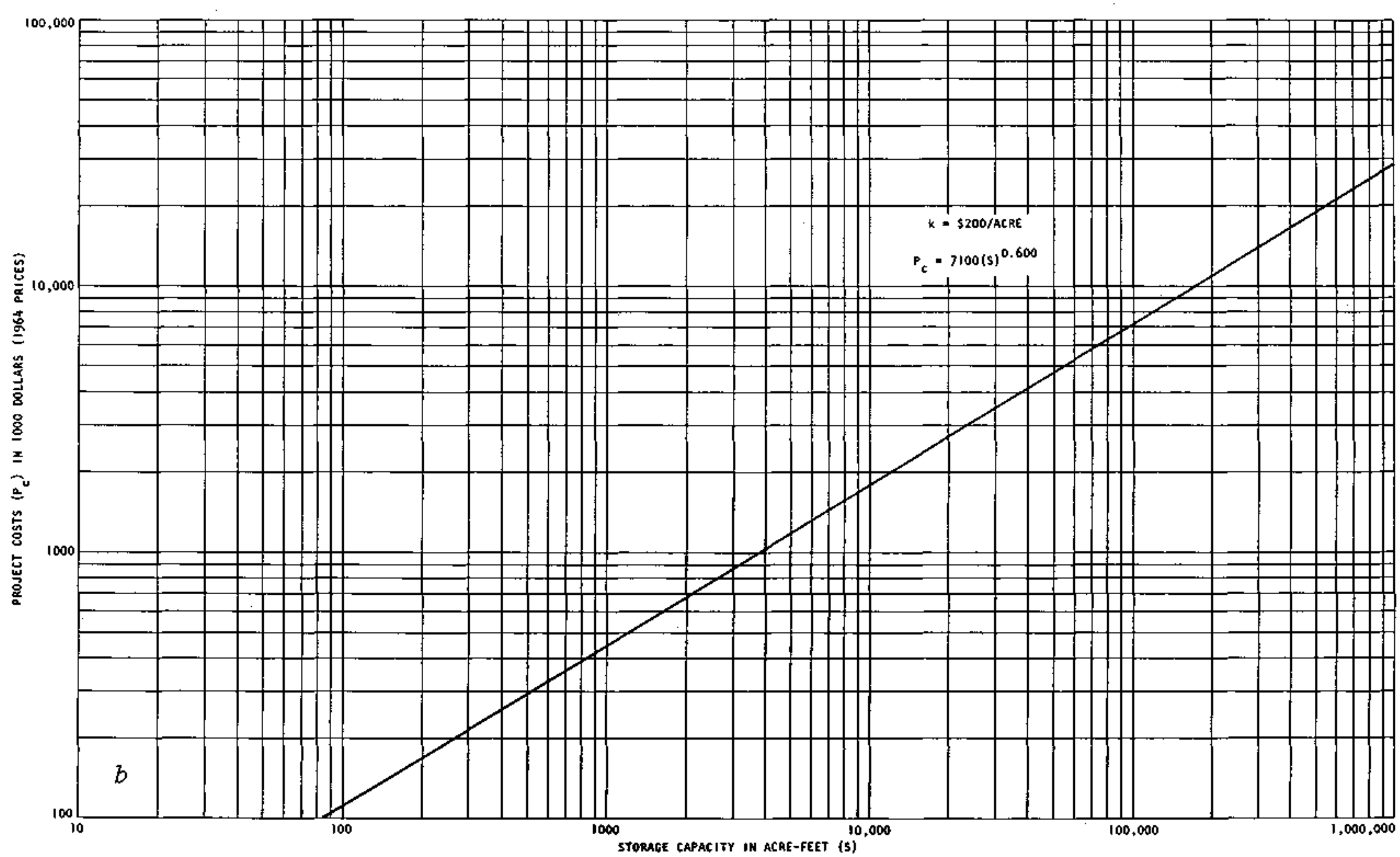
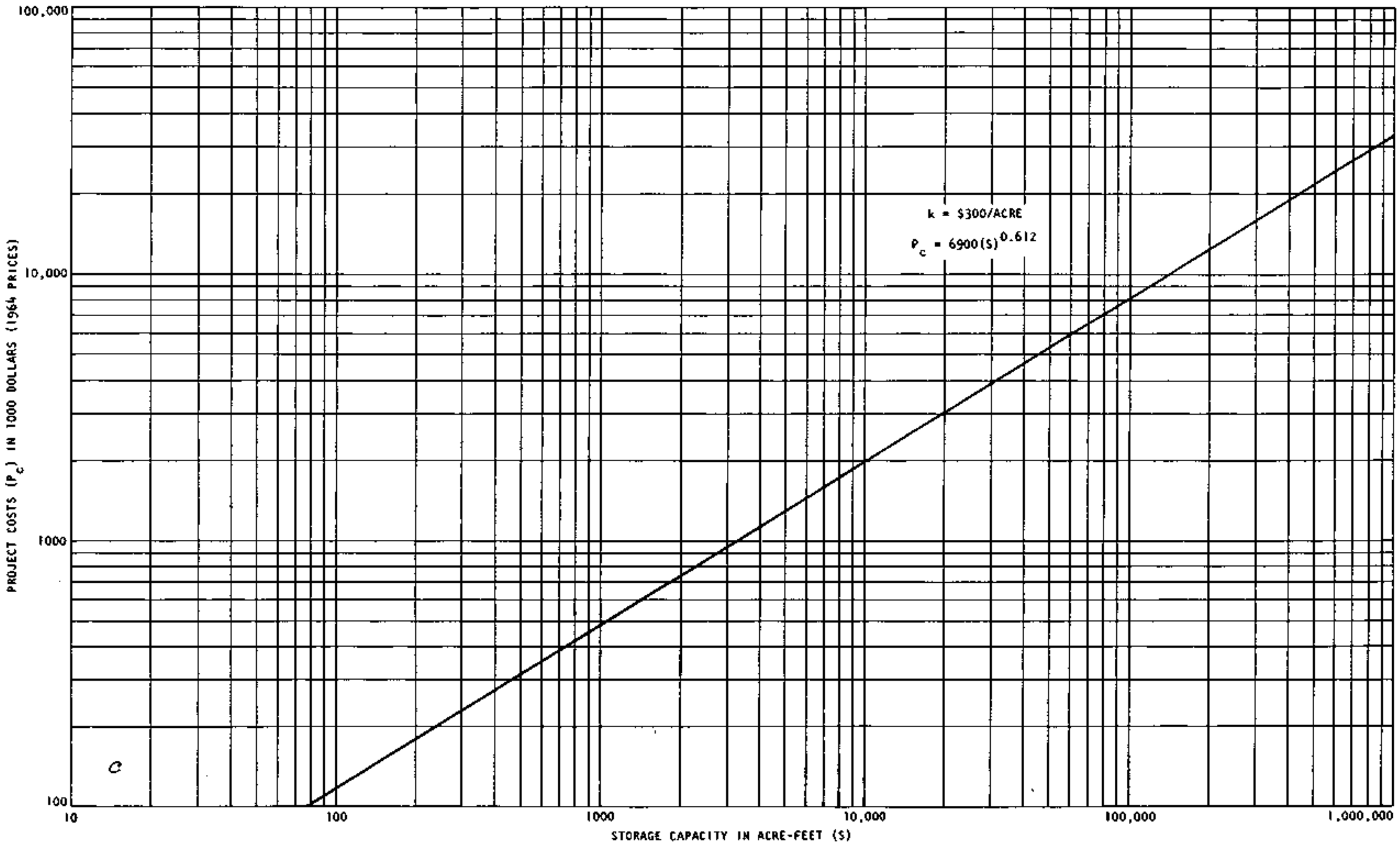



*Figure 3 (Continued)*

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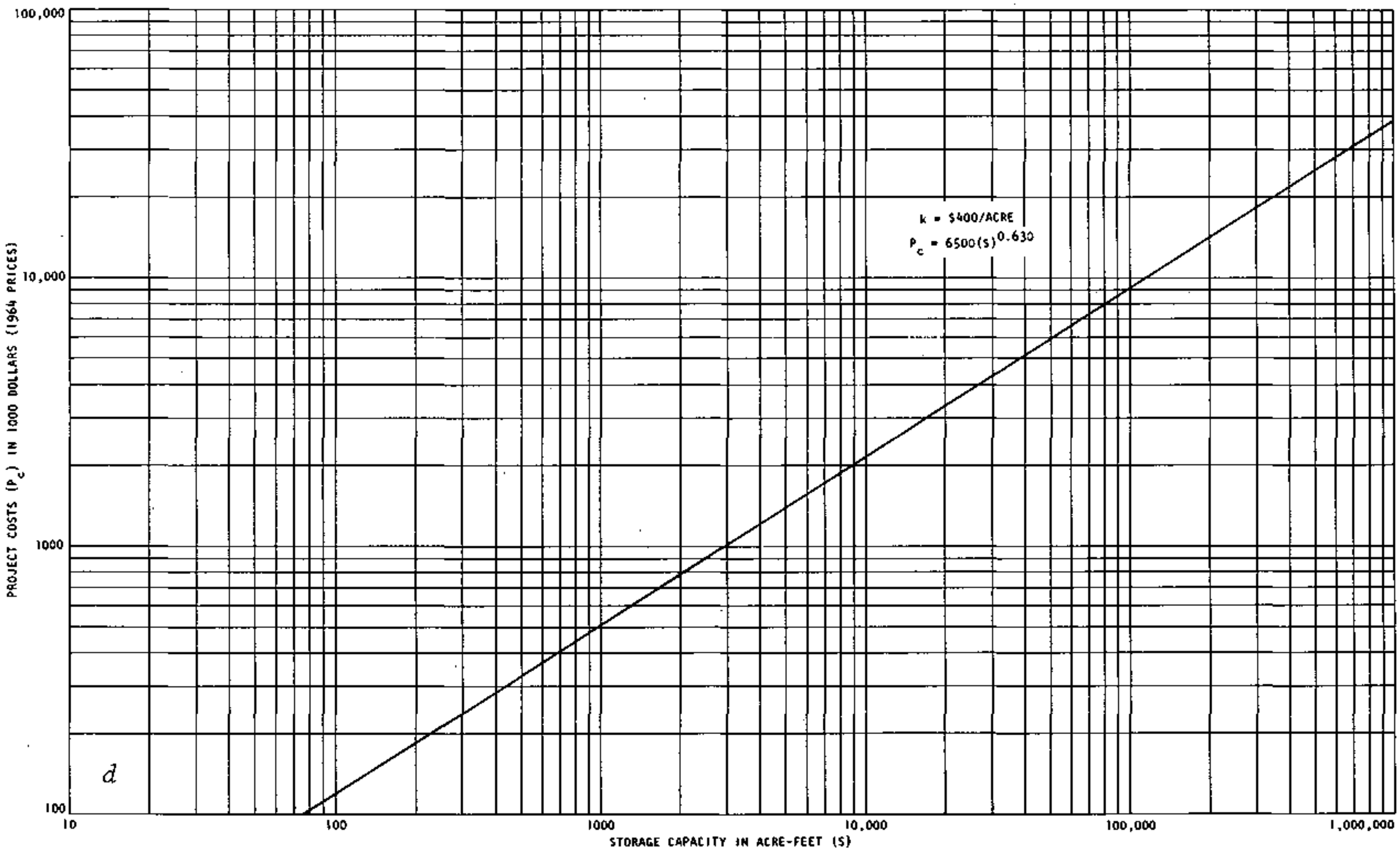


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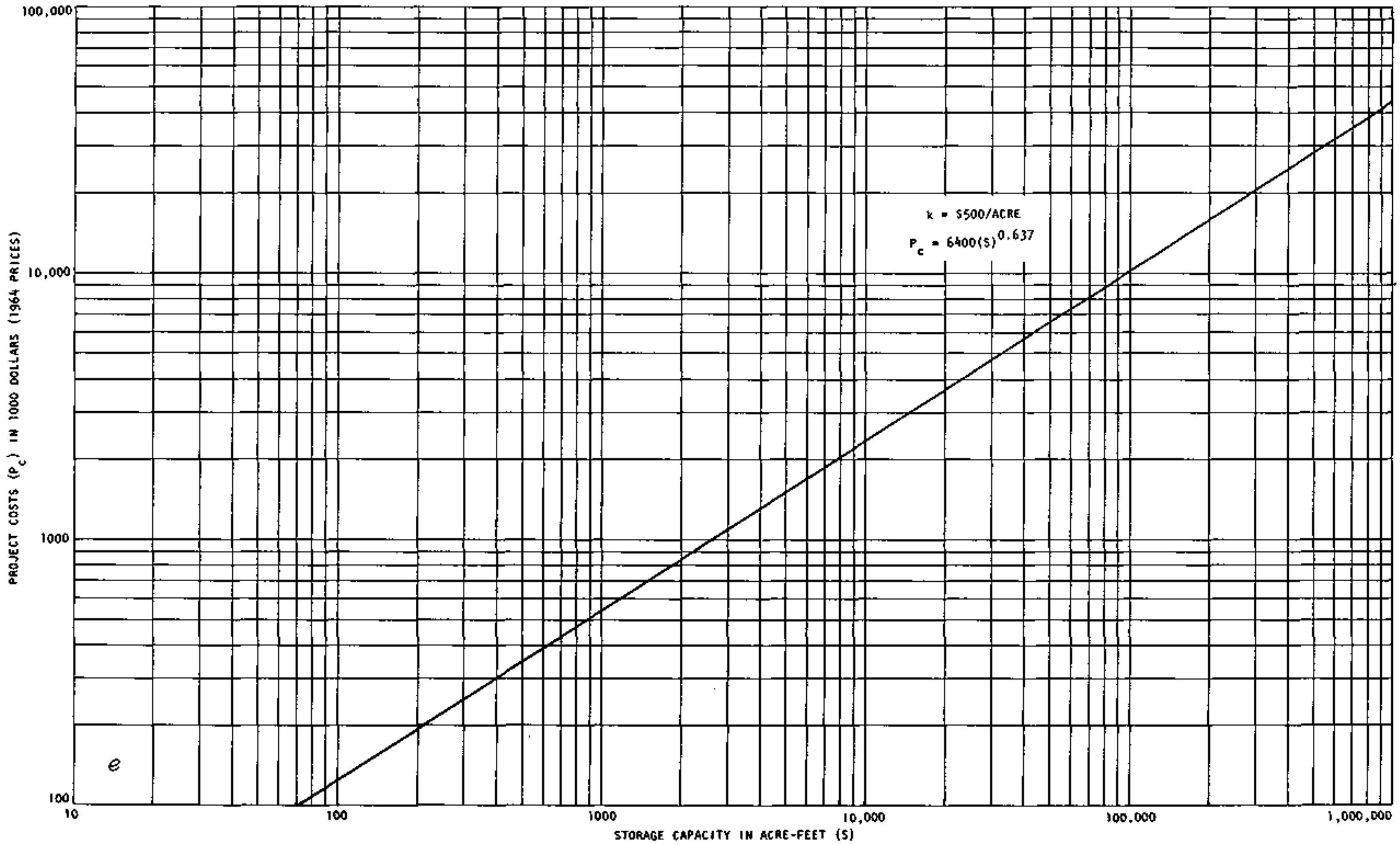


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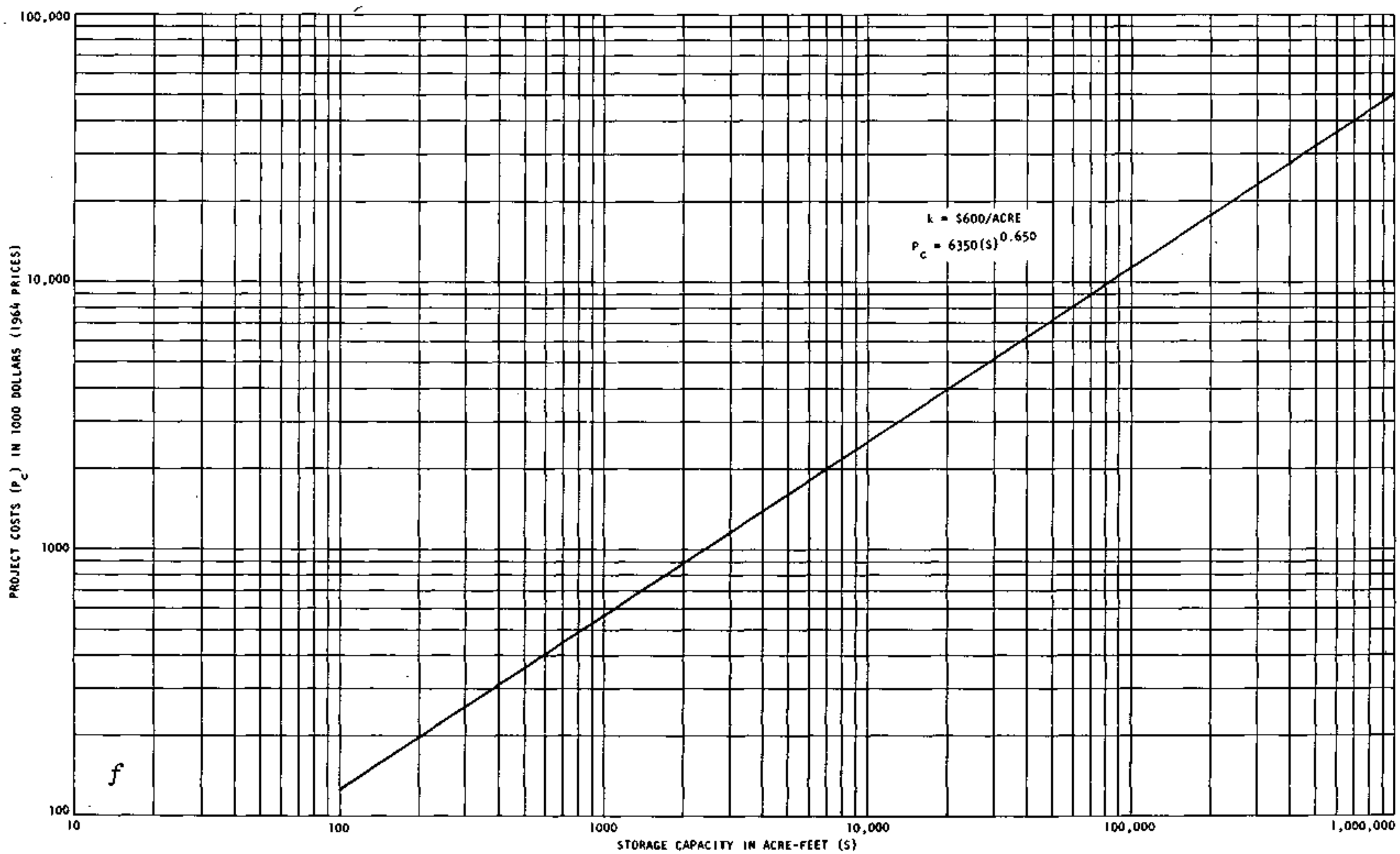


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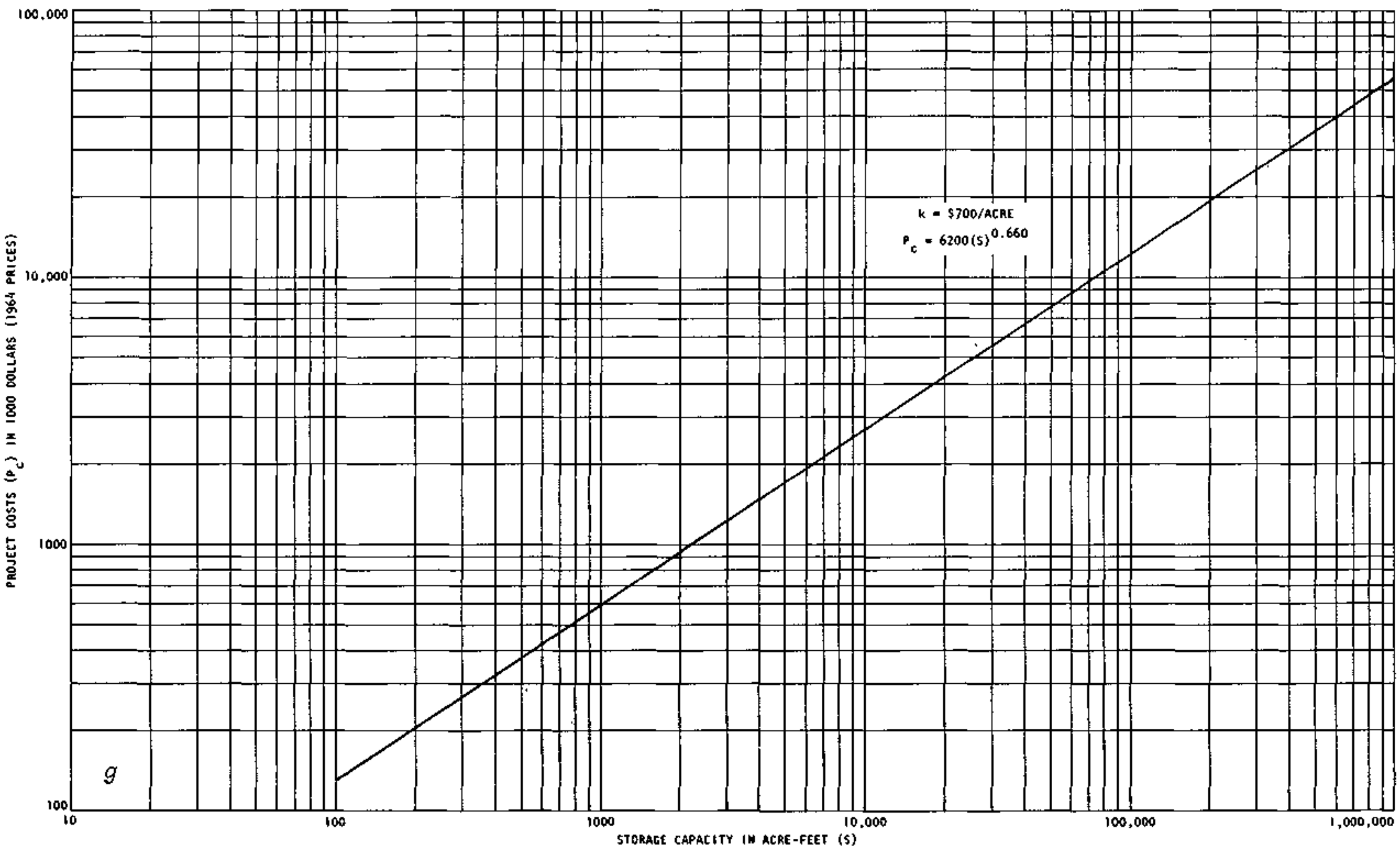


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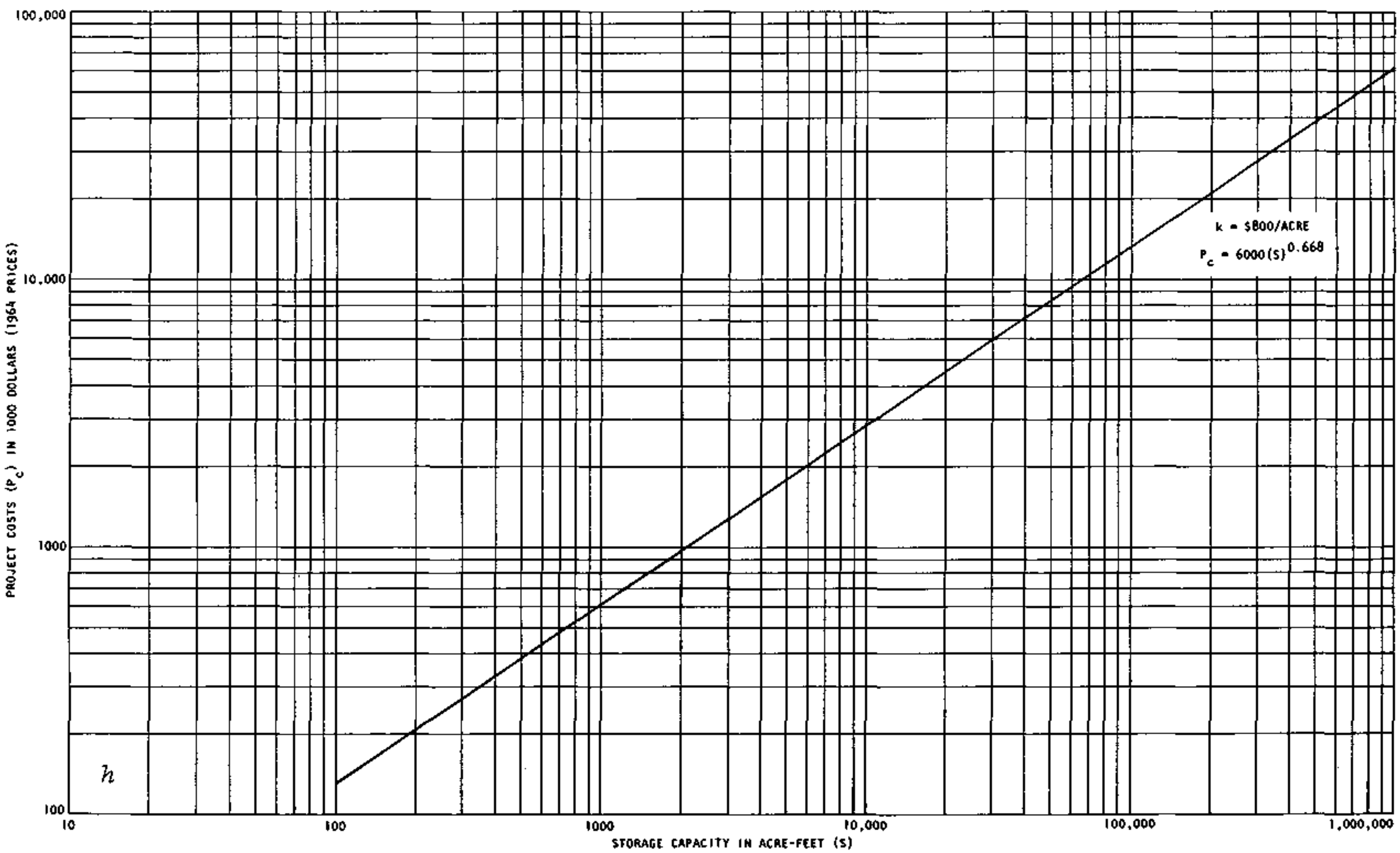


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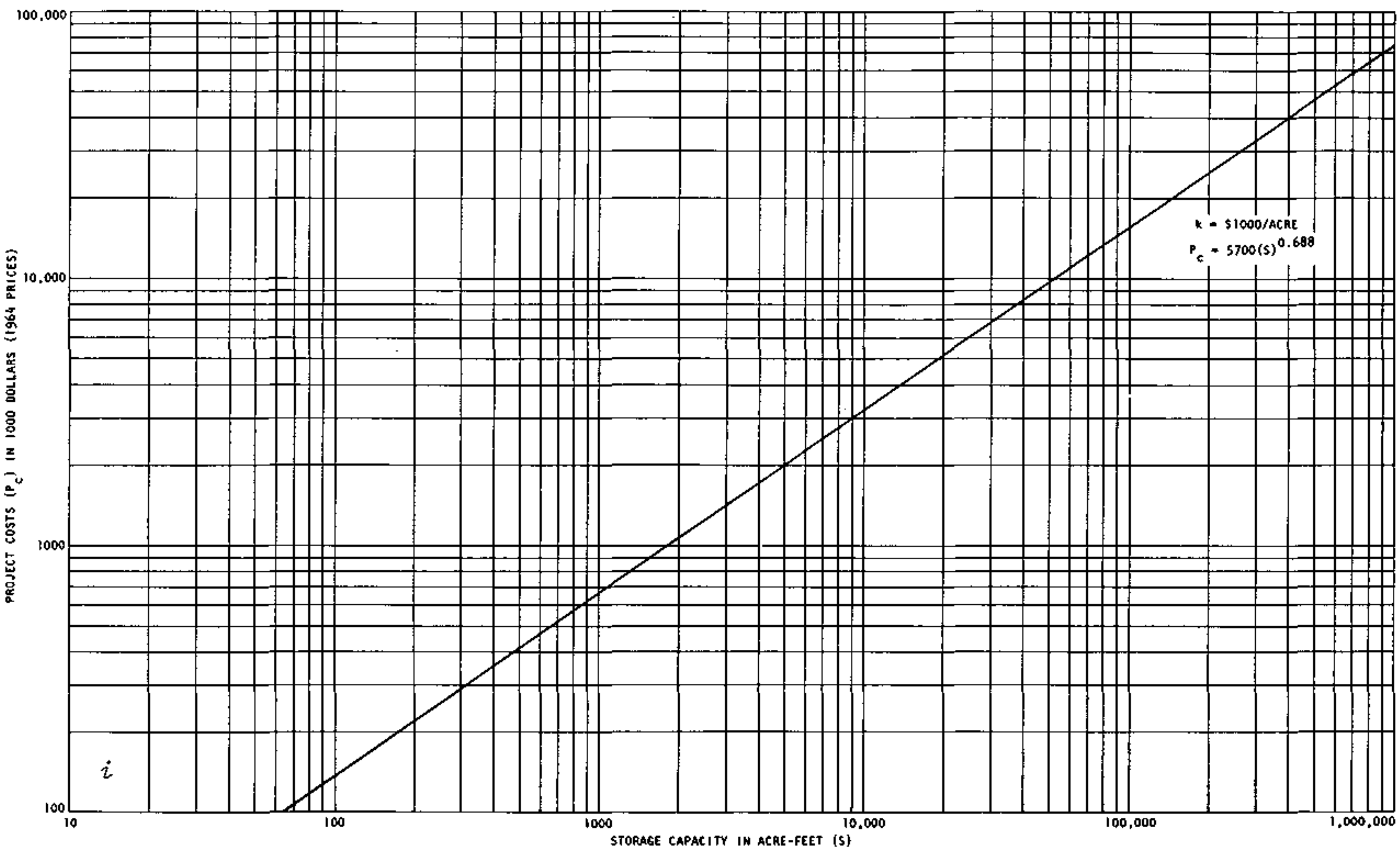


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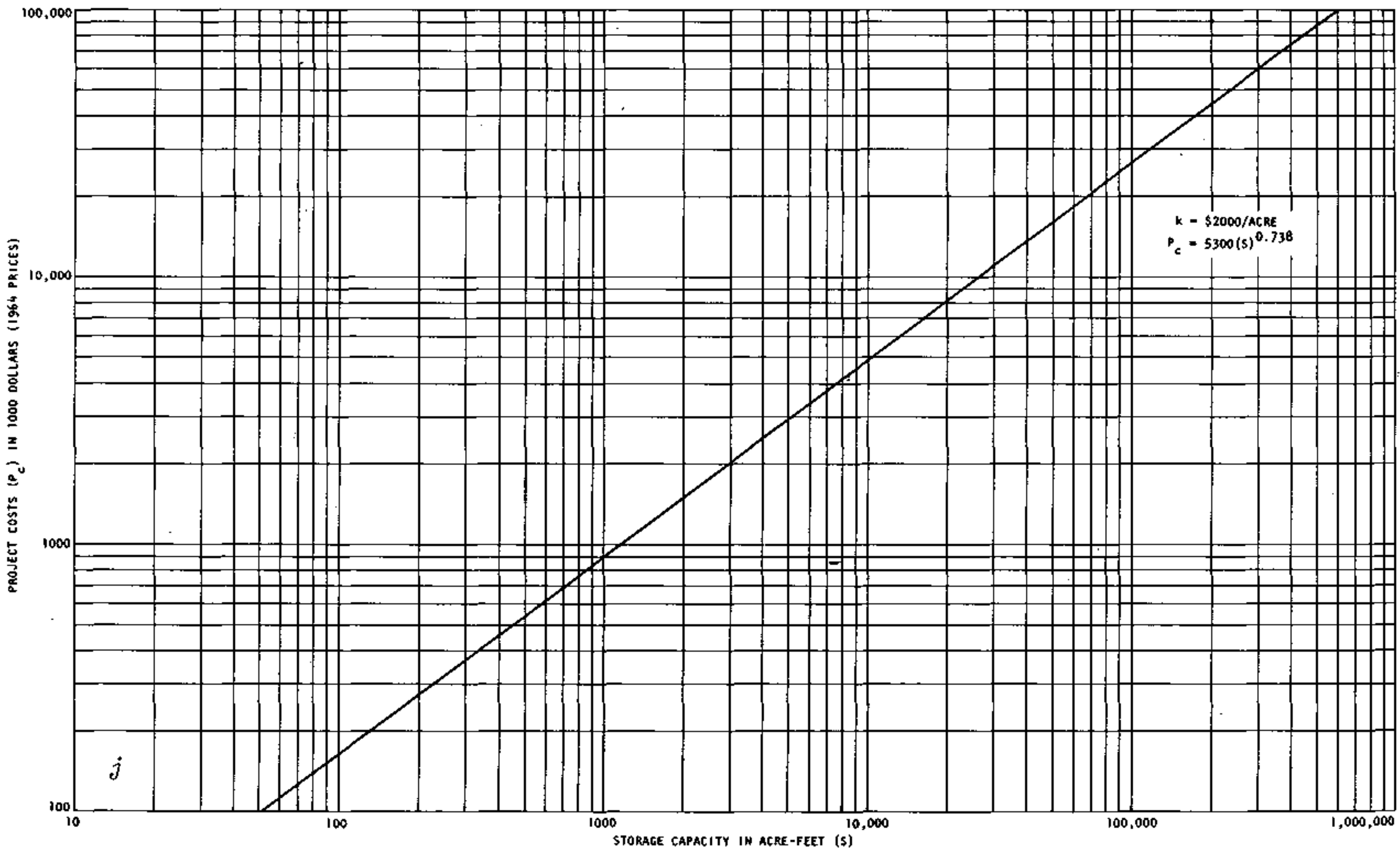


*Figure 3 (Continued)*

storage capacity of 100,000 acre-feet, the straight line prediction equation slightly over estimates.

The estimated project cost using the formula or fitted straight line represents the estimated project cost for 1964. To bring the estimated project cost to present date it must be multiplied by the ratio of present day Handy-Whitman cost index to the Handy-Whitman index[4] for 1964. The Handy-Whitman index was taken for the North Central Division (collecting and impounding reservoirs) and the index for 1964 was computed by taking the mean of the January 1, 1964, and July 1, 1964, values plus the value as of January 1, 1965, and dividing by two as follows:

$$\text{1964 index} = \frac{(345 + 353)/2 + 354}{2} = 351$$

Index values for more recent years were computed in the same manner, resulting in these values: 1965 index = 361, 1966 index = 374, 1967 index = 391.

## CONSTRUCTION COSTS VERSUS EARTH EMBANKMENT VOLUME

The relationship between construction cost and the earth embankment volume was examined as a possible check on the construction cost estimate versus reservoir capacity previously described. The results are shown in figure 4 by a linear function:

$$C = 2.20\ F$$

where

$F$ = earth fill in cubic yards

The data are so dispersed that the standard deviation is 83 percent above and 45.5 percent below the regression line. This relationship does not produce an acceptable check.

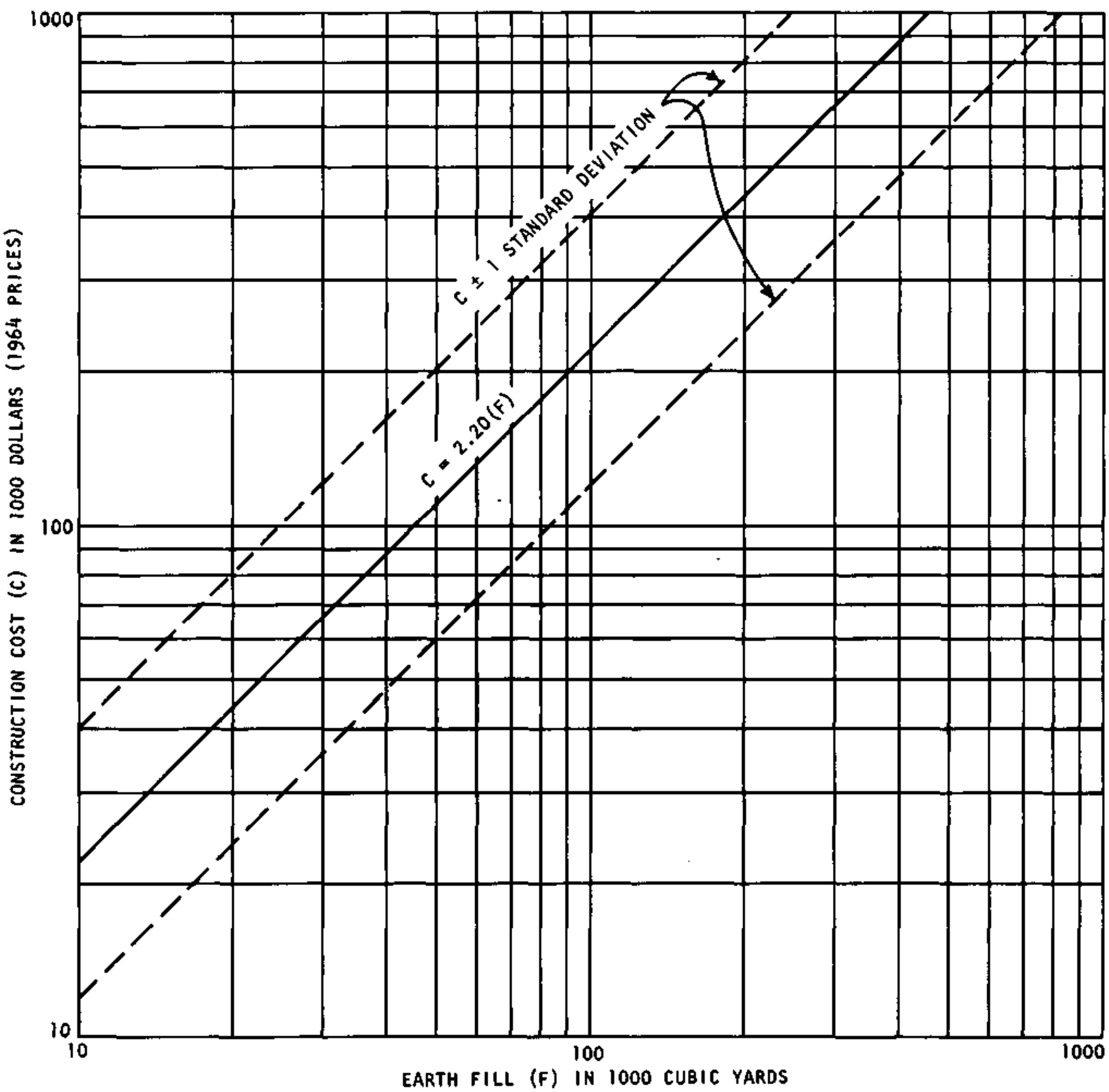


*Figure 4. Construction cost versus earth fill, 1964 dollars*

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