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Cost of Municipal Sewage Treatment Plants in Illinois

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COST OF MUNICIPAL SEWAGE TREATMENT PLANTS IN ILLINOIS

by Thomas A. Butts and Ralph L. Evans

ABSTRACT

This report summarizes the results of a study of municipal sewage treatment construction costs for 291 projects built in Illinois between 1957 and 1968. Most of the plants were built under the Federal Construction Grants Program (Public Law 660). Least squares regression analysis was used to relate design population equivalents to either unit costs in terms of dollars per design population equivalent or total costs in terms of dollars. The data were categorized into eight classifications for new plants and two for plant additions. Also, regression equations were developed for estimating lagoon land costs, plant operating costs, and FWPCA construction cost indexes.

Use of information presented in this circular should provide reasonable estimates of the initial investments involved in constructing and equipping sewage treatment plants in the state. Sample cost estimates are given for each type of plant analyzed. These estimates are not alternatives to detailed engineering cost analyses; rather, they are intended to permit reasonable estimates with a minimum of effort for comparative purposes.

INTRODUCTION

The published report *Water for Illinois, A Plan for Action*[1] has documented the known water resources for the state of Illinois. In order to preserve these resources for optimum utilization, advance planning is necessary to satisfy the waste water treatment needs of the state. These needs cannot be divorced from other aspects of water resource management such as proposed uses, distribution, and associated costs.

Studies are currently being pursued by the Illinois State Water Survey on various costs involved in the elements of water resources management. The results of some studies have been summarized in technical letters. Thus far, six have been 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, *Cost of Wells and Pumps,* July 1968; Technical Letter 11, *Cost of Water Treatment in Illinois,* October 1968; Technical Letter 12, *Cost of Municipal Sewage Treatment,* June 1969. In addition, *Cost of Reservoirs in Illinois* and *Cost of Municipal and Industrial Wells in Illinois, 1964-1966* were published in more detail as Circulars 96 and 98, respectively.

This report is a detailed summary of municipal sewage treatment plant construction costs in Illinois, which was presented in brief form in Technical Letter 12. It was prepared under the general supervision of Dr. William C. . Ackermann, Chief of the Illinois State Water Survey. Questionnaire preparation and mailing were performed by Shunn-dar Lin; illustrations were prepared by John W. Brother, Jr. The authors extend special thanks to all the people and organizations who contributed information to this study.

COST DATA

Most of the construction cost data represent plants built or improved from 1957 through 1968 under the Federal Construction Grants Program (Public Law 660) administered by the Federal Water Pollution Control Administration. Cost figures and design criteria were supplied by consulting engineers, the Illinois Sanitary Water Board, and the Great Lakes Regional Office of the Federal Water Pollution Control Administration. Approximately 325 projects were reviewed, and the data for 291 were considered adequate for statistical analysis. Generally, the project information not used was incomplete. For some new plants, design criteria were not readily available, or in the case of plant additions, the difference between the old and new plant sizes could not be resolved. Overall, however, sample sizes were sufficient in all classifications to develop equations that would give reliable estimates of construction costs.

Operating costs and land costs for lagoons were supplied entirely by consulting engineers. Operating costs were divided into two categories, i.e., lagoons and conventional sewage treatment plants. The operating cost data for conventional sewage treatment plants were limited. Since all types were grouped into one sample, the developed generalized equation is good only for gross estimating.

Data Adjustments

All construction cost data were adjusted to a common base and location using Federal Water Pollution Control Administration municipal waste treatment plant construction cost indexes.[2] The base period for these indexes is 1957-1959 (i.e., 1957-1959 = 100). The St. Louis index was used for plants in southern Illinois and the Chicago index for plants in northern Illinois. Figure 1 shows the counties which are included in these two areas. The dividing line between the Chicago and St. Louis areas can be approximated by U. S. Route 136 north of Springfield and Champaign.

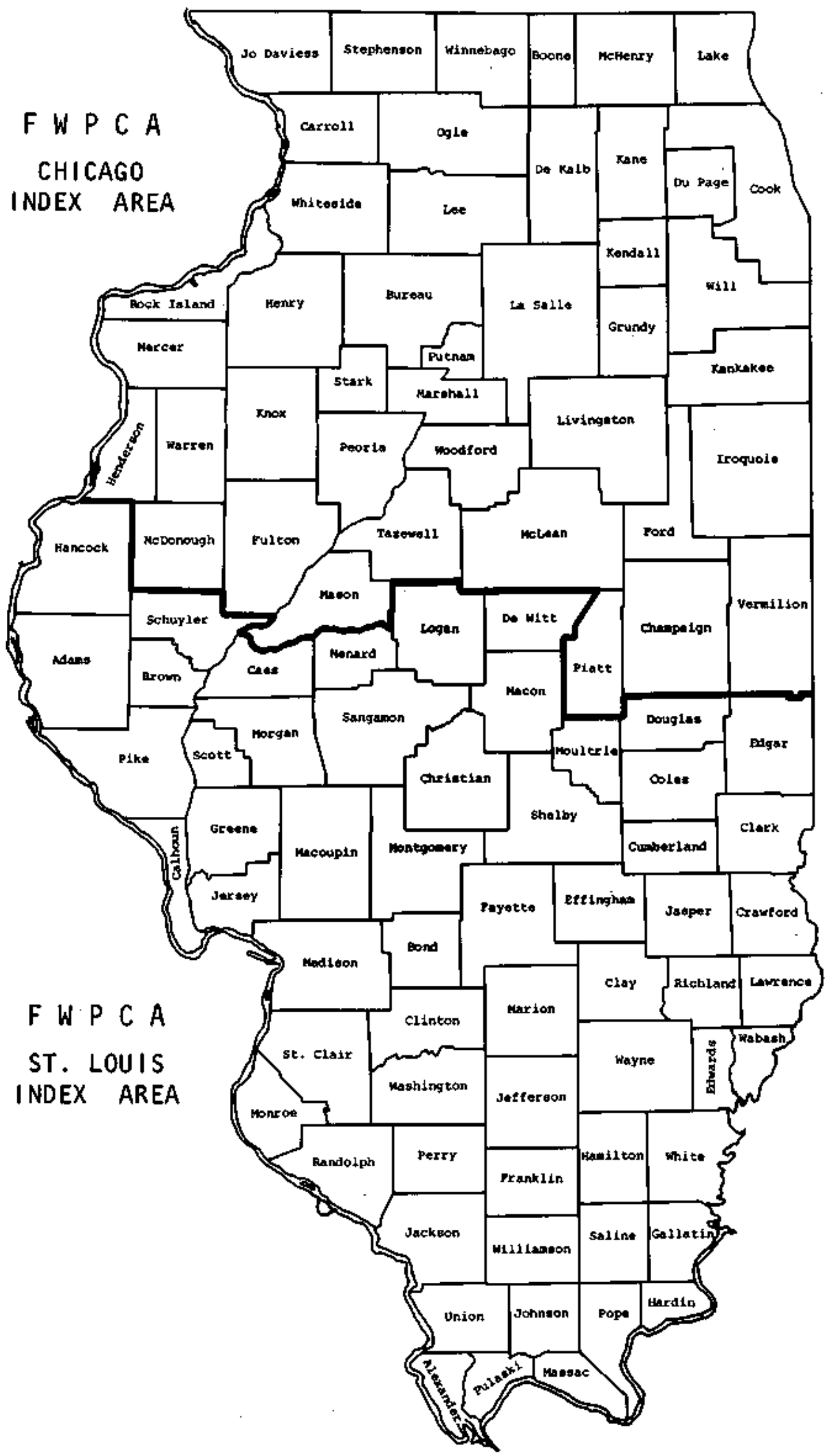

Figure 1. Chicago and St. Louis FWPCA sewage treatment plant construction cost index areas

Lagoon land costs were not adjusted to a common base; consequently, part of the error associated with the land cost curve is due to temporal differences.

Plant operating costs are for the period 1966-1967. Unit operating costs estimated from the formula, therefore, are representative of only this period.

Data Classification

Eight groupings of new plants and two of plant additions were used for estimating construction costs. The new plant classifications were: 1) lagoons, 2) primary with heated digesters, 3) primary with vacuum filters, 4) trickling filter-digester, 5) trickling filter-Imhoff tank, 6) activated sludge, constructed in place, having population equivalents (*PE*) equal to or less than 10,000, 7) activated sludge, constructed in place, having *PE's* greater than 10,000, and 8) activated sludge, factory built. Additions to existing plants were classified only as to whether they were trickling filter or activated sludge additions.

The term "lagoon" as used in this report designates only oxidation lagoons or ponds. It does not include lagoons designed primarily for physical removal of suspended matter or designed for tertiary treatment and effluent polishing.

Generally, in sanitary engineering terminology, an activated sludge plant manufactured to specifications in a factory and assembled either at the factory or in the field is called a "package plant"; a package plant which is assembled at the factory for shipment to the installation site is designated as "factory built." These definitions have not been strictly followed in this paper; "factory built" as used here is synonymous with "package." No effort was made to distinguish between the costs of units assembled at the factory and in the field. All the "package plant" data, therefore, have been classified as "factory built" because this terminology was felt to be more descriptive, especially to persons not working directly with waste water treatment methods.

For several of the eight new plant classifications, the cost data were divided into subgroups for analysis. Lagoon data were subclassified into single and multiple cell systems, into plants with and without pumping facilities, and into northern and southern Illinois plants. Both trickling filter plant classifications were subclassified into standard rate and high rate. Sufficient data were not available to realistically subclassify the two activated sludge classifications. However, except for a few cases, the constructed-in-place plants are either conventional or contact stabilization, and the factory built ones are either extended aeration or contact stabilization.

Operating costs were grouped under the headings of lagoons and treatment plants. Only limited operational cost data were available for the various types of treatment processes, and no differentiation could be made between them. However, since approximately two-thirds of the data were for activated sludge plants, the estimates for other processes will probably be very conservative.

Some inconsistencies appeared in the size of certain plants as reported by various agencies. For example, one agency reported one lagoon to have a design *PE* of 1000 while two others listed it as 790. In another case, one agency reported an activated sludge plant design *PE* of 1000 while another gave it as 1400. Where three agencies reported and two values were in agreement, the value of the two in agreement was used. A few cases had to be decided solely on judgment.

Sufficient data were available for developing an equation for estimating lagoon land costs. Land requirements play a significant part in lagoon design and often constitute the largest single expenditure. Consequently, fairly good records are available for developing estimates. However, for conventional plants, land costs are usually smaller in comparison with overall costs or they may not be considered as a separate entity in engineering estimates. In addition, many conventional plants are built on property already owned by a municipality or sanitary district. Consequently, the data available for making estimates for land costs for conventional plants are limited and inadequate for developing a mathematical expression for estimating purposes.

Method of Analysis

Least squares regression methods were used to relate costs to plant sizes. Except for lagoons, construction costs, in terms of dollars per design population equivalents, were related to design population equivalents. Lagoon construction and land costs were expressed in total dollars. Annual operating costs for all plants, except for lagoons, were expressed in terms of dollars per population equivalent of wastes treated. A flat yearly rate appeared to give a satisfactory estimate of lagoon operating costs.

Equations for estimating construction, operating, and land costs are in the general geometric form

$$C = KP^n$$

where

C = either construction, operating, or land costs
K = a regression constant
P = sewage treatment design capacity or average annual waste load treated
n = slope of the least squares regression line

In the initial analysis of the construction costs of plant additions, an assumption was made that costs are related to both the initial plant size and the size of the addition. The general equation, therefore, is in the form

$$C = KP^nS^m$$

where

C = cost of new addition to old plant
K = a regression constant
P = capacity of new addition
S = capacity of existing plant
n, m = slope constants

The cost and capacity symbols used in the regression equations are identified and defined in table 1.

Population equivalents (defined as 0.17 pounds per day of 5-day BOD at 20C) are used to identify plant sizes in place of or in conjunction with flow because most small to medium sized plants in Illinois are designed on an inflow basis of 100 gallons per capita per day. Consequently, cost predictions using flow as the independent variable would differ very little from those predictions using *PE*. Table 2 illustrates typical load and flow criteria used in the design of several Illinois treatment plants.

Two regression equations have been developed for each set of data. In addition to the regression line or line of best fit, an equation has been developed which is parallel to the best fit regression line and passes through the mean plus one standard error of estimate. This equation reflects the measure of dispersion of the data relative to the best fit line; it represents the cost which probably will not be exceeded 16 percent of the time. Both lines are included on the figures, the dashed line representing the line of best fit and the parallel solid line representing the value one standard error from the mean. The use of the standard-error line provides a conservative estimate, and this line is the basis for the cost prediction equations given in the tables.

Product moment correlation coefficients have been computed for each set of data. These, in conjunction with the standard error of estimate, give a good indication of the variability of the data and the predictive capability of the regression equations.

Trend lines were developed for predicting FWPCA Chicago and St. Louis construction cost indexes. Arithmetic trend analysis was applied to the indexes for the years 1952 through 1968. Indexes for the years 1930 through 1951 were not included because a sharp upward break occurred in them during the late 1940s.

The equation for the St. Louis area is:

$$I_s = 103.90 + 2.91\ (Y - 1960) \qquad (1)$$

and for the Chicago area:

$$I_c = 104.96 + 2.74\ (Y - 1960) \qquad (2)$$

Table 1. Abbreviations of Terms

C = unit construction cost, in dollars per design population equivalent

C_a = total annual operating cost, in dollars

C_L = total land cost, in dollars

C_o = unit annual operating cost, in dollars per population equivalent of waste being treated

C_T = total construction cost, in dollars

I_c = FWPCA Chicago construction cost index (1957-1959 = 100)

I_s = FWPCA St. Louis construction cost index (1957-1959 = 100)

P = design population equivalent

P_A = population equivalent added to existing plant

P_W = population equivalent of wastes being treated

PE = population equivalent, usually 0.17 lb BOD_5.

r = coefficient of correlation

Y = projection year

Table 2. Flow and Load Design Criteria for Typical Illinois Sewage Treatment Plants

Type of plant	Design BOD_5 load (PE)	Design flow (mgd)
Primary	6,000	0.60
	8,000	0.80
	10,000	1.30
Lagoon	1,000	0.10
	2,500	0.25
	5,500	0.55
Trickling filter	3,300	0.35
	7,500	0.75
	11,000	1.10
Activated sludge	1,500	0.15
	8,000	0.80
	17,500	1.78

The symbols are identified in table 1. The year 1960 was arbitrarily chosen for the base period in computing the indexes.

RESULTS

Oxidation Lagoons

Oxidation lagoons have become widely used in the last 15 years for treating sewage from small Illinois communities. Figure 2 shows the locations of 105 lagoons. Most of them have been constructed since 1957. The distribution of these installations within the state is interesting. Approximately two of every three are in southern Illinois, and none occurs in the east-central area. Approximately 75 percent of the installations are designed for population equivalents of 2000 or less; however, one is designed for 6000 *PE* and another for 8750 *PE.*

Lagoons may consist of a single cell, or they may have multiple cells which can be operated in either series or parallel. The Illinois Sanitary Water Board Technical Release 20-24 specifies the required design criteria.[3] For the southern, central, and northern areas of the state, the maximum permissible BOD_5 loadings per acre are 30, 26, and 22 pounds, respectively. The lagoons are credited with 75 percent BOD_5 removal.

For purpose of the cost evaluation, the lagoons were classified as either pumping or nonpumping installations. A higher cost trend was expected for installations requiring pumping facilities, but this did not prove to be the case.

Also, in analyzing the construction costs, the geographic location and the design layout, i.e., number of cells per lagoon system, were considered. Unit costs for lagoons in the Chicago area were compared with those in the St. Louis area. Figure 3 illustrates the relationships between unit costs and size for lagoons with and without pumping facilities in the respective areas. Poor correlations exist. Statistical tests were used to determine if differences exist between the means and variances of the various categories (table 3). At the 5 percent significance level, no differences could be detected between the means and variances for pumping and nonpumping facilities within each geographical grouping. However, in comparing all the Chicago data with all the St. Louis data, the Chicago mean and variance appeared to be higher. This appears logical since design criteria specified by the Illinois Sanitary Water Board[3] are more restrictive for the northern section of the state.

No statistically significant differences could be detected between the means and variances of multiple and single cell installations within the geographical categories. The mean unit costs for multiple and single cell lagoons were $24.25 and $23.38 per design *PE*, respectively, for the St. Louis area. For the Chicago

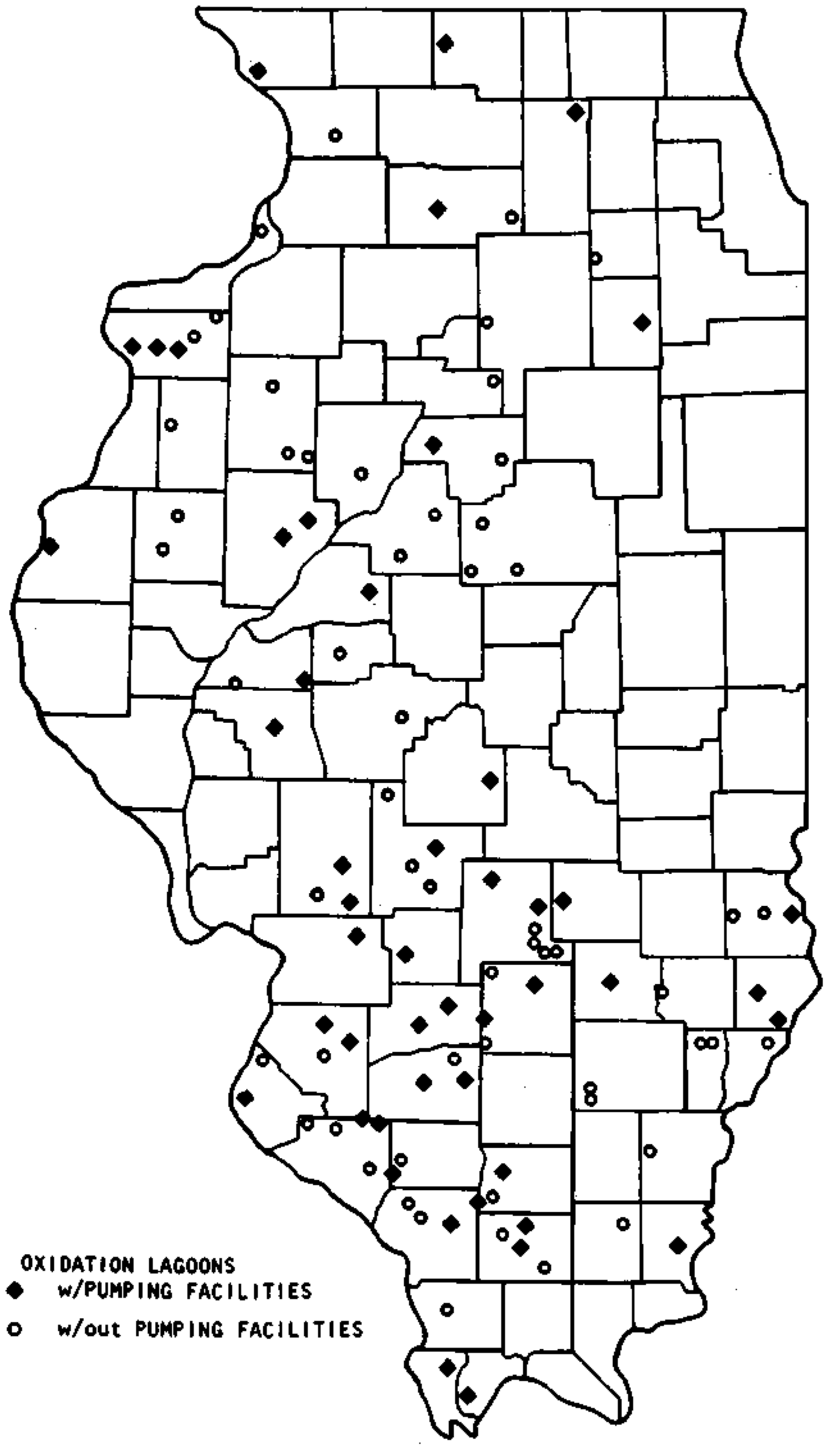

Figure 2. Distribution of oxidation lagoons for which cost data were analyzed

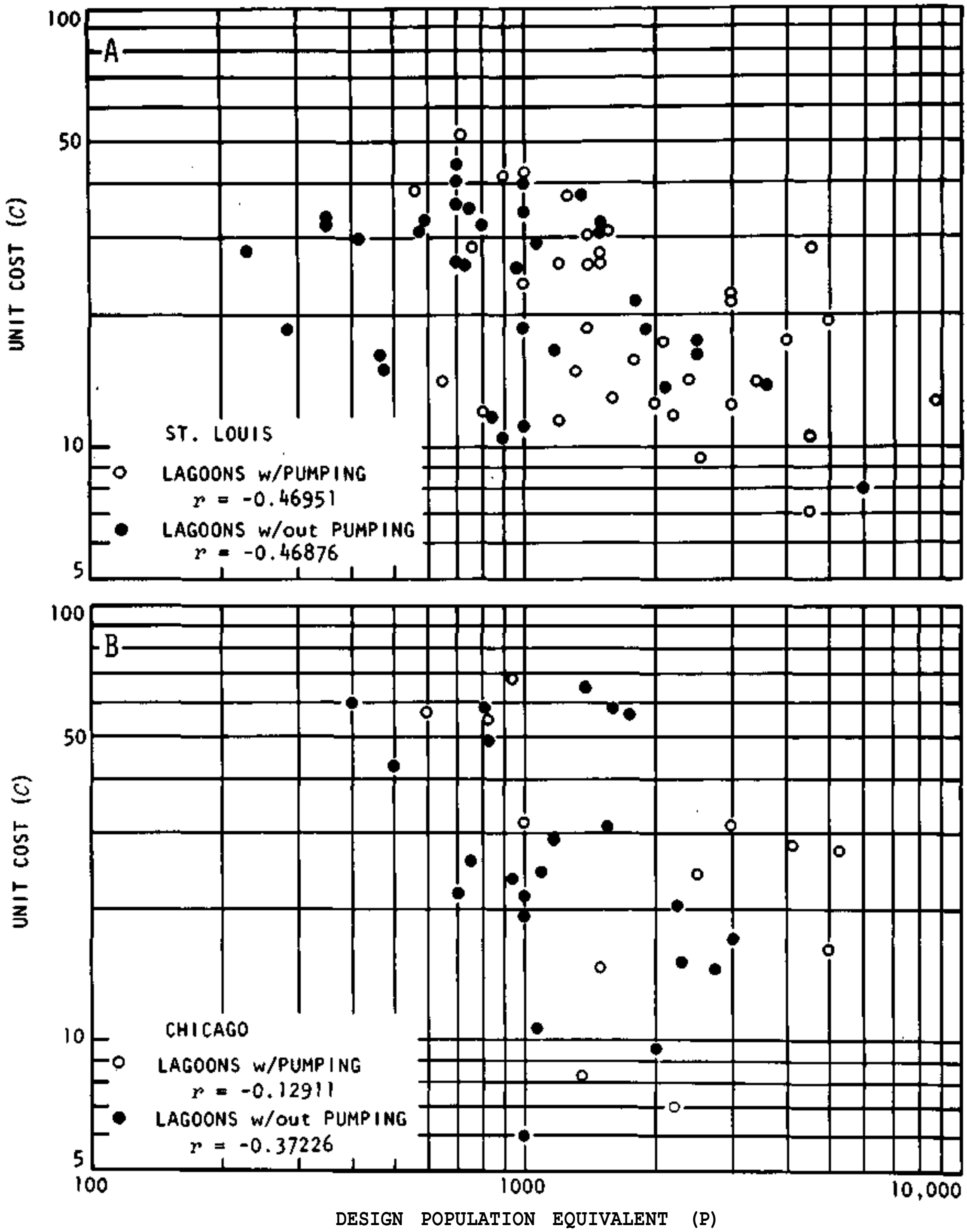

Figure 3. Unit construction costs for oxidation lagoons for southern Illinois, the St. Louis cost index area (A), and northern Illinois, the Chicago cost index area (B)

Table 3. Mean and Variance of Unit Lagoon Costs *($/PE)*

	St. Louis area			Chicago area			Illinois
Parameter	Pumping	No pumping	Total	Pumping	No pumping	Total	Total
Number in sample	37	34	71	12	22	34	105
Mean	22.59	25.07	23.78	30.84	31.79	31.45	26.27
Variance	118.15	98.99	108.99	392.60	352.53	355.78	199.10

area, the respective unit costs were $33-71 and $29.20 per design *PE*. The Chicago costs were significantly higher statistically in each classification than those for St. Louis.

Better correlations were achieved by comparing lagoon size to total lagoon cost. Prediction equations, based on these variables, were developed for the St. Louis and Chicago areas and for the state as a whole (figures 4, 5, and 6). Since no statistically significant difference existed between pumping and non-pumping facilities, the data were combined. Table 4 summarizes the three equations and their related statistical data. The equations represent lines parallel to the regression equation at a distance of one standard error from the mean value. Figure 5 and tables 3 and 4 show that the Chicago area data are quite variable, and the total costs for a given lagoon size are higher than for the St. Louis area. The equation developed for the whole state gives very conservative estimates for proposed southern Illinois installations of all sizes. However, the equation gives estimates below those obtained with the Chicago area equation for *PE*'s less than 2000 (table 5).

Table 4. Equations for Predicting Oxidation Lagoon Total Construction Costs

Prediction equation number and description	Number in sample	Correlation (r)	Prediction equation	Standard error of estimate	Range of *PE* low	Range of *PE* high
(3) St. Louis	71	0.794	$C_T = 266P^{.708}$	$14.6\text{x}10^3$	230	8750
(4) Chicago	34	0.540	$C_T = 788P^{.614}$	$31.0\text{x}10^3$	400	5250
(5) Illinois	105	0.711	$C_T = 349P^{.690}$	$19.6\text{x}10^3$	230	8750

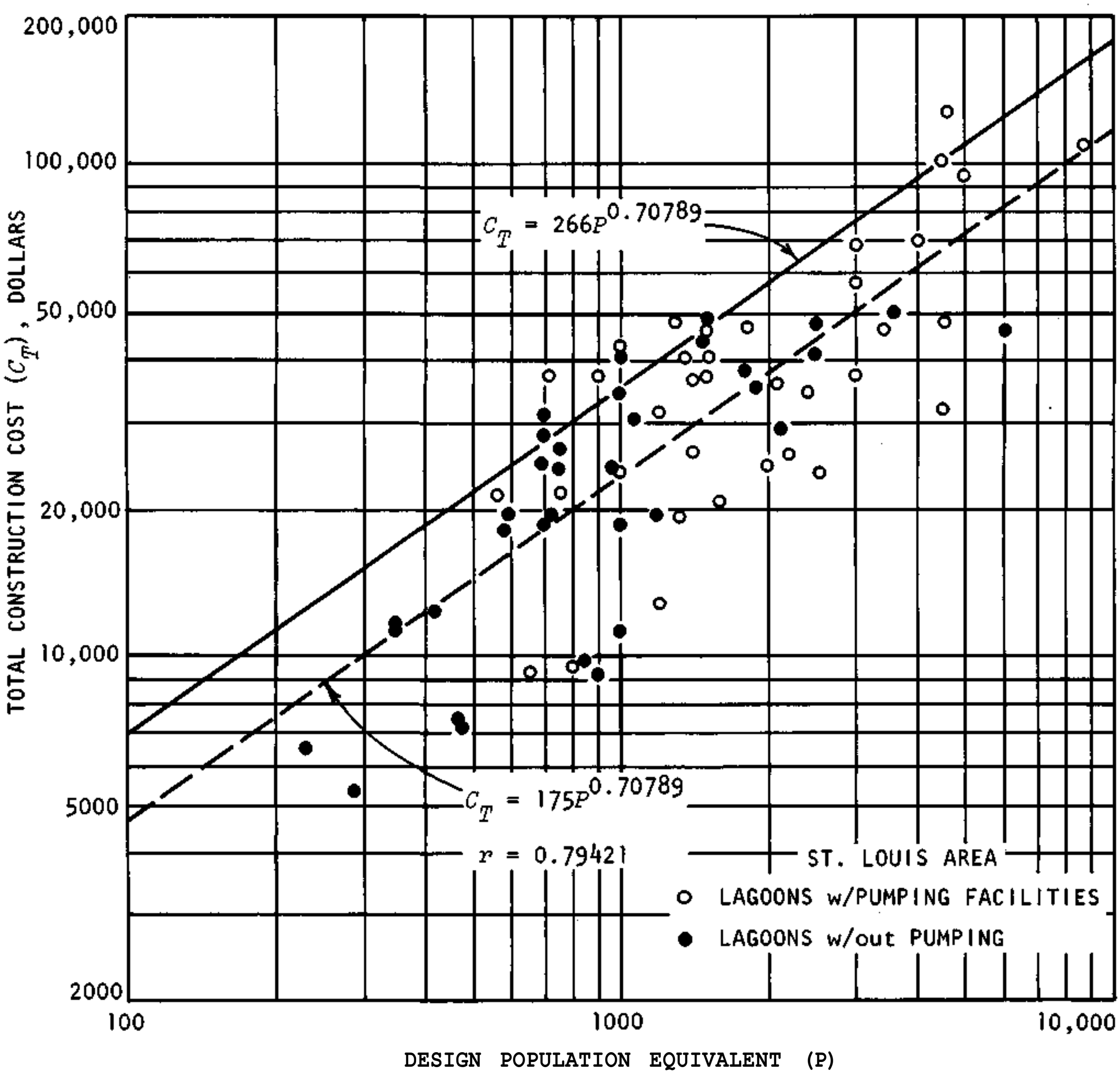

Figure 4. Total construction cost for oxidation lagoons in the St. Louis cost index area

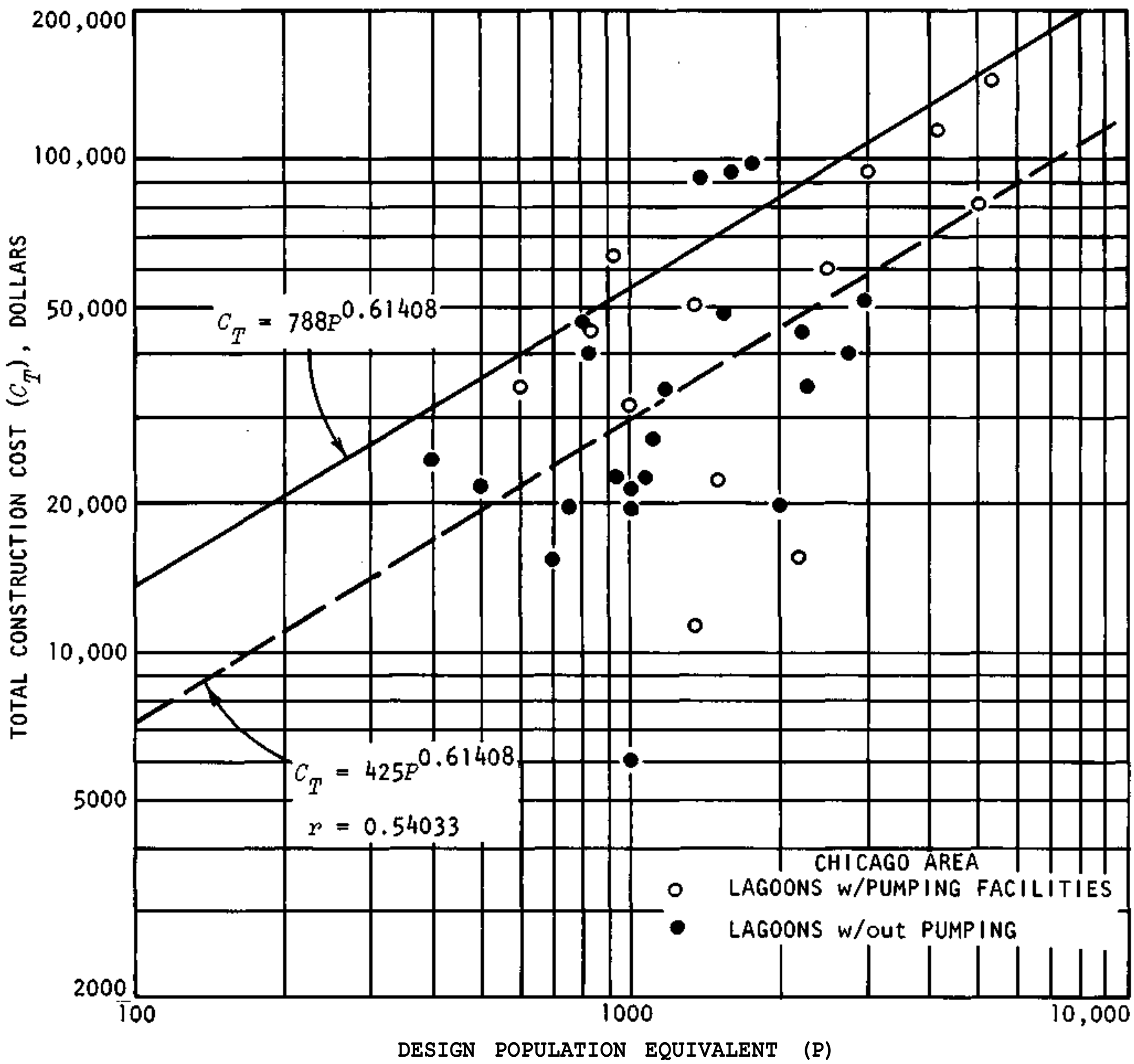

Figure 5. Total construction cost for oxidation lagoons in the Chicago cost index area

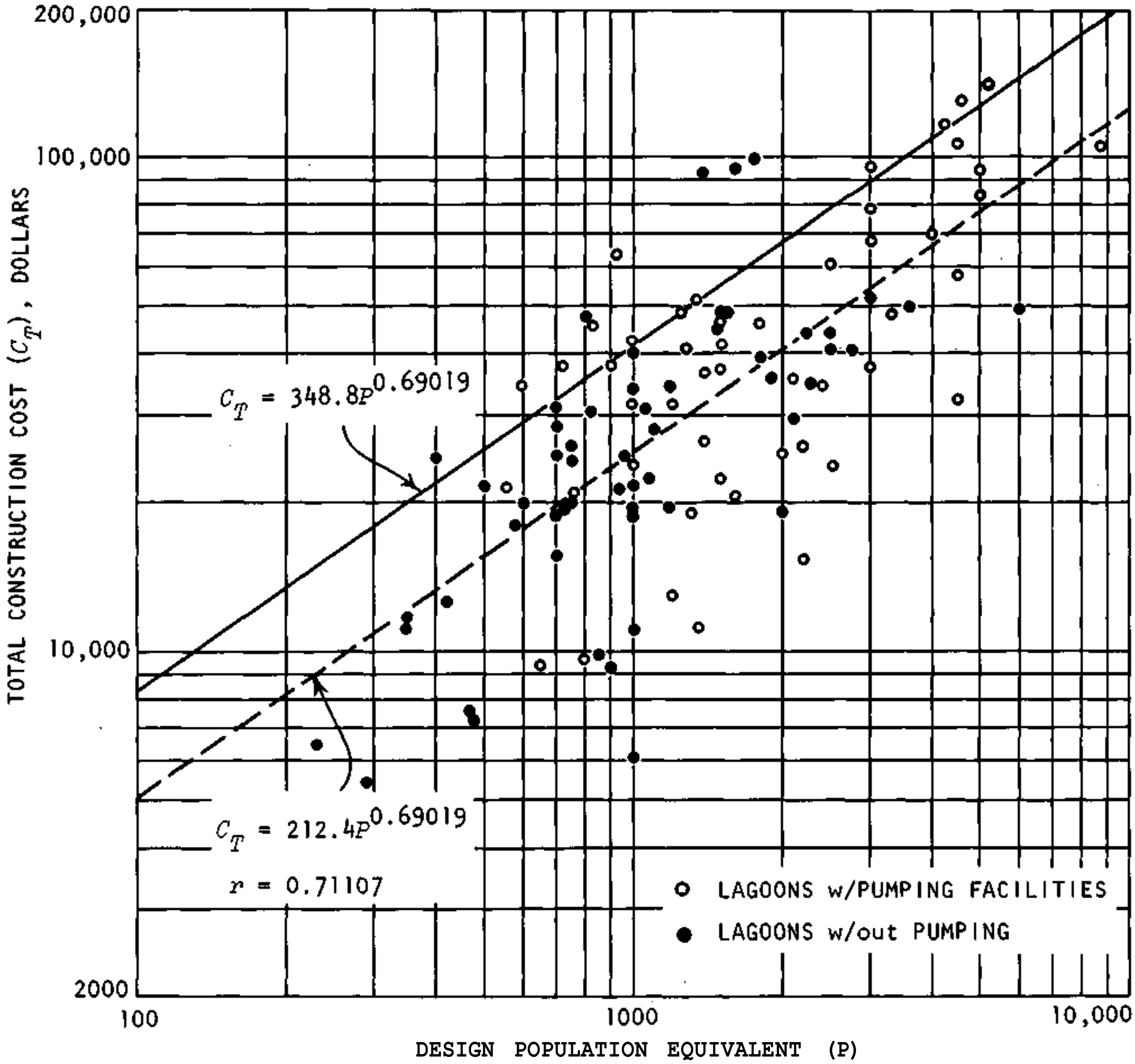

Figure 6. Total construction cost for oxidation lagoons for Illinois as a whole

Table 5. Comparison of Lagoon Construction Costs from Geographically Developed Equations

	Total cost ($) for given design population equivalent (P)			
Area	500	1000	2000	5000
St. Louis	21,600	35,320	57,700	110,400
Chicago	35,800	54,800	83,880	147,200
Illinois	30,600	50,500	83,600	162,800

Sample Problem 1. An oxidation lagoon is being considered for a northern Illinois community which has a population of 2000 and an industry discharging 85 pounds per day of BOD_5. Estimate the total construction cost in 1972 that would be expected to be exceeded only 16 percent of the time.

$$Y = 1972$$

$$P = 2000 + 85/0.17 = 2500$$

From figure 5 or equation 4:

$$C_T = \$96{,}130 \text{ (1957-1959 base).}$$

Adjusted to 1972 by equation 2:

$$I_c = 104.96 + 2.74\ (1972 - 1960) = 137.84$$

$$C_T = (96{,}130)(137.84)/100 = \$132{,}500$$

The cost of a lagoon of similar size in southern Illinois planned for 1972 would be as follows.

From figure 4 or equation 3:

$$C_T = \$67{,}700$$

Adjusted to 1972 by equation 1:

$$I_s = 103.90 + 2.91\ (1972 - 1960) = 138.94$$

$$C_T = (\$67{,}700)\ (138.94)/100 = \$94{,}100$$

Thus, the cost is estimated to be approximately $38,400 less for the southern installation.

Primary Plants

The sole use of primary treatment plants for treating domestic sewage is no longer acceptable in the state. Water quality standards adopted since 1966 dictate that secondary treatment must be provided throughout the state regardless of the available dilution or streamflow. Primary treatment generally consists of physical removal of solids and BOD_5 using settling tanks. Most tanks are mechanically cleaned, and the sludge is processed for final disposal with either anaerobic digesters or vacuum filters. A few primary plants consist of Imhoff tanks in which the sludge is digested in special compartments in the bottom portion of the tank.

Figure 7 shows the locations of most of the primary plants constructed since 1956. They are all located along either the Mississippi, Illinois, Ohio, or Rock Rivers. The plants have been classified into those having anaerobic digesters and those having vacuum filters. Two Imhoff primary plants are also identified.

Although primary plants can be considered obsolete for treating domestic sewage, an analysis of the data is presented because the results may be useful in special cases such as those associated with industrial wastes. Also, the data present a good basis for comparing the cost of plants using anaerobic digestion with those using vacuum filters.

Primary with Digesters. Fifteen plants of this type were analyzed. The distribution of unit costs versus design size is illustrated by figure 8. The prediction formula and related statistical data are summarized in table 6. The primary-digester plant data are more variable than the data for the vacuum filter plants.

Table 6. Equations for Predicting Primary Plant Unit Construction Costs

Prediction equation number and description	Number in sample	Correlation (r)	Prediction equation	Standard error of estimate	Range of PE low	Range of PE high
(6) Primary-digester	15	-.891	$C = 4290P^{-.506}$	10.96	3440	320,000
(7) Primary-vacuum	9	-.967	$C = 634P^{-.362}$	1.76	3850	242,000

Primary with Vacuum Filter. Nine plants of this type were analyzed. The distribution of unit costs versus design size is illustrated by figure 8. The prediction formula and related statistical data are summarized in table 6. The vacuum filter data are considerably less variable than the digester data. The

Figure 7. Distribution of primary plants for which cost data were analyzed

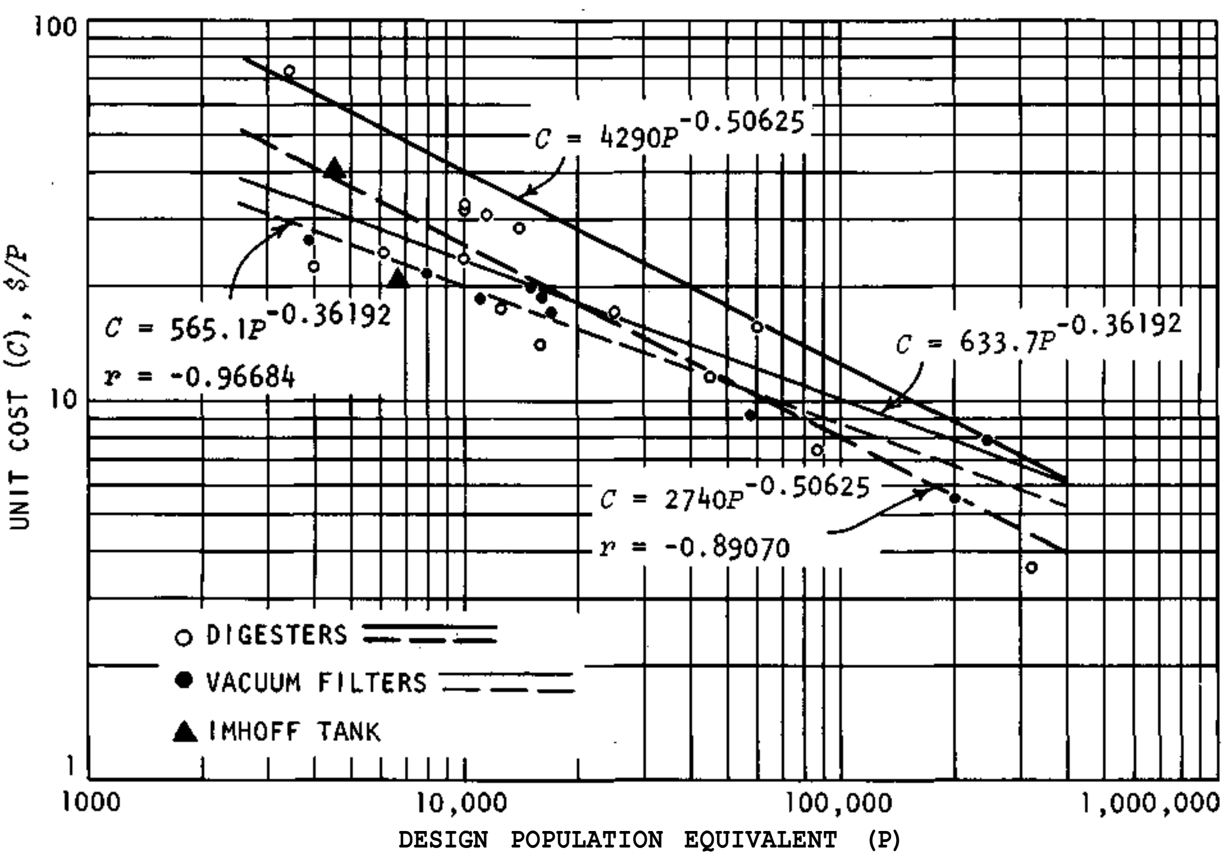

Figure 8. Unit construction coat for primary plants which have separate sludge handling

line representing values which will probably be exceeded only 16 percent of the time is only slightly above the "best fit" regression line. For a given size plant within the limits investigated, the initial capital cost of installing a vacuum filter will probably be less than for a digester. The two costs tend to converge, however, as plant sizes increase.

Imhoff Tank. Sufficient data were not available to develop prediction equations for this type of installation. However, the two pieces of data obtained indicate that Imhoff tank construction costs may not be significantly lower than those for either the digester or vacuum filter plants (see figure 8). The major advantages of the Imhoff tank are simpler operation and lower operational and maintenance costs.

Sample Problem 2. A northern Illinois industry has found that with the aid of chemicals a primary settling tank can be used to remove the BOD_5 and suspended solids sufficiently to meet stream standards. The sludge is to be conditioned for disposal with a vacuum filter. Estimate a reasonable cost for the primary plant portion of this installation where the flow is 2.5 million gallons per day and the plant is to be installed in 1972. Assume one *PE* equals a flow of 100 gallons per day.

$$Y = 1972$$

$$I_c = 137\text{-}84 \text{ (see problem 1)}$$

$$P = 2.5\times10^6/100 = 25{,}000$$

From figure 8 or equation 7:

$$C = \$16/P$$

The total 1972 estimated construction cost is:

$$c_T = (c)(p)(I_c/100)$$

$$C_T = (16)(25{,}000)(1.3784) = \$551{,}360$$

Trickling Filter Plants

Trickling filter plants are used throughout the state for providing secondary treatment. This type of plant can be used to achieve BODc reductions up to 90 percent under a wide range of BODc, loadings. Trickling filter plants consist of two basic designs: 1) trickling filters with Imhoff tanks and 2) trickling filters with separate sludge treatment. Trickling filter-Imhoff tank installations are generally designed to meet the needs of small communities; operating ski 11 and operating costs are minimal for the relatively high degree of treatment which can be achieved. Separate sludge treatment is usually accomplished by heated digesters or rotary vacuum filters. Trickling filter-separate sludge treatment plants are generally used for larger communities than those served by trickling filter-Imhoff systems.

Figure 9 shows the distribution of most of the trickling filter plants which have been built since 1956. Note the distribution of the plants in relation to the distribution of lagoons shown in figure 2. The heaviest concentrations of trickling filter plants are in the east-central and northern sections of the state where lagoons are less predominant.

Trickling Filter-Separate Sludge Treatment. Twenty-one of these plants were analyzed. Twenty used digesters for sludge treatment; one used a vacuum filter. Each plant was identified as to whether the trickling filter was a high rate or a standard rate unit. The distribution of the data and the resultant prediction lines are given in figure 10A. A statistical summary of the data relative to the prediction equation is given in table 7. No difference could be readily detected between the high and standard rate unit costs. The lone vacuum filter plant unit cost appeared to differ little from the overall cost trend; consequently, it was included in the analysis of the equation labeled trickling filter-digester.

Table 7. Equations for Predicting Trickling Filter Unit Construction Costs

Prediction equation number and description	Number in sample	Correlation (r)	Prediction equation	Standard error of estimate	Range of PE low	Range of PE high
(8) Trickling filter-digester	21	-.729	$C = 1069P^{-.350}$	9.77	2300	33,800
(9) Trickling filter-Imhoff	22	-.737	$C = 738P^{-.328}$	8.31	900	4,000

Trickling Filter-Imhoff Tank. Twenty-two of these plants were analyzed. Only four were high rate filter plants, and since their unit costs fit the general cost distribution of the standard rate plants, the data were combined. The resultant equations and related statistical criteria are shown on figure 10B and in table 7. Note that all the trickling filter-Imhoff tank plants are for *PE's* of 4000 or less, whereas the digester plants range between 2300 and 33,800 *PE.*

Sample Problem 3. A small northern Illinois community of 3000 plans to start construction of new treatment facilities in 1972 to meet the needs of a projected

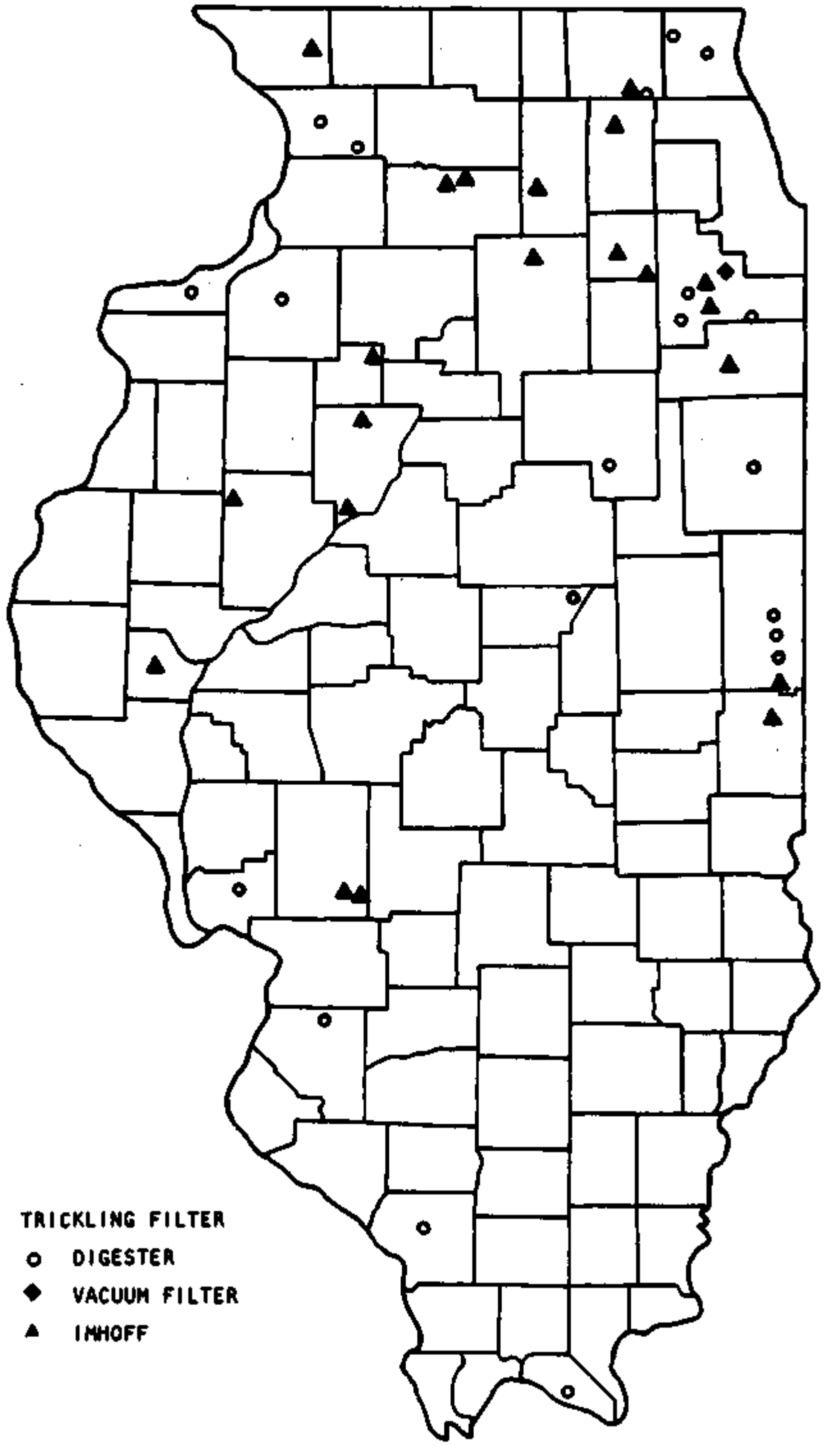

Figure 9. Distribution of trickling filter plants for which cost data were analyzed

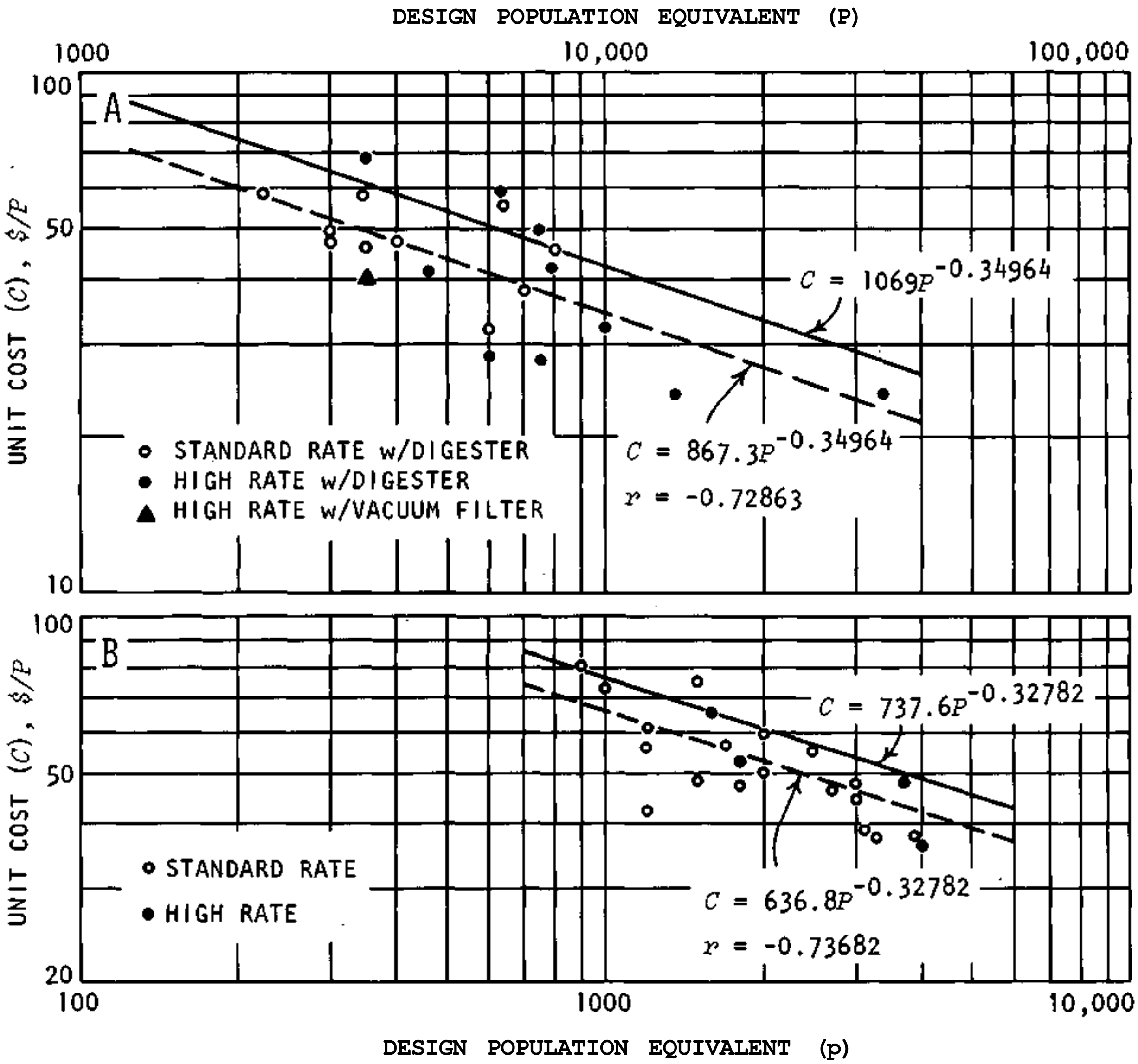

Figure 10. Unit construction costs for trickling filter plants with separate sludge handling (A) and with Imhoff tank (B)

1980 population of 4000. Compare the estimated construction costs of a trickling filter-digester plant with that of a trickling filter-Imhoff tank plant.

$$Y = 1972$$

$$I_c = 137.84 \text{ (see problem 1)}$$

$$P = 4000$$

From figure 10 or equations 8 and 9:

$$C = \$58.80/P \quad \text{(digester)}$$

$$C = \$48.60/P \quad \text{(Imhoff)}$$

The total estimated construction costs are:

$$C_T = (C)(P)(I_c/100)$$

$$C_T = (58.80)(4000)(1.3784) = \$324{,}200 \quad \text{(digester)}$$

$$C_T = (48.60)(4000)(1.3784) = \$268{,}000 \quad \text{(Imhoff)}$$

Significant monetary savings for small communities can be realized by using the Imhoff tank in place of the digester, with little or no sacrifice in treatment efficiency.

Activated Sludge Plants

The activated sludge process is a popular method of treating sewage in the state. It is adaptable for use in large and small communities. The recent development of package or factory built activated sludge plants has made the process economically available to many small communities. Figure 11 shows the geographic distribution of most of the activated sludge plants built in Illinois since 1956. Note that these plants, like the trickling filter type, are most predominant in the east-central and northern areas.

The majority of the constructed-in-place installations are either standard design or contact stabilization plants. No attempt has been made to distinguish between types in the analysis of the data. Removals of 90 percent of BOD5 can generally be achieved by either the standard activated sludge process or contact stabilization.

Most of the factory built municipal installations are contact stabilization plants; 36 of the 39 plants analyzed were of this type. A few municipalities use extended aeration plants, as do many privately owned establishments. Factory built contact stabilization units are credited by the Illinois Sanitary Water

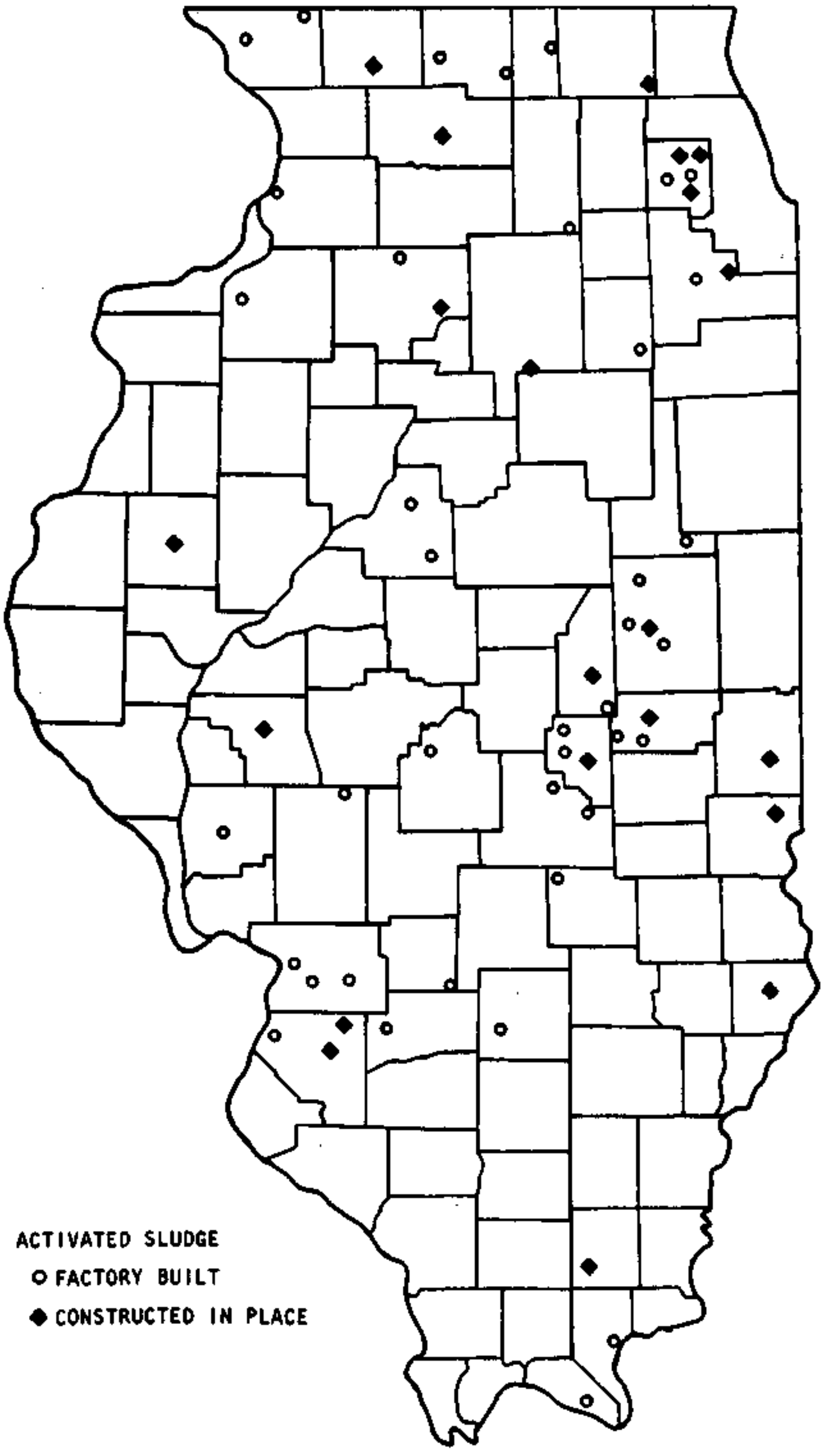

Figure 11. Distribution of activated sludge plants for which cost data were analyzed

Board with efficiencies up to 90 percent, whereas extended aeration removal efficiencies have been limited to 70 percent.[3] However, extended aeration plants, when used as the principal treatment process, are generally followed with a polishing pond.

Constvuoted-in-Place Plants. Twenty-two constructed-in-place plants were analyzed; of these 19 were new installations and 3 were additions to existing primary plants. Figure 12A shows the distribution of the data for these plants. A break appeared to occur in the data at about the 10,000 *PE* line. Consequently, two prediction equations were developed, one for *PE's* less than 10,000 and another for *PE's* greater than 10,000. Two points, one at 10,000 *PE* and another at 12,000 *PE*, were used in common in the statistical development of both prediction equations. Table 8 summarizes the equations and their related statistical data. The data for 10,000 *PE* or greater have a relatively flat slope. This results in what appears to be an insignificant correlation coefficient. However, the best fit equation has a standard error of estimate lower than that for the equation developed for the highly correlated data with *PE's* less than 10,000. Note from figure 12 that the unit cost of adding an activated sludge unit to an existing primary plant appears to be as high as or higher than a complete new plant.

Table 8. Equations for Predicting Activated Sludge Unit Construction Costs

Prediction equation number and description	Number in sample	Correlation (r)	Prediction equation	Standard error of estimate	Range of *PE* low	Range of *PE* high
(10) Constructed in place ≤ 10,000 *PE*	16	-.838	$C = 3746P^{-.493}$	9.38	2,000	10,000
(11) Constructed in place ≥ 10,000 *PE*	8	-.282	$C = 91P^{-.09}$	7.45	10,000	50,000
(12) Factory built	39	-.671	$C = 1298P^{-.402}$	12.82	750	10,000

Factory Built Plants. Thirty-nine factory built plants installed since 1956 were analyzed. Of these, 36 were for *PE's* of 5000 or less. One was designed for 10,000 *PE.* These plants have probably been used, to a large degree, in place of Imhoff-trickling filter plants for small communities. The data illustrated in figure 12B indicate that the variability of costs for a given design *PE* may be large. For example, the unit costs of the 10 plants at the 2000 *PE* design level were evenly distributed between approximately $40.00 and $76.00 per design *PE.* The regression equation and related statistical data are given in table 8.

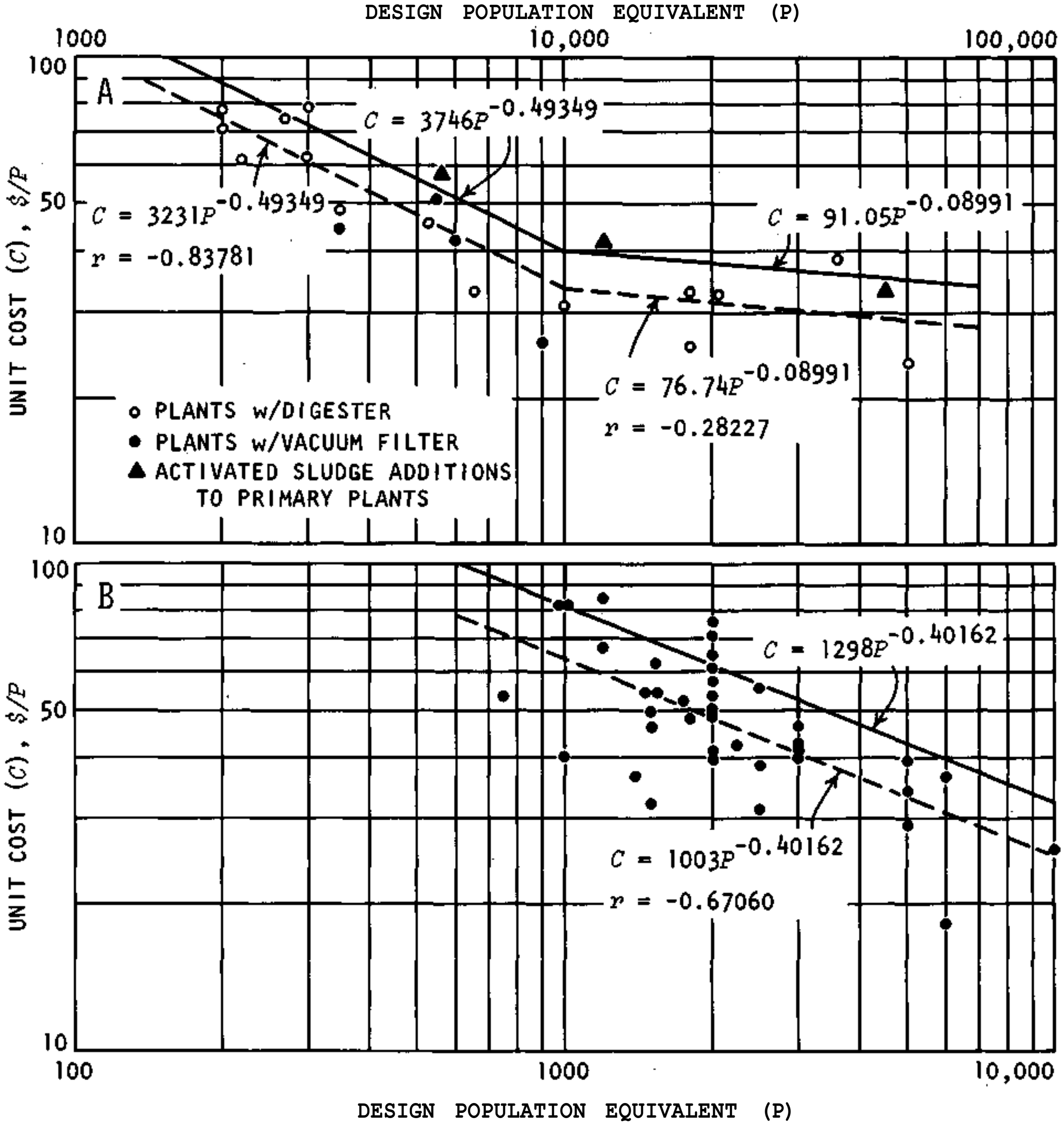

Figure 12. Unit construction costs for activated sludge plants when constructed in place (A) and when factory built (B)

Sample Problem 4. Estimate the costs of a constructed-in-place and a factory built activated sludge plant for the conditions specified in problem 3.

$$Y = 1972$$

$$I_c = 137.84$$

$$P = 4000$$

From figure 12 or equations 10 and 12:

$$C = \$62.50^{*}$$

$$C = \$46.30^{**}$$

The total construction costs are:

$$C_T = (C)(P)(I_c/100)$$

$$C_T = (62.50)(4000)(1.3784) = \$344{,}000^{*}$$

$$C_T = (46.30)(4000)(1.3784) = \$255{,}000^{**}$$

*(constructed in place)

**(factory built)

A considerable savings can probably be realized by installing a factory built plant rather than having one constructed in place. Also, a factory built plant would be significantly less costly than a trickling filter plant with separate sludge digestion (see results of problem 3); however, the cost would be only slightly less than for a comparable trickling filter-lmhoff type of installation.

Additions to Existing Secondary Plants

Cost relationships were developed for trickling filter and activated sludge additions to existing secondary treatment facilities. An analysis of this data was done separately from new plants because it was thought that, for a given design *PE*, additions would be less costly. Also, the size of the original plant has an influence on the construction cost of the addition. Figure 13 illustrates this by showing that larger plants are more likely to require proportionally larger *PE* additions.

Extensive use was made of federal[4] and state[5] waste water treatment plant inventories to determine the size of the additions to existing facilities.

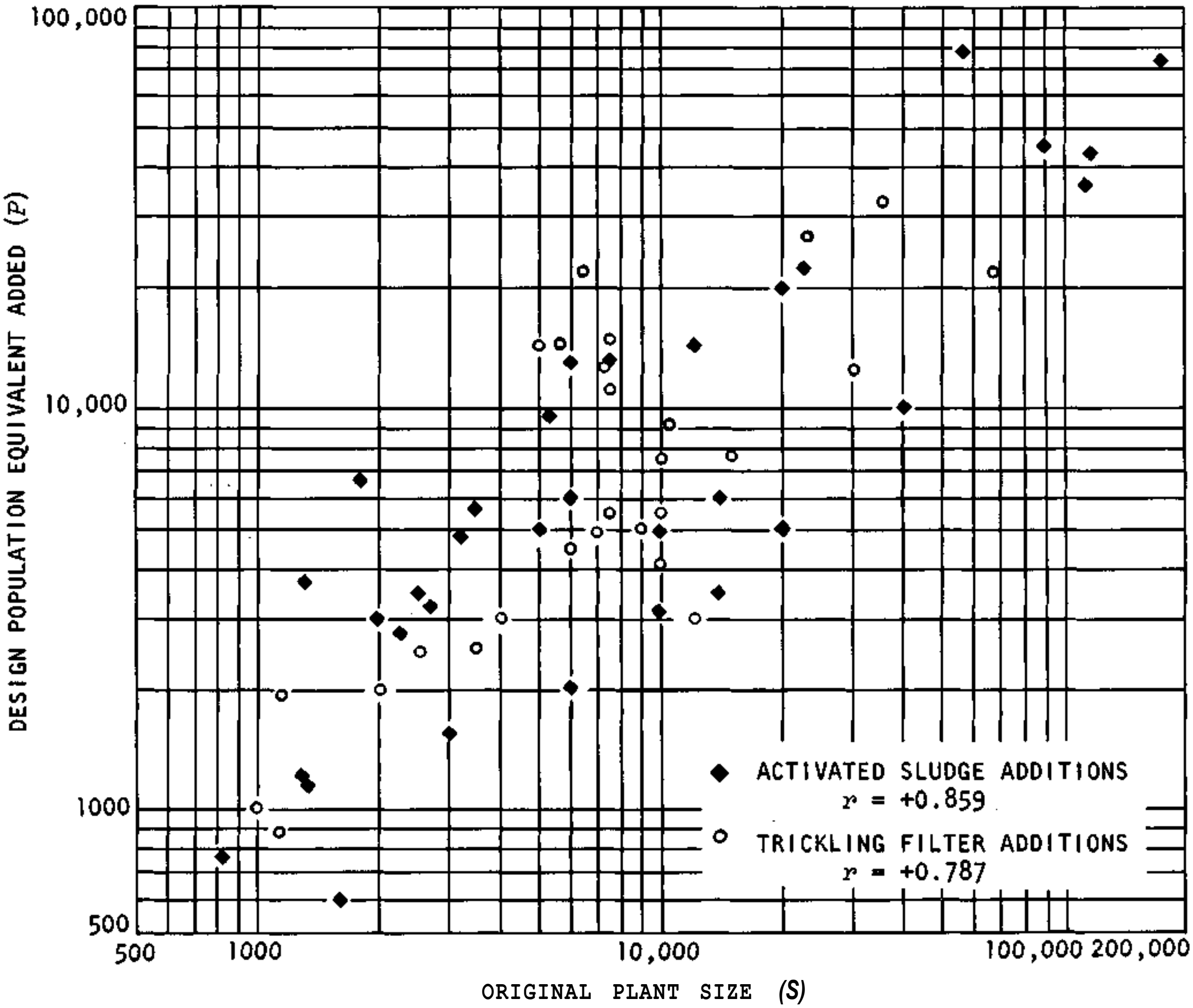

Figure 13. Relationship between original treatment plant size and size of new addition

Trickling Filter Additions. Twenty-seven additions to trickling filter plants were analyzed. Individual relationships between the unit costs and design *PE* added, as well as the original plant size, are illustrated on figures 14A and 14B; the prediction equations and their related statistical data are summarized in table 9. The correlation between unit costs and original plant *PE* is low as illustrated by figure 14B.

Table 9. Equations for Predicting Unit Construction Costs of Additions to Existing Secondary Plants

Prediction equation number and description	Number in sample	Correlation (r)	Prediction equation	Standard error of estimate	Range of *PE* low	high
(13) Trickling filter	27	-.734	$C = 1470P_A^{-.395}$	14.42	880	32,600
(14) Activated sludge	33	-.780	$C = 1594P_A^{-.375}$	19.02	600	79,000

The best fit equation developed to relate both *PE* added and original plant PE to unit cost is:

$$C = 785.3P_A^{-0.53025} S^{0.16654} \qquad (15)$$

and the equation at one standard error of estimate above and parallel to equation 15 is:

$$C = 1116P_A^{-0.53025} S^{0.16634} \qquad (16)$$

The multiple correlation coefficient is -0.760; this is only slightly better than the -0.734 value found for the relationship between *PE* added and unit costs (figure 14A). The standard error of estimate for equation 15 is $14.00 per *PE* design compared with $14.42 per *PE* design for the best fit equation relating *PE* added to unit costs. This indicates that the predictive capability is not greatly increased by including the original plant size variable in the development of the prediction equation.

Activated Sludge Additions. Thirty-three activated sludge additions to existing secondary plants were analyzed in the same manner as that used for the trickling filter additions. Figures 15A and 15B illustrate the individual relationships; the prediction formula and related statistical data are summarized in table 9. A relatively high correlation was found to exist between the original plant size and unit costs in contrast to the low value found for trickling filter additions.

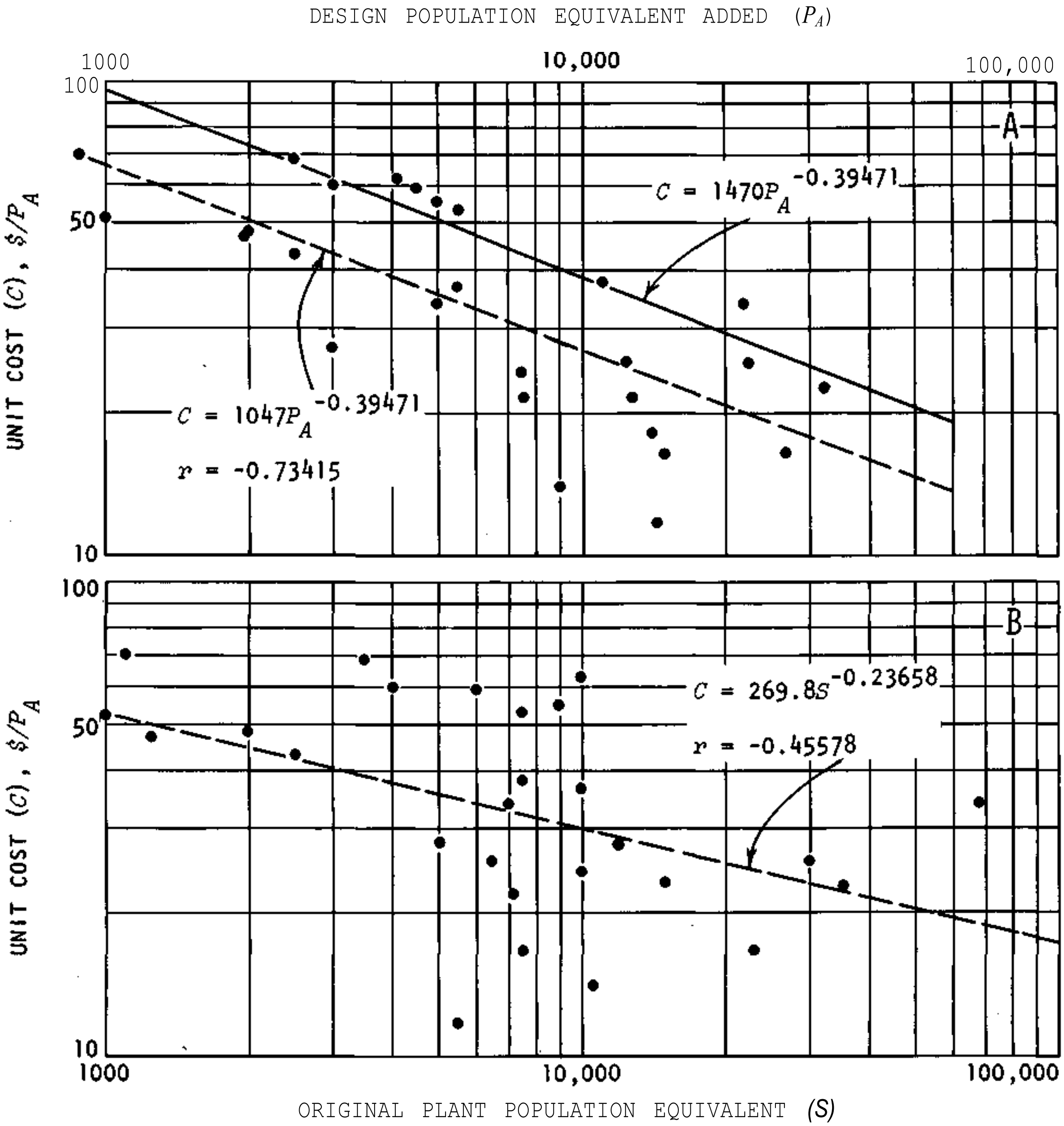

Figure 14. Unit construotion costs of trickling filter additions as related to the size of the addition (A) and the size of the original plant (B)

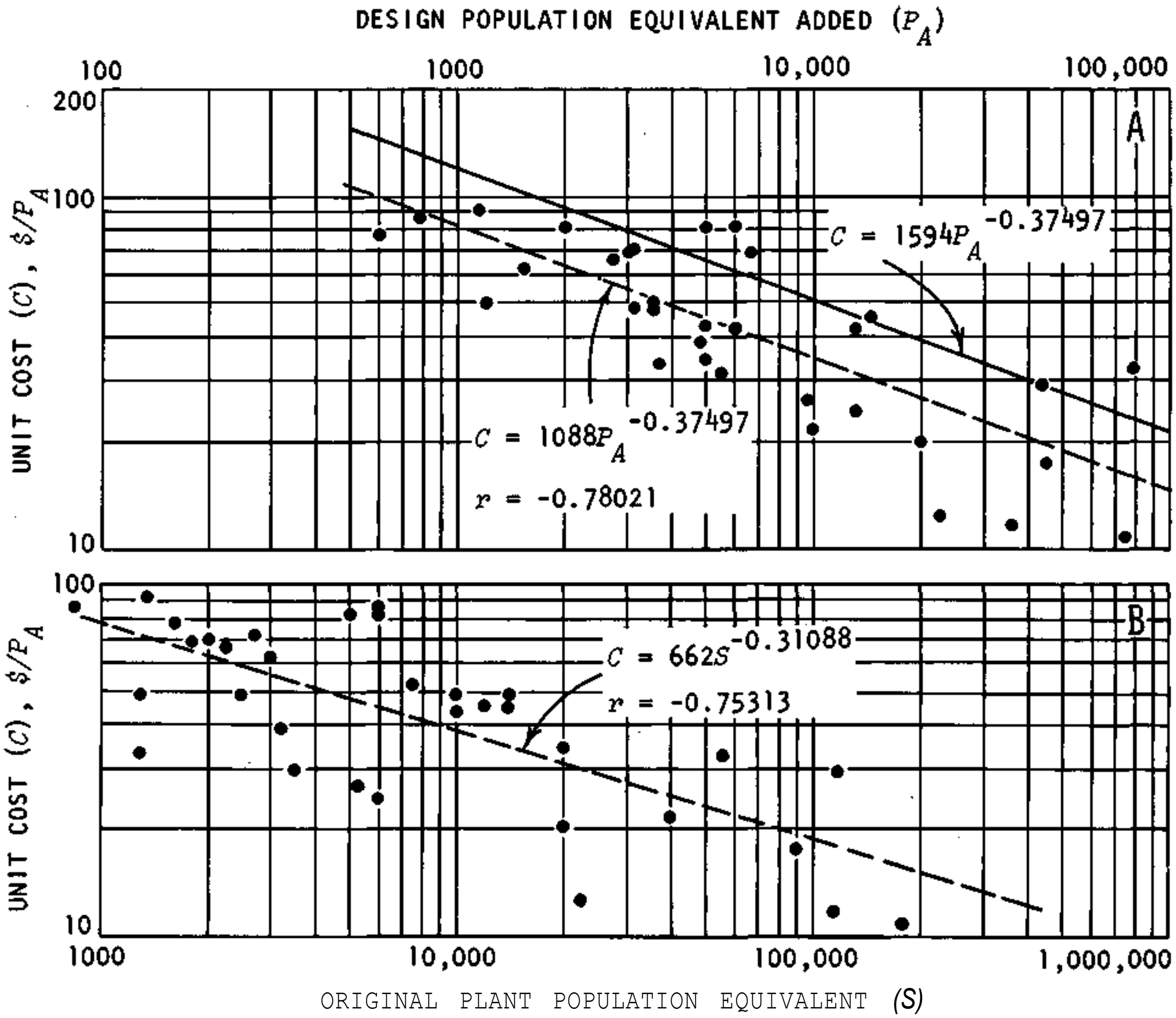

Figure 15. Unit construction costs of activated sludge additions as related to the size of the addition (A) and the size of the original plant (B)

The best fit equation developed to relate both *PE* added and original plant size to unit costs is:

$$C = 1118 P_A^{-0.24429} S^{-0.13073} \tag{17}$$

and the equation at one standard error of estimate above and parallel to equation 17 is:

$$C = 1625 P_A^{-0.24429} S^{-0.13073} \tag{18}$$

The multiple correlation coefficient is -0.797 compared with -0.780 obtained for the relationship between *PE* added and unit costs (figure 15A). The standard error or estimate for equation 17 is $18.54 per *PE* design compared with $19.02 per *PE* design for the best fit equation given in figure 15A.

Sample Problem 5. The community identified in problem 3 has decided to enlarge its existing secondary plant from 2000 to 4000 *PE* instead of building a new one. Estimate the cost of the addition using 1) a trickling filter and 2) an activated sludge process.

$$Y = 1972$$

$$I_c = 137.84$$

$$P_A = 2000$$

From figures 14A and 15A or equations 13 and 14:

$$C = \$73.20/P_A{}^{*}$$

$$C = \$92.20/P_A{}^{**}$$

The total construction costs are:

$$C_T = (C)(P_A)(I_c/100)$$

$$C_T = (73.20)(2000)(1.3784) = \$199{,}000^{*}$$

$$C_T = (92.20)(2000)(1.3784) = \$254{,}000^{**}$$

^(trickling filter)

**(activated sludge)

The results from problems 3, 4, and 5 are summarized in table 10. Several facts become evident. Trickling filters, both new plants and additions to

Table 10. Summary of Estimated Construction Costs from Sample Problems 3, 4, and 5

Problem number	Type of construction	Unit cost	Total cost
3	New trickling filter-digester	\$58.80	\$324,200
3	New trickling filter-Imhoff	48.60	268,000
4	New activated sludge, constructed in place	62.50	344,000
4	New activated sludge, factory built	46.30	255,000
5	Trickling filter addition	73.20	199,000
5	Activated sludge addition	92.20	254,000

existing plants, are less costly than constructed-in-place activated sludge installations. The unit costs for additions needed to bring a plant up to a given design capacity are higher than unit costs of a new plant designed for the given capacity; the total cost, however, would be less for the addition. For the sample problem used, the estimated cost of a complete new 4000 *PE* factory-built activated sludge plant is approximately equal to that for a 2000 *PE* constructed-in-place activated sludge addition.

Lagoon Land and Operating Costs

Land costs for 44 of the 105 lagoons investigated were available for analysis, Figure 16 shows the relationship between design *PE* and total land costs. The prediction formula and related statistical data are presented in table 11. The data are quite variable, and have not been adjusted to a base period. Equation 19 can be used to make estimates throughout the state; however, since over 75 percent of the data are from southern Illinois, the equation is biased.

Table 11. Equations for Predicting Lagoon Land Cost and Conventional Plant Unit Annual Operating Costs

Prediction equation number and description	Number in sample	Correlation (r)	Prediction equation	Standard error of estimate	Range of *PE* low	Range of *PE* high
(19) Lagoon land costs	44	.682	$C_L = 22.1P^{.877}$	6.17×10^3	230	6,000
(20) Conventional plant operating costs	26	-.765	$C_o = 23.3P_W^{-.213}$	1.15	500	447,000

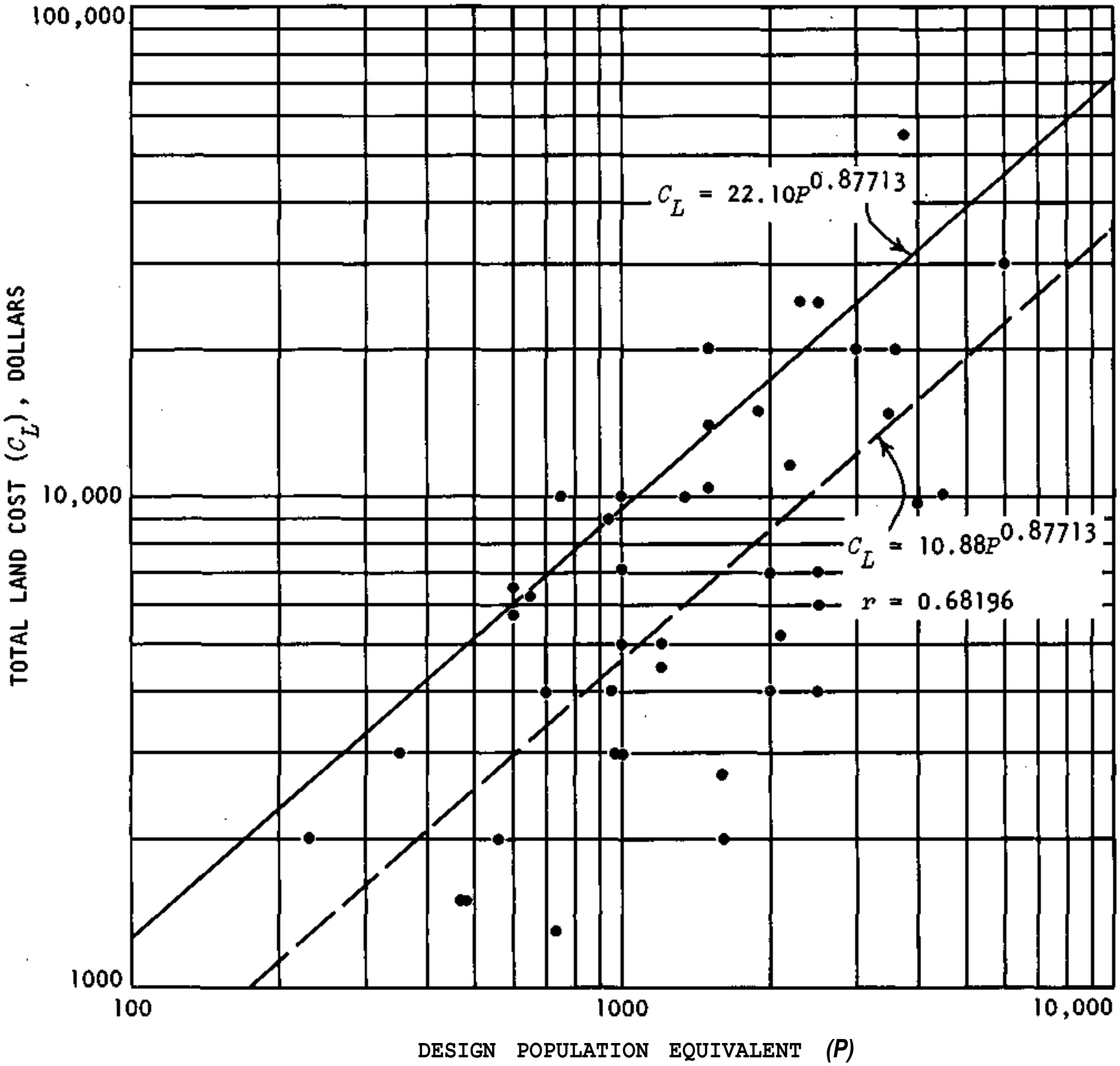

Figure 16. Land cost for oxidation lagoons

Operating costs were available for 36 lagoons. No relationship could be established between operating costs and lagoon size. The median total yearly operating cost was approximately $1000. Only 16 percent of the values exceed $2700; this conservative value is reasonable for estimating purposes.

Conventional Plant Operating Costs

Operating cost data for 26 conventional sewage treatment plants were available for analysis. Of these, 19 were activated sludge, 5 trickling filter, and 2 primary plants. All the data were combined and an equation was derived relating unit annual operating costs to the population equivalent of the wastes being treated (P_W). The equation and related statistical data are given in table 11. The operating costs, including those for the lagoons, are for the 1966-1967 operating period and have not been adjusted to a base period.

Sample Problem 6; Estimate the cost of the land required to build the lagoon described in problem 1. From figure 16 or equation 19 at a P = 2500:

$$C_T = \$21,000$$

This would represent approximately 14 percent of the total cost for a northern Illinois lagoon and approximately 18 percent for a southern Illinois lagoon.

Sample Problem 7: Estimate the annual operating cost for the new plant described in problem 3 when operating at 80 percent of its design capacity.

$$P_W = (80\%/100)(P)$$

$$P_W = (0.80)(4000) = 3200$$

From equation 20 in table 11:

$$C_o = \$4.17/P_W$$

The annual operating cost is:

$$C_a = (4.17)(3200) = \$13,350$$

SUMMARY

Table 12 has been prepared to summarize the relative costs predicted by the use of the various equations which have been developed. The oxidation lagoon costs have been estimated from the equation developed for Illinois as a whole (equation 5 in table 4). The trickling filter-Imhoff tank process, being basically the least costly, was used as a measure of comparison.

Table 12. Construction Cost Comparisons of Illinois Sewage Treatment Plants for 1957-1959 Base

Type of treatment plant	Total cost for design *PE*'s of						Cost ratio * for design *PE*'s of					
	500	1000	2000	5000	10,000	30,000	500	1000	2000	5000	10,000	30,000
Primary -- digester			183,000	287,800	403,700	696,900			1.50	1.27	1.12	0.92
Primary -- vacuum filter			80,900	145,300	226,000	456,000			0.66	0.64	0.63	0.61
Trickling filter-digester		95,100	149,900	272,000	426,900	872,400		1.24	1.23	1.20	1.19	1.16
Trickling filter-Imhoff	48,000	76,600	122,100	226,100	360,200	753,900	1.00	1.00	1.00	1.00	1.00	1.00
Activated sludge, constructed in place		124,900	176,000	293,200	397,800	1,081,000		1.63	1.44	1.30	1.10	1.43
Activated sludge, factory built	53,500	81,000	122,600	212,200	321,200		1.11	1.06	1.00	0.94	0.89	
Trickling filter additions	63,250	96,200	146,400	254,900	387,700	753,900	1.32	1.26	1.19	1.13	1.08	1.00
Activated sludge additions	77,500	119,500	184,300	326,850	504,000	1,002,000	1.61	1.56	1.50	1.45	1.40	1.33
Oxidation lagoon without land cost	25,400	41,000	66,200	124,000	201,000		0.53	0.54	0.54	0.55	0.56	
Oxidation lagoon with land cost	30,600	50,500	83,600	162,800	272,300		0.64	0.66	0.68	0.72	0.76	

* *Ratio of construction costs to trickling filter-Imhoff costs*

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