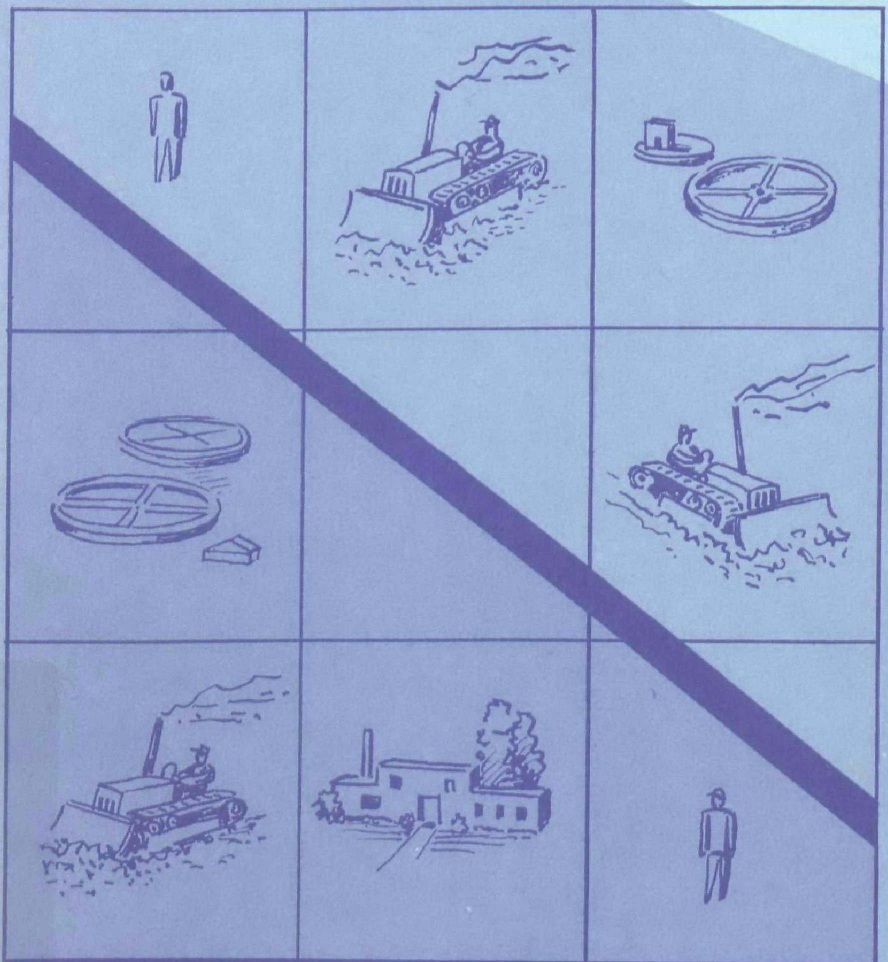
MODERN SEWAGE TREATMENT PLANTS
How much do they cost?



U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

PUBLIC HEALTH SERVICE

Modern Sewage Treatment Plants—
How Much Do They Cost?

A Practical Guide to Estimating Municipal Sewage Treatment Plant Construction Costs

(Based on Studies of Projects Built With PHS Grants—1956–63)

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
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Foreword

To stimulate the construction of sewage treatment works in the United States and to clean up the municipal wastes which are being discharged into the Nation's watercourses, lakes, and coastal waters, the Federal Government offers grants-in-aid incentives to municipalities. The program was initiated under the Federal Water Pollution Control Act of 1956, and has continued with increased financial assistance authorized by the 1961 amendments to the Act.

Basically, this legislation was planned to encourage communities to invest their own funds to augment Federal contributions. The program has worked. For every dollar of Federal funds, municipalities have invested from $4 to $5 of their own money in the pollution control effort.

Over and above its value as a pollution control catalyst the Federal grants program has made it possible for the Public Health Service to document important details in sewage works design, construction, and financing. Information on types of treatment used, bases of design, contract bids, and other basic data has been processed by modern business techniques and evaluated for guideline purposes.

One of the most useful guidelines derived from the PHS data reflects the varying costs of sewage treatment plant construction as influenced by size of plant, type of treatment, regional differences in wage scales and building material prices, and other factors.

These data have produced valid answers to the important question: How much does a modern sewage treatment plant cost? The answers provide a dependable base for future financing practices and will enable municipalities to plan their treatment facilities and fiscal operations with proper preliminary accuracy.

The Public Health Service and others in the sanitary engineering profession, have made previous studies and published their findings as guides to sewage treatment plant cost-estimating. The information here reported is believed to be more truly authentic and defines more sharply the treatment process categories. If it sheds new light on the question of sewage treatment plant costs and the factors influencing construction costs, it will have achieved it purpose.

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Abbreviations

AS	Activated Sludge
ENR	Engineering News-Record Magazine
ENR–C	Engineering News-Record Construction Cost Index
IT	Imhoff Tank Treatment
ITT	Imhoff-Type Treatment
MGD	Million Gallons per Day
PCC	Cost per Capita
PE	Population Equivalent
PHS	Public Health Service
PHS–STP	Public Health Service Sewage Treatment Plant Construction Cost Index
P–SD	Primary Treatment With Separate Sludge Digestion
r	Correlation Coefficient
S_E	One Standard Error of Estimate
SP	Stabilization Pond
TF–P	Trickling Filter Plus Primary Treatment
TF–ITT	Trickling Filter Plus Imhoff-Type Treatment

Definition of Terms

Sewage: Liquid carried wastes of a community from domestic, commercial, and industrial sources.

Interceptor sewer: Pipe or conduit used to collect and transport sewage from points of final collection to point of treatment.

Outfall sewer: Pipe or conduit used to transport the effluent from the treatment facility to the point of final discharge.

Sewage treatment plant: Manmade structures which subject sewage to treatment by physical, chemical, or biological processes for the purpose of removing or altering its objectionable constituents and rendering it less offensive or dangerous.

Sewage treatment construction cost: Construction contract cost plus an allowance of 20 percent for administrative, engineering, legal, and fiscal costs (cost of land is excluded).

Design population: Number of people a facility is designed to serve.

Design flow: Hydraulic load for which facility is designed.

Population equivalent: Sewage, including industrial wastes, converted on a strength equivalent basis, to a domestic population value. (For BOD, the strength equivalent is taken as 0.20 pound of BOD per day=1 PE.)

Area of influence: One of the 20 commercial marketing areas into which the country has been divided for statistical purposes.

Least squares method: Statistical procedure of fitting a line or curve to a distribution of points.

Simple correlation: Statistical comparison between two variables to determine their interdependence.

Multiple correlation: Statistical comparison between more than two variables to determine their interdependence.

Correlation coefficient: A measure of the interrelationship of one variable with respect to another.

Standard error: The minimal sum of squares of the differences between the actual values and the estimated values for a distribution of points.

Expected cost curve: An estimating curve established on the basis of actual construction cost data by the method of least squares.

Upper limit cost curve: Curve calculated at a factor of one standard error of estimate above the expected cost curve.

Lower limit cost curve: Curve calculated at a factor of one standard error of estimate below the expected cost curve.

Cost interval: Range of costs falling between the upper and lower limit cost curves.

Ratio of the upper limit: Ratio of the upper limit cost to the expected cost at the mean of the distribution.

Ratio of the lower limit: Ratio of the lower limit cost to the expected cost at the mean of the distribution.

Valid size range: Interval of reliable data for the dependent variable which marks the limits of the expected cost curve.

Primary treatment: The removal of settleable organic and inorganic solids by the process of sedimentation.

Secondary treatment: Treatment of sewage by biological methods, following primary treatment.

Imhoff tank treatment: A form of primary treatment employing the classic Imhoff two-story tank, consisting of an upper sedimentation chamber and a lower digestion chamber, with no mechanical equipment.

Imhoff-type treatment: A form of primary treatment employing a two-story tank consisting of an upper sedimentation chamber and a lower digestion chamber, with some type of mechanical equipment.

Primary treatment—separate sludge digestion: A form of primary treatment which employs a separate structure for digestion of sludge.

Stabilization pond: A pond designed for the treatment of sewage by natural aerobic processes, with or without the addition of supplemental aeration or chemicals.

Activated sludge treatment: A secondary treatment process which brings settled sewage into contact with biologically active sludge in the presence of excess oxygen.

Trickling filter—separate sludge digestion: A secondary treatment process, following primary treatment, using a bed of coarse material over which the settled sewage is distributed, followed by final clarification.

Trickling filter—Imhoff-type treatment: Identical to—trickling filter—separate sludge digestion, but employing Imhoff-type treatment for the primary phase.

Introduction

The desire to *own* something must be supported by *the ability to own* something. Whether it be the purchase of a home or an automobile; or the construction of a house, garage, or a sewage treatment plant, the cost of the commodity is of great importance. It is more than that; it is basic to the ability to own and to care for anything. It is so basic that knowledge of how much it will cost should precede any actions to purchase or construct the desired facility.

It is the responsibility of municipal officials faced with the need for sewage treatment facilities; of designers charged with the task of planning sewage works; of regulatory agencies vested with the authority to approve methods and physical processes to achieve desired degrees of treatment; of developers and planners required to provide sewage handling systems; and of investors faced with bond purchase decisions, to have authentic information on how much the required installation should cost.

Actual project costs do not become available until plans and specifications have been completed and approved, bids for construction work, materials and equipment have been received, and contracts have been let. Yet, there is need for preliminary concepts of what the eventual cost will be long before these finalization steps have been taken. In short, there is need for valid "measuring sticks" or guidelines which will supply preliminary cost estimates for projects.

There is no substitute for *actual* cost information, but cost estimates play an important role in the preliminary stages of sewage treatment works planning, despite the fact that decisions often must be based on water pollution control needs rather than availability of funds. While the size of a project may be firmly established by the population to be served, the population equivalent as measured by organic loading on the proposed treatment plant, or the volume of flow to be handled, and while the degree of treatment may be dictated by the specific pollution control needs and the dilution conditions in the effluent-receiving water resource, knowledge of what the project may cost will be of great value:

- It may determine, to some extent, the degree of treatment to be provided.
- It may dictate whether a project should be phased out in stages rather than a full-scale works on a one-time basis.
- It may ascertain the future period for which capacity will be provided, or for which actual construction will be scheduled on a long-range plan.
- It may help determine the use or nonuse of certain equipment and instrumentation facilities in the design, or their installation at some later date.
- It can help municipal officials develop master plans, not only for sewage works facilities but for other civic projects, and for their rational financing on long-range bases.
- It can serve as a guide in judging the validity of competitive bids when contracts are to be let.
- It can help guide bond issue referenda and assure investors in such bonds of the stability of the offerings.

These examples of the serviceability of construction cost estimates point up the great responsibility which devolves on developers of such estimating tools. They demonstrate the need for using cost statistics of known validity in offering cost-estimating guidelines, and for lucid interpretation of such data in terms of their limitations as well as their proven values. They serve as warnings that estimates are no more than *estimates;* that the estimate must be used by persons versed in their applications, or lack of applications, to specific projects; that estimates are no substitute for actual cost experiences by designers and officials; and that estimates, at best, cannot, and do not, reflect total project costs.

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In providing rule-of-thumb data on construction costs, there is always the hazard that the uninitiated may judge the merits of comparative treatment processes on the basis of comparative costs, alone. This report would be remiss if it did not point out that relative costs, alone, cannot dictate the choice of treatment process in a great majority of sewage works projects. Such decisions must be based on the degree of treatment needed and the method which can best supply it, on the availability of sites suitable for the type of treatment chosen, and on the applicability of the general environment and area development, both present and long-range, to certain treatment processes.

Throughout this report one factor is stressed repeatedly: That the cost estimate data do not cover certain important items in the overall cost of the project as built in, and on, the ground. These noncovered items include administrative, engineering, financing and other services, and, of great importance, the land costs. Certain types of treatment require more land area than others and this must be given serious consideration before design decisions are made.

The annual investment in municipal waste treatment construction has more than tripled in the past 7 years. This, plus the many changes which have evolved in treatment methods, such as modifications in the activated sludge treatment process, increased use of stabilization ponds and package-type treatment plants, has increased the need for shortcut preliminary cost estimating aids. Though they be no more than cost "indicators," such tools can be of value to consulting engineers, water pollution control agencies, municipal officials, and others.

Recognizing this need, the Public Health Service in 1958, initiated a study in the construction costs of sewage treatment facilities. From this basic beginning the investigations have been updated and made to reflect more specifically the costs of construction in the municipal sewage treatment field. The comprehensive estimating tables and curves presented in this report are the results of these studies.

Earlier Construction Cost Studies

Since the studies here documented are an extension and a sharpening of findings from previous cost studies, it is appropriate to record briefly the data presented in reports of these earlier investigations.

Cost Study of 20 Plants: 1958

The first of these investigations was published in 1958 (*1*), 2 years after the Federal incentive grants program was authorized by PL–660. This study concerned itself with engineering design practices, costs of construction, and estimated operation and maintenance costs for projects assisted under the program. The analysis was based on 20 small secondary sewage treatment plants in the upper Midwest. Four projects were selected at random from each of five States: Illinois, Indiana, Michigan, Ohio, and Wisconsin. Included were six activated sludge plants, eight standard-rate trickling filter plants, and six high-rate trickling filter plants.

That portion of the investigation dealing with construction costs drew its data from actual contract prices. It did not include the cost of land, nor engineering, administrative and legal services. The cost data from these 20 projects were evaluated against the parameters of design population, population equivalent, and design flow to establish unit cost curves of the second degree for each parameter.

Cost Study of 380 Plants: 1958

Availability of data on the increasing number of treatment plants receiving Federal construction grants continued to offer further opportunity for development of cost estimating techniques. Another investigation was reported in 1958, based on 380 projects in various parts of the United States. This report presented construction cost estimating curves for the general categories of primary treatment, secondary treatment, and stabilization ponds (*2*).

These data reflected probable construction costs and did not include land, engineering, administrative, and legal costs. Interceptor and outfall sewers, pumping stations and similar ancillary works were excluded; projects involving plant additions and enlargements were not considered. The Engineering News-Record Construction Cost Index (ENR–C) was employed in the study to convert all cost data, nationally, to a "common denominator" of cost. The estimating data were statistically developed by the application of least square methods.

Cost Study of Stabilization Ponds: 1959

The Public Health Service then continued its probe of sewage treatment plant costs on an even more specialized basis. The third analysis of engineering and financial criteria was based on data from 31 new sewage stabilization ponds located in seven Midwestern States (*3*). The projects involved treatment of domestic sewage with little or no industrial wastes.

Data for this analysis included the contract cost of excavation and earth placement, cost of piping within the confines of the pond, inlet and outlet structures, and the cost of fencing and seeding. These costs were analyzed and related to surface area on a cost per acre basis to equalize surface loading variations. It was reported that the construction costs, as defined, accounted for about 80 percent of the total cost of a stabilization pond. The remaining 20 percent included engineering, legal, administrative, and contingency costs. It is pointed out that the cost of land, often involving much larger areas than the so-called standard treatment plants, was not included in the cost evaluation. Cost of pumping stations, interceptors, and outfall sewers were also excluded.

Study of Specific Processes: 1960

The following year, the Public Health Service reported a similar study which expanded and refined the preceding investigations (*4*). This investigation added specifically to previous cost studies. Instead of covering the generalized categories of primary, secondary and stabilization pond treatment, it evaluated costs for six specific types of treatment: Imhoff tank; conventional primary treatment with separate sludge digestion; activated sludge; trickling filters with separate sludge digestion; trickling filters with Imhoff-type treatment; and stabilization ponds. The analyses produced data based on cost per capita and design population, presented in the form of estimating curves. The data from a wide geographical area were analyzed by the statistical method of least squares. Costs were evolved by the same criteria used in previous studies, including the ENR–C Index.

Operation and Maintenance Cost Studies: 1961

In February 1961, the investigations into cost estimating aids were extended to cover the operation and maintenance (O & M) of sewage treatment plants (*5*). The report presented data on actual annual costs directly associated with plant operation and maintenance, excluding costs for central administration, billing and collection of sewer charges, and expenditures for capital maintenance.

The data, collected from 320 sewage treatment plants that had been in operation for a minimum of 5 years, were analyzed by the statistical methods of least squares. These costs were evaluated on the basis of design flow, population served, and population equivalent, and resulted in the development of unit cost estimating curves of an inverse function form. Only unit cost data for design flow and population served were presented in the studies because insufficient data were available for cost estimations on the basis of population equivalent. The resulting cost data were presented for four types of treatment: Primary; standard-rate trickling filter; high-rate trickling filter; and activated sludge.

These studies emphasized the need for a more specific evaluation of sewage treatment plant construction costs over a period of time than could be obtained through the use of the ENR–C Index—an index covering the broad complex of all construction work. To meet this need, the Public Health Service undertook the development of, and reported on, a fixed base, weighted cost index, which reflects the changing purchasing power of the funds invested in sewage treatment plant construction.

Cost Study of $1 Million High-Rate Filter Plant: 1963

The index was established on the basis of a $1 million hypothetical high-rate trickling filter plant using prices prevailing in the Kansas City, Mo., area. The quantities of labor, material and construction equipment, and overhead and profit were established on the basis of the model plant and remained constant. Unit prices varied from month to month in accordance with published prices in the Engineering News-Record and U.S. Bureau of Labor Statistics Wholesale Prices. To make this cost index more representative of the whole country, indexes were developed for 20 trade areas covering the United States. These trade area indexes were averaged on a monthly basis to obtain the national index.

Current Cost Study

The authenticity of cost estimation data is dependent on the number of projects involved in establishing criteria, the inclusiveness of the types of projects, and the local conditions under which the projects have been constructed. The growing number of sewage treatment projects of various types receiving Federal construction grants has made it possible for the Public Health Service to improve its cost analysis procedures and to evolve construction cost estimating data of greater value to municipal officials, consulting engineers and others.

Availability of these expanded data has made it possible for the Service to go beyond a mere updating of past cost estimating information. This report, therefore, is based on data refinements of an important nature. They represent:

1. The use of a more responsive index to eliminate variations in treatment plant costs due to geographic location and time differences
2. Presentation of unit costs on the basis of design population, design flow, and design population equivalent
3. Evaluation of construction costs for a greater number of specific types of treatment.

These refinements have vastly extended the value of data resulting from earlier investigations. The report, therefore, tends to be more responsive to current developments in the sewage treatment field than previous studies.

Procedures of Analysis

Source of Data

The study is based on a tabulation of design and cost information for 1,504 sewage treatment projects constructed under the PL–660 program. This source provided the most comprehensive data yet available for the sewage treatment field, in terms of numbers of projects and geophysically widespread construction conditions. All sections of the Nation, except Alaska, the District of Columbia, Guam, and the Virgin Islands are represented. A detailed listing by States for each type of treatment involved in the study appears in table I.

Criteria for Analysis

The cost data employed in the study represent actual cost information of projects constructed under the incentive grants program. These costs, therefore, can be compared with earlier studies, (*1*), (*2*), (*3*), (*4*), and (*5*), since they also represent only contract costs and not total cost of the various types of treatment facilities. Only those projects for which costs could be identified were included in the study. Costs were not included for such facilities as interceptor and outfall sewers; pumping stations not contiguous to the plant; and administrative, engineering, and legal services.

A detailed review of the costs making up the study, and of the costs excluded from the analysis, showed that construction costs of a project represent approximately 80 percent of the total. The additional costs which were excluded for this investigation can be incorporated in probable total project costs by increasing the construction estimates by a factor of 20 percent. The study does

TABLE I

Distribution of Projects by State and Type of Treatment

State	Type of treatment																				
	Imhoff tank			Imhoff-type			Primary treatment – separate sludge digestion			Stabilization ponds			Trickling filter—separate sludge digestion			Trickling filter—Imhoff-type			Activated sludge		
	PCC	MGD	PE	PCC	MGD	PE	PCC	MGD	PE	PCC	MGD	PE	PCC	MGD	PE	PCC	MGD	PE	PCC	MGD	PE
Alabama				2	1		5	3		5	5		18	9	9				8	5	5
Alaska																					
Arizona										2	2		1			2	1	1			
Arkansas	1						1			21	19		5						1	1	1
California							16	7		3	3		10	2	2	1			8	3	5
Colorado										11	7		9	4	4						
Connecticut							5	3					5	3	4				2	2	2
Delaware	1				1		1	1													
District of Columbia																					
Florida							7	5					15	7	7				5	2	3
Georgia	1						4	1		1	1		13	3	3				2	2	2
Guam																					
Hawaii							1	1													
Idaho							10	4		11	9		1	1	1				1	1	1
Illinois	1			2			9	6		18	16		11	6	6	9	4	5	5	4	4
Indiana				3	2		5	2		6	5		6	2	2	5	2	2	6	4	5
Iowa							5	1		7	5		12	5	5	19	6	6			
Kansas	1						6	4		33	24		20	4	4	8	2	2			
Kentucky				1	1		5	3					12	7	7	2	1	1	5	2	2
Louisiana	1			1	1		4	2		7	7		9	5	5	8	2	2	5	1	1
Maine	1						3	3		1	1								2	2	2
Maryland				1	1		1						1	1	1	1			2	1	1
Massachusetts	1						2						2	1	1	2	2	2	5	3	3
Michigan							13	6		1	1		6	1	2	2	2	2	4	1	1
Minnesota							4	1		11	10		22	8	9	3	2	3	1		
Mississippi	1									37	23		2								
Missouri							1	1		71	50		6	2	2	3	2	2	1		
Montana				1	1		2	2		32	19										
Nebraska	2			1			7	5		42	25		7	1					9	6	7
Nevada										1											
New Hampshire	2									3	1										
New Jersey				1			3						2	1	1				1		
New Mexico										2	1		8	3	3	2					
New York	6			2	1		11	5					5	2	2	1			3	2	2
North Carolina	1			3	3		3	1		7	6		24	10	8	9	6	6	5	3	3
North Dakota										74	18										
Ohio	3			4	1		10	2		1			8	4	4	8	1	1	18	11	11
Oklahoma							1			29	20		8	3	3	3	1				
Oregon							6	1		12	7		9	1	1	2			2	1	1
Pennsylvania	1			1			12	6					14	4	4	2			5	3	3
Puerto Rico	1												1	1	1	1	1	1			
Rhode Island							1						1								
South Carolina							3	1		6	6		10	3	3	1			2		1
South Dakota										48	24					1					
Tennessee				2			9	3		2	2		17	10	10	5	4	4	2	1	1
Texas							1						21	8	7	14	8	7	6	4	4
Utah										1			11	7	7				1	1	1
Vermont	2			1	1		6	6													
Virginia	8			7	1		12	4					6	1	1	4	1	1	3	1	1
Virgin Islands																					
Washington	2			2	2		9	2		17	8		3	2	2				1		
West Virginia	1			8	6		11	4		1	1		2	1	1	1	1	1			
Wisconsin	5			2	1		10	3		13	12		26	7	10	2	2	2	16	9	12
Wyoming							2			23	12		1	1	1				1	1	1
Total	43			45	24		227	99		560	350		370	141	143	121	51	51	138	77	86

not include land costs because of their wide and unpredictable variations.

If actual construction costs of completed sewage treatment plants are to be of value in estimating the probable cost of proposed projects of similar types, the "known" data must be translated into costs per some established unit or units which will apply as well to the "unknown" installation. Three such units, or parameters, of cost are available as "common denominators":

1. The flow for which the plant is designed.
2. The population which the plant is designed to serve.
3. The population equivalent to which the plant is designed to serve, including the organic loadings from industrial-commercial operations tributary to the community sewer system.

Review of the data for the 1,504 plants selected for the study indicated that any of these 3 parameters could be used since sufficient information was available in all categories. Upon the basis of this finding, the decision was made to employ all three parameters in developing unit construction costs. This was done to make available to governmental and private organizations using estimating aids, a choice as to the most reliable cost relationships for any particular project.

Treatment Processes Covered in This Cost Study

To facilitate the cost studies it was necessary to select the treatment categories into which the available cost data could be grouped. The following seven subdivisions were chosen for analysis on the basis of available data:

1. Imhoff tank plants
2. Imhoff-type plants
3. Primary treatment—separate sludge digestion plants
4. Stabilization ponds
5. Activated sludge plants
6. Trickling filters—separate sludge digestion plants
7. Trickling filters—Imhoff-type plants.

To obtain a more specific definition of the factors influencing costs of construction, it would have been desirable to subdivide each treatment category further as to type—such as modifications of the activated sludge process; trickling filter design; chlorination facilities; and other features. However, the available data did not include a sufficient number of projects to make this type of differentiation valid. Therefore, all plants were classified on the basis of the principal treatment unit or process employed. For clarification purposes, a brief description of the projects in each of these subdivisions follows. (For additional descriptive information, consult the "Definition of terms," p. vi.)

Imhoff tank plants (IT).—Projects included in this treatment category are those primary plants having self-contained digestion units, but which do not have mechanically equipped settling compartments. Plants in this group are not followed by any additional form of treatment; they provide primary treatment only.

Imhoff-type plants (ITT).—All primary plants which are of the self-contained digestion classification and do not meet the description of the preceding category are grouped under this heading. These plants are equipped with mechanical skimmers and/or sludge removal equipment. As in the preceding category these systems are the only means of treatment provided.

Primary treatment—separate sludge digestion plants (P–SD).—This group represents the remainder of the primary-type plants. All systems in this category employ gravity settling as did the preceding two groups. However, these plants employ separate structures for sludge digestion and/or storage. This classification, therefore, excludes Imhoff tank plants or Imhoff-type plants.

Stabilization ponds (SP).—The projects included in this category are all stabilization ponds (lagoons) which are designed as the principal form of aerobic treatment for raw sewage. No distinction is made as to number of cells provided, or flow patterns involved. Both single and multicell ponds, as well as series and/or parallel-operated systems, are included.

Activated sludge plants (AS).—This category is composed of projects which employ primary settling, aeration by either diffused air or mechanical means, and final settling.

This group includes both prefabricated package-type plants and site-constructed facilities. Had sufficient information been available to make a distinction between package-type and site-constructed plants, a more realistic picture of the activated sludge category would have been possible.

Trickling filter—separate sludge digestion plants (TF–P).—In this category are those projects which employ the trickling filter method of treatment, preceded by primary treatment utilizing separate sludge digestion, and followed by final clarification. Systems which employ multiple-stage units were not separated from the single-stage type. In addition, no distinction was made in this study between standard-rate and high-rate filter plants. Trickling filter plants which include other secondary treatment processes, such as activated sludge or stabilization ponds, are not included in this category.

Trickling filters—Imhoff-type plants (TF–ITT).—The projects in this category include trickling filters which are placed between a primary treatment unit and some form of final clarifier. The difference between this and the preceding category (TF–P) is that the primary treatment stage in this category is of the Imhoff type. Again, no distinction has been made between standard-rate and high-rate systems and no differentiation was made between the flow patterns of single and multiple-stage plants.

Selection of an Index

Sewage treatment plant construction costs vary from month to month, as well as from area to area. To adjust for this variable condition and to establish cost limits which can be applied with reasonable accuracy, it was necessary to use a cost index to reflect the relationship of the price of a commodity to the price of a similar commodity for a specific base period, and/or specific location (*6*).

In previous unit cost analyses (*2*) and (*4*), the Engineering News-Record Construction Cost Index (ENR–C) was employed for converting cost variations to a standard base. This index, however, as its title indicates, was designed for use in general construction and quite naturally, did not provide for the specific needs of the sewage plant construction field. Obviously the use of a cost index specifically developed for sewage treatment construction would yield more representative and workable estimating data. Therefore, the Public Health Service Sewage Treatment Plant Construction Cost Index (PHS–STP) was developed and has been used in this report.

The inclusion of a cost index has served to "stabilize" the cost variations which are inherent in any cost comparison. The use of an index which is related to a fixed base, as is the PHS–STP index, adjusts the costs from any particular time period to the base period of the index (1957–59=100). Thus, all costs used in the study are in terms of 1957–59 dollars.

To account for area cost variations, the 20 trade areas of the PHS–STP index were used. These areas are shown in figure 1, with each area's influence city designated. It was assumed that the costs of all projects located in each area would vary directly as the index for the influence city, and they were so adjusted. The projects from Hawaii and Puerto Rico were adjusted on the basis of the National Index value.

Mechanics of Analysis

With the parameters of cost comparison defined, it was necessary to select the appropriate statistical methods by which to analyze the data and from which resulting conclusions could be made. The use of more than two parameters opened up new possibilities of analysis. Not only was it possible to analyze the data in three independent correlations, but it appeared reasonable to investigate the development of a multiple comparison of cost with more than one cost parameter.

The first step in the procedure of comparing unit costs to each of the other parameters, was the visual representation of the sample. A Cartesian presentation showed a skewed distribution of the sample to the right. In an attempt to reduce the sample spread, a log-log plot was made. With the distribution spread considerably reduced through the use of logarithms of both variables, the method of least squares was employed to fit an appropriate curve to the data. By testing the standard forms of curves by this statistical tool, it was found that a straight line within a log-log environment best fitted the distribution (*7*) (*8*).

The specific description of the curve which best fits a particular sample distribution in this study can be determined by a simultaneous solution of the two normal equations:

$$Na+b\Sigma X=\Sigma Y \qquad (1)$$

$$a\Sigma X+b\Sigma X^2=\Sigma XY \qquad (2)$$

where,

N=Number of observations.

ΣX=Sum of logs of the design population (population equivalent, flow);

ΣX^2=Sum of squares of the log of the design population (population equivalent, flow);

ΣY=Sum of logs of 10 times the unit cost (except in cost per unit flow correlation when it is the sum of log of the unit cost);

ΣY^2=Sum of squares of the logs of 10 times the unit cost (except in case of flow correlation in which factor of 10 is not included);

ΣXY=Sum of cross products of logs of X and Y;

a=Y intercept (constant), and

b=Slope of the line.

By the simultaneous solution of equations (1) and (2), the constants a and b can be found, determining the equation which best describes a sample distribution. The equation is—

for the cost per capita or population equivalant studies:

$$\log 10Y=a+b\log X \qquad (3);$$

and for the cost per unit flow study:

$$\log Y=a+b\log X \qquad (3_c)$$

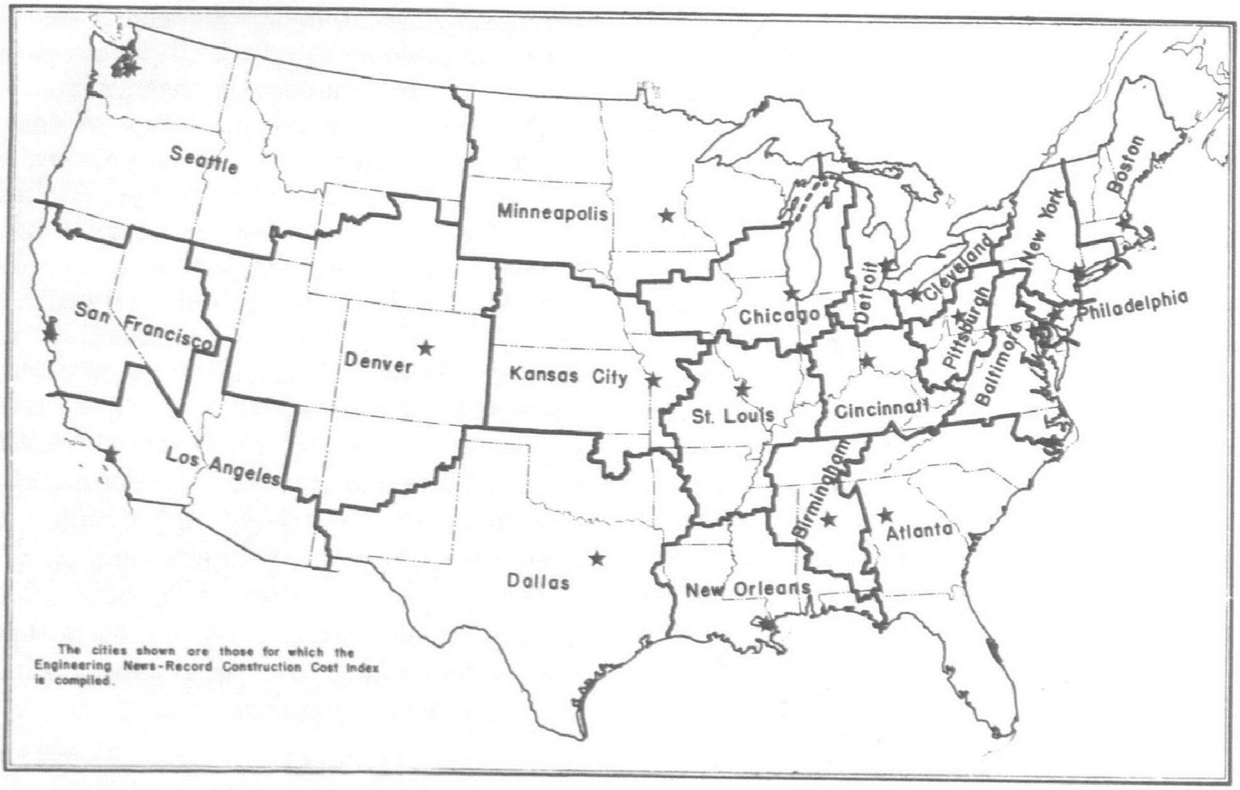

FIGURE 1.—Map of 20 Index Cities and Their Assigned Areas of Cost Influence

Equations (3) and (3_c) represent the curves of best estimate for the sample distribution, so as to minimize the variance between the known values and the estimated values. Since the actual cost estimating curve could not be expected to intersect all of the unit project costs, an indication of their location with respect to the computed curve is needed. This distribution is described by the standard error of estimate which relates the sum of the squares of the difference between the actual values and the estimated values.

Combining the calculated estimating curve (3) or curve (3_c) with the standard error of estimate, the sample's mean value as well as its scatter are fully described. This completely characterizes the distribution. Figure 2 graphically illustrates this relationship.

Figure 2 illustrates the typical estimating curve used in this report. In every case the sample for each category of treatment is shown in a logarithmic coordinate system. Upon each distribution is superimposed the appropriate statistically developed estimating curve. The solid line is the expected cost curve as determined from the calculated equation. The dashed lines above and below the solid line define the cost interval. The interval is calculated to contain one standard error of estimate (S_E) on either side of the calculated curve.

The correlation coefficient (r) serves as a measure of the relationship of one variable to the other. Therefore, to measure how well the cost is described by the unit factor or parameter used, this coefficient "r" is calculated. The value of the correlation coefficient varies between 0 and ± 1.

All data used in this analysis were handled with electronic data processing equipment using the punchcard technique. This procedure will allow new data to be introduced at any future time with little difficulty, and it eliminates errors common to manual calculating methods.

Example of Cost Analysis

To illustrate the procedure of analysis used in this investigation, the activated sludge treatment category is presented as an example. This example concerns itself only with the calculations involved in the study. Later sections of this report discuss geographical representativeness of the particular sample.

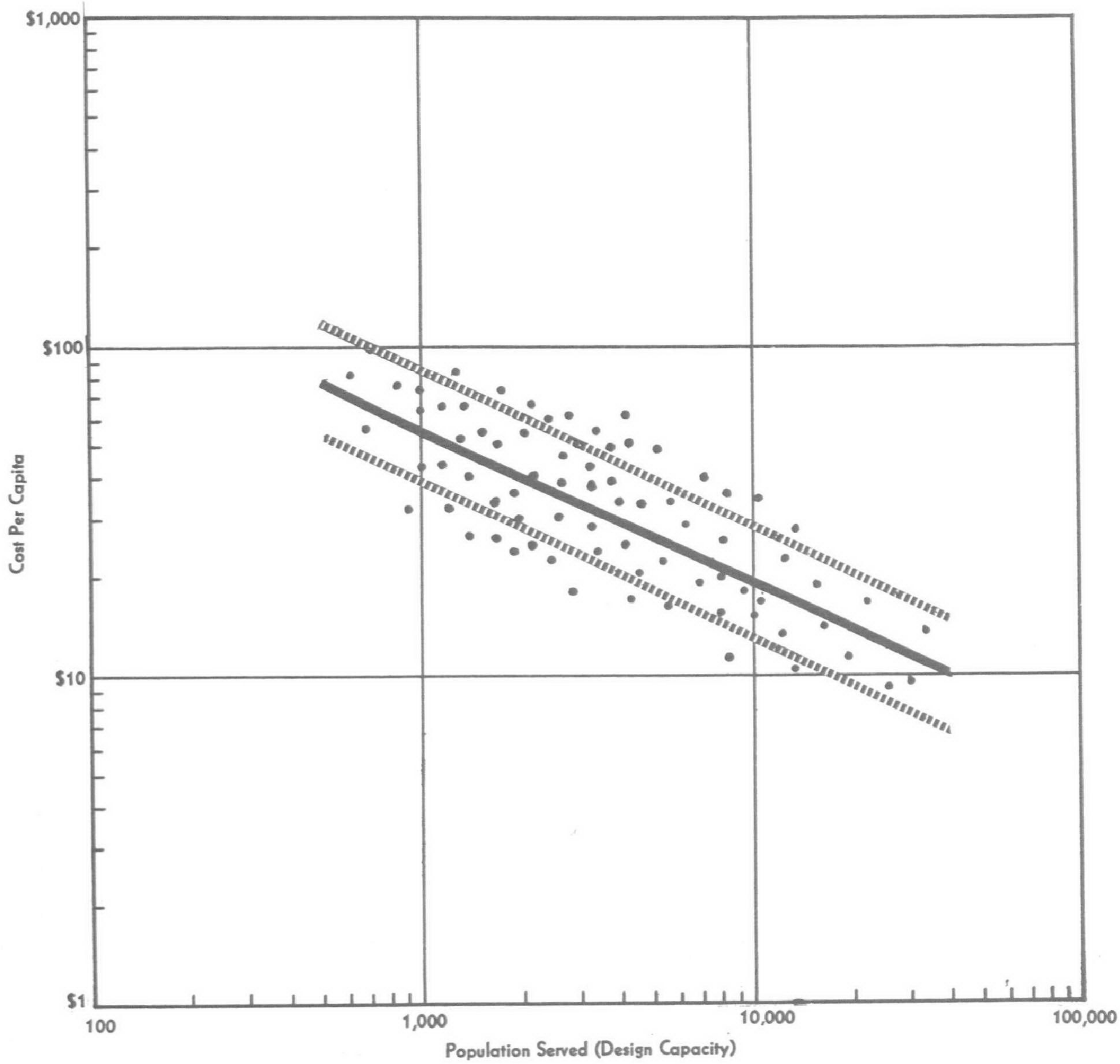

FIGURE 2.—Typical Unit Cost Estimating Curve

This analysis relates design population to the cost per capita. For this purpose, data from 138 projects were available. The required values for the solution of the normal least squares equations (1) and (2) are:

$N=138$

$\Sigma X=491.69060$

$\Sigma X^2=1,810.184795$

$\Sigma Y=359.226848$

$\Sigma Y^2=961.938606$

$\Sigma XY=1,292.629537$

Substituting these values, then, in equations (1) and (2) and solving them simultaneously results in the determination of the constants a and b:

$a=3.6533024$

$b=-0.2782395$

These constants, when substituted in the general equation (3) with appropriate sign, result in the equation which best describes the 138 projects on a cost per capita basis:

$$\log 10\ Y=3.6533024-0.2782395 \log X$$

Since this equation, by definition, represents the best description of the sample and is only the in-

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TABLE II

Construction cost per capita (design capacity)

Activated Sludge Treatment

(1957–59 dollars)

Design population	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$84. 39	$124. 98	$185. 07	250 to 100, 000
1, 000	44. 47	65. 85	97. 52	
10, 000	23. 43	34. 70	51. 39	
100, 000	12. 35	18. 29	27. 08	

Ratio of the upper limit = 1.4809
Ratio of the lower limit = 0.6753
Correlation coefficient (r) = −0.73

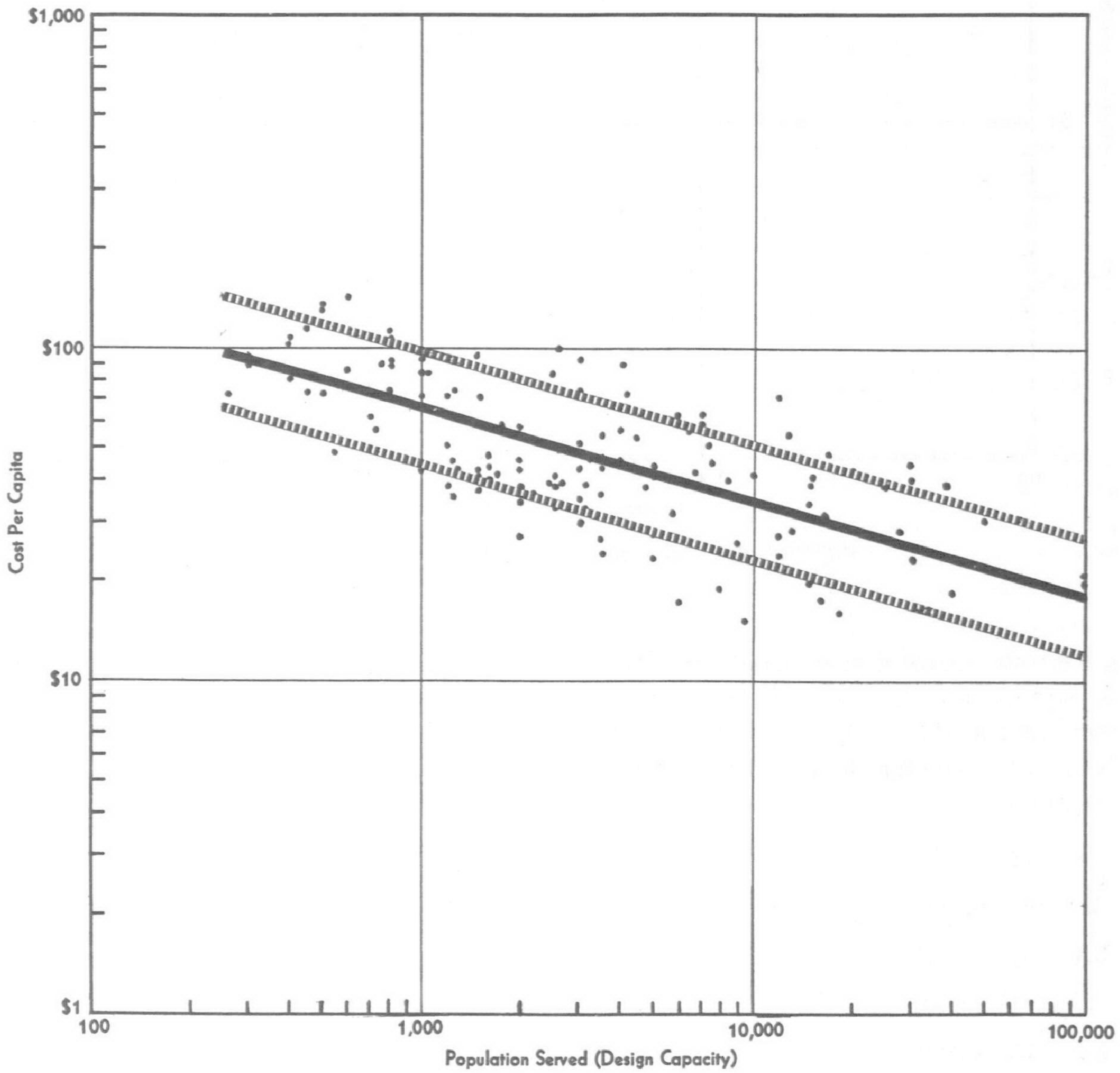

FIGURE 3.—Construction Cost per Capita—Activated Sludge Plants

dicated estimating line, it is necessary to define a reasonable cost range on either side of this curve to allow for a spread of costs. To establish this cost range, one standard error is calculated for the sample at its mean, and applied above and below the estimated cost level to produce an upper limit cost and a lower limit cost. These upper and lower limit costs, when related to the expected cost, yield a ratio of the upper limit and a ratio of the lower limit, respectively. These two extremes define the interval in which the construction cost of activated sludge systems can be expected to fall approximately two-thirds of the time.

Since the data used for the independent variable were limited to only certain portions of the logarithmic scale and did not extend to its extremes, use of the developed cost curves beyond the limits of the data would be of doubtful validity. In an attempt to provide the estimators with some guide to these limitations, a valid size range has been determined for each estimating equation.

Before this information can be totally functional in making cost estimates it should be represented in a graphical form for rapid use. To facilitate the development of a graphic presentation of this curve, the per capita costs for four even populations were chosen for ease of calculation. They were solved from the activated sludge equation on page 9. A tabulation of these results is given in table II.

From the data in table II, a logarithmic presentation of design population versus cost can be prepared (fig. 3).

Illustration of Use of Curves

To illustrate the use of the curves as an estimating tool, a hypothetical problem is presented: Estimating the cost of an activated sludge plant to be constructed in the Denver, Colo., area of influence for a community of 10,000 population in March 1964.

Solving the calculated equation (p. 9) for the expected cost per capita for a community of 10,000 people, a value of $34.70 per person is obtained. Since this curve was developed on the basis of 1957–59 dollars, it is necessary to update the estimate using the PHS–STP index. The March 1964 index value for the Denver area of influence was 1.0343.

Combining the cost figure, and the PHS–STP index value, the expected construction cost is: 1.0343 ($34.70) = $35.89/capita. To convert this cost to the estimated contract cost, it is necessary to multiply the cost per capita by the design popultaion: $35.89 (10,000) = $358,900. The cost of $358,900 is the most probable construction cost. To obtain the total estimated cost of the project, the construction cost would be increased by approximately 20 percent.

To establish the possible cost range for this project, in addition to the expected cost estimate, it is necessary to multiply the expected construction cost, as tabulated above, by the ratios of the upper and the lower limits. The result would be the most probable cost range for the project.

Treatment Plant Costs per Capita

The following statistical evaluations of sewage treatment plant construction costs are based on: (1) cost per capita; (2) cost per population equivalent; and (3) cost per unit flow. All data are based on design capacity.

This study covered the relationship between sewage treatment plant construction cost per capita and design population. Data from 1,504 projects have been used. Table I (p. 5) shows the types of treatment and specific geographic locations of the plants included in the study.

It should be noted that the statistical reliability of the per capita cost data is greatly enhanced by the large number of projects included in each sample. The following discussion covers the individual treatment types on a cost per capita basis:

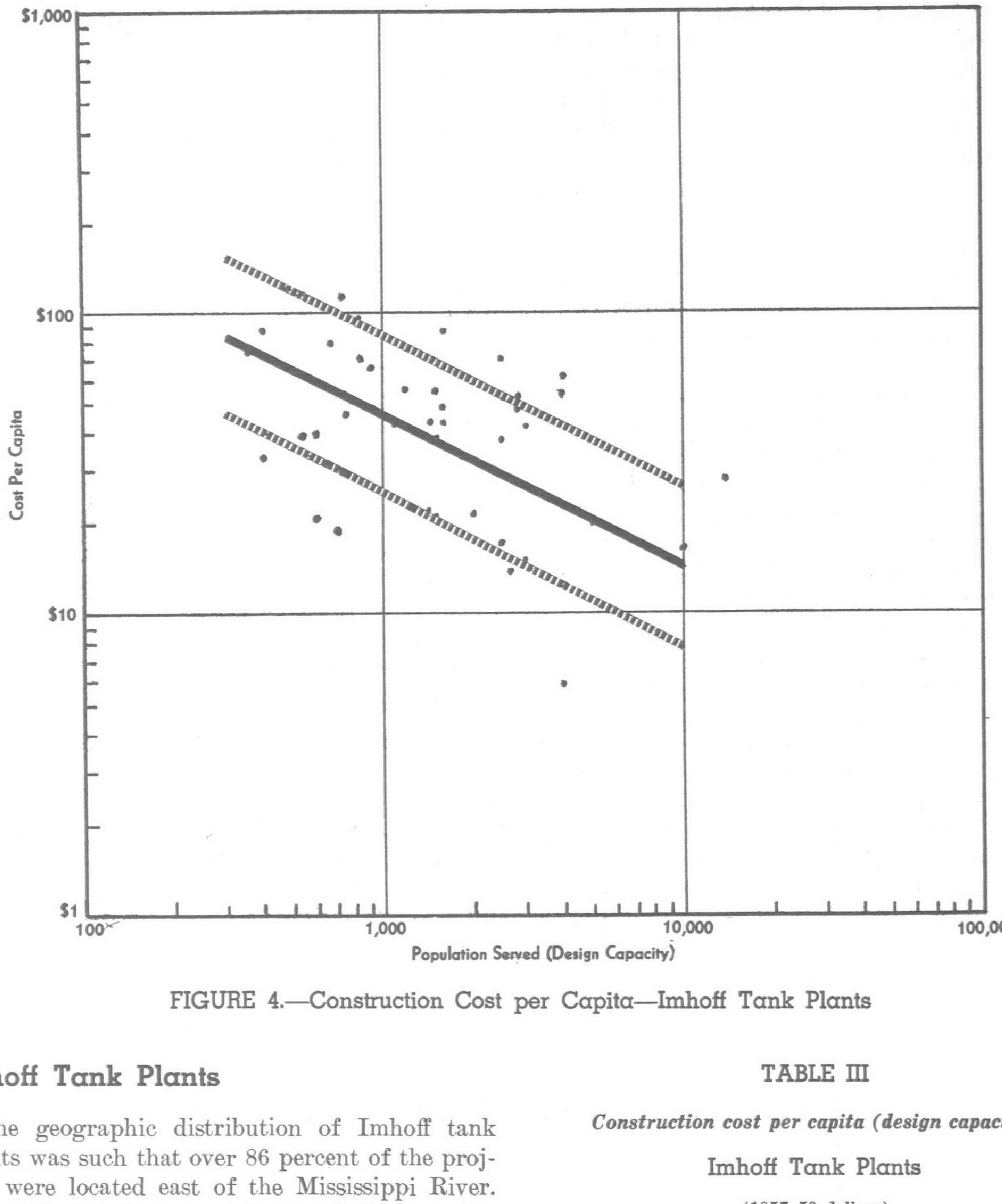

FIGURE 4.—Construction Cost per Capita—Imhoff Tank Plants

Imhoff Tank Plants

The geographic distribution of Imhoff tank plants was such that over 86 percent of the projects were located east of the Mississippi River. Six of the 43 plants were located in Kansas, Arkansas, Nebraska, and Washington—the only Western States for which data were available for this phase of the cost study.

The cost curve best fitting this group of projects appears in figure 4 and is represented in equation form by:

$$\log 10\ Y = 4.1833312 - 0.50830469 \log X$$

Solution of this equation for specific population values appears in table III.

TABLE III

Construction cost per capita (design capacity)

Imhoff Tank Plants

(1957–59 dollars)

Design population	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$80. 23	$146. 80	$268. 59	300 to 10, 000
1, 000	24. 89	45. 54	83. 33	
10, 000	7. 72	14. 13	25. 85	
100, 000	2. 40	4. 38	8. 02	

Ratio of upper limit = 1.8297
Ratio of lower limit = 0.5465
$r = -0.60$

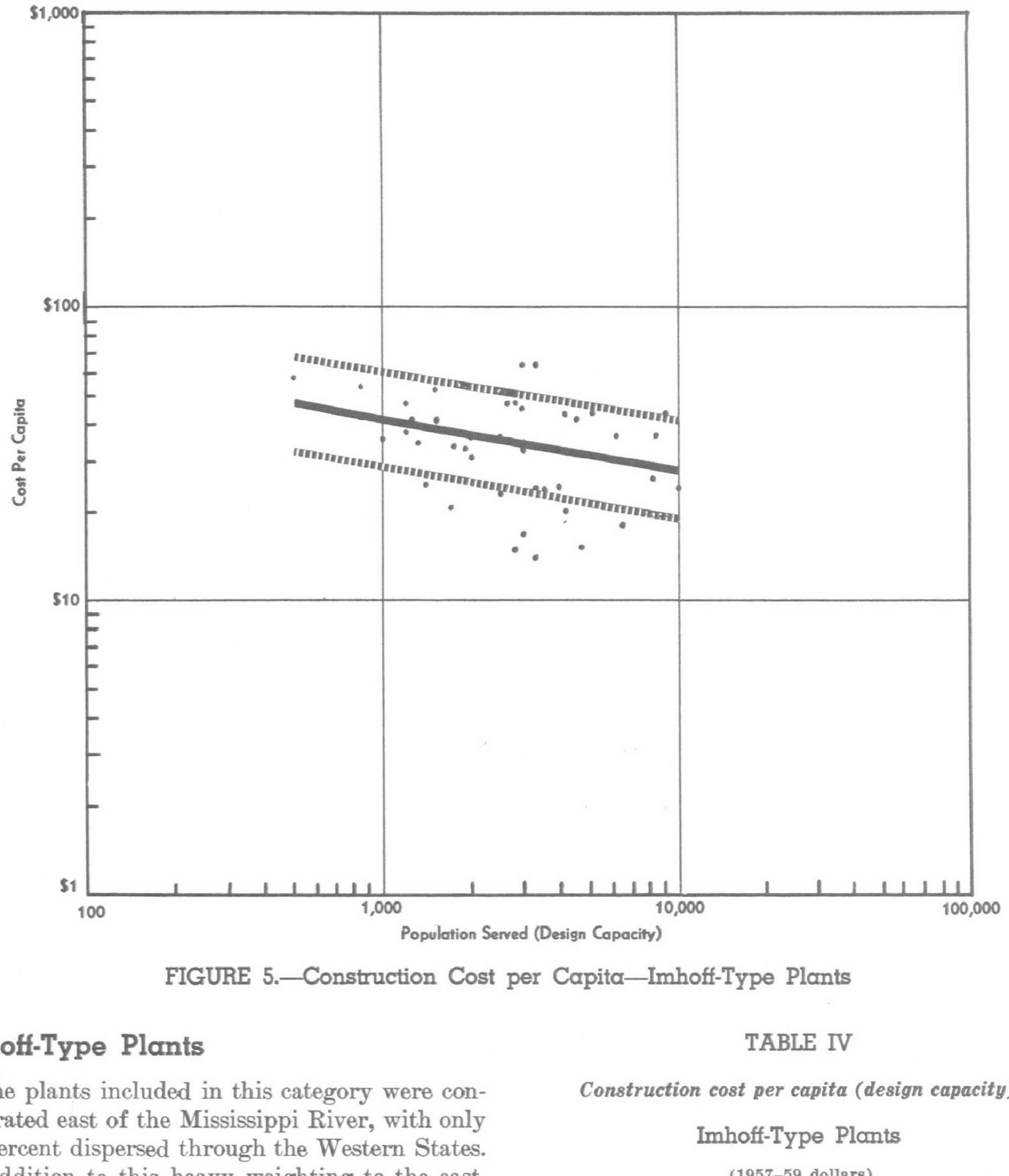

FIGURE 5.—Construction Cost per Capita—Imhoff-Type Plants

Imhoff-Type Plants

The plants included in this category were concentrated east of the Mississippi River, with only 10 percent dispersed through the Western States. In addition to this heavy weighting to the east, the sample is strongest in the States of Virginia and West Virginia where 30 percent of the projects were centered.

For the 47 projects providing cost data for this type of treatment, the curve best satisfying the distribution is represented in equation form by:

$$\log 10\ Y = 3.2640685 - 0.20820798 \log X$$

Graphically, this curve is represented in figure 5 and can be reproduced by a log-log plot of the data appearing in table IV.

TABLE IV

Construction cost per capita (design capacity)

Imhoff-Type Plants

(1957–59 dollars)

Design population	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$50. 93	$70. 41	$97. 33	500 to 10, 000
1, 000	31. 53	43. 59	60. 26	
10, 000	19. 53	26. 99	37. 31	
100, 000	12. 09	16. 71	23. 10	

Ratio of upper limits = 1.3823
Ratio of lower limits = 0.7234
$r = -0.40$

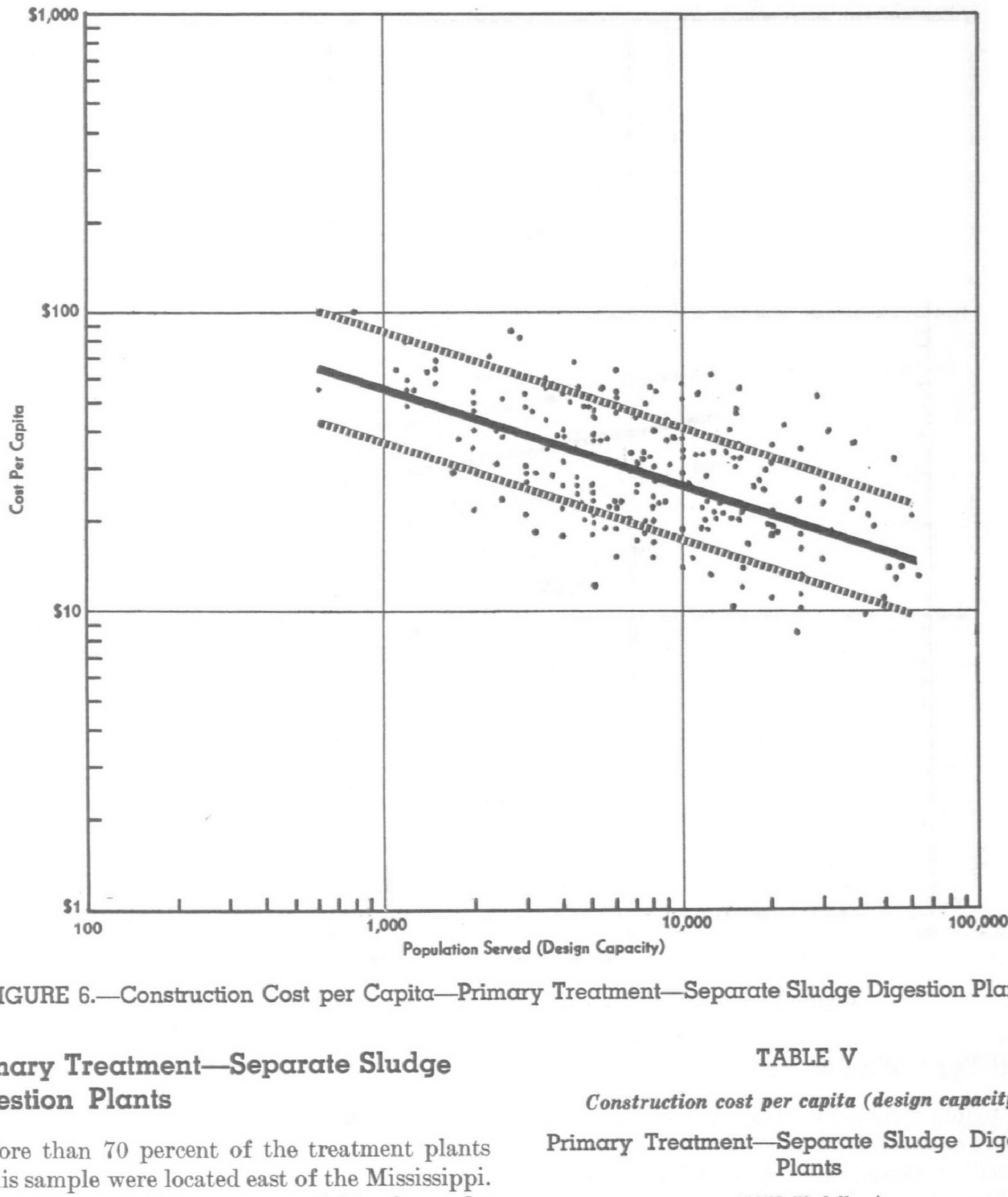

FIGURE 6.—Construction Cost per Capita—Primary Treatment—Separate Sludge Digestion Plants

Primary Treatment—Separate Sludge Digestion Plants

More than 70 percent of the treatment plants in this sample were located east of the Mississippi. Very little cost data were available from the southwest quadrant of the Nation.

The expected cost curve derived from the 233 plants included in this sample appears in figure 6 and has the equation form of:

$$\log 10\ Y = 3.6863572 - 0.31290299 \log X$$

Should cost figures be desired for other populations, within the cost range of 600 to 150,000 design population, other than those tabulated in table V, they can be extrapolated from figure 6 or obtained by use of the equation.

TABLE V

Construction cost per capita (design capacity)

Primary Treatment—Separate Sludge Digestion Plants

(1957–59 dollars)

Design population	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$77. 12	$114. 96	$171. 36	600 to 150, 000
1, 000	37. 52	55. 93	83. 37	
10, 000	18. 25	27. 21	40. 56	
100, 000	8. 88	13. 24	19. 73	

Ratio of upper limit = 1.4906
Ratio of lower limit = 0.6709
$r = -0.66$

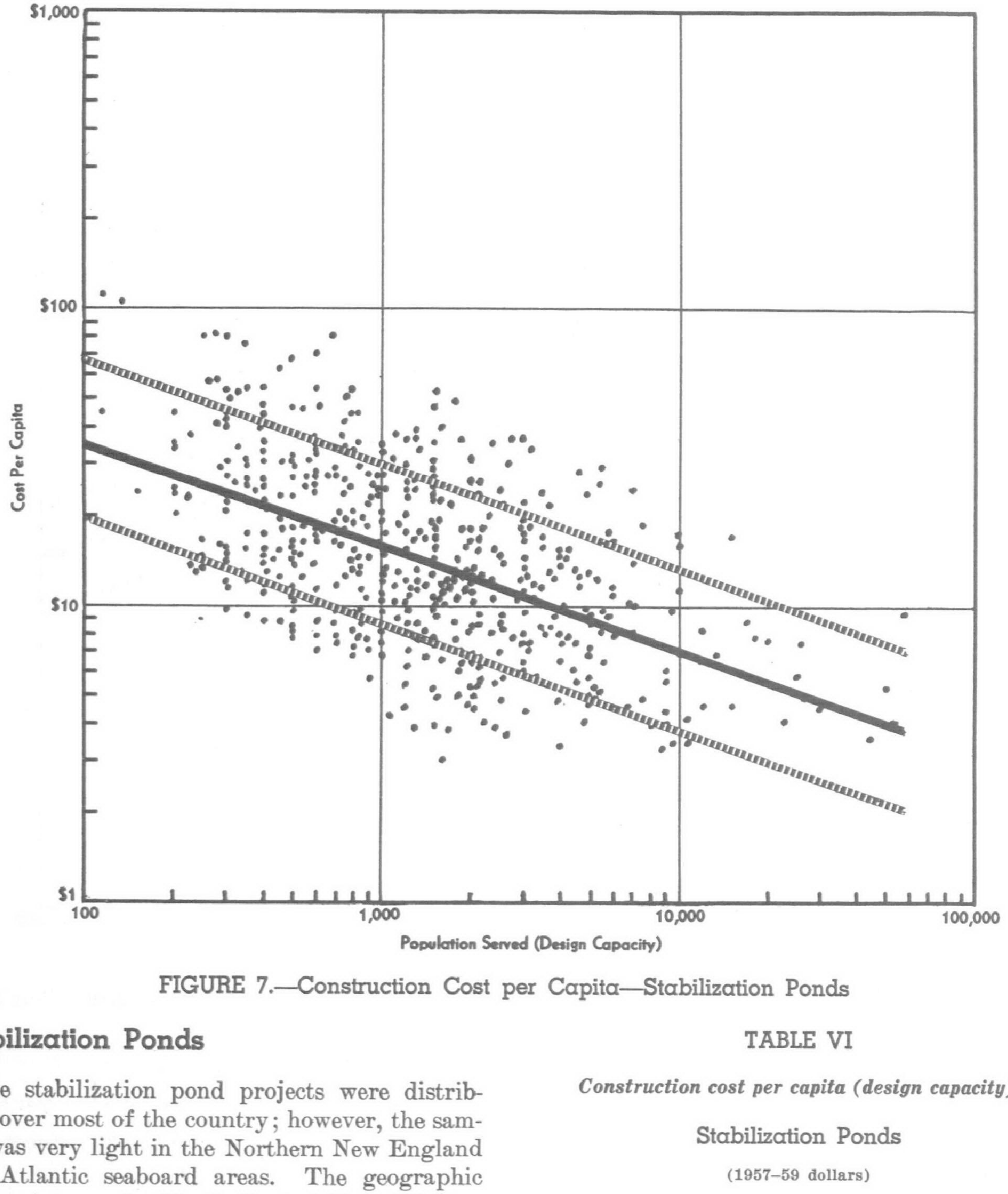

FIGURE 7.—Construction Cost per Capita—Stabilization Ponds

Stabilization Ponds

The stabilization pond projects were distributed over most of the country; however, the sample was very light in the Northern New England and Atlantic seaboard areas. The geographic focal point was the North Central United States, where approximately 60 percent of the sample originated.

Data from 560 stabilization ponds served as the basis for the construction cost curve which appears in figure 7. The equation which best describes this cost distribution is:

$$\log 10\ Y = 3.2663415 - 0.35310975 \log X$$

Table VI presents a summary of the per capita costs calculated for four specific populations.

TABLE VI

Construction cost per capita (design capacity)

Stabilization Ponds

(1957–59 dollars)

Design population	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$19. 96	$36. 31	$66. 10	100 to 60, 000
1, 000	8. 85	16. 10	29. 31	
10, 000	3. 92	7. 14	13. 00	
100, 000	1. 74	3. 17	5. 77	

Ratio of upper limit = 1.8199
Ratio of lower limit = 0.5495
$r = -0.54$

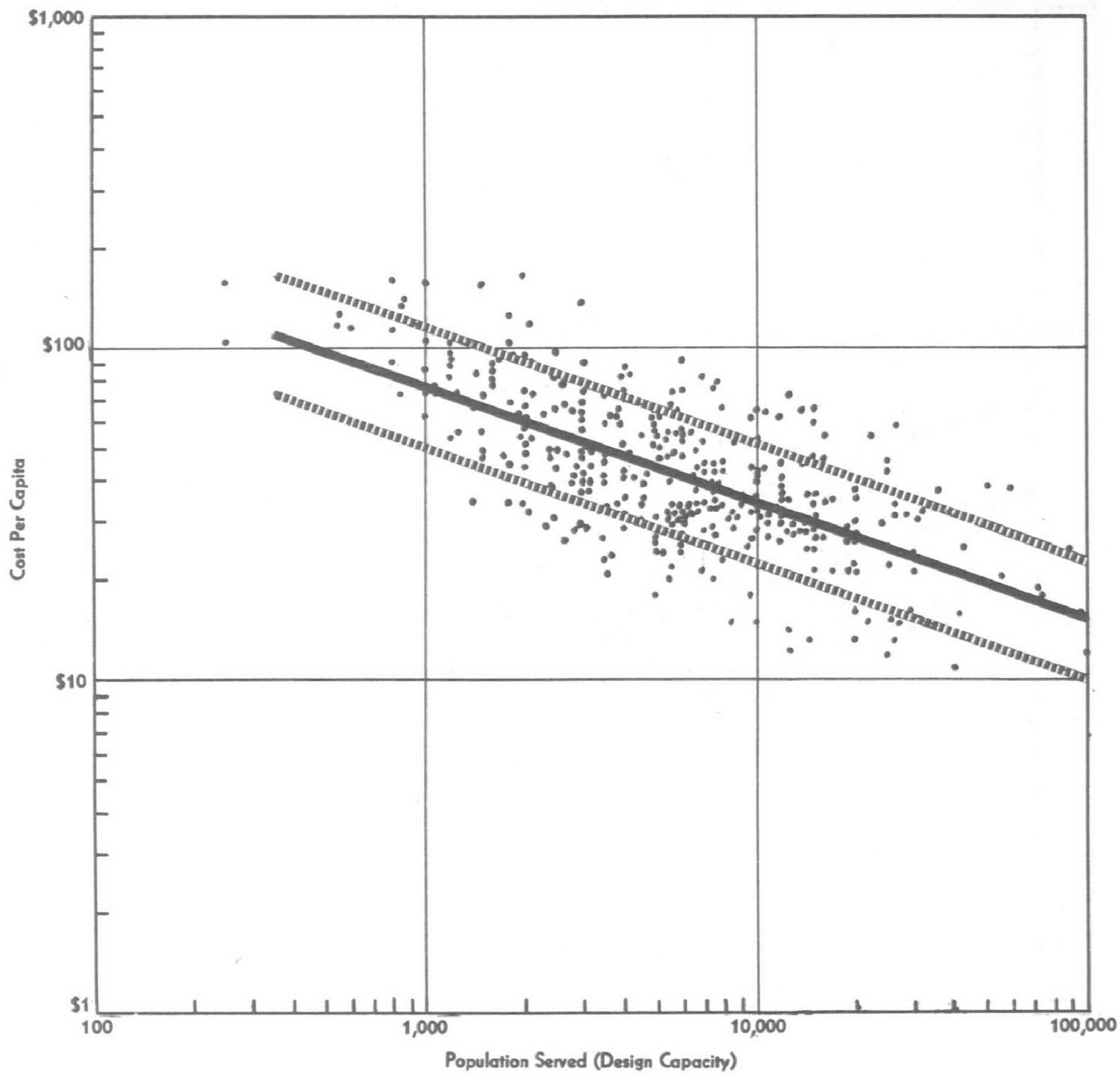

FIGURE 8.—Construction Cost per Capita—Trickling Filters—Separate Sludge Digestion Plants

Trickling Filter—Separate Sludge Digestion Plants

The 374 projects making up this category were dispersed throughout the country. Five States—Kansas, Minnesota, North Carolina, Texas, and Wisconsin—contained 30 percent of the sample. The geographic location of the trickling filter—separate sludge digestion plants is shown in table I (p. 5).

A summary of costs at different population levels appears in table VII. This tabulation of cost results from the solution of the equation

$$\log 10\ Y = 3.8827576 - 0.33673892 \log X$$

which is graphically presented in figure 8.

TABLE VII

Construction cost per capita (design capacity)

Trickling Filter—Separate Sludge Digestion Plants

(1957–59 dollars)

Design population	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$109. 83	$161. 91	$238. 70	350 to 100, 000
1, 000	50. 58	74. 57	109. 93	
10, 000	23. 29	34. 34	50. 63	
100, 000	10. 73	15. 81	23. 32	

Ratio of upper limit = 1.4743
Ratio of lower limit = 0.6783
$r = -0.66$

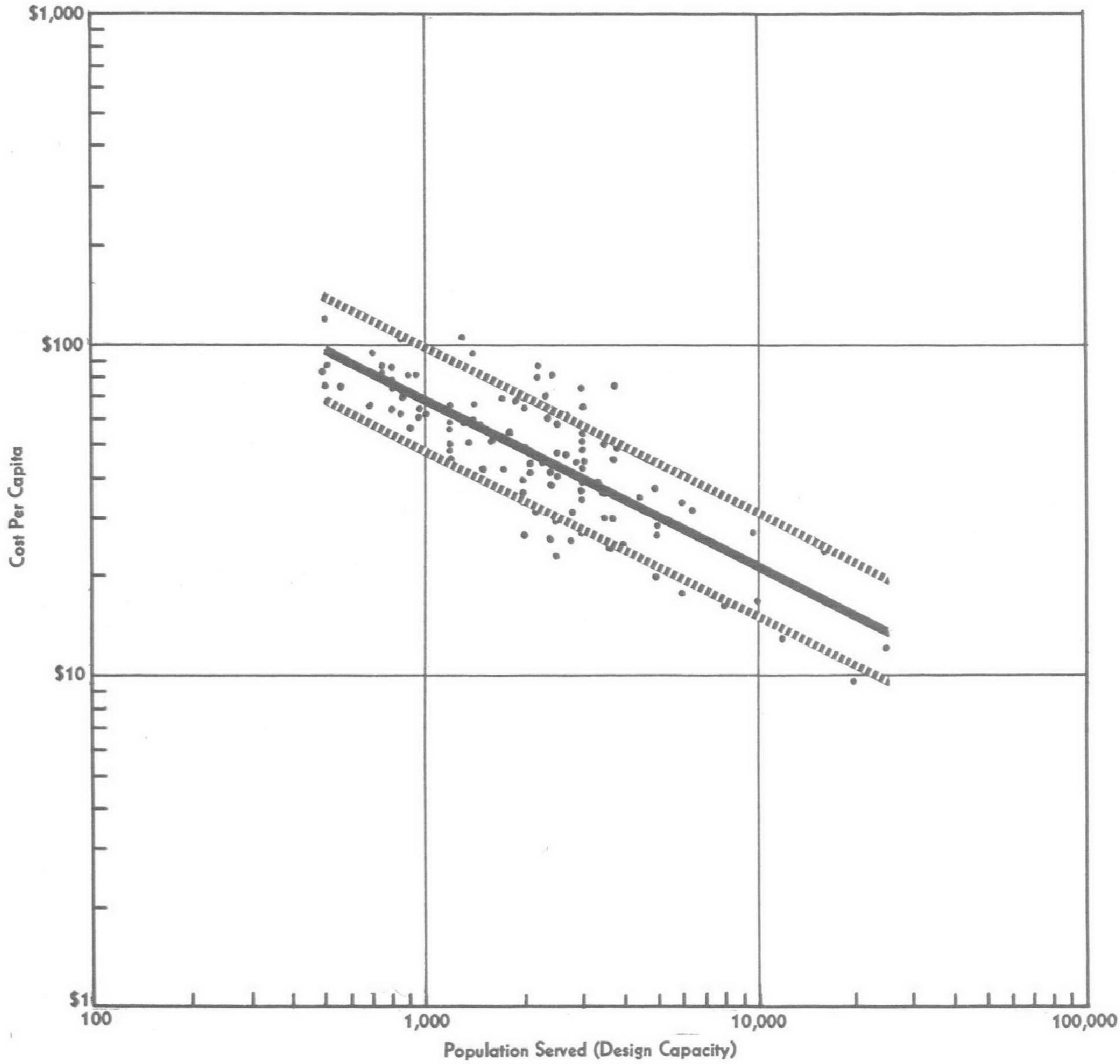

FIGURE 9.—Construction Cost per Capita—Trickling Filter—Imhoff-Type Plants

Trickling Filter—Imhoff-Type Plants

The 121 treatment plants of this type are located throughout the Central United States, and in several of the Western States such as Arizona, California, New Mexico, and Oregon. Almost 30 percent of the projects are located in the two States of Iowa and Texas. Data were available from very few projects in the Northern New England States and the southeastern section of the country.

Table VIII presents unit costs for the four selected population levels. These results are graphically portrayed in figure 9. The most probable estimating equation based on the 121 projects involved in the sample is:

$$\log 10\ Y = 4.4201461 - 0.52710008 \log X$$

TABLE VIII

Construction cost per capita (design capacity)

Trickling Filter—Imhoff-Type Plants

(1957–59 dollars)

Design population	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$169. 71	$232. 24	$317. 82	500 to 25, 000
1,000	50. 42	69. 00	94. 43	
10,000	14. 98	20. 50	28. 05	
100,000	4. 45	6. 09	8. 33	

Ratio of upper limit = 1.3685
Ratio of lower limit = 0.7307
$r = -0.79$

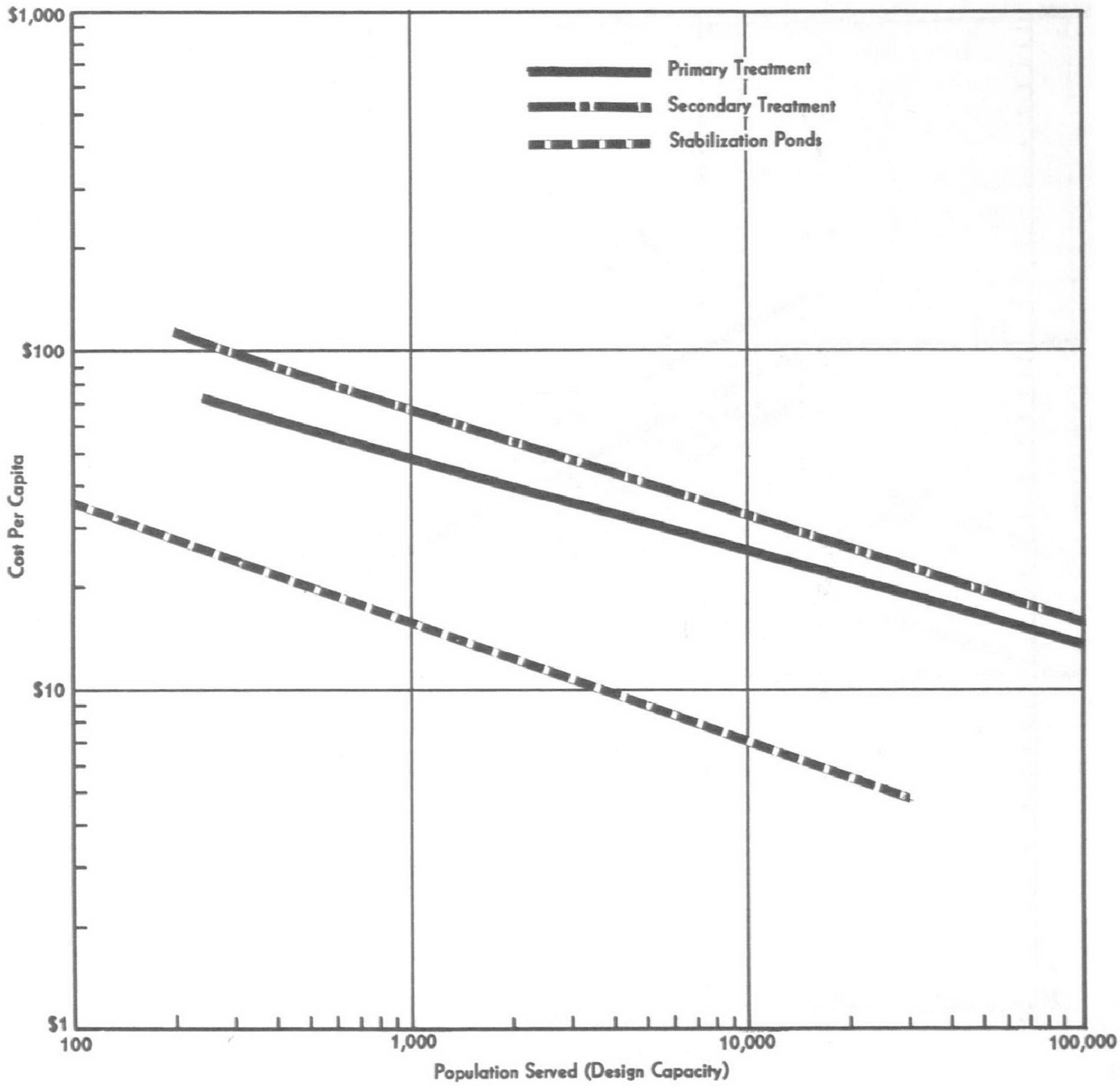

FIGURE 10.—Construction Cost per Capita—Composite Comparison by Types of Treatment

Activated Sludge Plants

This category of treatment plants included 138 projects representative of all parts of the Nation except the southwestern area. About 65 percent of the projects were located east of the Mississippi River; the influence of the Central United States and west coast was exerted on the cost data in this group in a more limited way.

The curve that represents the most probable construction cost for this type treatment is shown graphically in figure 3 (p. 10), and is expressed mathematically by the equation:

$$\log 10\ Y = 3.6533024 - 0.27823950 \log X$$

Table II (p. 10) presents several solutions to this equation for different population levels.

Comparison of Per Capita Cost by Types of Treatment

The individual cost data for the seven different methods of treatment make it possible to compare the types, one to the other. Before presenting such a comparison, it is of interest first to compare graphically the three general categories of treatment: primary treatment; secondary treatment; and stabilization ponds. For this analogy the primary and secondary curves in figure 10 have been developed from the composite cost data used in the previously presented curves. This composite cost information was developed from the following sources:

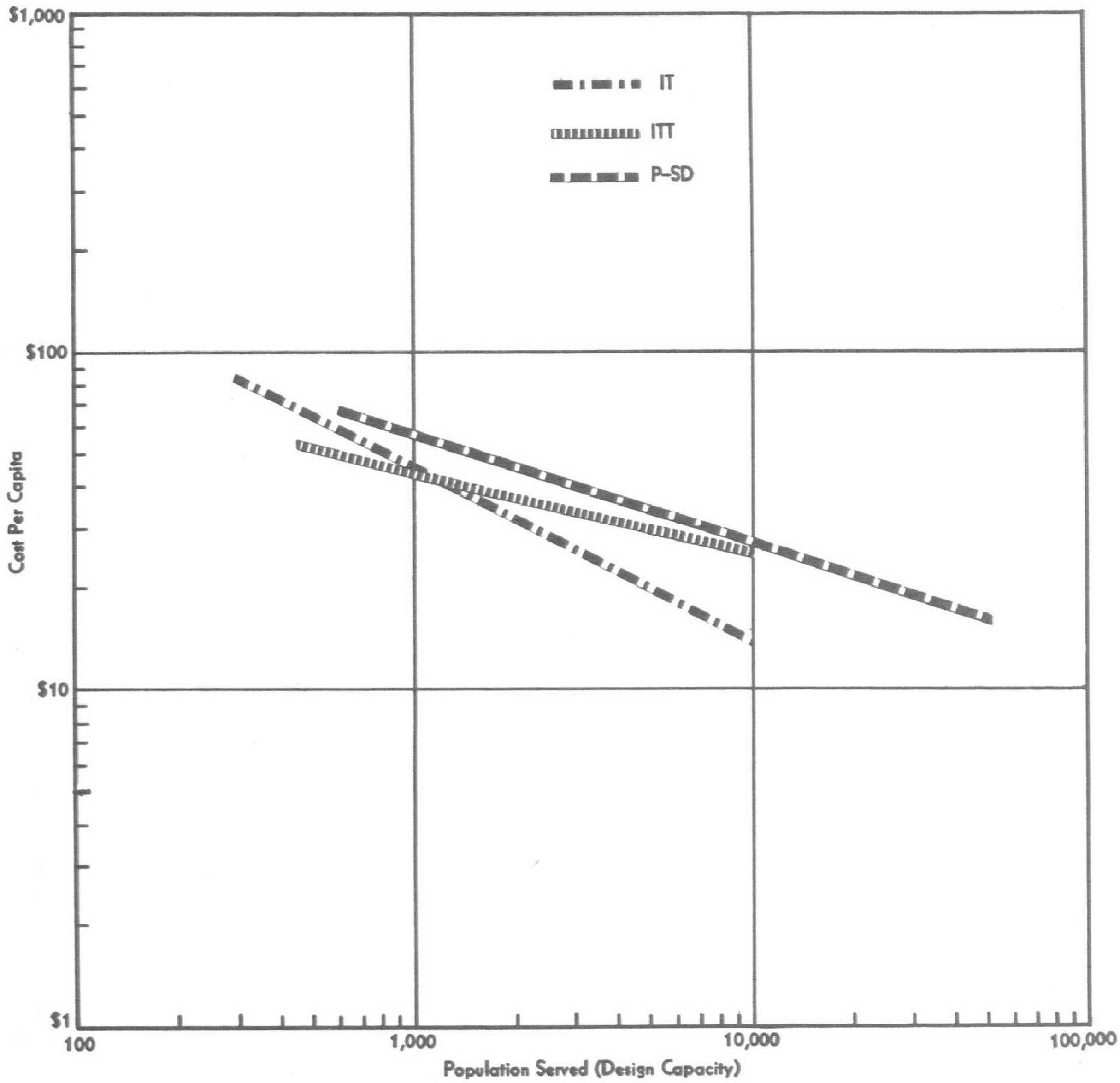

FIGURE 11.—Construction Cost per Capita—Primary Types of Treatment

(1) Primary curve (IT data; ITT data; and P–SD data).

(2) Secondary curve (AS data; TF–P data; and TF–ITT data).

The relationship of the secondary cost curve to the primary curve demonstrates the obvious fact that the construction of secondary treatment plants is more expensive than construction of primary facilities. The relative difference in costs between stabilization ponds and the two other general categories is not surprising. These curves reflect only construction costs and do not include land costs. Land demands for stabilization ponds may play a significant role when comparing total costs of this form of treatment to that of primary and secondary processes.

It is desirable to reiterate here that construction cost—and, in fact, total cost—is not the only factor involved in choice of degree of treatment and treatment processes. The choice is often dictated by other considerations.

Comparative costs—primary treatment.—A comparison of the three construction cost curves relating to primary treatment is shown in figure 11.

The IT cost curve would tend to intersect with the P–SD curve at a population level of approximately 300. With increasing population the Imhoff curve and the conventional primary cost curve diverge at a very rapid rate. This divergence is due, in part, to the increase in equipment demands for P–SD facilities. In addition to the equipment factors, the lower cost of constructing

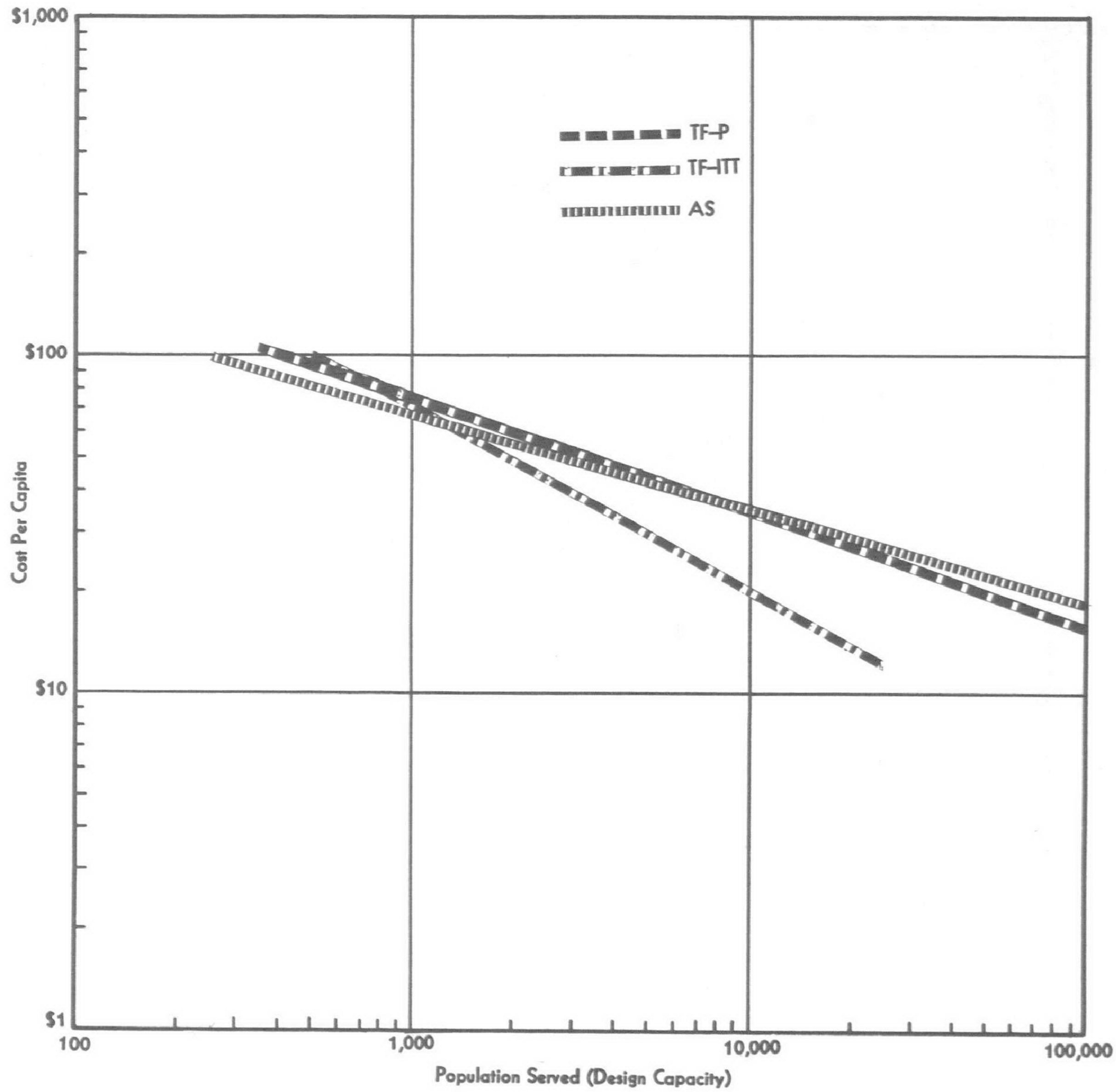

FIGURE 12.—Construction Cost per Capita—Secondary Types of Treatment

the Imhoff self-contained digestion units as compared to separate sludge digestion units of the conventional primary-type further explains this cost divergence.

Imhoff-type facilities at the lower population levels appear to be the least expensive of the three forms of primary treatment shown in figure 11. Even with the addition of mechanical equipment, this type of plant tends to cost less per capita to build than do Imhoff plants. This cost differential is explained by the almost exclusive use of prefabricated package-type plants in these lower population ranges, which are assumed to be less expensive to build than are on-site-constructed Imhoff tanks.

With increasing population the ITT curve intersects the IT cost curve and apparently would tend to intersect the P–SD curve. This might be attributed to the substantial increases in construction costs of ITT plants at these higher population levels. These increases could be caused by the more frequent use of field-constructed facilities over factory-assembled plants, combined with the rapid increase in mechanical equipment costs for increasing populations.

Comparative costs—secondary treatment.—The final phase of this cost comparison deals with the graphic collation of the three curves appearing in figure 12 which cover the secondary treatment category.

The trickling filter—Imhoff-type plant curve for the most part reflects a per capita cost which is lower than either the TF–P curve or the AS curve. An initial comparison of TF–ITT plants with TF–P facilities discloses that the only apparent difference between the two is in the method of primary treatment employed in each. Similar reasoning would apply to these curves (TF–P and TF–ITT) as that which applies to the behavior of the P–SD curve and the IT curve.

The third curve in figure 12 reflects costs per capita for activated sludge treatment facilities. It should be noted that this curve is developed from projects which include prefabricated package-type plants as well as on-side-constructed facilities. If sufficient information were available, a more realistic evaluation of construction costs for activated sludge systems could have been obtained by separating the sample into various modified processes as well as various construction methods.

At the lower population levels, the AS curve reflects a lower cost per person than either of the two trickling filter curves. This condition may be attributable to the increased economy of factory-fabricated package-type plants used to serve these lower population ranges.

With increasing population, however, the AS curve intersects both filter curves. This intersection of the two filter curves by the AS curve was unexpected, since earlier cost investigations did not show the activated sludge curve intersecting the TF–P curve. Based on a considerably larger sample and improved statistical correlation, it is believed that the change in slope reflects existing conditions in the sewage treatment field. It is further hypothesized that the AS curve could have been influenced by the use of cost data for modified AS systems, the construction of which varies in unit cost from so-called conventional activated sludge plants.

Treatment Plant Costs per Population Equivalent

In the design of sewage treatment facilities for communities receiving both industrial and domestic sewage flows, an accepted criterion of design is that of population equivalent served. This parameter converts the industrial component of sewage flow to a strength equivalent to that of typical domestic sewage. The use of population equivalent as a design factor, is generally limited to secondary treatment facilities because they are designed to remove and reduce organic loadings.

The steady increase in the construction of systems receiving both industrial wastes and domestic sewage led to the decision to collate construction costs and population equivalents served by projects of the secondary treatment type. A sample of 280 projects serves as the statistical basis of this phase of the study.

Activated Sludge Plants

The statistical basis of the cost data in this category is a sample of 86 projects, with 75 percent located east of the Mississippi River. Nine States west of the Mississippi account for about one-quarter of the cost data. Over one-quarter of the plants were located in the two States of Ohio and Wisconsin.

The construction cost estimating curve best describing this sample is shown in figure 13. The equation, presented in its log form is:

$$\log 10\ Y = 4.8716858 - 0.35073541 \log X$$

A tabulation of data that can be used to reproduce this cost curve appears in table IX. The population equivalents listed were chosen for convenience of calculation.

TABLE IX

Construction cost per population equivalent (design capacity)

Activated Sludge Plants

(1957–59 dollars)

Design population equivalent	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$98. 72	$147. 98	$221. 83	250 to 60, 000
1, 000	44. 02	65. 99	98. 92	
10, 000	19. 63	29. 42	44. 11	
100, 000	8. 75	13. 12	19. 67	

Ratio of upper limit = 1.4990
Ratio of lower limit = 0.6671
$r = -0.74$

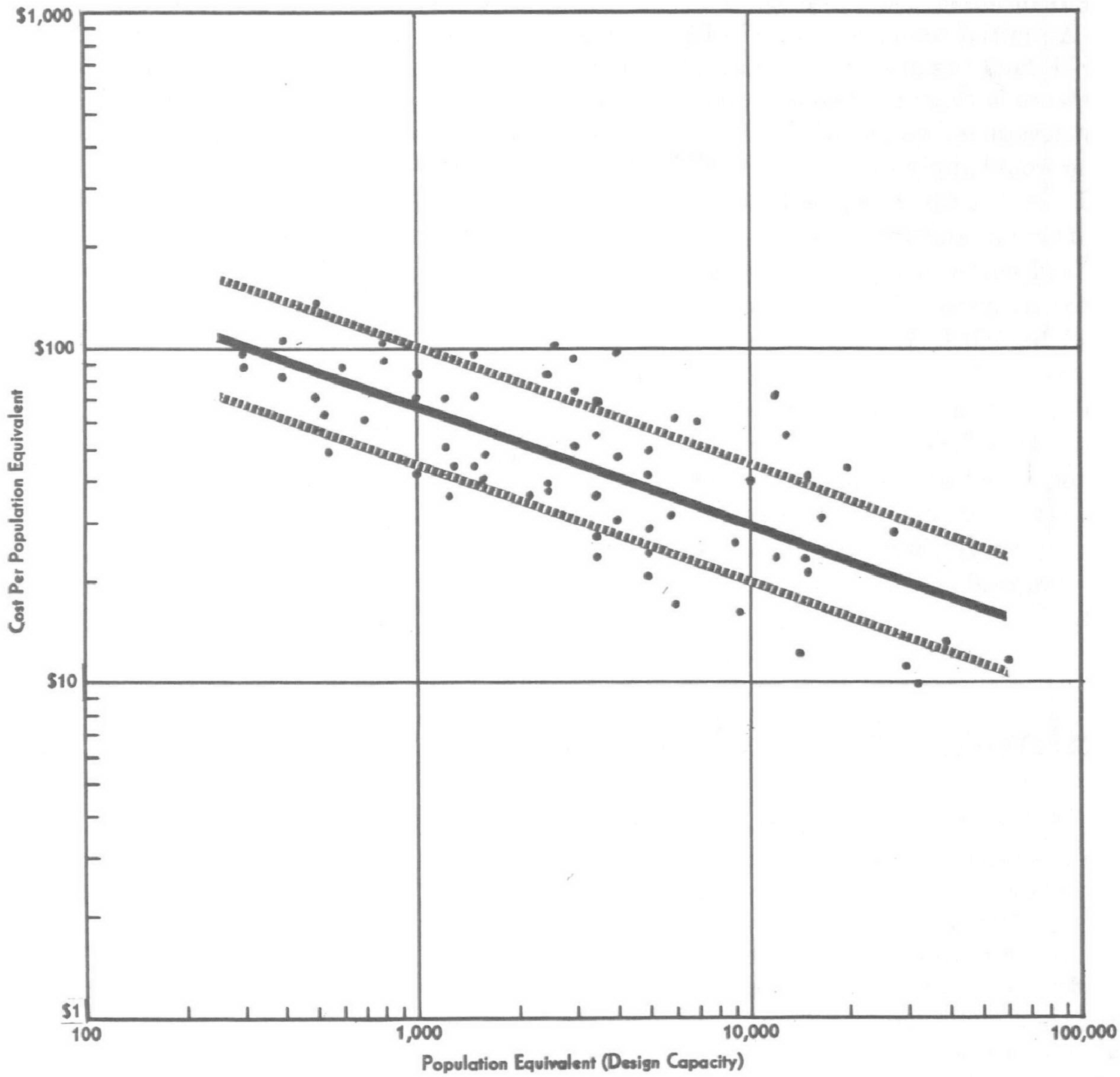

FIGURE 13.—Construction Cost per Population Equivalent—Activated Sludge Plants

Trickling Filter—Separate Sludge Digestion Plants

Cost data for 143 projects were employed in this facet of the study. Projects were from all parts of the United States with the exception of 11 States for which no data were available. The Northern New England area did not influence the curve. The seven States of North Carolina, Tennessee, Wisconsin, Alabama, Minnesota, Texas, and Utah, on the other hand, had the greatest influence on the estimating cost data since approximately 40 percent of the sample came from these States. Table I (p. 5) indicates the States which influenced this cost study.

The expected cost equation is:

$$\log 10\ Y = 5.1805624 - 0.42566682 \log X$$

Costs for selected populations are tabulated in table X. These data served as an aid in developing the curve shown in figure 14.

Trickling Filter—Imhoff-Type Plants

This type of treatment included no population equivalent cost data from States lying west of the Rocky Mountains. With the exception of cost in-

TABLE X

Construction cost per population equivalent (design capacity)

Trickling Filter—Separate Sludge Digestion Plants

(1957–59 dollars)

Design population equivalent	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$149. 25	$213. 41	$305. 16	350 to 75, 000
1, 000	56. 01	80. 09	114. 51	
10, 000	21. 02	30. 05	42. 97	
100, 000	7. 89	11. 28	16. 12	

Ratio of upper limit = 1.4299
Ratio of lower limit = 0.6994
$r = -0.74$

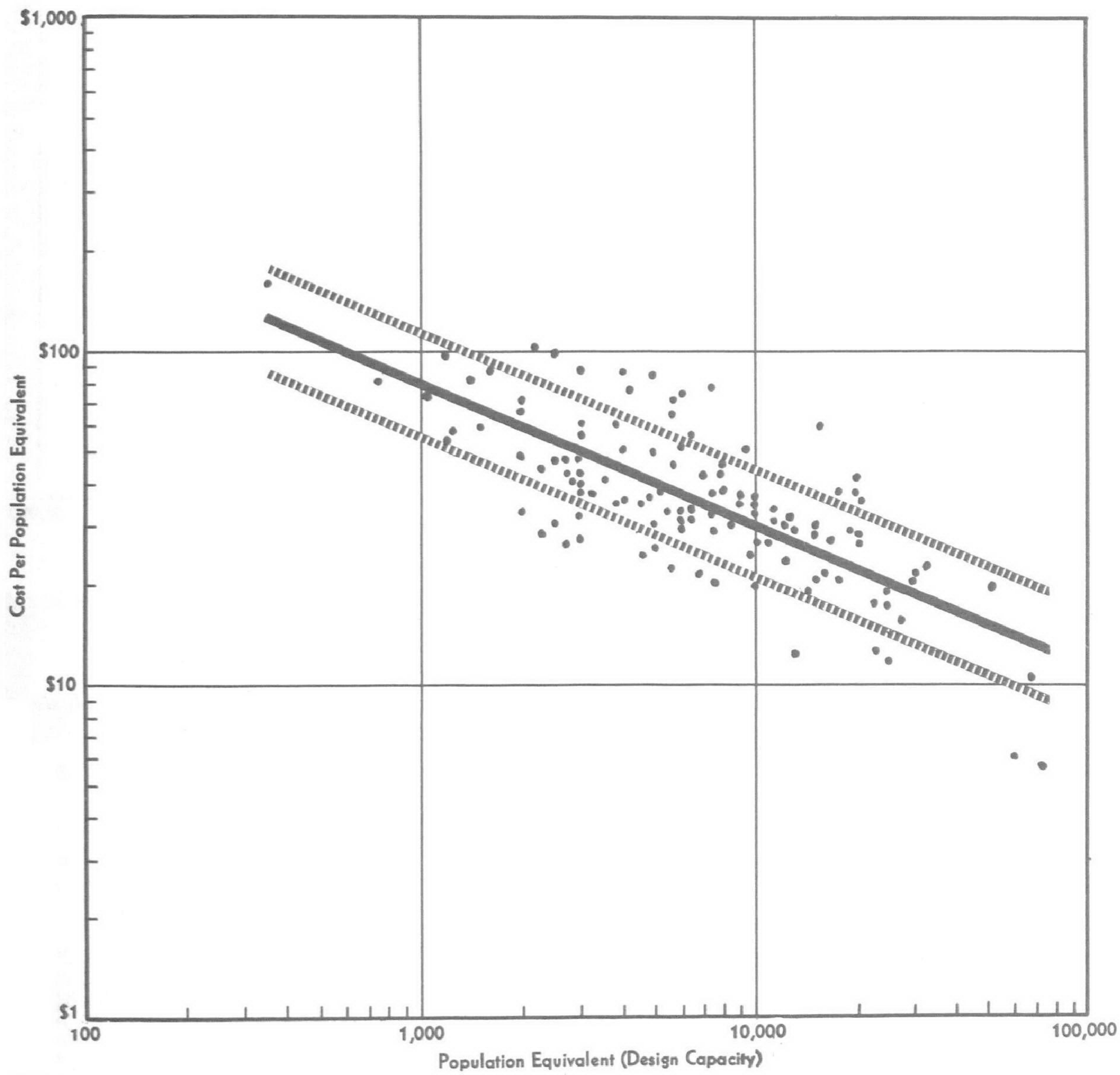

FIGURE 14.—Construction Cost per Population Equivalent—Trickling Filter—Separate Sludge Digestion Plants

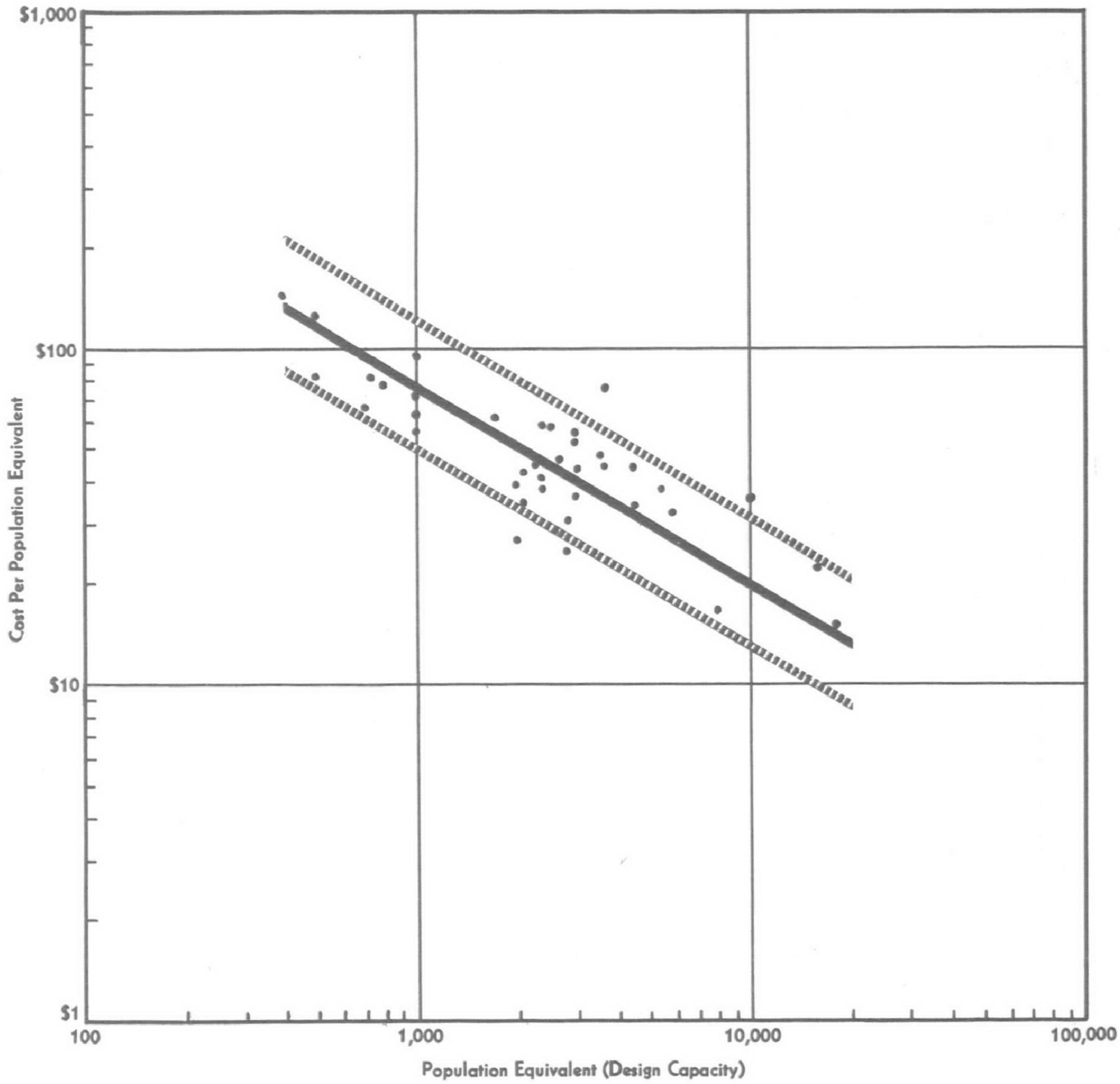

FIGURE 15.—Construction Cost per Population Equivalent—Trickling Filter—Imhoff-Type Plants

formation from the eight States of Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Oklahoma, and Texas, all the data were from States lying east of the Mississippi River. It should be noted that representation was only nominal from the southeastern portion of the Nation. Over one-quarter of the cost data from the 51 projects making up the sample were provided by two States: North Carolina and Texas.

The estimating cost curve for this type of treatment is:

$$\log 10\ Y = 5.6743457 - 0.59384713\ \log X$$

Unit cost results appear in table XI and are shown graphically in figure 15.

TABLE XI

Construction cost per population equivalent (design capacity)

Trickling Filter—Imhoff-Type Plants

(1957–59 dollars)

Design population equivalent	Construction costs			Valid size range
	Lower limit	Expected value	Upper limit	
100	$195. 95	$306. 66	$479. 92	400 to 20, 000
1, 000	49. 92	78. 13	122. 27	
10, 000	12. 72	19. 90	31. 15	
100, 000	3. 24	5. 07	7. 94	

Ratio of upper limit = 1.5650
Ratio of lower limit = 0.6390
$r = -0.73$

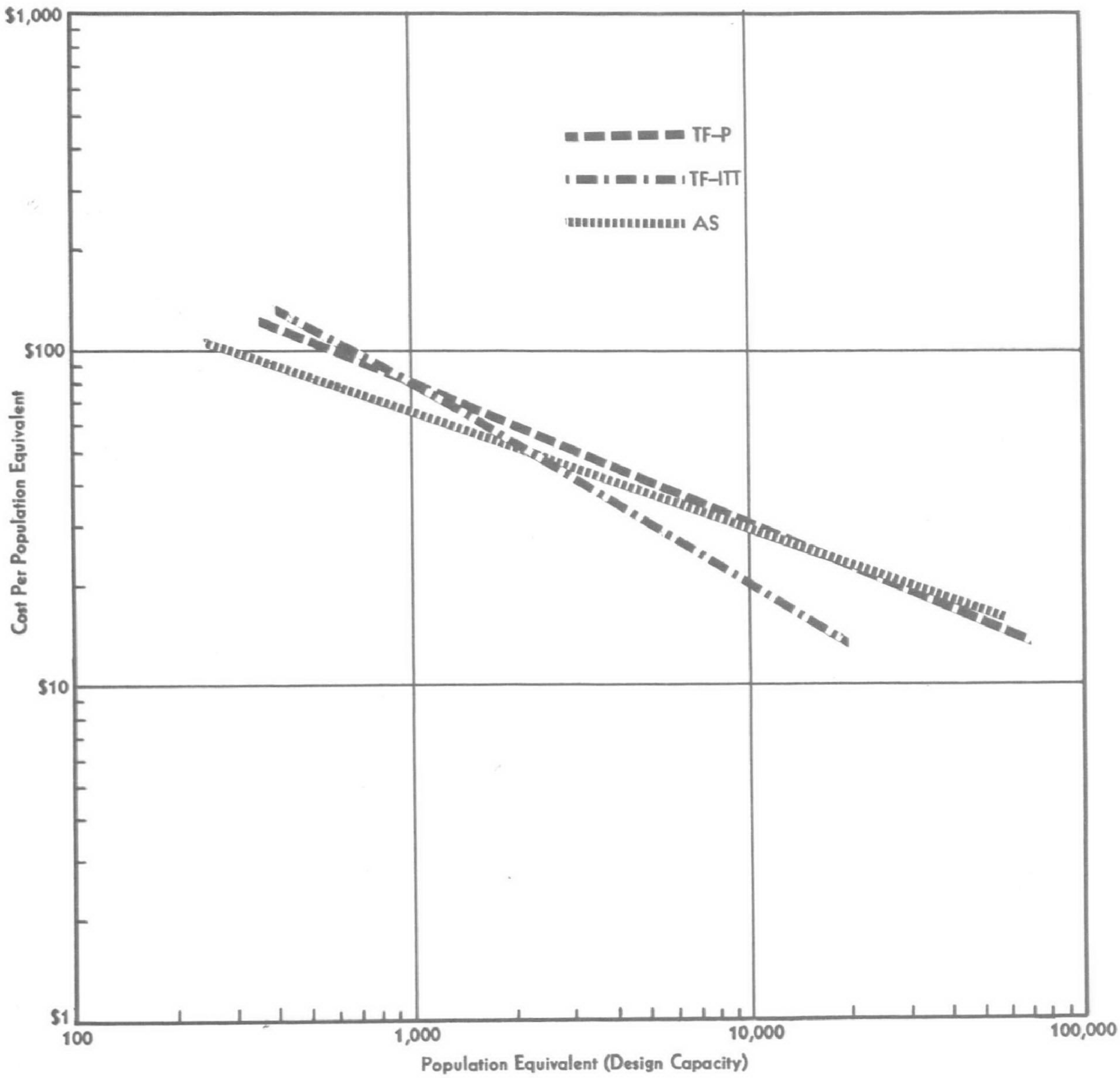

FIGURE 16.—Construction Cost per Population Equivalent—Cost Comparison by Types of Treatment

Comparison of Population Equivalent Costs by Types of Treatment

As in the case of the cost per capita study, a comparison of the data on costs per population equivalent is desirable. Figure 16 reflects the three cost per PE curves for secondary treatment plants.

Since the PE, by definition, is always higher than the design population when industrial wastes are included in the sewage flow, the cost per PE will naturally be less than the cost per capita for the same project. In all cases, the cost per PE curves have a greater slope than the cost per capita curves. This slope differential evidently is caused by the increasing percentage of industrial wastes with increasing population.

The relationship of the three curves in figure 16 is generally the same as for the cost per capita curves of the three secondary treatment processes shown in figure 12 (p. 20). This was expected since, in a large number of the projects, particularly in the smaller communities, the design population was equal to the PE. In the remainder, the effect of PE would have been felt equally by similar secondary treatment processes.

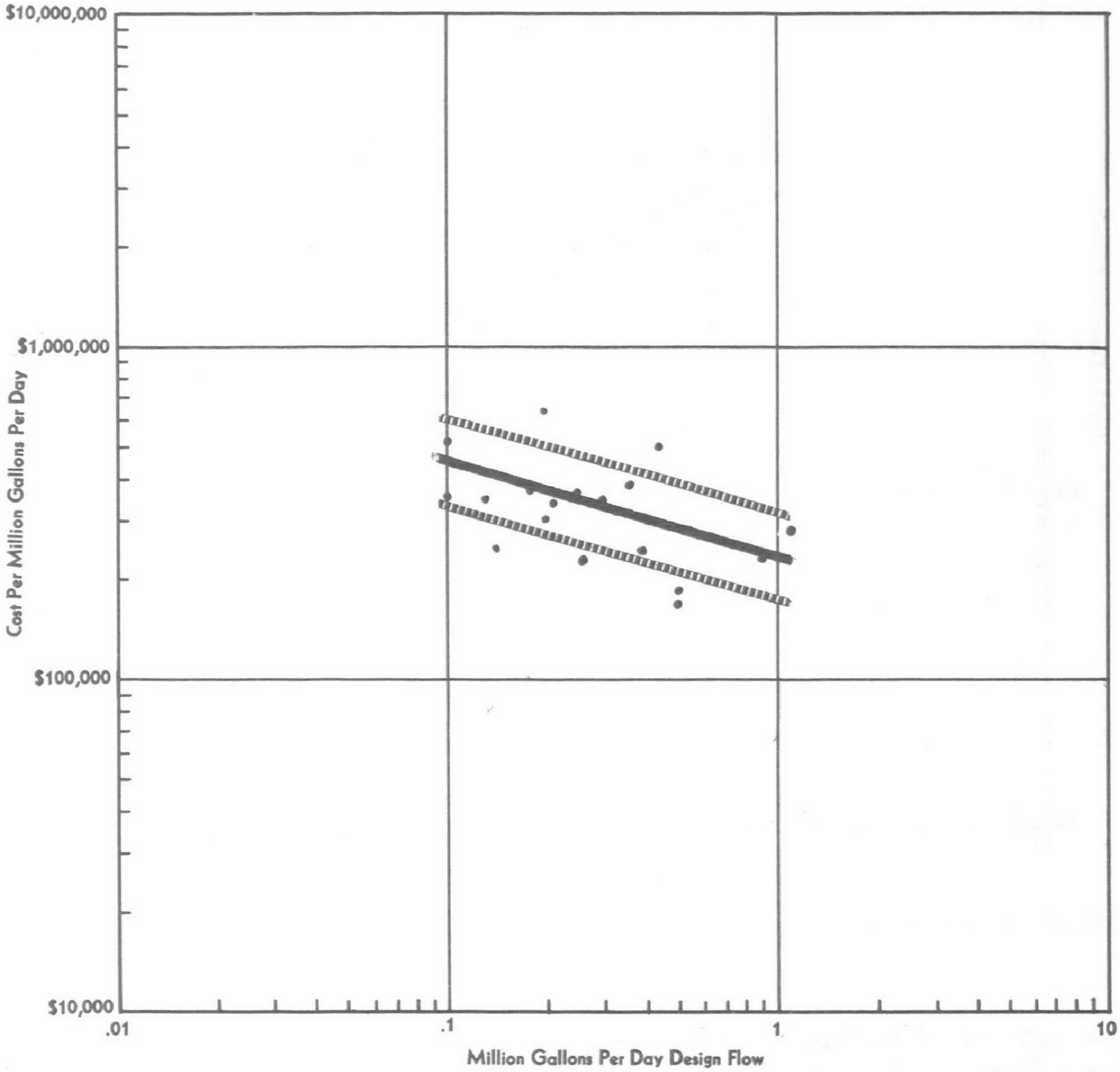

FIGURE 17.—Construction Cost per Unit Flow—Imhoff-Type Plants

Treatment Plant Costs per Unit Flow

The third group of cost comparisons collates construction cost against design flow in million gallons per day (MGD). The sample involved in establishing these cost data was composed of plants receiving principally domestic flow; however, in many cases both domestic and industrial wastes flows were involved. Cost data from over 750 projects formed the statistical basis for the estimating curves on cost per unit design flow.

Since hydraulic loading is one of the basic factors in the design for both primary and secondary systems, curves were developed for both categories of treatment. For lack of sufficient data, Imhoff tank plants have been eliminated from this portion of the report.

The only other difference between this portion of the report and the preceding two sections is that the construction cost is not multiplied by a factor of 10. Hence, the general equation for the curves will take the form:

$$\log Y = a + b \log X \quad\text{---------------}\quad (3_c)$$

Imhoff-Type Plants

The geographic distribution of the 24 projects from which the cost curve for this type of treatment was developed is not balanced. The sample covers almost every State east of the Mississippi but only the three States of Washington, Montana, and Louisiana west of the Mississippi. The State of West Virginia exerted the greatest influence on the curve by supplying 25 percent of the sample.

The most descriptive curve developed by the cost information available in this sample is represented by this equation:

$$\log Y = 5.2132021 - 0.27927265 \log X$$

Figure 17 reflects this equation in graphic form. A tabulation of the expected costs for four selected flows appears in table XII.

TABLE XII

Construction cost per unit flow (design capacity)

Imhoff-Type Plants

(1957–59 dollars)

Design flow (MGD)	Construction costs			Valid size range (MGD)
	Lower limit	Expected value	Upper limit	
0. 1	$337, 128. 70	$451, 498. 84	$604, 668. 78	0. 095 to 1. 100
1. 0	177, 224. 23	237, 347. 14	317, 866. 61	
10. 0	93, 164. 53	124, 770. 38	167, 098. 44	
100. 0	48, 975. 39	65, 590. 18	87, 841. 49	

Ratio of upper limit = 1.3392
Ratio of lower limit = 0.7467
$r = -0.56$

Primary Treatment Separate Sludge Digestion Plants

The 99 projects of this type for which cost data could be obtained were not uniformly distributed over the country. Most were located east of the Mississippi River with some of the data stemming from States in the northwestern quarter of the Nation. With the exception of seven projects in California, the southwestern portion of the country exerted little influence on the cost data. The six States of Vermont, New York, Michigan, Illinois, Idaho, and California accounted for 38 percent of the sample.

Cost ranges and expected costs for specific flows have been tabulated in table XIII. These data were the basis for the estimating cost curve appearing in figure 18. The equation which best describes the sample is:

$$\log Y = 5.7085596 - 0.44604400 \log X$$

TABLE XIII

Construction cost per unit flow (design capacity)

Primary Treatment—Separate Sludge Digestion Plants

(1957–59 dollars)

Design flow (MGD)	Construction costs: Lower limit	Construction costs: Expected value	Construction costs: Upper limit	Valid size range (MGD)
0. 1	$429, 165. 71	$655, 347. 62	$1, 000, 733. 50	0. 40 to 10. 000
1. 0	153, 667. 03	234, 653. 70	358, 322. 54	
10. 0	55, 022. 07	84, 020. 18	128, 301. 08	
100. 0	19, 701. 21	30, 084. 28	45, 939. 51	

Ratio of upper limit = 1.5270
Ratio of lower limit = 0.6549
$r = -0.76$

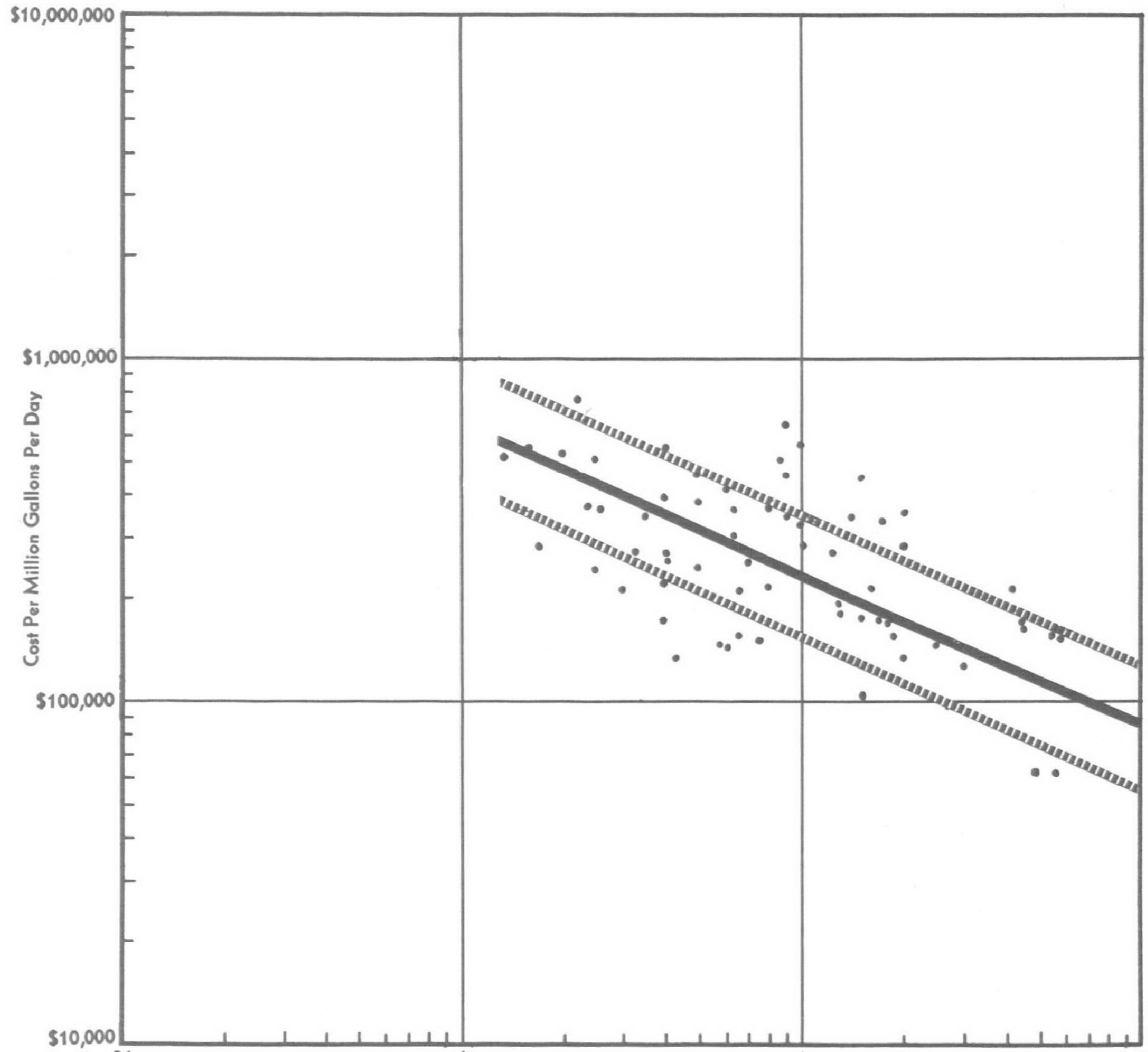

FIGURE 18.—Construction Cost per Unit Flow—Primary Treatment—Separate Sludge Digestion Plants

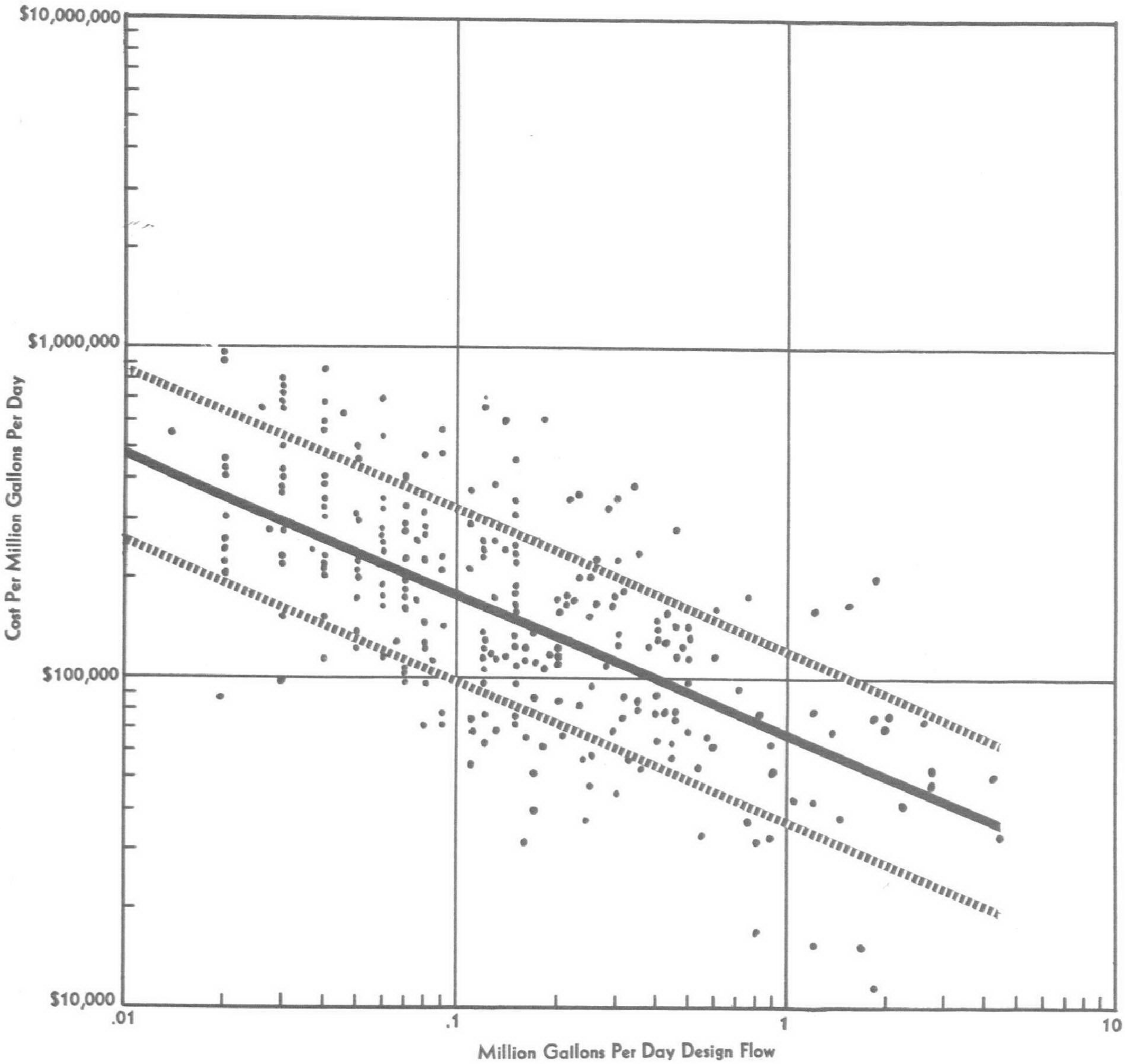

FIGURE 19.—Construction Cost per Unit Flow—Stabilization Ponds

Stabilization Ponds

The projects which formed the basis of this cost study were well distributed nationally except for the New England area, where only two projects were located—one each from Maine and New Hampshire. The eight States of Arkansas, Kansas, Mississippi, Missouri, Nebraska, North Dakota, Oklahoma, and South Dakota, provided 61 percent of the data. The State of Missouri exerted the greatest single influence on the cost data with 50 of the sample's 350 projects located in that State.

The equation which best characterizes the available cost data statistically is:

$$\log Y = 5.107643 - 0.42570017 \log X$$

This equation is presented in graphic form in figure 19. Expected costs for specific flows have been tabulated in table XIV.

TABLE XIV

Construction cost per unit flow (design capacity)

Stabilization Ponds

(1957–59 dollars)

Design flow (MGD)	Construction costs			Valid size range (MGD)
	Lower limit	Expected value	Upper limit	
0. 1	$99, 599. 29	$180, 328. 36	$326, 491. 46	0. 01 to 4. 50
1. 0	37, 372. 83	67, 664. 96	122, 510. 01	
10. 0	14, 023. 48	25, 390. 05	45, 969. 67	
100. 0	5, 262. 06	9, 527. 16	17, 249. 29	

Ratio of upper limit = 1.8105
Ratio of lower limit = 0.5523
$r = -0.65$

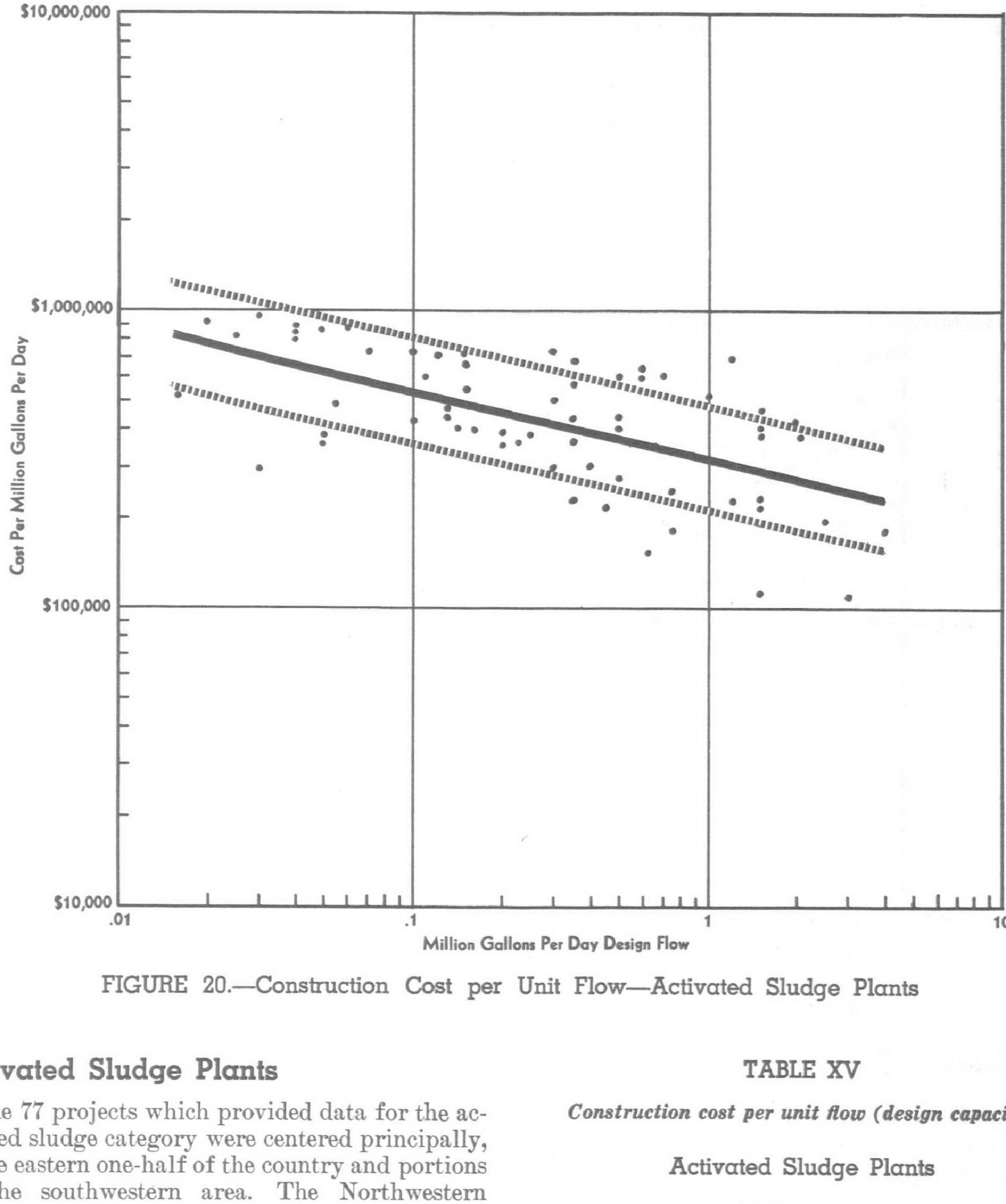

FIGURE 20.—Construction Cost per Unit Flow—Activated Sludge Plants

Activated Sludge Plants

The 77 projects which provided data for the activated sludge category were centered principally, in the eastern one-half of the country and portions of the southwestern area. The Northwestern States exerted very little influence on the cost curve, with information available only from Oregon, Idaho, Wyoming, Utah, and Nebraska. Projects for this sample were heavily centered in the States of Ohio and Wisconsin where 30 percent of the cost data originated.

The expected estimating equation is:

$$\log Y = 5.1954670 - 0.22968263 \log X$$

Figure 20 is the graphic presentation of this equation. Table XV reflects the costs per unit flow for the four specific flow loadings.

TABLE XV

Construction cost per unit flow (design capacity)

Activated Sludge Plants

(1957–59 dollars)

Design flow (MGD)	Construction costs			Valid size range (MGD)
	Lower limit	Expected value	Upper limit	
0. 1	$365, 864. 12	$544, 630. 08	$810, 743. 42	0. 015 to 4. 00
1. 0	215, 594. 21	320, 936. 35	477, 750. 02	
10. 0	127, 044. 15	189, 119. 58	281, 525. 87	
100. 0	74, 863. 82	111, 443. 26	165, 895. 89	

Ratio of upper limit = 1.4886
Ratio of lower limit = 0.6718
$r = -0.60$

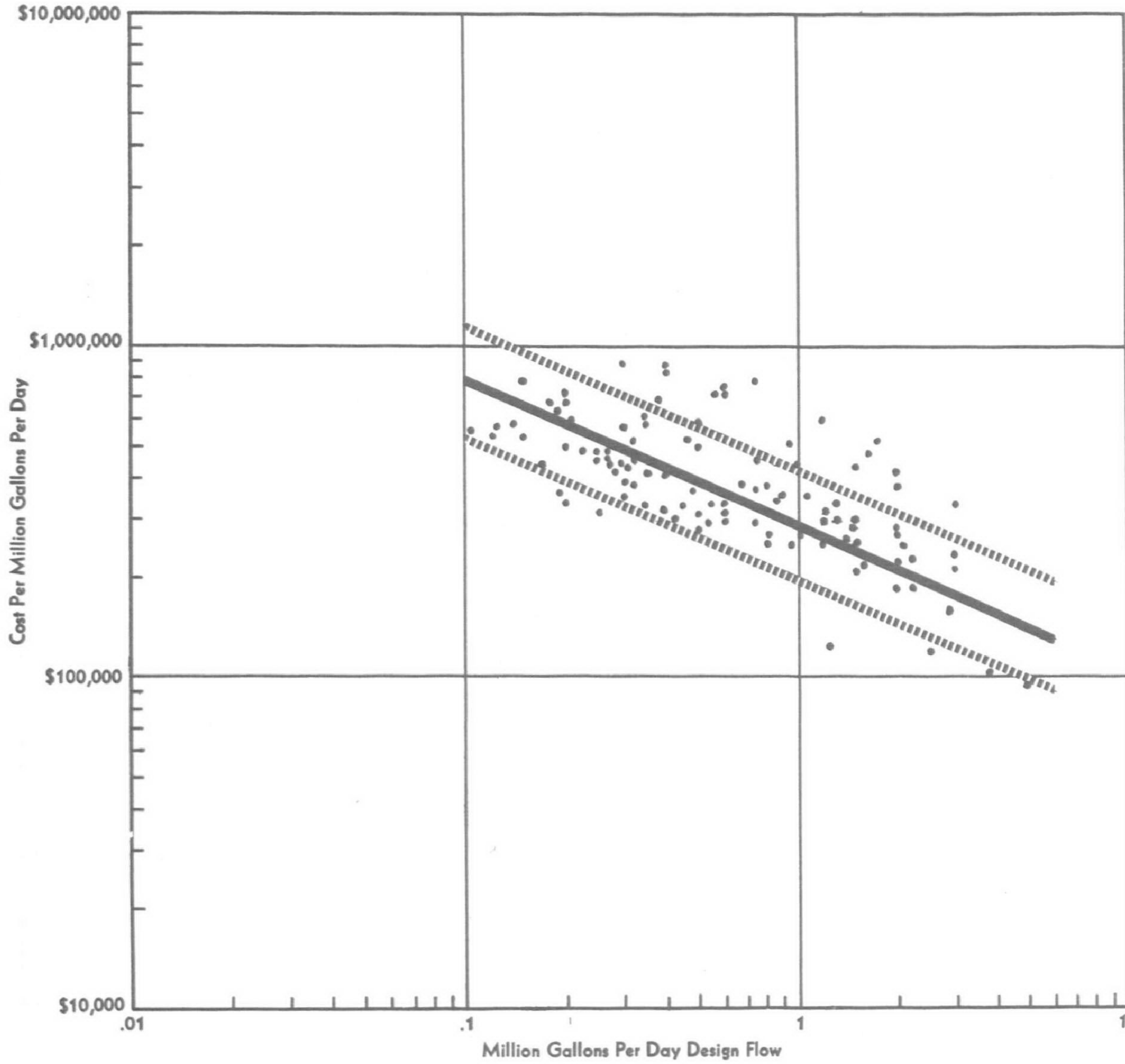

FIGURE 21.—Construction Cost per Unit Flow—Trickling Filters—Separate Sludge Digestion Plants

Trickling Filter—Separate Sludge Digestion Plants

The 141 projects which made up the TF–P category were distributed throughout the Nation. The three States of North Carolina, Tennessee, and Wisconsin accounted for almost one-fourth of the sample, with 10 projects each.

The estimating equation is:

$$\log Y = 5.7630257 - 0.43474996 \log X$$

Solution of this equation for particular flows will yield expected costs per MGD. A tabulation of these costs for four specific flows appears in table XVI. A graphic presentation of these data is given in figure 21.

TABLE XVI

Construction cost per unit flow (design capacity)

Trickling Filter—Separate Sludge Digestion Plants

(1957–59 dollars)

Design flow (MGD)	Construction costs			Valid size range (MGD)
	Lower limit	Expected value	Upper limit	
0. 1	$529, 168. 77	$782, 575. 04	$1, 157, 331. 50	0. 10 to 5. 00
1. 0	194, 466. 21	287, 591. 43	425, 312. 09	
10. 0	71, 465. 12	105, 688. 06	156, 299. 55	
100. 0	26, 262. 99	38, 839. 70	57, 439. 11	

Ratio of upper limit = 1.4789
Ratio of lower limit = 0.6762
$r = -0.73$

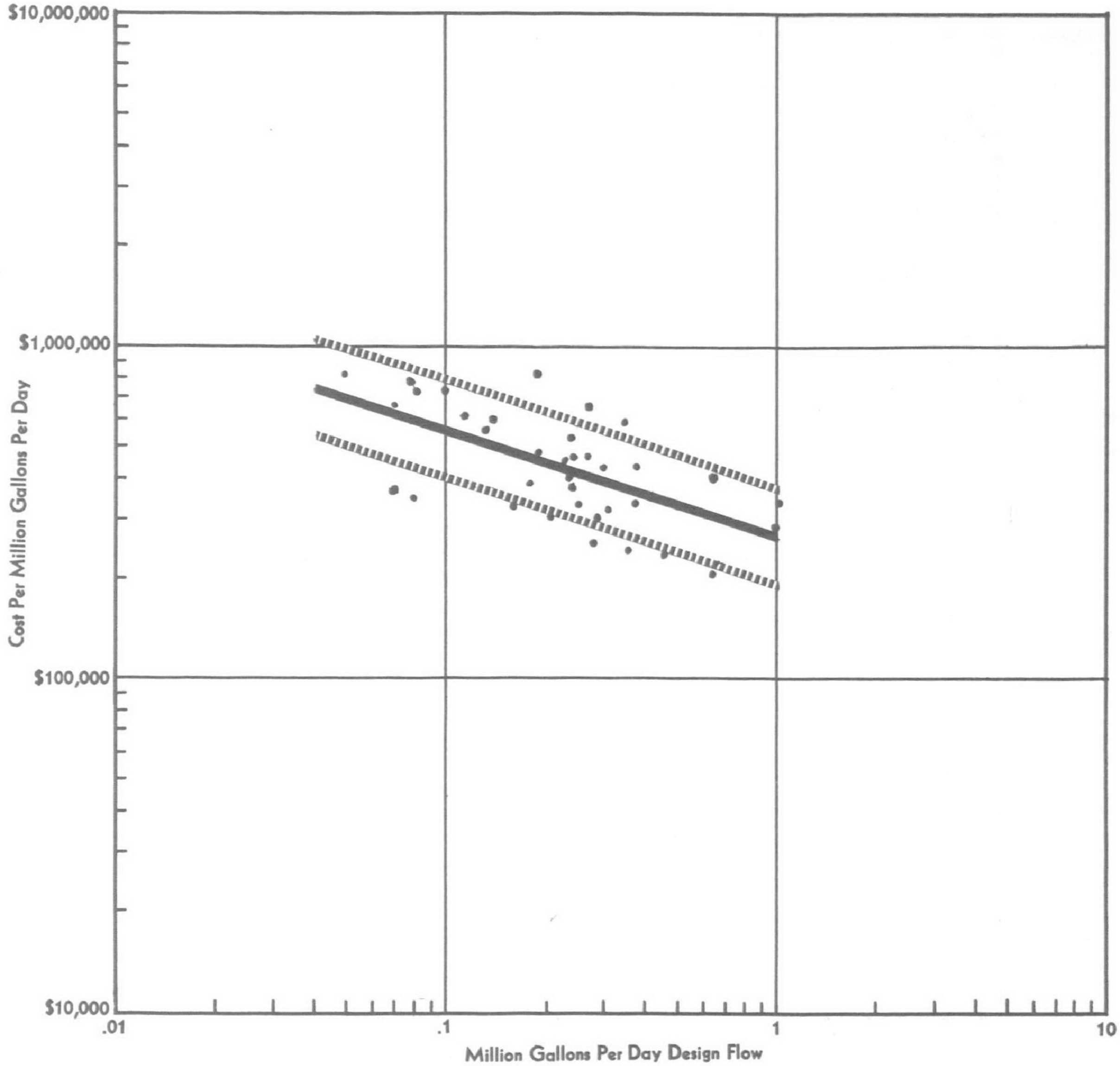

FIGURE 22.—Construction Cost per Unit Flow—Imhoff-Type Plants

Trickling Filter—Imhoff-Type Plants

The 51 projects in the sample were, for the most part, located east of the Mississippi River. Massachusetts was the only New England State providing data; seven Western States were represented. Table I (p. 5) lists the projects contributing to this sample. The greatest cost data influence for this curve was provided by the three States of Texas, Iowa, and North Carolina, in which 40 percent of the projects were located.

The equation best fitting the distribution of cost data is:

$$\log Y = 5.3845334 - 0.32009689 \log X$$

TABLE XVII

Construction cost per unit flow (design capacity)

Trickling Filter—Imhoff-Type Plants

(1957–59 dollars)

Design flow (MGD)	Construction costs			Valid size range (MGD)
	Lower limit	Expected value	Upper limit	
0. 1	$399, 469. 35	$555, 059. 78	$771, 251. 57	0. 10 to 1. 00
1. 0	191, 155. 27	265, 608. 87	369, 061. 61	
10. 0	91, 472. 28	127, 100. 08	176, 604. 65	
100. 0	43, 771. 62	60, 820. 35	84, 509. 44	

Ratio of upper limit = 1.3895
Ratio of lower limit = 0.7197
$r = -0.63$

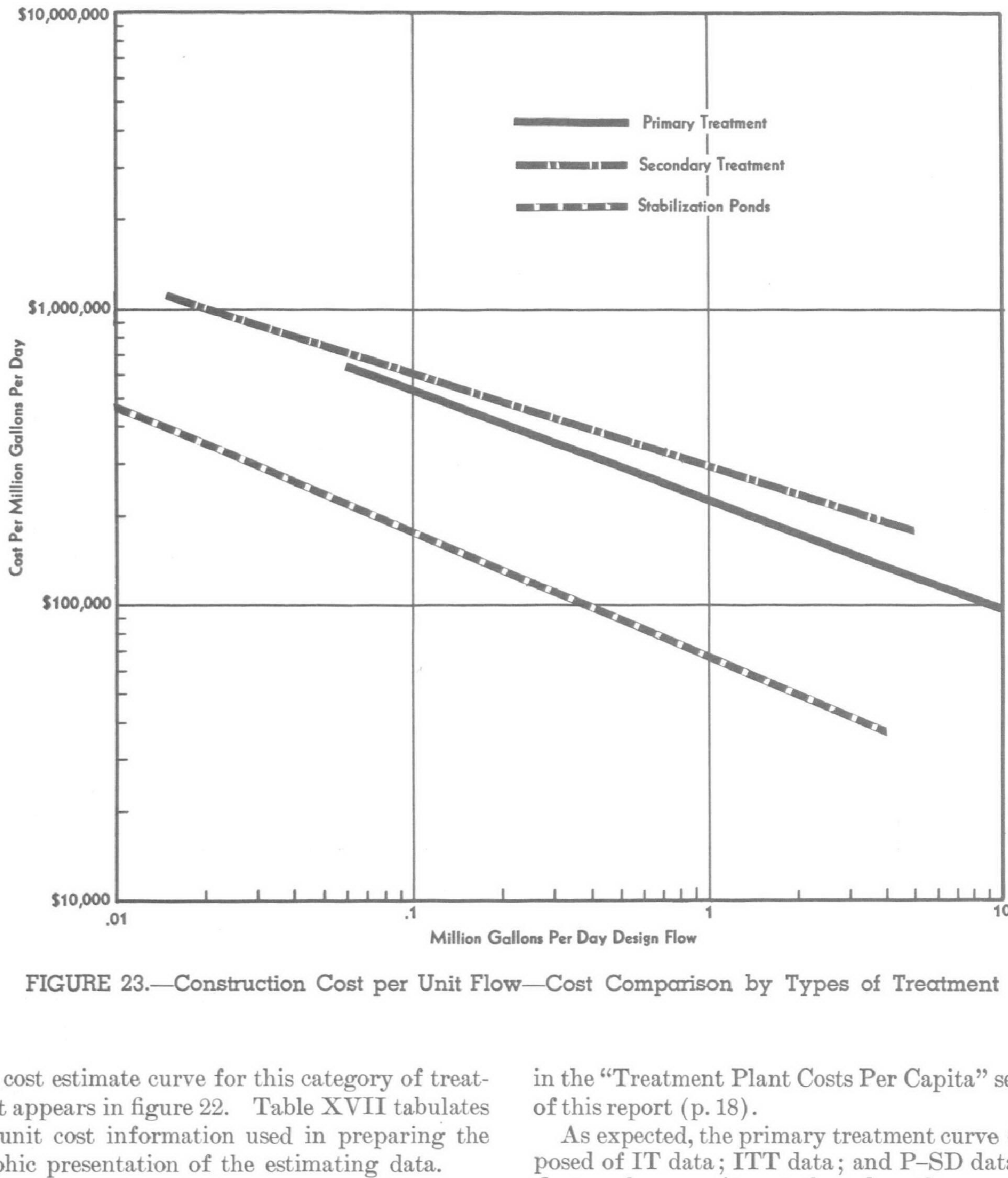

FIGURE 23.—Construction Cost per Unit Flow—Cost Comparison by Types of Treatment

The cost estimate curve for this category of treatment appears in figure 22. Table XVII tabulates the unit cost information used in preparing the graphic presentation of the estimating data.

Comparison of Unit Flow Costs by Types of Treatment

A comparison of the composite primary and secondary treatment cost curves with the individual curve for stabilization ponds, in terms of volume of flow provided in the design, appears in figure 23. A similar comparison was undertaken in the "Treatment Plant Costs Per Capita" section of this report (p. 18).

As expected, the primary treatment curve (composed of IT data; ITT data; and P–SD data) reflects a lower unit cost than does the secondary treatment cost (based on AS data; TF–P data; and TF–ITT data). However, the relationship of these two curves, with respect to each other, varies from that noted in the previous comparison of the same two category curves in the cost per capita study. The differences in slope which exist between the curves as seen in figure 23 and the cost per capita curves in figure 10 (p. 18) occur between the primary category curves and the stabilization pond curves, respectively.

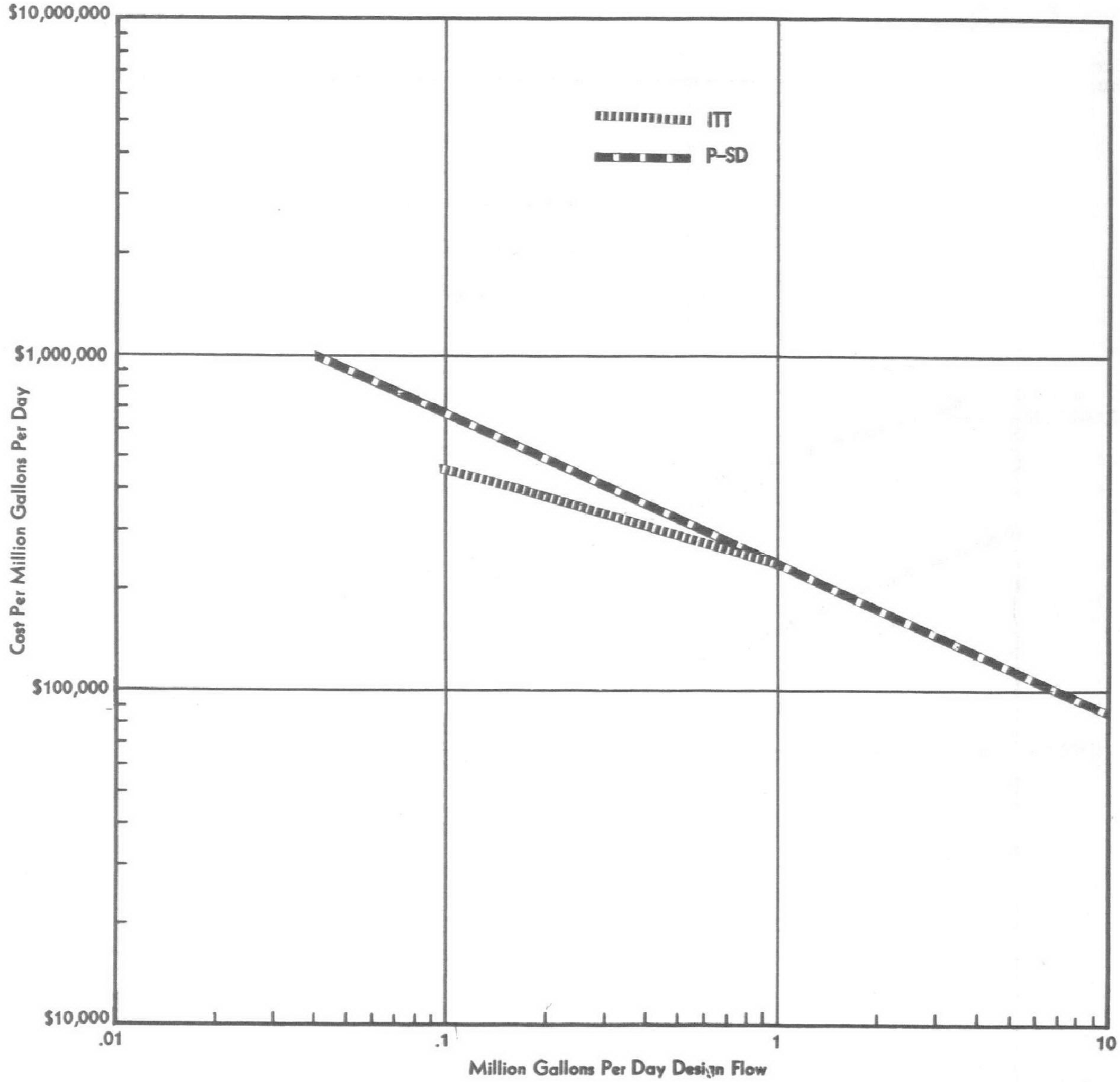

FIGURE 24.—Construction Cost per Unit Flow—Primary Types of Treatment

By subdividing the primary treatment category curve into its two component parts, a comparison of the ITT curve to the P–SD cost curve is shown graphically in figure 24.

The ITT curve depicts lower unit costs at the smaller flow levels, no doubt due to the preponderance of package-type plant systems in this size range. Package-type plant systems are assumed to be less expensive to construct than on-site-constructed facilities for the small population groups.

The two curves intersect at the 1–MGD point and, thereafter the ITT curve reflects a higher unit cost. This phenomenon was anticipated, due to the combined effect of the greater cost of on-site-constructed facilities for the larger flows and the rapid increase in costs of the mechanical equipment used in these larger ITT-type plants.

Figure 25 presents a graphic comparison between the AS cost curve and the TF–P curve per unit of flow. The curves reflect the same relationship to one another that they did in the other two studies of cost per capita and cost per population equivalent. The only difference that was observed between these two curves was their wider divergence. This greater angle of inclination between the AS and TF–P curves could have been caused by the effects of increased flows from industrial sources in the larger communities.

The TF–ITT curve in figure 25 shows an unusual and unexpected pattern with respect to the other two curves, as compared to earlier studies. Based upon its statistical characteristics, however, the curve best describes the sample which it represents.

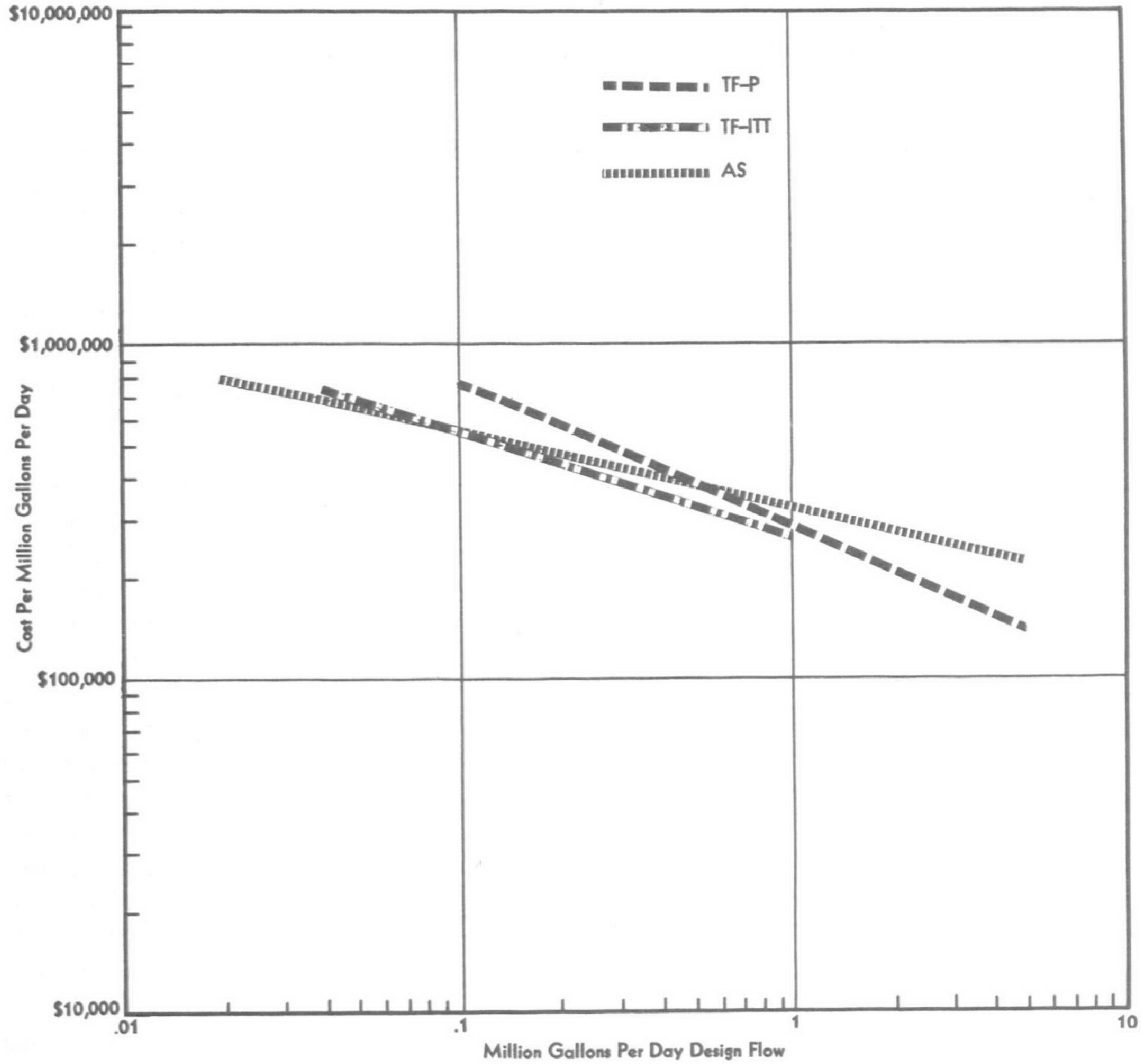

FIGURE 25.—Construction Cost per Unit Flow—Secondary Types of Treatment

Limitations of Cost Estimating Data

Before these curves can be used as effective, realistic estimating aids by municipal officials, planners, developers, designers, regulatory agencies, and investors in sewage works bonds, the limitations of cost estimating tools must be understood. There are two general limitations that affect the use of the estimating data presented in this report.

The first stems from the geographic distribution of the projects which made up the samples for each type of treatment. Certain areas of the United States may have had little or no influence on the raw cost data, while certain other areas may have been proportionately overrepresented. This emphasizes the importance of the PHS–STP cost index system, which largely compensates for cost variations associated with different geographic locations.

The second limitation which may affect the use of these estimating curves is the limited plant sizes or capacities covered by the curves. Extension of any of the curves would be unwarranted, since there is no statistical basis for such extrapolations. The curves should be used only within their valid size ranges, as stated in the presentation of results for each curve, since reliable data did not exist beyond these limits.

Within these limitations the estimating curves should be useful for determining the probable cost of construction for a particular type of treatment plant. It must be noted that cost estimates obtained from these curves will be unit cost estimates for *construction only* expressed in 1957–59 dollars.

TABLE XVIII

Available unit cost estimating curves

Treatment type	Cost per capita		Cost per population equivalent		Cost per unit flow	
	Figure	Page No.	Figure	Page No.	Figure	Page No.
IT	4	12	None	-------	None	-------
ITT	5	13	None	-------	17	26
P-SD	6	14	None	-------	18	28
SP	7	15	None	-------	19	29
AS	3	10	13	22	20	30
TF-P	8	16	14	23	21	31
TF-ITT	9	17	15	24	22	32

Updating of any estimate may be accomplished through use of the PHS-STP index in accordance with the illustration presented on page 11.

To obtain the total cost estimate for a project, the construction cost estimate must be increased by 20 percent to properly consider engineering, legal, administrative, and other costs not included in the construction contracts which the Public Health Service used in its studies. Land costs must also be added.

The cost curves presented in this report are set forth as aids in the preparation of cost estimates for sewage treatment plant construction. However, these costs are statistically derived and therefore can only be used as a guide to the actual costs. For this reason, instead of limiting the costs estimating curves to a single curve, each one has been encased in a "cost envelope," or an interval between high and low costs. The construction cost of a particular system can be expected to fall within this cost interval approximately two-thirds of the time. Sixteen individual cost estimating curves have been developed for seven different types of treatment plants. A cumulative summary of these curves available for estimating purposes is provided in table XVIII.

Table XVIII indicates that more than one estimating curve has been developed for six of the seven treatment plant types. This choice of curves raises the question, "Which curve gives the best cost estimate?" It is believed that the unit cost estimating curves based on design flow are the most responsive indicators of sewage treatment plant construction costs. However, each estimator must determine for himself which parameter best serves his purpose for his specific project.

When comparing the individual curves developed for the same type of treatment process there is a distinct probability that several different estimates will be obtained. In all cases, however, estimates derived from these curves should fall within the "cost interval" for the same individual treatment category in the various cost studies. Minor variations can be rationalized and should cause no significant concern.

Recapitulation of the Studies

(1) Detailed analyses of construction costs for sewage treatment plants of various types and sizes in all sections of the United States, built with Federal grants-in-aid, have made it possible to develop dependable preliminary cost estimating data, reflecting the overall conditions influencing the cost of construction of similar facilities.

(2) Utilization of the PHS–STP Index as the base of the study has assured more representative estimating cost data since the index more specifically reflects the conditions involved in sewage treatment plant construction.

(3) More extensive cost data in each treatment category, obtained from the increased number of construction projects aided by Federal grants, have statistically strengthened the estimating data developed from this information.

(4) More definitive subdivisions of major treatment categories have made it possible to develop more specialized cost estimating data for these processes.

(5) Periodic reexamination of available cost information will be necessary to insure reliability of future cost data, and to reflect changing trends in sewage treatment processes and plant construction methods.

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