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Research and Development

Estimating Water Treatment Costs

Volume 3
Cost Curves Applicable to 2,500 gpd to 1 mgd Treatment Plants

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ESTIMATING WATER TREATMENT COSTS

Volume 3. Cost Curves Applicable to 2,500 gpd to 1 mgd Treatment Plants

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid hazardous water pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research - a most vital communications link between the researcher and the user community.

The cost of water treatment processes that may be used by small water supply systems to remove contaminants included in the National Interim Primary Drinking Water Regulations is of interest to the U.S. Environmental Protection Agency, State and local agencies, and consulting engineers. Volume 3 presents construction and operation and maintenance cost curves for 27 unit processes or package type systems that are especially applicable to small water supply systems with treatment capacities between 2,500 gpd and 1 mgd. These 27 processes were selected for their ability to remove, either individually or in combination, contaminants included in the National Interim Primary Drinking Water Regulations.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

This report is Volume 3 of a four-volume study that presents construction and operation and maintenance cost curves for 99 unit processes that are especially applicable (either individually or in combination) to the removal of contaminants listed in the National Interim Primary Drinking Water Regulations. This volume presents 27 cost curves applicable to small water supply systems (2,500 gpd to 1 mgd).

Volume 1 summarizes the four volumes and discusses the cost-estimating approaches that were used to develop the cost curves and the treatment techniques applicable to contaminant removal. Volume 1 also presents a series of examples demonstrating the use of the cost curves. Volume 2 discusses 72 unit processes that are particularly suited to large water supply systems (1 to 200 mgd). Information is also included on enhanced virus and asbestos removal using modifications of standard unit processes. Volume 4 is a computer user's manual and contains a computer program that can be used to retrieve and update all cost data contained in the four volumes.

Conceptual designs were formulated for each unit process and from these, construction costs were then then developed. The construction costs are presented in tabular format, in terms of eight categories: Excavation and sitework, manufactured equipment, concrete, steel, labor, pipe and valves, electrical equipment and instrumentation, and housing. The construction cost curves were checked for accuracy by a second consulting engineering firm, Zurheide-Herrmann, Inc., using cost estimating techniques similar to those used by general contractors in preparing their bids. Construction costs are also shown plotted versus the most appropriate design parameter for the process, such as pounds per day for chemical feed systems and gallons per minute (or day) for package components.

Operation and maintenance requirements were determined individually for three categories: Energy, maintenance material, and labor. Energy requirements for the building and the process were determined separately.

All costs are presented in terms of October 1978 dollars, and a discussion is included on cost updating. For construction cost, either of two methods may be used. One is the use of indices that are specific to each of the eight categories used in the original determination of construction cost. The second method is the use of an all-encompassing index such as the Engineering News Record Construction Cost Index. Operation and maintenance requirements may be readily updated or adjusted to local conditions, since labor requirements are expressed in hours per year, electrical requirements in kilowatt-hours per year, diesel fuel in gallons per year, and natural gas in standard cubic feet per year.

This report was submitted in fulfillment of Contract No. 68-03-2516 by Culp/Wesner/Culp under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period November 1, 1976 to January 1, 1979, and work was completed as of July 2, 1979.

CONTENTS

FIGURES

TABLES

ABBREVIATIONS AND SYMBOLS

ft	--	foot
ft^2	--	square foot
ft^3	--	cubic feet
G	--	velocity gradient - feet per second per foot
gal	--	gallon
gpd	--	gallons per day
gpd/ft^2	--	gallons per day per square foot
gpm	--	gallons per minute
hr	--	hours
kg	--	kilogram
kw-hr	--	kilowatt-hour
l	--	liter
lb	--	pound
lpd	--	liters per day
lpd/m^3	--	liters per day per cubic meter
lps	--	liters per second
m	--	meter
m^2	--	square meter
m^3	--	cubic meter
m^3/d	--	cubic meters per day
m^3/s	--	cubic meters per second
mg	--	million gallons
mg/l	--	milligrams per liter
mgd	--	million gallons per day
min	--	minutes
mph	--	miles per hour
psi	--	pounds per square inch
scf	--	standard cubic foot
tdh	--	total dynamic head
tu	--	turbidity unit
yd^3	--	cubic yard
yr	--	year

METRIC CONVERSIONS

English Unit	Multiplier	Metric Unit
cu ft	0.028	m^3
cu yd	0.75	m^3
ft	0.3048	m
gal	3.785	l
gal	0.003785	m^3
gpd	0.003785	m^3/d
gpd/ft^2	40.74	lpd/m^2
gpm	0.0631	l/s
lb	0.454	kg
mgd	3785	m^3/d
mgd	0.0438	m^3/sec
sq ft	0.0929	m^2

ACKNOWLEDGEMENTS

This report was prepared under the direction of Dr. Robert M. Clark, EPA Municipal Environmental Research Laboratory, Office of Research and Development. The report was prepared by Robert C. Gumerman, Russell L. Culp, Sigurd P. Hansen, Thomas S. Lineck, and Bruce E. Burris of Culp/Wesner/Culp. Ms. Karin J. Wells of Culp/Wesner/Culp was responsible for typing of the Final Report.

Mr. Ronald M. Dahman of Zurheide-Herrmann, Inc., was responsible for checking all unit costs. Dr. Isadore Nusbaum and Mr. Dean Owens were respective sub-consultants on the reverse osmosis and ion exchange curves.

Special acknowledgement is given to Mr. Keith Carswell, Dr. Robert M. Clark, Mr. Jack De Marco, Dr. Gary Logsdon, Dr. O. Thomas Love, Mr. Benjamin Lykins, Jr., Mr. Thomas J. Sorg, all of the EPA Municipal Environmental Research Laboratory, who reviewed the Final Report.

Mrs. Anne Hamilton was the technical editor for all four volumes of this report.

SECTION 1

INTRODUCTION

SCOPE

This report is Volume 3 of a four-volume study that presents construction and operation and maintenance cost curves for 99 unit processes that are especially applicable (either individually or in combination) to the removal of contaminants listed in the National Interim Primary Drinking Water Regulations.[1,2,3] This volume presents the cost for 27 unit processes that are particularly suited to small water supply systems (2,500 gpd to 1 mgd). The costs were developed to a high level of accuracy initially and were then checked by a second engineering consulting firm, Zurheide-Herrmann, Inc., using cost-estimating techniques similar to those used by general contractors in preparing their bids. The cost information for the 27 unit processes is presented in both graphic and tabular form for both construction and operation and maintenance. A description of the methodology used to derive the cost curves and to update them is presented in Volume 1 of the report.

BACKGROUND

When the Safe Drinking Water Act (PL 93-523)[4] was enacted on December 16, 1974, it was recognized that the cost of an equivalent level of treatment would be greater for a small water supply system than for a large utility. In general, this greater financial impact on small systems is due to a loss of economy of scale rather than to the quality of the raw water supply. The treatment requirements may be similar for large and small systems, but the unit costs of treatment for the small water supply system will generally be higher.

To reduce the unit cost of treating water in small quantities, different types of treatment techniques or treatment configurations are normally utilized for small treatment systems. For example, package plants are commonly employed to reduce capital costs for small treatment facilities. The use of package c pre-fabricated facilities rather than custom designed, reinforced concrete structures can significantly reduce small treatment facility costs. In other cases, costs may be reduced by using processes that are seldom utilized in large treatment plants - reverse osmosis, ion exchange, and ultra filtration , for example.

PURPOSE AND OBJECTIVES

The purpose of Volume 3 is to present the cost of treatment processes and techniques that are applicable to the treatment of flows between 2,500 and 1 million gpd. Construction costs were developed and are presented in terms of eight individual components; operation and maintenance costs were developed and are presented in terms of four components. This approach was used to facilitate both the original cost derivation, as well as to facilitate the updating of costs.

The unit processes presented in this volume are:

1. Package Complete Treatment Plants
2. Package Gravity Filtration Plants
3. Package Pressure Filtration Plants
4. Filter Media
5. Package Vacuum Diatomite Filters
6. Package Pressure Diatomite Filters
7. Package Ultrafiltration Plants
8. Package Granular Activated Carbon Columns
9. Potassium Permanganate Feed Systems
10. Polymer Feed Systems
11. Powdered Activated Carbon
12. Chlorine Feed Systems
13. Ozone Generation Systems and Contact Chambers
14. Chlorine Dioxide Generating and Feed Systems
15. Ultraviolet Light Disinfection
16. Reverse Osmosis
17. Pressure Ion Exchange Softening
18. Pressure Ion Exchange Nitrate Removal
19. Activated Alumina Fluoride Removal
20. Bone Char Fluoride Removal
21. Package Raw Water Pumping Facilities
22. Package High-Service Pumping Stations
23. Steel Backwash/Clearwell Tanks
24. Sludge Hauling to Landfill
25. Sludge Disposal to Sanitary Sewers
26. Sludge Dewatering Lagoons
27. Sand Drying Beds

SECTION 2

COST CURVES

CONSTRUCTION COST CURVES

The construction cost curves were developed using equipment cost data supplied by manufacturers, cost data from actual plant construction, unit takeoffs from actual and conceptual designs, and published data. When unit cost takeoffs were used to determine costs from actual and conceptual designs, estimating techniques from Richardson Engineering Services Process Plant Construction Estimating Standards[5], Mean's Building Construction Cost Data[6], and Dodge Guide for Estimating Public Works Construction Costs[7] were often utilized. The cost curves that were developed were then checked and verified by a second engineering consulting firm, Zurheide-Herrmann, Inc., using an approach similar to that which a general contractor would utilize in determining his construction bid. Every attempt has been made to present the conceptual designs and assumptions that were incorporated into the curves. Adjustment of the curves may be necessary to reflect site-specific conditions, geographic or local conditions, or the need for standby power. The curves should be particularly useful for estimating the relative economics of alternative treatment systems and for the preliminary evaluation of general cost level to be expected for a proposed project. The curves contained in this report are based on October 1978 costs.

The construction cost was developed by determining and then aggregating the cost of eight principal components, which were utilized primarily to facilitate accurate cost updating (discussed in a subsequent section of this chapter). The division will also be helpful where costs are being adjusted for site-specific, geographic, and other special conditions. The eight categories include the following general items:

Excavation and Site Work. This category includes work related only to the applicable process and does not include any general site work such as sidewalks, roads, driveways, or landscaping.

Manufactured Equipment. This category includes estimated purchase cost of pumps, drives, process equipment, specific purpose controls, and other items that are factory made and sold with equipment.

Concrete. This category includes the delivered cost of ready-mix concrete and concrete-forming materials.

Steel. This category includes reinforcing steel for concrete and miscellaneous steel not included within the manufactured equipment category.

Labor. The labor associated with installing manufactured equipment, and piping and valves, constructing concrete forms, and placing concrete and reinforcing steel are included in this category.

Pipe and Valves. Cast iron pipe, steel pipe, valves, and fittings have been combined into a single category. The purchase price of pipe, valves, fittings, and associated support devices are included within this category.

Electrical Equipment and Instrumentation. The cost of process electrical equipment, wiring, and general instrumentation associated with the process equipment is included in this category.

Housing. In lieu of segregating building costs into several components, this category represents all material and labor costs associated with the building, including heating, ventilating, air conditioning, lighting, normal convenience outlets, and the slab and foundation.

The subtotal of the costs of these eight categories includes the cost of material and equipment purchase and installation, and the subcontractor's overhead and profit. To this subtotal, a 15-percent allowance has been added to cover miscellaneous items not included in the cost takeoff, as well as contingency items. Experience at many water treatment facilities has indicated that this 15-percent allowance is reasonable. Although blanket application of this 15-percent allowance may result in some minor inequities between processes, these are generally balanced out during the combination of costs for individual processes into a treatment system.

The construction cost for each unit process is presented as a function of the most applicable design parameter for the process. For example, construction costs for package gravity filter plants are plotted versus capacity in gallons per minute, whereas ozone generation system costs are presented versus pounds per day of feed capacity. Use of such key design parameters allows the curves to be utilized with greater flexibility than if all costs were plotted versus flow.

The construction costs shown in the curves do not equal the final capital cost for the unit process. The construction cost curves do not include costs for special sitework, general contractor overhead and profit, engineering, interest, land, or legal, fiscal, and administrative services during construction. These cost items are all more directly related to the total cost of a project than to the cost of the individual unit processes. They therefore are most appropriately added following summation of the cost of the individual unit processes, if more than one unit process is required. An example calculation for a 350-gpm package complete treatment plant is presented in Section 3 of this volume, and a number of other examples are given in Volume 1 of this report. These examples illustrate the recommended method for the addition of these costs to the construction cost.

OPERATION AND MAINTENANCE COST CURVES

Operation and maintenance curves were developed for: (1) energy requirements, (2) maintenance material requirements, (3) labor requirements, and (4) total operation and maintenance cost. The energy categories included are: process energy, building energy, diesel fuel, and natural gas. The operation and maintenance requirements were determined from operating data at existing plants, at least to the extent possible. Where such information was not available, assumptions were made based on the experience of both the author and the equipment manufacturer, and such assumptions are stated in the description of the cost curve.

Electrical energy requirements were developed for both process energy and building-related energy, and they are presented in terms of kilowatt-hours per year. This approach was used to allow adjustment for geographical influence on building-related energy. For example, though lighting requirements average about 17.5 kw-hr/ft^2 per year throughout the United States, heating, cooling, and ventilating requirements vary from a low of about 8 kw-hr/ft^2 per year in Miami, Florida, to a high of about 202 kw-hr/ft^2 per year in Minneapolis, Minnesota. The building energy requirements presented for each process are in terms of kilowatt-hours per year, and were calculated using an average building-related demand of 102.6 kw-hr/ft^2 per year. This is an average for the 21 cities included in the Engineering News Record (ENR) Index. An explanation of the derivation of this figure is included in Volume 1, Appendix B of this report. The computer program developed as a portion of this Project will allow use of other building-related energy demands than 102.6 kw-hr/ft^2 per year. Process electrical energy is also included in the electrical energy curve, and it was calculated using manufacturers data for required components. Where required, separate energy curves for natural gas and diesel fuel are also presented. When using the curves to determine energy requirements, the design flow or parameter should be utilized to determine building energy, and the operating flow or parameter should be used to determine process energy, diesel fuel, and natural gas.

Maintenance material costs include the cost of periodic replacement of component parts necessary to keep the process operable and functioning. Examples of maintenance material items included are valves, motors, instrumentation, and other process items of similar nature. The maintenance material requirements <u>do not include the cost of chemicals</u> required for process operation. <u>Chemical costs must be added separately</u>, as will be shown in the subsequent example. The operating parameter or flow should be used to determine maintenance material requirements.

The labor requirement curve includes both operation and maintenance labor, and it is presented in terms of hours per year. The operating parameter or flow should be used to determine the labor requirement.

The total operation and maintenance cost curve is a composite of the energy, maintenance material, and labor curves. To determine annual energy costs, unit costs of \$0.03/kw-hr of electricity, \$0.0013/ft^3 of natural gas, and \$0.45/gal of diesel fuel were utilized. The labor requirements were converted to an annual cost using an hourly labor rate of \$10.00/hr, which includes salary and fringe benefits. The computer program that was developed as a portion of this project and that is presented in Volume 4 of this report will allow utilization of other unit costs for energy and labor.

UPDATING COSTS TO TIME OF CONSTRUCTION

Continued usefulness of the curves developed as a portion of this project depends on the ability of the curves to be updated to reflect inflationary increases in the prices of the various components. Most engineers and planners are accustomed to updating costs using one all-encompassing index, which is developed by tracking the cost of specific items and then proportioning the costs according to a predetermined ratio. The key advantage of a single index is the simplicity with which it can be applied. Although use of a single index is an uncomplicated approach, there is much evidence to indicate that these time-honored indices are not understood by many users and/or are inadequate for application to water works construction.

The most frequently utilized single indices in the construction industry are the ENR Construction Cost Index (CCI) and Building Cost Index (BCI). These ENR indices were started in 1921 and were intended for general construction cost monitoring. The CCI consists of 200 hr of common labor, 2,500 lb of structural steel shapes, 1.128 tons of Portland cement and 1,008 board feet of 2 x 4 lumber. The BCI consists of 68.38 hr of skilled labor plus the same materials included in the CCI. The large amount of labor included in the CCI was appropriate before World War II; however, on most contemporary construction, the index labor component is far in excess of actual labor used.

To update the construction cost using the CCI, which was 265.38 in October 1978, the following formula may be utilized:

$$\text{Updated Cost} = \text{Total Construction Cost from Curve } \left(\frac{\text{Current CCI}}{265.38}\right)$$

This approach may also be utilized in the computer program that was developed for this report.

Although key advantages of the ENR indices include their availability, their simplicity, and their geographical specificity, many engineers and planners believe that these indices are not applicable to water treatment plant construction. The rationale for this belief is that the indices do not include mechanical equipment or pipe and valves that are normally associated with such construction, and the proportional mix of materials and labor is not specific to water treatment plant construction.

An approach that may be utilized to overcome the shortcomings of the ENR indices relative to water works construction is to apply specific indices to the major cost components of the construction cost curves. This approach allows the curve to be updated using indices specific to each category and weighted according to the dollar significance of the category. For the eight major categories of construction cost, the following Bureau of Labor Statistics (BLS)[8] and ENR indices were utilized as a basis for the cost curves included in this report.

Cost Component	Index	October 1978 Value of Index
Excavation and Sitework	ENR Skilled Labor Wage Index (1967)	247
Manufactured Equipment	BLS General Purpose Machinery and Equipment - Code 114	221.3
Concrete	BLS Concrete Ingredients Code 132	221.1
Steel	BLS Steel Mill Products Code 1013	262.1
Labor	ENR Skilled Labor Wage Index (1967 Base)	247
Pipe and Valves	BLS Valves and Fittings Code 114901	236.4
Electrical Equipment & Instrumentation	BLS Electrical Machinery and Equipment - Code 117	167.5
Housing	ENR Building Cost Index (1967 Base)	254.76

The principal disadvantages of this approach are the lack of geographical specificity of the BLS indices and the use of seven indices rather than a single index.

To update the construction costs using the above two ENR and six BLS indices, the construction cost from the construction cost curve must first be broken down into the eight component categories. One acceptable method of accomplishing this breakdown is to utilize all the detailed cost estimates included in the construction cost table to determine the average percent of the subtotal construction cost for each of the eight (or fewer) construction cost components. The appropriate index for each component can then be used to update the component cost. For example, in the construction cost table for package complete treatment plants, the sum of the manufactured equipment costs for the eight designs is $566,190, and the subtotal of construction costs for these eight designs is $1,355,310. The ratio of these two costs is 0.4178, meaning that on the average, manufactured equipment is 41.78 percent of the subtotal construction cost. Therefore, if the construction cost curve gives a construction cost of $250,000, and the BLS General Purpose Machinery and Equipment Index is 250, the manufactured equipment cost would be:

$$\text{Manufactured Equipment Cost} = 0.4178\ (\$250{,}000)\ \left(\frac{250}{221.3}\right) = \$118{,}000$$

When this approach is used with each of the components of construction cost, the updated sum gives the subtotal of construction cost, and the updated total construction cost is obtained by adding 15 percent to this updated subtotal cost. Either this approach or the previously described approach using the CCI may be used with the computer program presented in Volume 4 of this report.

Updating of total operation and maintenance costs may be accomplished by updating the three individual components: energy, labor, and maintenance material. Energy and labor are updated by applying the current unit cost to the kilowatt-hour and labor requirements obtained from the energy and labor curves. Maintenance material costs, which are presented in terms of dollars per year, can be updated using the Producer Price Index for Finished Goods. The maintenance material costs in this report are based on an October 1978 Producer Price Index for Finished Goods of 199.7.

FIRMS THAT SUPPLIED COST AND TECHNICAL INFORMATION

During the development of both construction and operation and maintenance cost curves, a large number of equipment manufacturers and other firms were contacted to determine cost and technical information. The help provided by those that did respond is sincerely appreciated, for the information furnished was instrumental in assuring a high level of accuracy for the curves. The manufacturers and other firms that provided input to this study were:

Acrison, Inc.
Advance Chlorination Equipment
Aqua-Aerobic Systems, Inc.
Aquafine Corporation
BIF, a Division of General Signal Corporation
Bird Centrifuge
Capital Control Company
Ralph B. Carter Company
Chemical Separations Corporation
Chicago Bridge and Iron Company
Chicago, Rock Island and Pacific Railroad Company
Chromalloy, L.A. Water Treatment Division
Clarkson Industries, Inc., Hoffman Air & Filtration Division
Colt Industries, Inc., Fairbanks Morse Pump Division
Continental Water Conditioning
Copeland Systems
Crane Company, Cochrane Environmental Systems
Curtiss-Wright Corporation
DeLaval Turbine, Inc.
Dorr-Oliver, Inc.
Dravo Corporation
The Duriron Company, Inc., Filtration Systems Division
E.I. Dupont De Nemours & Company, Inc.
The Eimco Corporation
Electrode Corporation, Subsidiary of Diamond Shamrock Corporation
Englehard Industries

Envirex, Inc. - A Rexnord Company
Environmental Conditioners
Environmental Elements Corp., Subsidiary of Koppers Co., Inc.
Envirotech Corporation
Fischer and Porter Company
FMC Corporation
General Filter Company
Infilco Degremont, Inc.
Ionics, Inc.
Johns-Manville
Kaiser Chemicals
Keystone Engineering
Komline-Sanderson Engineering Corporation
Merck & Co., Inc., Calgon Company
Mixing Equipment Company, Inc.
Morton-Norwick Products, Inc., Morton Salt Company
Muscatine Sand and Gravel
Nash Engineering Company
Neptune Micro Floc, Inc.
Nichols Engineering & Research Corp., Neptune International Corp.
Northern Gravel Company
Ozark-Mahoning Company
Pacific Engineering & Production Company of Nevada
PACO
R.H. Palmer Coal Company
Passavant Corporation
PCI Ozone Corp., A Subsidiary of Pollution Control Industries, Inc.
Peabody Welles, Inc.
Peerless Pump
Pennwalt Corporation
The Permutit Company, Inc., Division of Sybron Corporation
Reading Anthracite Company
Robbins & Meyers, Inc., Moyno Pump Division
Rohm and Haas Company, Fluid Process Chemicals Department
Shirco, Inc.
D.R. Sperry & Company
Sybron Corporation, R.B. Leopold Co. Division
TOMCO2 Equipment Company
Union Carbide Corporation - Linde Division
Universal Oil Products Company, Fluid Systems Division
U.S. Filter Co., Inc., Calfilco Division
Westvaco Corporation, Chemical Division
Western States Machine Company
Worthington Pump, Inc.
Zimpro, Inc.

PACKAGE COMPLETE TREATMENT PLANTS

Construction Cost

The use of package complete treatment plants (coagulation, flocculation, sedimentation and filtration) has grown substantially during the last 10 years. These plants, which are available either as factory-preassembled units or field-assembled modules, significantly reduce the cost of small facilities (110,000 gpd to 2 mgd). The units are automatically controlled and require only minimal operator attention.

Cost estimates were developed for standard manufactured units incorporating 20 min of flocculation, tube settlers rated at 150 gpd/ft^2, mixed-media filters rated at 2 and 5 gpm/ft^2, and a media depth of 30 in. The costs include premanufactured treatment plant components, mixed media, chemical feed facilities (storage tanks and feed pumps), flow measurement and control devices, pneumatic air supply (for plants of 200 gpm and larger) for valve and instrument operation, effluent and backwash pumps, all necessary controls for a complete and operable unit, and building. The three smaller plants utilize low-head filter effluent transfer pumps and are to be used with an above-grade clearwell. The larger plants gravity discharge to a below-grade clearwell. A typical installation is shown in Figure 1.

Raw water intake and pumping facilities, clearwell storage, high-service pumping, and sitework, exclusive of foundation preparations, are not included in the costs.

Construction costs are presented in Figure 2 and Table 1.

Operation and Maintenance Cost

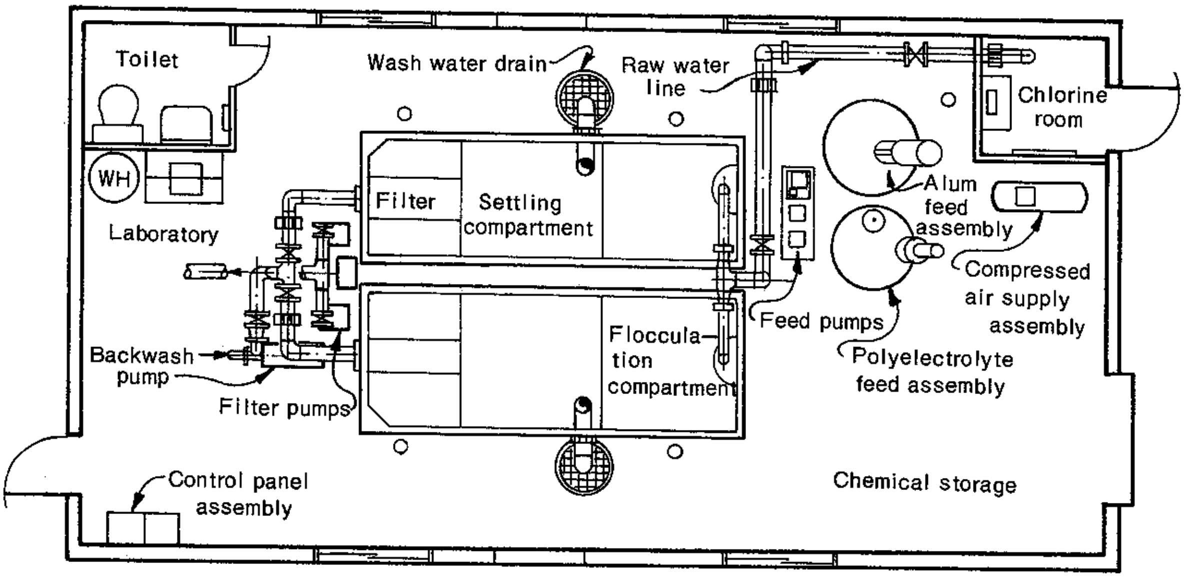
Complete treatment package plants (coagulation, flocculation, sedimentation, and filtration) are designed for essentially unattended operation - that is, they backwash automatically on the basis of headloss or excessive filtered water turbidity and return to service.

The principal use of energy is for building heating, cooling, and ventilation, and these requirements have been based on a completely housed plant. Process energy is required for flocculators, rapid mix, chemical pumping, and filter backwash.

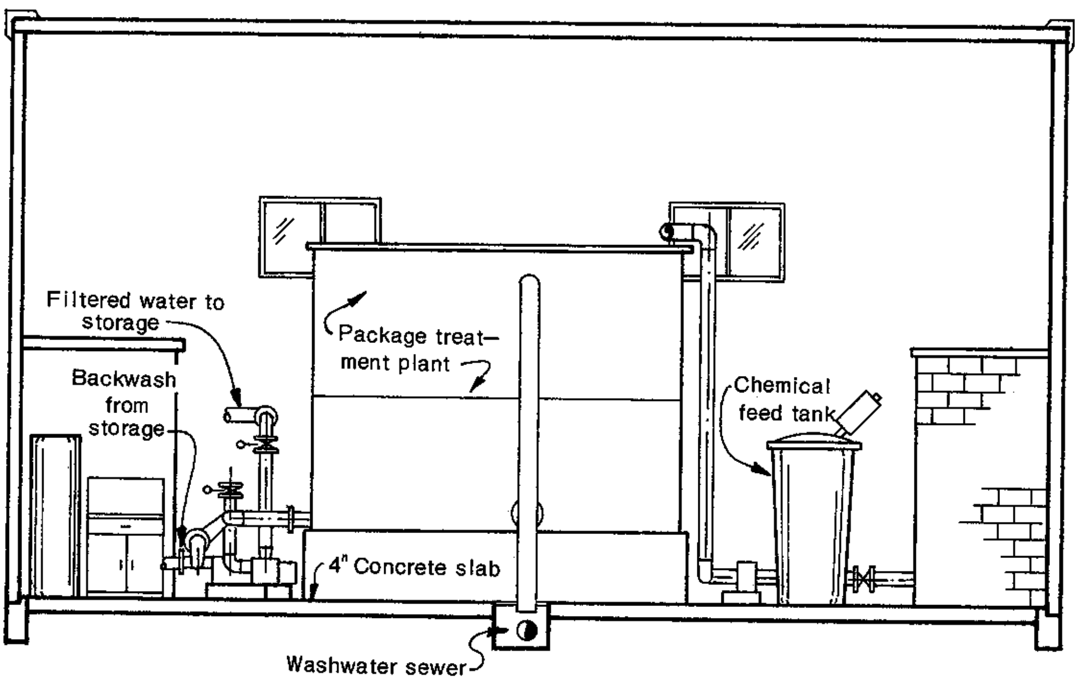
The cost of maintenance material was based on information obtained from typical operating installations. Included are the costs of anthracite coal to replace that lost during backwash, miscellaneous small replacement parts for controls and instrumentation, and other general supplies related to the operation of the treatment plant proper. Excluded are those costs related to treatment plant administrative activities, laboratory services, chemicals or other related supplies, and general facility maintenance.

Operator attention is required to replenish treatment chemicals, make proper chemical dosage requirements, perform routine laboratory quality assurance tests, and carry out necessary daily maintenance and other housekeeping tasks. Labor estimates were based on performance of these tasks.

Operation and maintenance requirements for plant filtration rates of 2 and 5 gpm/ft^2 are presented in Figures 3 and 4 and summarized in Table 2.



PLAN VIEW



ELEVATION VIEW

Figure 1. Typical package complete water treatment plant installation.

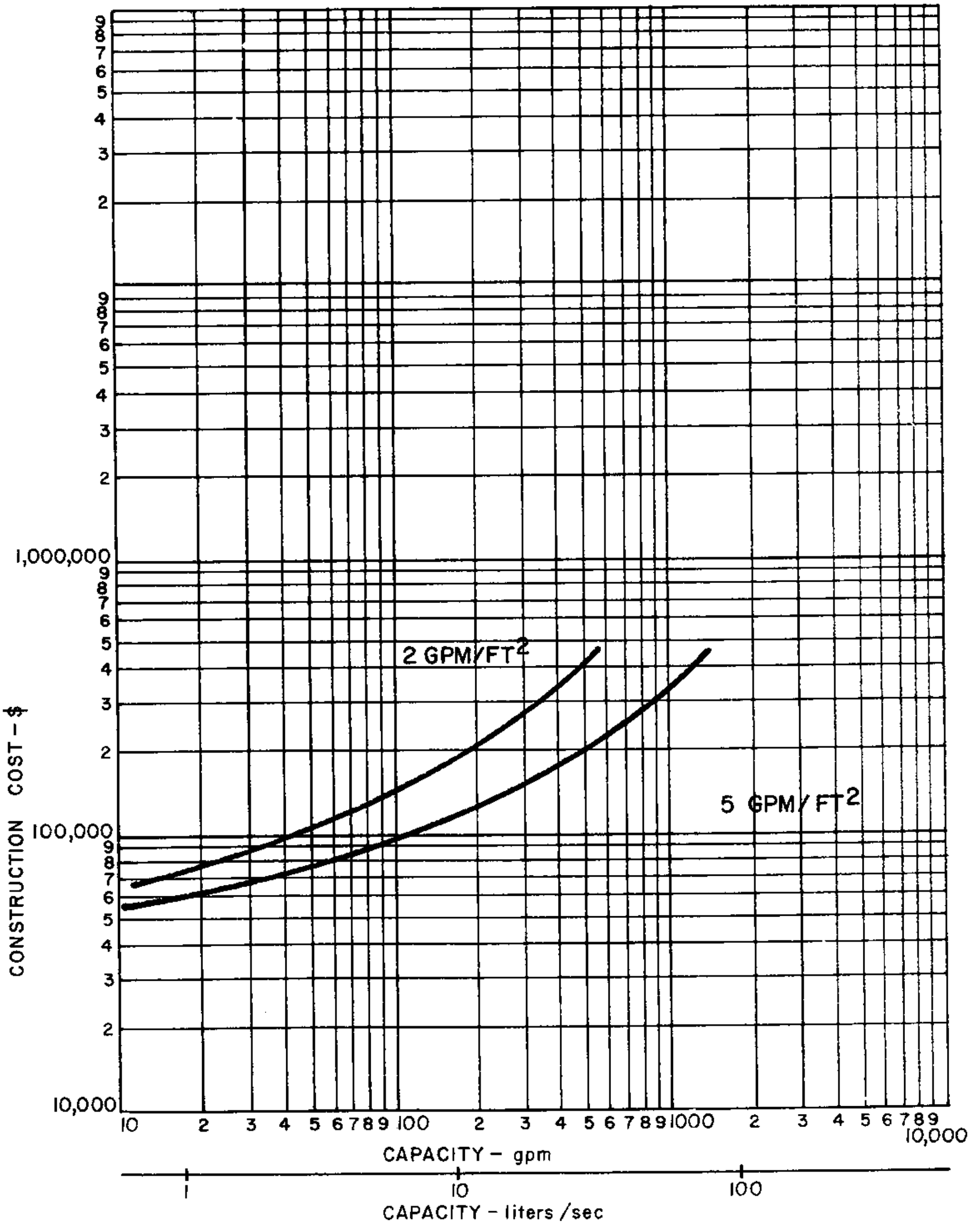


Figure 2. Construction cost for package complete treatment plants at filtration rates of 2 and 5 gpm/ft^2

Table 1

Construction Cost for

Package Complete Treatment Plants

Cost Category	Plant Capacity (gpm)							
	4* and 10+	8 and 20	40 and 100	80 and 200	140 and 350	225 and 560	280 and 700	560 and 1,400
Excavation and Sitework	$ 210	$ 270	$ 390	$ 550	$ 810	$ 340	$ 1,310	2,210
Manufactured Equipment	13,050	16,340	30,770	53,040	72,140	89,110	106,090	185,650
Concrete	370	460	690	1,100	1,950	2,070	3,110	4,590
Labor	5,360	6,310	7,360	10,720	14,290	17,660	25,230	39,410
Pipe and Valves	1,060	1,170	1,590	2,980	3,610	4,360	5,950	9,250
Electrical and Instrumentation	16,360	17,570	21,580	21,580	26,990	30,140	49,100	67,210
Housing	15,960	17,460	21,740	29,240	48,840	51,080	73,150	103,880
SUBTOTAL	52,370	59,580	84,120	119,210	168,630	195,260	263,940	412,200
Miscellaneous and Contingency	7,860	8,940	12,620	17,880	25,290	29,290	39,590	61,830
TOTAL	60,230	68,520	96,740	137,090	193,920	224,550	303,530	474,030

*Lower capacity represents a filtration rate of 2 gpm/ft^2.
+Higher capacity represents a filtration rate of 5 gpm/ft^2.

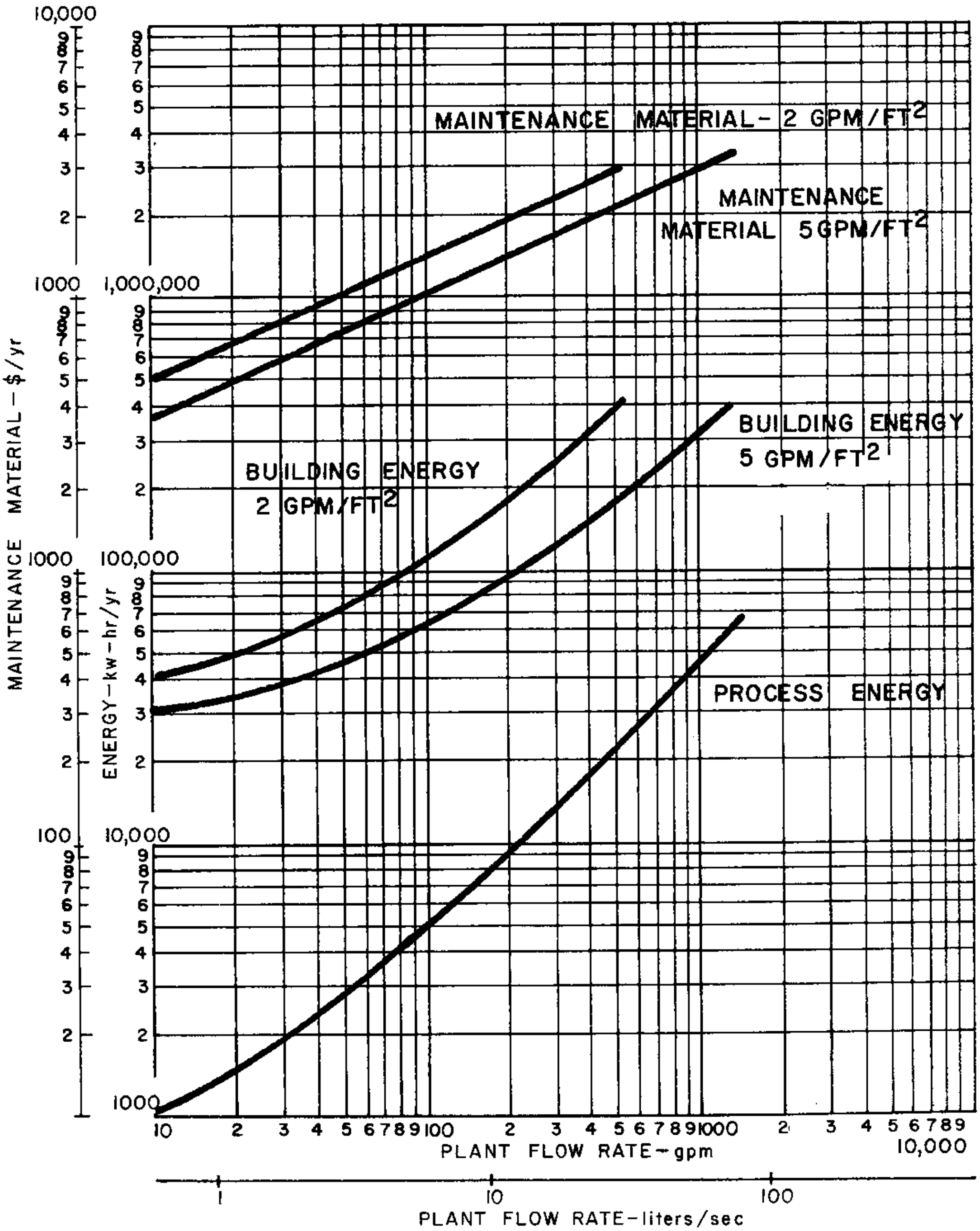


Figure 3. Operation and maintenance requirements for package complete treatment plants - building energy, process energy, and maintenance material at filtration rates of 2 and 5 gpm/ft^2.

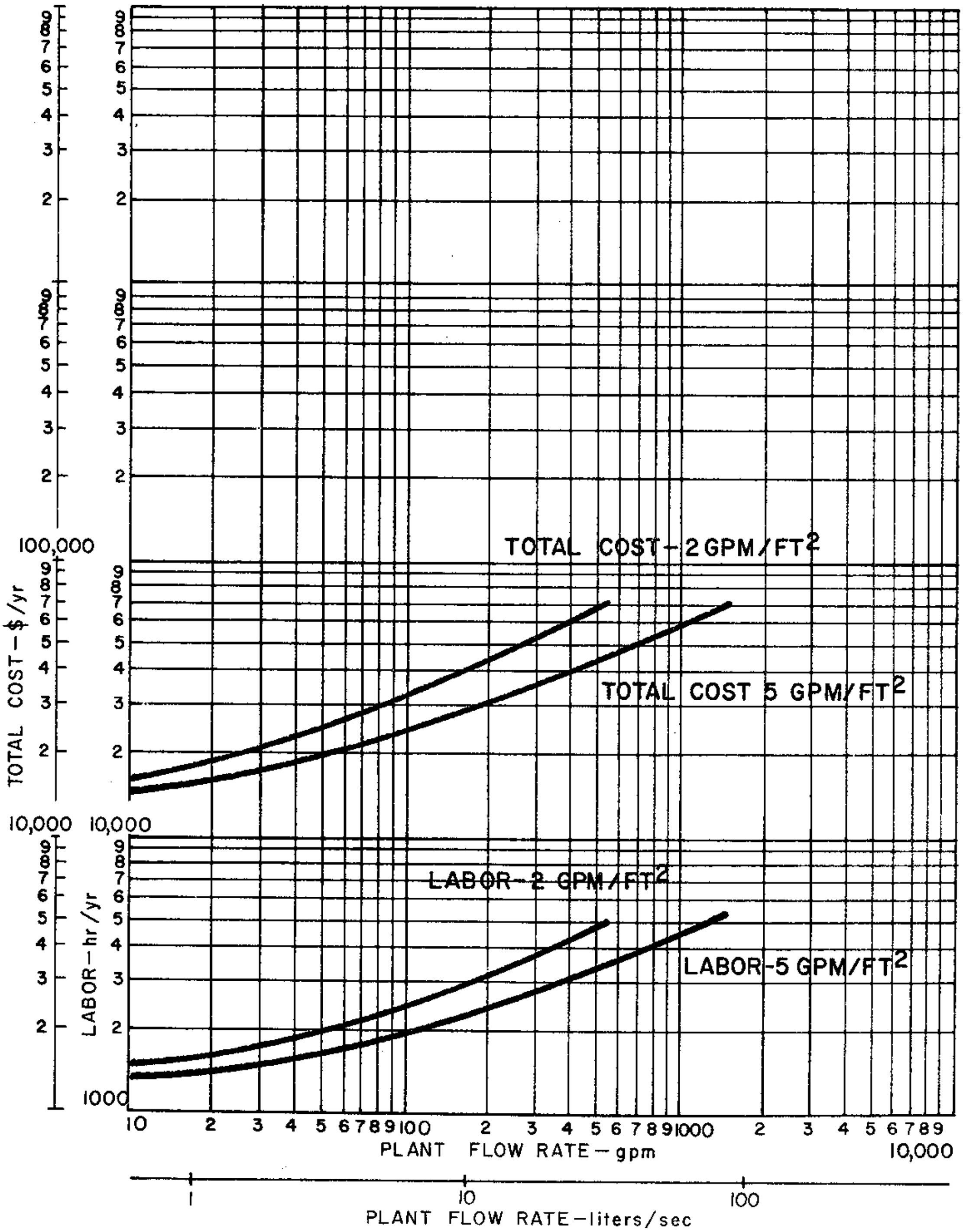


Figure 4. Operation and maintenance requirements for package complete treatment plants - labor and total cost at filtration rates of 2 and 5 gpm/ft^2.

Table 2

Operation and Maintenance Summary for

Package Complete Treatment Plants

Plant Capacity (gpm)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
Filtration Rate of 2 gpm/ft^2:						
4	30,780	320	31,100	$ 320	$1,460	$ 15,850
8	38,780	390	39,170	590	1,460	16,360
40	61,560	3,210	64,770	860	1,750	20,300
80	98,500	3,950	102,450	1,600	3,200	36,670
140	174,420	6,920	181,340	1,920	3,600	43,360
225	184,680	11,060	195,740	2,140	3,600	44,010
280	277,020	13,830	290,850	2,570	3,600	47,300
560	410,400	27,660	438,060	3,210	5,400	70,350
Filtration Rate of 5 gpm/ft^2:						
10	30,780	780	31,560	320	1,460	15,870
20	38,780	1,560	40,340	590	1,460	16,400
100	61,560	7,810	69,370	860	1,750	20,440
200	98,500	9,470	107,970	1,600	3,200	36,840
350	174,420	16,580	191,000	1,920	3,600	43,650
560	184,680	26,520	211,200	2,140	3,600	44,480
700	277,020	33,150	310,170	2,570	3,600	47,880
1,400	410,400	66,300	476,700	3,210	5,400	71,510

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

PACKAGE GRAVITY FILTRATION PLANTS

Construction Cost

Cost estimates were developed for package gravity filtration plants preceeded by a 1-hr detention basin. The capacity range utilized was 80 to 1,400 gpm for filtration rates of 2 and 5 gpm/ft^2 and a media depth of 30 in. Package filtration plants with capacities smaller than 80 gpm are not recommended because operational skill and attention are often severely limited. At flows less that 80 gpm, package complete treatment plants (coagulation, flocculation, settling, and filtration) are generally recommended.

Conceptual designs for the cost estimates are presented in Table 3. These conceptual designs are representative of package gravity filter plants currently in widespread service, and much of the construction cost data utilized was obtained from equipment manufacturers and from actual installations. The conceptual designs analyzed in the report include a 1-hr detention control basin before filtration. The contact basin removes rapidly settling materials such as sand and silt that could hamper operation of the filters, and it also provides additional time for coagulant dispersion and flocculation. The contact basin serves to dampen the effects on coagulant requirements caused by raw water quality changes and provides the operator with additional time to make necessary chemical dosage changes. The efficiency of chlorine disinfection is also enhanced by the detention time provided in the contact basin.

Cost estimates are for filter vessels that are open-top, cylindrical steel tanks sized to permit shop fabrication and over-the-road shipment. The plants are complete, including filter vessels, mixed media, piping, valves, controls, electrical system, backwash system, surface wash system, chemical feed systems (alum, soda ash, polymer, and chlorine), raw water pumps (no intake structure), 1-hr detention pre-filter contact basin, backwash/clearwell storage basin, building, and other ancillary items required for a complete and operable installation.

The estimated construction costs for filtration rates of 2 and 5 gpm/ft^2 are shown in Figure 5 and presented in Table 4.

Operation and Maintenance Cost

Building-related electrical energy for lighting, ventilation, heating, and other uses was projected for each size facility based on floor area of the structure. In all cases, the filters, piping, controls, chemical feed equipment, and other mechanical appurtenances are entirely enclosed. Process-related energy is for filter supply pumping, filter backwash, and filter surface wash.

The cost of maintenance material was estimated from background information obtained from several operating facilities. This item includes the cost of anthracite coal to replace that which is backwashed out of the filters, miscellaneous small parts for controls and instrumentation, recorder ink, and charts and other general supplies related only to actual operation

Table 3

Conceptual Design for

Package Gravity Filter Plants

Plant Capacity (gpm)		Filter Vessels				
2 gpm/ft^2	5 gpm/ft^2	Number of Units	Filter Area (ft^2)	Diameter (ft)	Total Filter Area (ft^2)	Housing Area (ft^2)
80	200	2	20	5	40	1,500
140	350	2	38	7	76	1,800
225	560	2	50	8	100	1,800
280	700	2	79	10	158	1,800
560	1,400	3	113	12	339	3,600

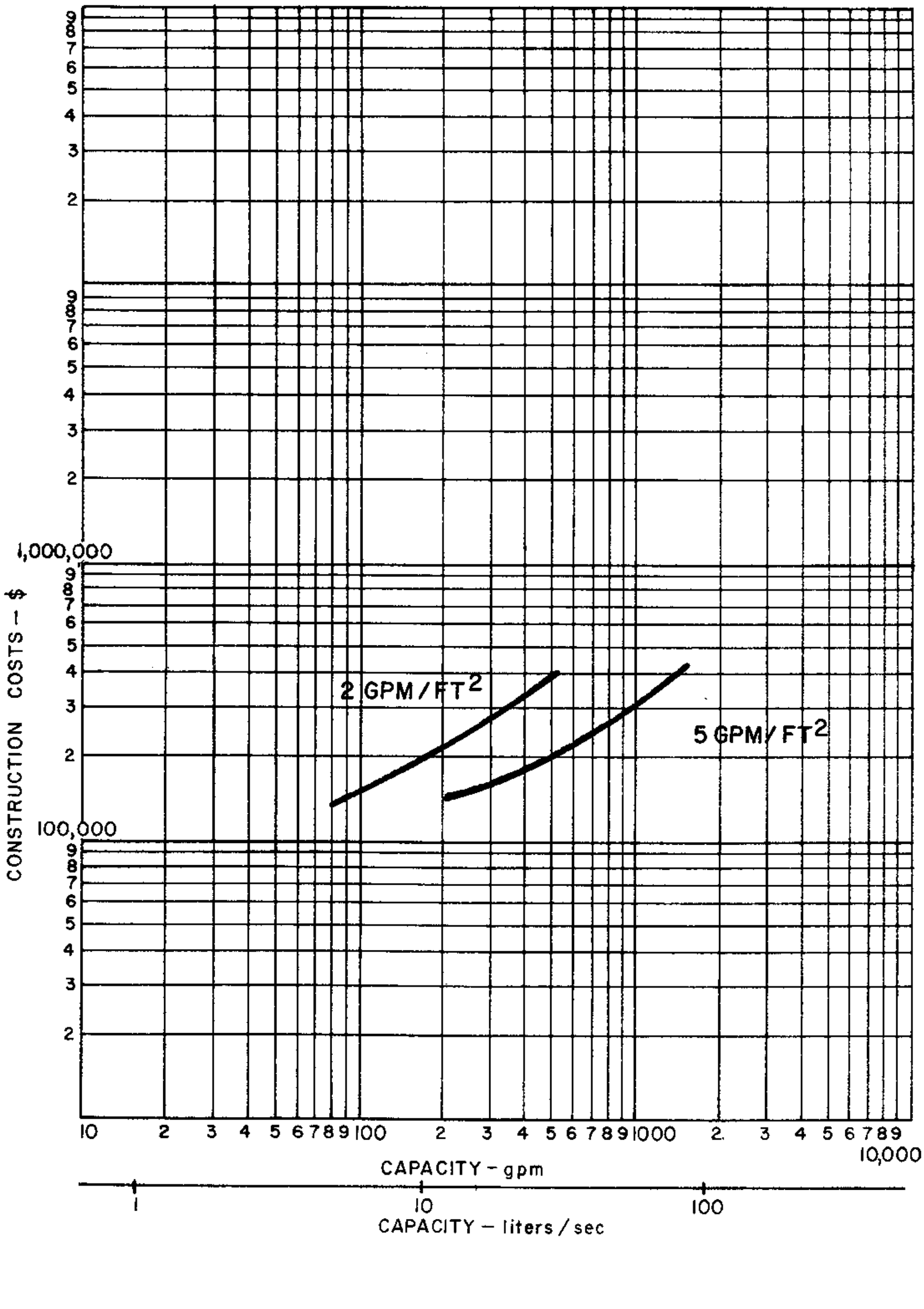


Figure 5. Construction cost for package gravity filter plants at filtration rates of 2 and 5 gpm/ft^2.

Table 4

Construction Cost for

Package Gravity Filter Plants

Cost Category	Plant Flow Rate (gpm) 80* and 200+	140 and 350	225 and 560	280 and 700	560 and 1,400
Excavation and Sitework	$830	$1,140	$1,510	$1,660	$2,800
Manufactured Equipment	28,640	37,130	40,310	53,040	95,480
Concrete	14,840	20,670	28,090	30,740	50,350
Labor	11,800	13,340	14,330	17,290	27,040
Pipe and Valves	6,870	8,910	11,810	12,380	26,870
Electrical and Instrumentation	20,410	26,070	32,450	48,580	84,800
Housing	48,190	57,830	57,830	57,830	115,660
SUBTOTAL	131,580	165,090	186,330	221,520	403,000
Miscellaneous and Contingency	19,740	24,760	27,950	33,230	60,450
TOTAL	151,320	189,850	214,280	254,750	463,450

*Lower capacity represents a filtration rate of 2 gpm/ft^2.
+Higher capacity represents a filtration rate of 5 gpm/ft^2.

of the filters. These costs do not include those related to administrative activities, laboratory chemicals or supplies, general facility maintenance nor do they include treatment chemicals.

Labor requirements were developed assuming that the treatment facilities would be only partially attended over a 24-hr period. This mode of operation is typical for modern package treatment plants that are designed to perform unattended and to backwash automatically on the basis of headloss or excessive filtered water turbidity and then return to service.

Operation and maintenance requirements for filtration rates of 2 and 5 gpm/ft^2 are presented in Figures 6 and 7 and summarized in Table 5.

PACKAGE PRESSURE FILTRATION PLANTS

Construction Cost

Package pressure filters can be used for iron and manganese removal from well waters, and in some States, as a final treatment process following chemical coagulation and clarification of surface waters. Pressure filters are available from many manufacturers with either rapid sand, dual-media or mixed-media filter beds. Units can be either totally automatic or manual in operation.

Construction costs were developed for package pressure filtration plants of capacities ranging between 1,000 gpd and 0.5 mgd, for filtration rates of 2 and 5 gpm/ft^2 and a media depth of 30 in. Conceptual designs for the plants are shown in Table 6, and a typical installation is shown in Figure 8. Vessel sizes selected are those generally available in the industry. Costs are based on completely housed filtration plants.

All units are skid mounted, completely self-contained, and include a single vertical pressure vessel with internals, automatic control valves, filter supply pump, filter media (mixed), backwash pump, and control panel. Included with each unit are two chemical feed units including tank, mixer, and chemical feed pump. Finished water is discharged to an at-grade storage tank/clearwell, which is not included in the cost estimate.

Backwash water is pumped from the storage tank by an end suction centrifugal pump. The filter supply pump is also an end suction centrifugal pump and requires a flooded suction. The filter units are designed for automatic operation. Backwash is initiated by excessive headloss or by elapsed operating time. Surface wash is obtained from a separate pump or from a pressure distribution system through a backflow preventer.

Estimated construction costs are presented in Table 7 and illustrated in Figure 9.

Operation and Maintenance Costs

Operating and maintenance costs have been developed from estimates of energy, labor, and maintenance material requirements for the conceptual

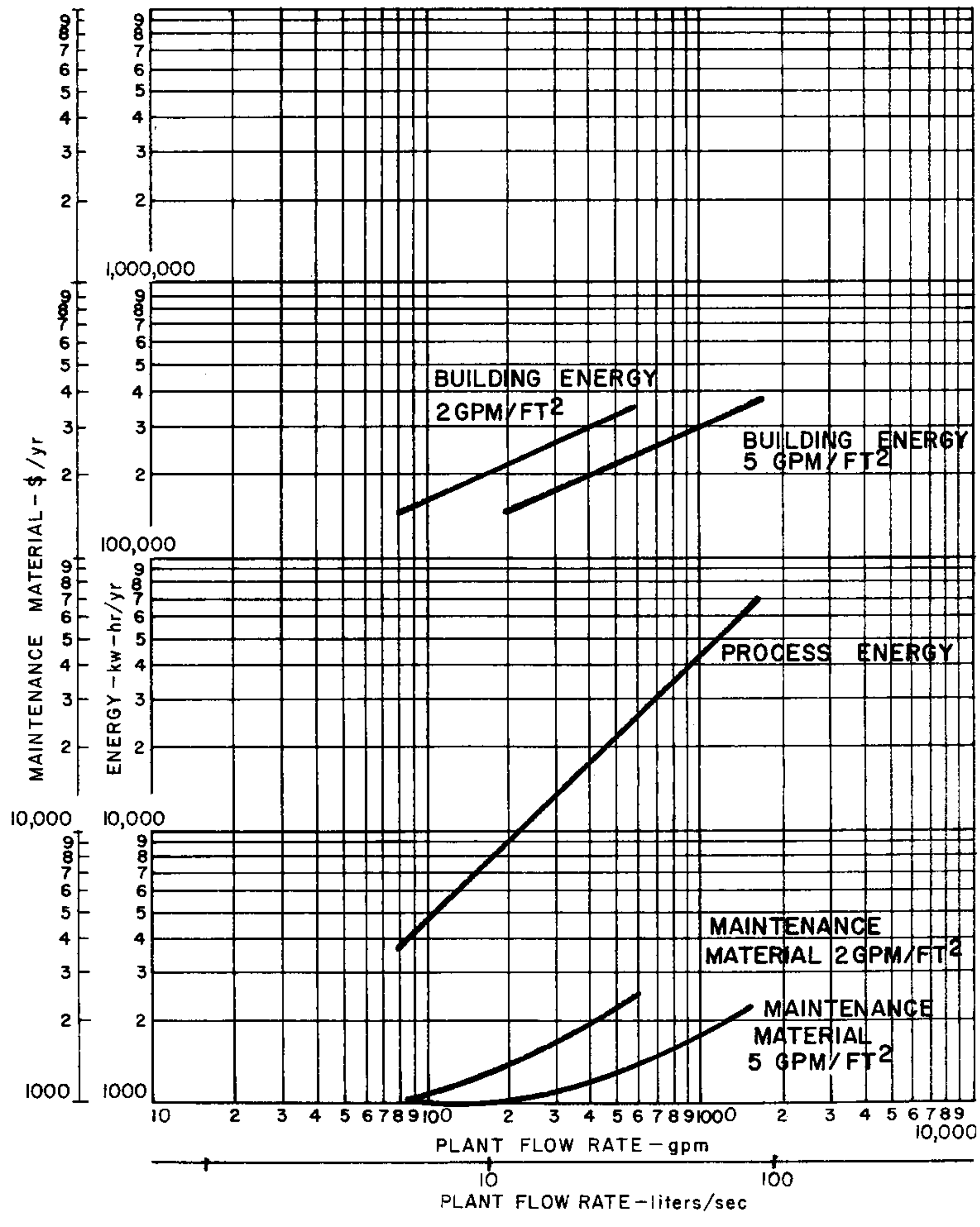


Figure 6. Operation and maintenance requirements for package gravity filter plants - building energy, process energy, and maintenance material at filtration rates of 2 and 5 gpm/ft^2.

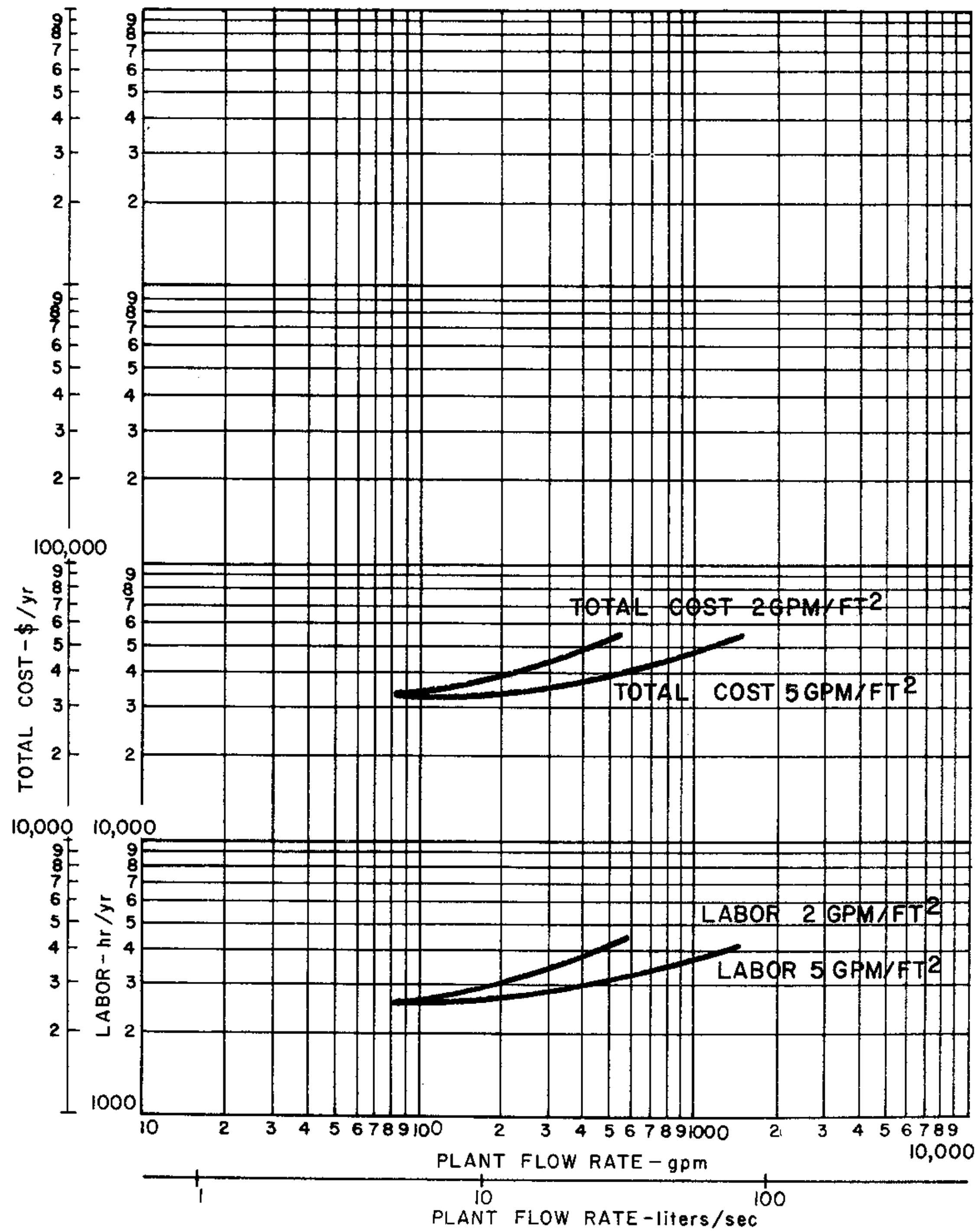


Figure 7. Operation and maintenance requirements for package gravity filter plants - labor and total cost at filtration rates of 2 and 5 gpm/ft^2.

Table 5

Operation and Maintenance Summary for

Package Gravity Filter Plants

Plant Capacity (gpm)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
Filtration rate of 2 gpm/ft^2:						
80	153,900	3,950	157,850	1,070	2,920	35,010
140	184,680	6,920	191,600	1,280	2,920	36,230
225	184,680	11,064	195,740	1,390	3,650	43,760
280	184,680	13,830	198,510	1,600	3,650	44,060
560	360,000	27,660	387,660	2,670	4,380	58,100
Filtration rate of 5 gpm/ft^2:						
200	153,900	9,470	163,370	1,070	2,920	35,170
350	184,680	16,580	201,260	1,280	2,920	36,520
560	184,680	26,250	210,930	1,390	3,650	44,220
700	184,680	33,150	217,830	1,600	3,650	44,630
1,400	360,000	66,300	426,300	2,670	4,380	59,260

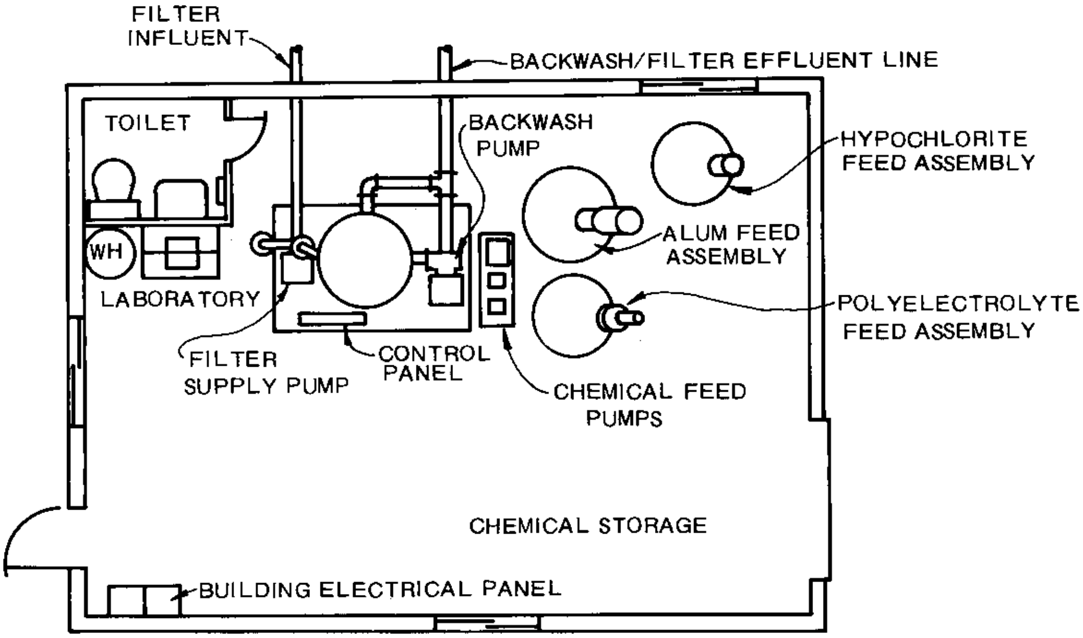
*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 6

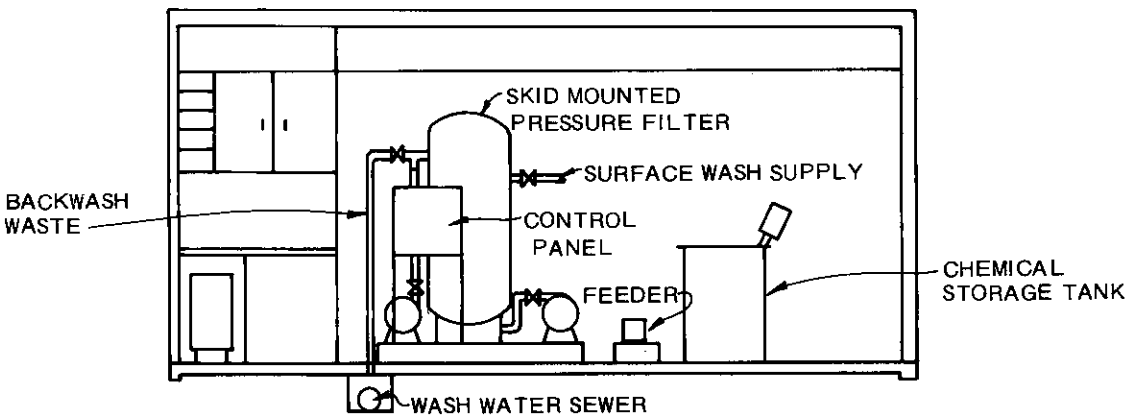
Conceptual Design for

Package Pressure Filtration Plants

Plant Capacity (gpm)		Filter Vessels				
2 gpm/ft^2 Filtration Rate	5 gpm/ft^2 Filtration Rate	Number of Units	Filter Area (ft^2)	Diameter (ft)	Total Filter Area (ft^2)	Housing Area (ft^2)
0.7	1.7	1	0.34	0.67	0.34	240
7	17	1	3.14	2	3.14	300
28	70	1	12.6	4	12.6	480
70	170	1	34.2	6.5	34.2	896
140	350	1	64	9	64	1,080



PLAN VIEW



ELEVATION VIEW

Figure 8. Typical package pressure filter installation.

Table 7

Construction Cost for

Package Pressure Filtration Plants

Cost Category	Plant Capacity (gpd)				
	0.7* and 1.7+	7.0 and 17	28 and 70	70 and 170	140 and 350
Excavation and Sitework	$ 110	110	130	210	230
Manufactured Equipment	4,650	16,180	24,530	39,110	58,350
Concrete	380	470	690	1,170	1,380
Labor	1,380	4,800	7,290	11,620	17,340
Piping and Valves	530	640	900	1,170	1,490
Electrical and Instrumentation	1,780	4,230	6,470	10,680	14,970
Housing	7,710	9,640	15,420	28,790	34,700
SUBTOTAL	16,540	36,070	55,430	92,750	128,460
Miscellaneous and Contingency	2,480	5,410	8,310	13,910	19,270
TOTAL	19,020	41,480	63,740	106,660	147,730

*Lower capacity represents a filtration rate of 2 gpm/ft^2.
+Higher capacity represents a filtration rate of 5 gpm/ft^2.

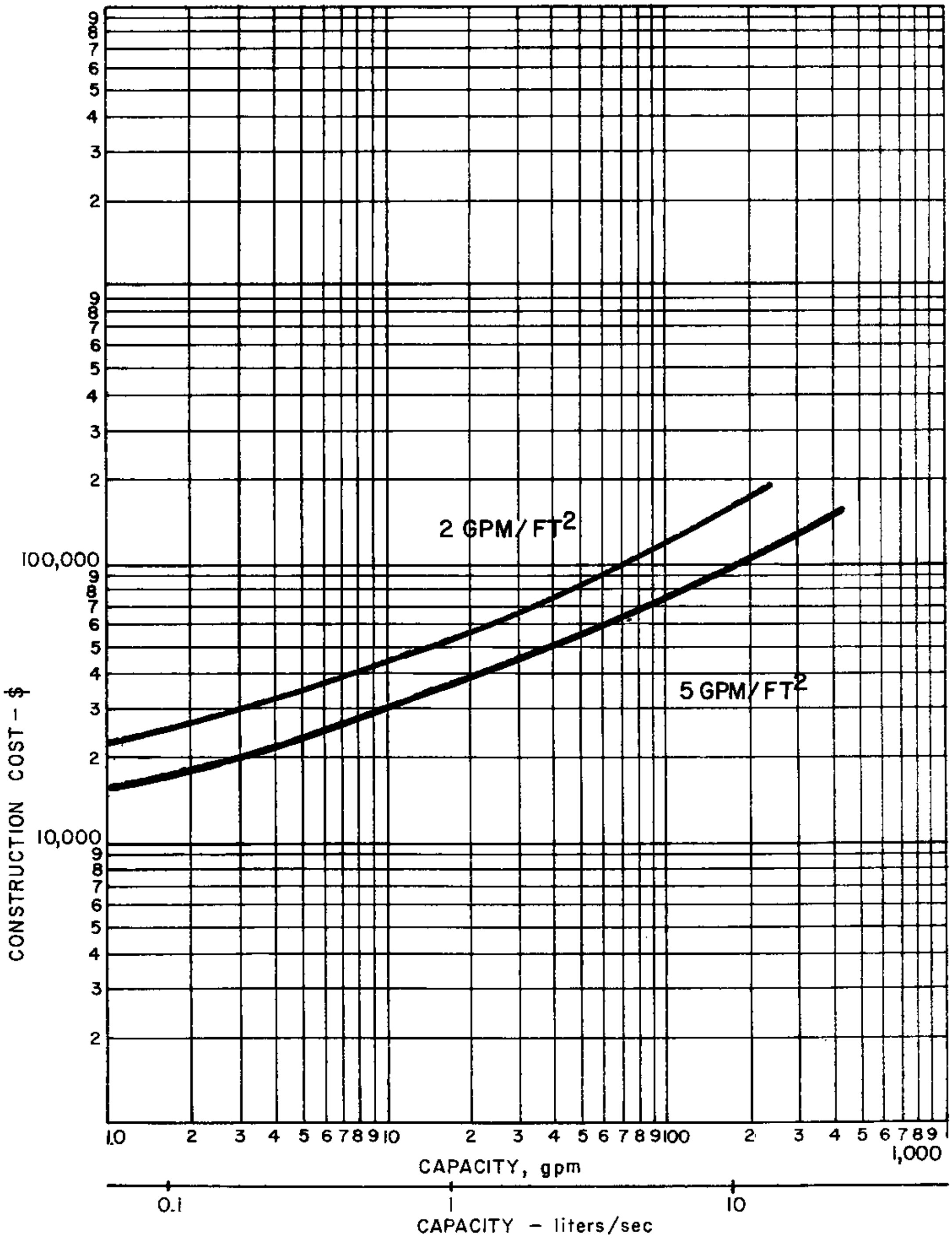


Figure 9. Construction cost for package pressure filtration plants at filtration rates of 2 and 5 gpm/ft^2.

designs presented in Table 6. Building energy requirements are for heating, cooling, ventilation, and lighting. Process energy, which is not nearly as large as building-related energy, is for backwash and filter supply pumping and the chemical feeders.

Maintenance material requirements are related primarily to replacement of pump seals, application of lubricants, replacement of parts for chemical feed pumps, instrumentation repair, and general facility maintenance supplies. The maintenance material costs do not include the cost of treatment chemicals.

Labor requirements were developed assuming that the treatment plant operates automatically and virtually unattended. Operator attention is only necessary to prepare the treatment chemicals, establish proper dosages, carry out routine quality assurance tasks, and perform necessary maintenance tasks. No allowance was included for administrative or laboratory labor.

Operation and maintenance requirements for filtration rates of 2 and 5 gpm/ft^2 are summarized in Table 8 and illustrated in Figures 10 and 11.

FILTER MEDIA

Construction Cost

Filter media costs were developed for rapid sand (30 in. silica sand), dual media (20 in. anthracite coal and 10 in. silica sand), and mixed media (16.5 in. anthracite coal, 9 in. silica sand, and 4.5 in. garnet sand). A supporting gravel depth of 12 in. was used with each different filter media. It was assumed that all materials would be contained in 50- and 100- lb bags and truck-shipped to the job site. Mixed media are generally placed under technical direction of the manufacturer, and separate costs are presented for installation with and without manufacturer's supervision. It should be noted that filter media (mixed) costs are included in the curves for package complete treatment plants, package gravity filtration plants, and package pressure filtration plants.

Costs for filter media, supporting gravel, and contractor installation for filters ranging in size from 4 to 280 ft^2 are presented in Table 9 and Figure 12.

PACKAGE PRESSURE DIATOMITE FILTERS

Construction Cost

Construction costs were developed for a series of diatomaceous earth filter units capable of treating flows between 28,000 gpd and 1 mgd. The conceptual designs used to develop these construction costs are presented in Table 10. A filtration rate of approximately 1 gpm/ft^2 of filter area, in accordance with standard industry practice, was used to determine filter size. The cost estimates are for a complete installation, including diatomaceous earth storage, preparation and feed facilities, pressure filtration units, filter supply pump, filter valves, interconnecting pipe and fittings, and control panel for automatic operation. Housing costs were

Table 8

Operation and Maintenance Summary for

Package Pressure Filtration Plants

Plant Capacity (gpm)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
Filtration Rate of 2 gpm/ft^2:						
	24,620	50	24,670	$ 50	365	$ 4,440
0.7	30,780	450	31,230	160	365	4,750
28	49,250	1,830	51,080	210	425	5,990
70	91,930	4,950	96,880	370	500	8,270
140	110,810	9,270	120,080	480	730	11,380
Filtration Rate of 5 gpm/ft^2:						
1.7	24,620	120	24,740	50	365	4,440
17	30,780	1,220	32,000	160	365	4,770
70	49,250	5,040	54,290	210	425	6,090
170	91,930	9,820	101,750	370	500	8,420
350	110,810	24,550	135,360	480	730	11,840

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

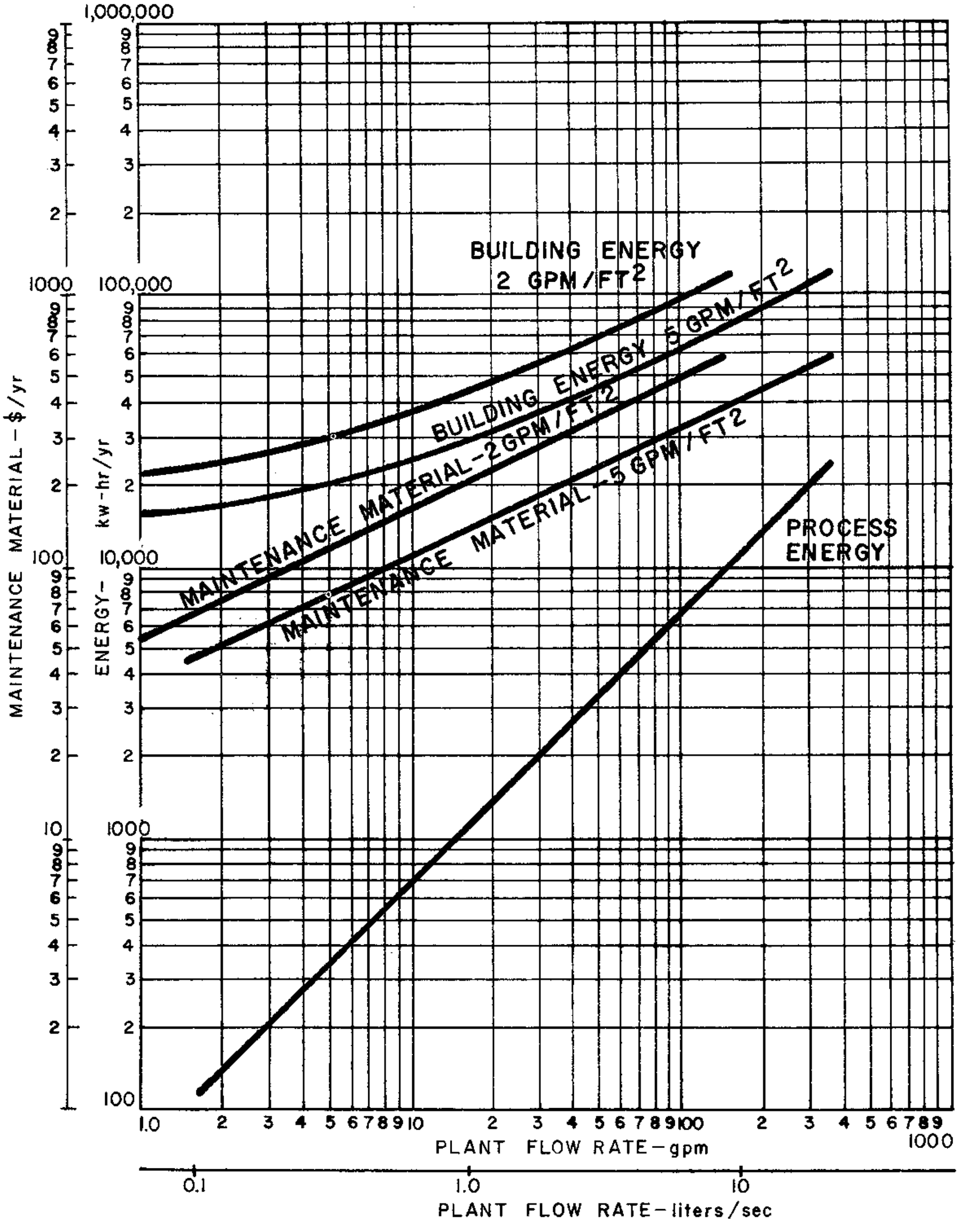


Figure 10. Operation and maintenance requirements for package pressure filtration plants - building energy, process energy, and maintenance material at filtration rates of 2 and 5 gpm/ft^2.

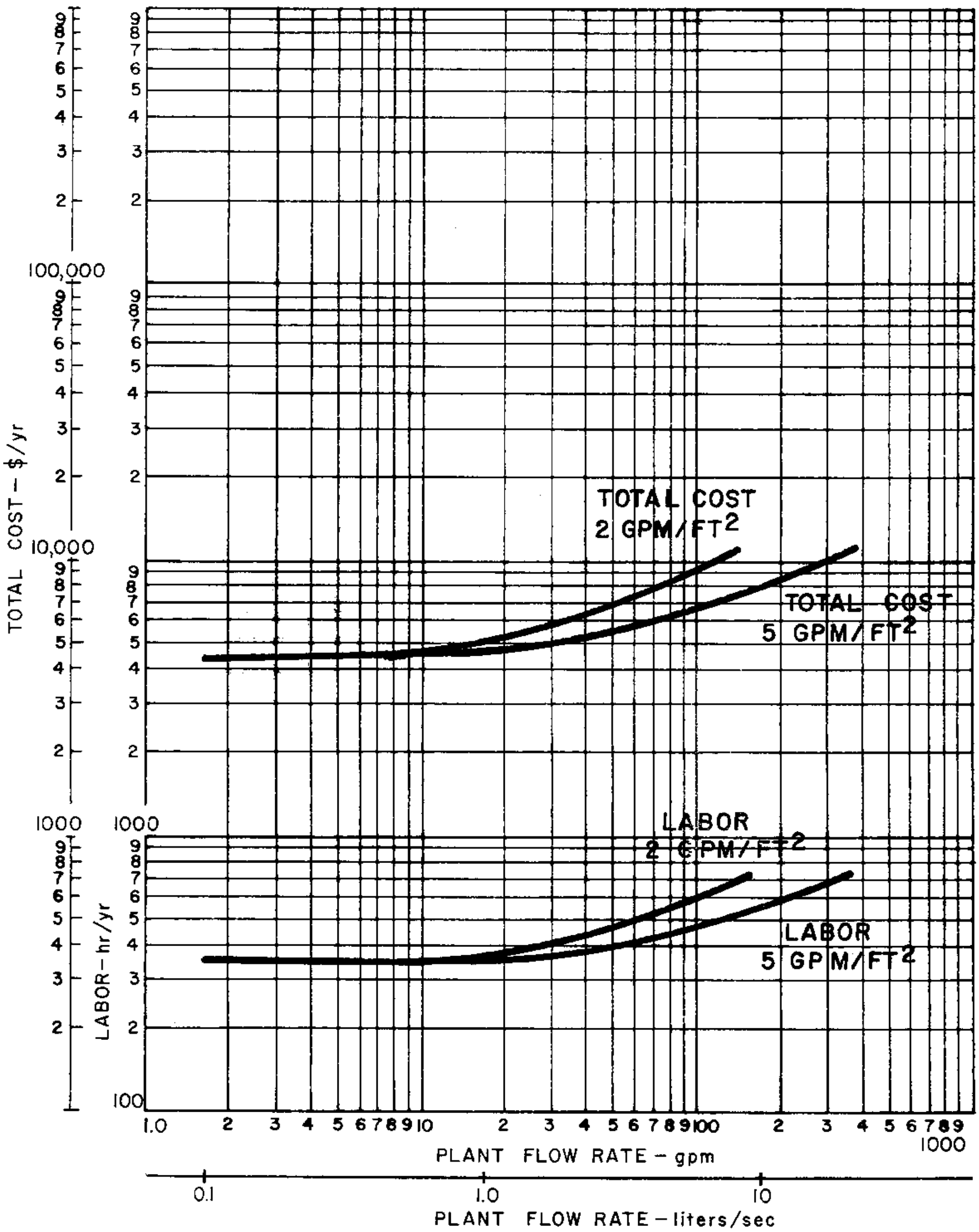


Figure 11. Operation and maintenance requirements for package pressure filtration plants - labor and total cost at filtration rates of 2 and 5 gpm/ft^2.

Table 9

Construction Cost for Filter Media

Filter Area (ft^2)	Rapid Sand	Dual Media (Coal-Sand)	Mixed Media	Mixed Media - Installation with Manufacturer's Supervision
4	$230	$310	$470	$1,470
10	490	660	900	1,900
20	980	1,220	1,720	2,720
40	1,620	1,980	3,200	4,450
100	3,160	4,600	7,200	8,450
140	4,420	6,250	9,020	10,270
280	8,120	11,980	17,200	18,700

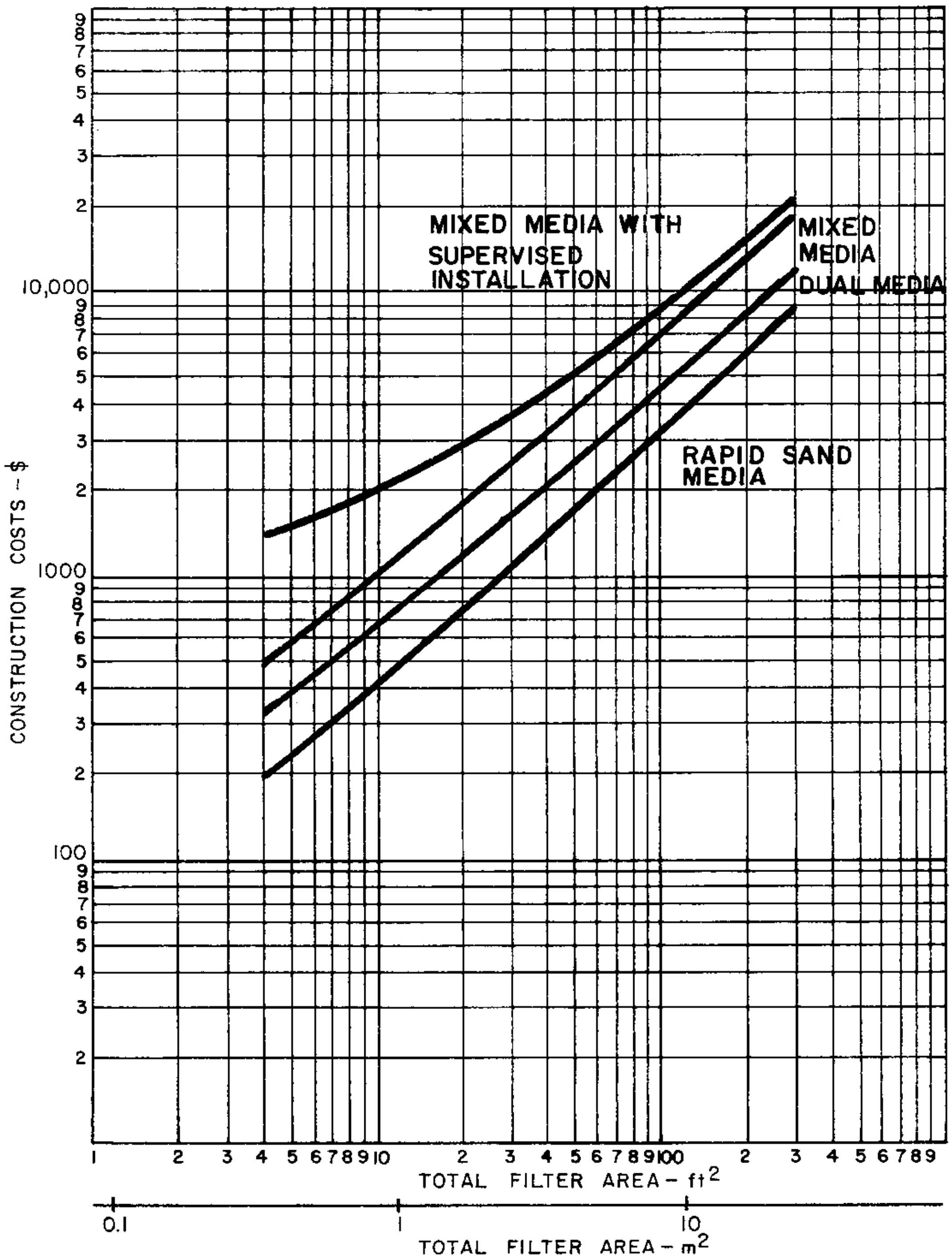


Figure 12. Construction Cost for filter media.

Table 10

Conceptual Design for

Package Pressure Diatomite Filters

Plant Flow (gpd)	Number of units	Tank Diameter in.	Filter Surface Area (ft^2)	Filter Rate (gpm/ft^2)	Housing (ft^2)
28,000	1	16	19.2	1	260
86,000	1	24	55	1	280
140,000	1	36	102	1	310
280,000	1	42	202	1	460
560,000	2	42	404	1	500
1,000,000	3	48	750	1	750

developed assuming total enclosure of the filters in a modular steel building, with minimum additional space for access on all sides of the filter units for maintenance.

Construction costs are presented in Table 11 and Figure 13.

Operation and Maintenance Cost

Process energy is for filter pumps, backwash pumps, mixers, and other items associated with the filter system. A cycle time of 24 hr between backwashes was assumed in developing electrical requirements. The energy requirements do not include those associated with raw water or finished water pumping.

Maintenance material requirements are related primarily to replacement of pump seals, application of lubricants, chemical feed pump replacement parts, and general facility maintenance supplies. Maintenance material cost estimates were furnished by manufacturers and are based on years of experience at many plants. Costs for treatment chemicals, including diatomaceous earth, are excluded. It should be noted that diatomaceous earth is a costly chemical, and its cost must be included.

Labor requirements were developed assuming that the diatomite filter installation operates automatically and virtually unattended. Operator attention is necessary only for preparation of body feed and precoat, and for verification that chemical dosages are proper and that the equipment is producing a high-quality filtered water.

Operation and maintenance requirements are summarized in Table 12 and are illustrated in Figures 14 and 15.

PACKAGE VACUUM DIATOMITE FILTERS

Construction Cost

Construction cost estimates were developed for package vacuum diatomite filters with capacities ranging from 30 to 720 gpm. These units are preassembled at the factory and require minimal onsite assembly and installation attention. The construction features and operating principles of package vacuum diatomite filters generally parallel those of larger units.

The conceptual designs used to develop the construction costs are presented in Table 13. A filtration rate of 1 gpm/ft^2 of filter area, in accordance with manufacturer's recommendations, was used to size the filters. The costs are for a complete installation, including diatomaceous earth storage, preparation and feed facilities, vacuum filtration units, filter pumps and motors, filter valves, interconnecting pipe and fittings, and control panel for automatic operation. The costs also include sitework and excavation within the immediate vicinity of the plant, building floor slab, and modular steel building. The plant was assumed to be totally enclosed. Excluded are costs associated with pretreatment, clearwell storage, and high-service pumping.

Table 11

Construction Cost for

Package Pressure Diatomite Filters

Cost Category	Plant Capacity (gpd)					
	28,000	86,000	140,000	280,000	560,000	1,000,000
Excavation and Sitework	$ 200	$ 210	$ 220	$ 300	$ 320	$ 500
Manufactured Equipment	17,250	21,400	32,600	34,200	71,400	105,000
Concrete	200	220	250	340	380	560
Steel	100	120	130	160	170	220
Labor	4,500	4,800	5,200	5,700	6,300	8,000
Pipe and Valves, Pumps	1,500	1,600	1,800	2,300	3,100	3,800
Electrical & Instrumentation	2,500	2,500	2,800	3,200	4,200	7,000
Housing	13,850	13,850	13,850	15,000	16,600	19,300
SUBTOTAL	40,100	44,700	56,850	61,200	102,470	144,380
Miscellaneous and Contingency	6,020	6,700	8,530	9,180	15,370	21,660
TOTAL COST	46,120	51,400	65,380	70,380	117,840	166,040

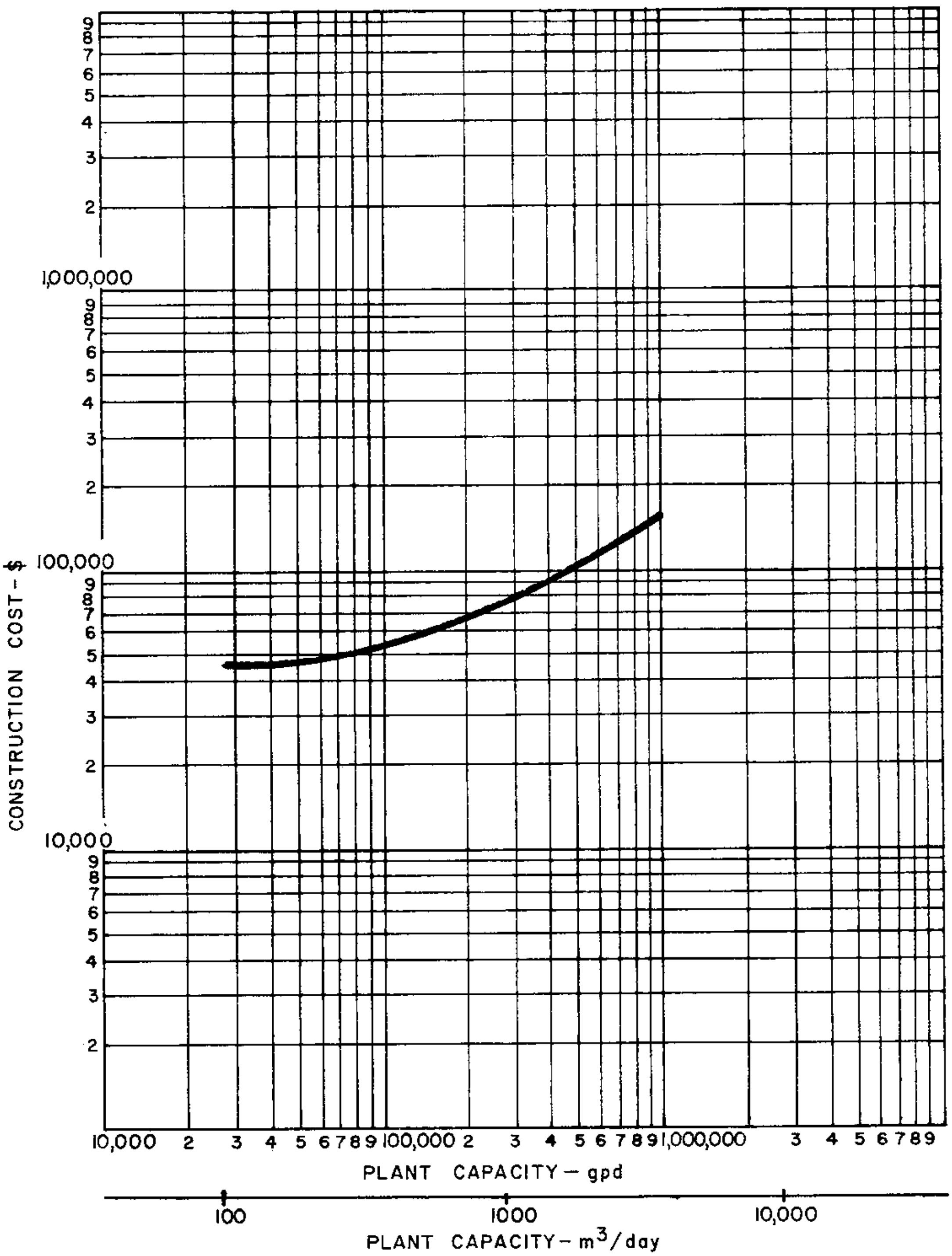


Figure 13. Construction Cost for package pressure diatomite filters.

Table 12

Operation and Maintenance Summary for
Package Pressure Diatomite Filters

Plant Flow Rate (gpd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
28,000	26,700	1,380	28,080	$150	700	$7,990
86,000	28,700	4,140	32,840	250	750	8,740
140,000	31,800	6,900	38,700	300	900	10,460
280,000	47,200	13,800	61,000	400	1,100	13,230
560,000	51,300	27,600	78,900	550	1,500	17,920
1,000,000	77,100	51,740	128,840	750	2,900	33,620

*Calculated using $0.03/kw-hr and $10.00/ hr of labor.

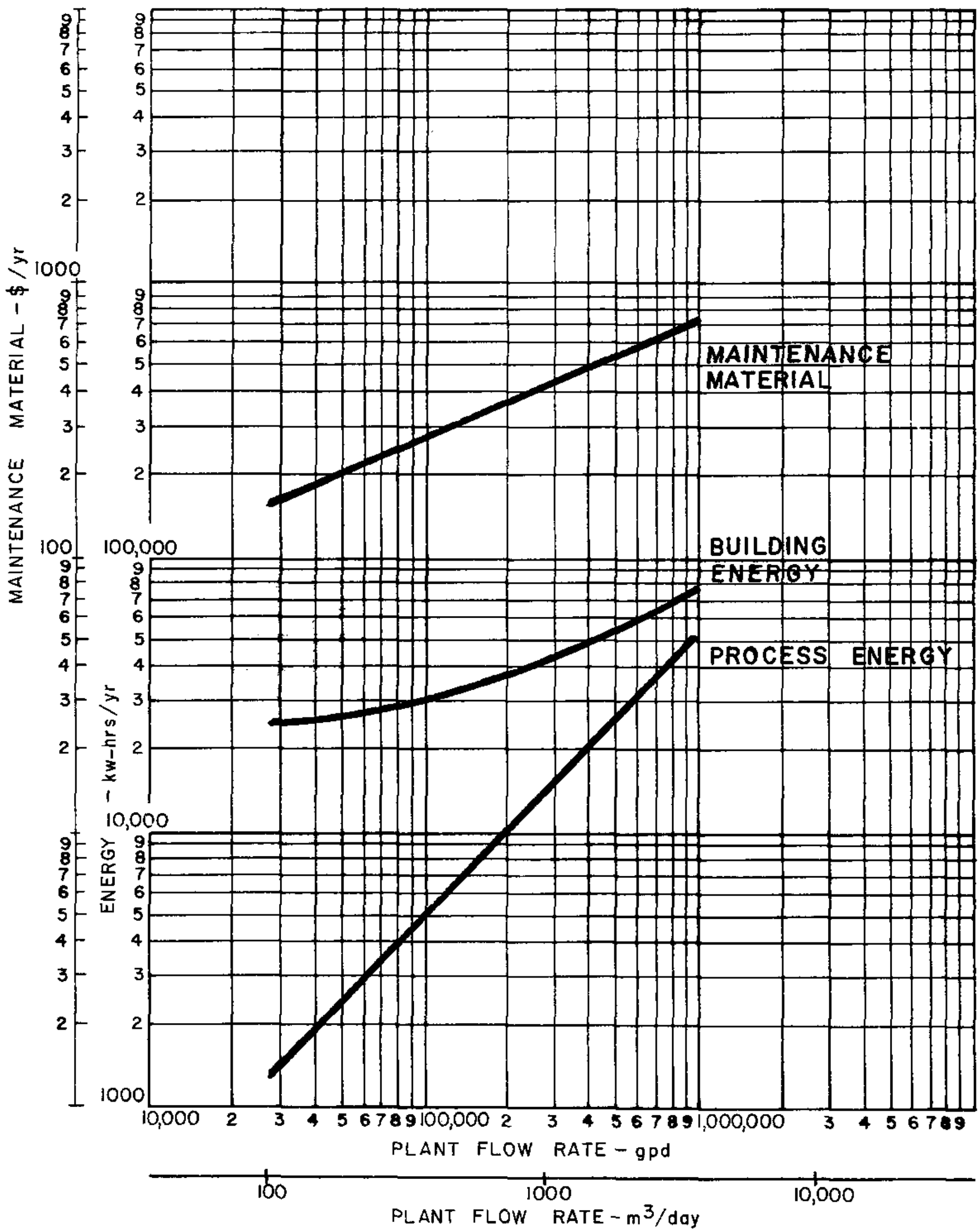


Figure 14. *Operation and maintenance requirements for package pressure diatomite filters - building energy, process energy, and maintenance material*

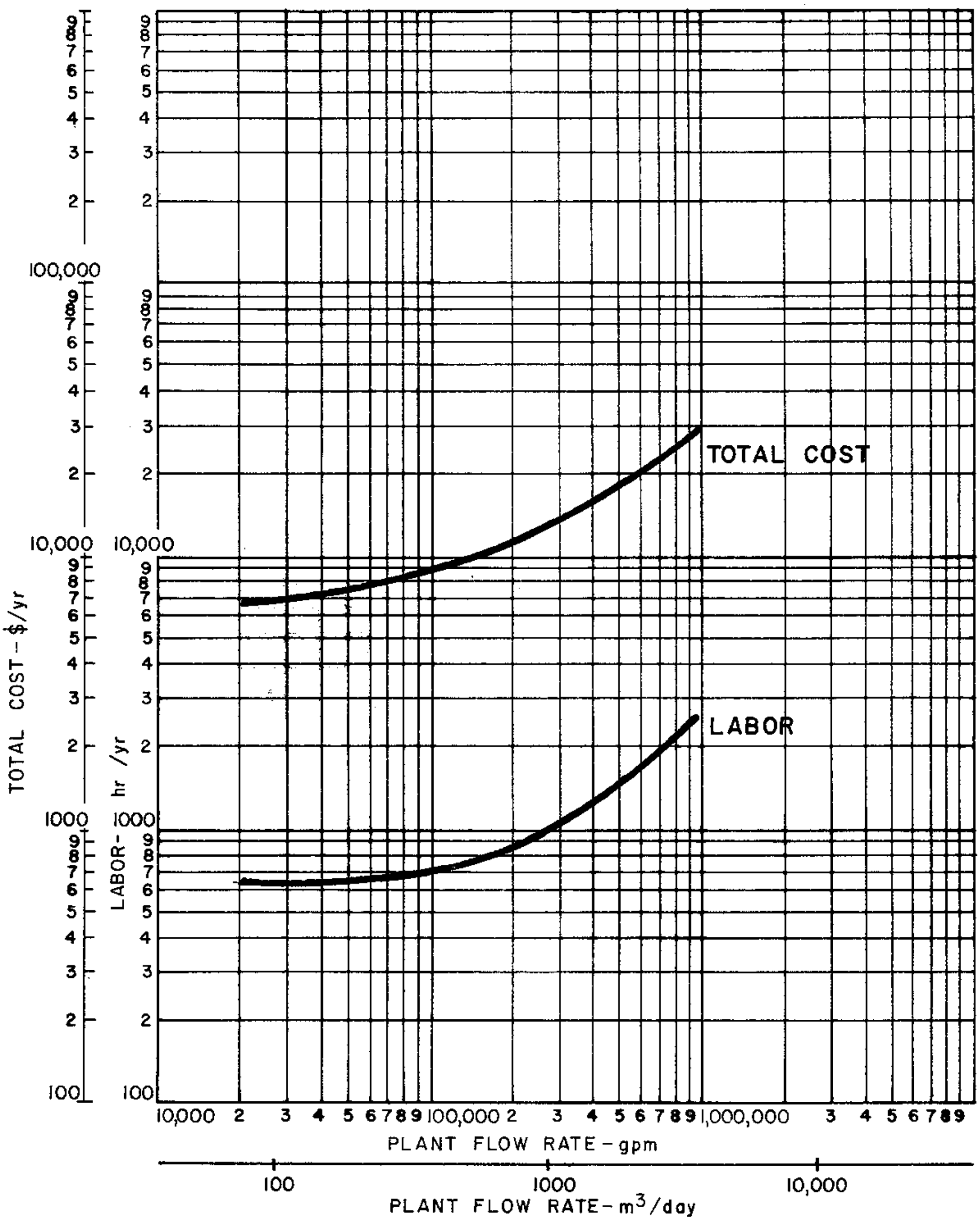


Figure 15. Operation and maintenance requirements for package pressure diatomite filters - labor and total cost.

Table 13

Conceptual Designs for

Package Vacuum Diatomite Filters

Plant Flow (gpm)	Filter Area (ft^2)	Filter Rate (gpm/ft^2)	Housing Requirements (ft^2)
30	30	1	260
120	120	1	310
180	180	1	460
360	360	1	500
720	720	1	740

Construction costs are presented in Table 14 and are also shown in Figure 16.

Operation and Maintenance Cost

Operating and maintenance requirements were developed from estimates of energy and labor requirements for the treatment unit conceptual designs listed in Table 13. The information used to develop these requirements was furnished by manufacturers and is representative of minimum operating requirements.

Process electrical energy usage is for filter pumps, hold pumps, mixers, and other items associated with the filter system. A cycle time of 24 hr between backwashes was assumed in developing electrical requirements. The process energy requirements do not include those associated with raw water or finished water pumping.

Maintenance material requirements are related primarily to replacement of pump seals, application of lubricants, instrument and chemical feed pump replacement parts, and general facility maintenance supplies. Costs for treatment chemicals, including diatomaceous earth, are not included. It should be noted that diatomaceous earth is a costly chemical, and its cost must be included.

Labor requirements were developed assuming that the diatomite filter installation operates automatically and virtually unattended. Operator attention is necessary only for preparation of body feed and precoat, chemical feed adjustment, and measurement of product water quality.

Operation and maintenance requirements are summarized in Table 15 and illustrated in Figures 17 and 18.

PACKAGE ULTRAFILTRATION PLANTS

Construction Cost

Ultrafiltration is a relatively new process that can have application for the removal of suspended and colloidal material from water without the need for coagulation. It is applicable where the water supply has a fouling index of less than 10, an index that is characteristic of most well waters and low-turbidity surface waters. The ultrafiltration process utilizes a specially extruded hollow-fiber membrane that excludes particles larger than 0.01µm. The pore structure of the membrane, unlike reverse osmosis membranes, permits passage of inorganic salts and other electrolytes. The membranes are cleaned by backwashing, which restores the original porosity and allows continuous use for indefinite periods. Ultrafiltration systems perform efficiently at pressures of 10 to 100 psig.

Construction costs were developed for package ultrafiltration systems ranging from 2,500 gpd to 1 mgd in capacity. Table 16 provides conceptual design information used to develop the construction costs. The costs include skid-mounted ultrafiltration units containing the hollow-fiber

Table 14

Construction Cost for

Package Vacuum Diatomite Filters

Cost Category	Plant Flow (gpm)				
	30	120	180	360	720
Excavation and Sitework	$200	$220	$300	$320	$480
Manufactured Equipment	28,000	45,000	50,000	70,000	120,000
Concrete	200	250	380	400	600
Steel	150	180	260	290	420
Labor	2,030	2,800	3,600	4,500	6,400
Pipe and Valves	2,400	3,100	4,000	5,150	8,100
Electrical & Instrumentation	1,750	1,750	1,750	1,800	2,300
Housing	11,250	12,050	15,500	16,250	20,900
SUBTOTAL	45,980	65,350	75,790	98,710	159,200
Miscellaneous and Contingency	6,900	9,800	11,370	14,810	23,880
TOTAL COST	52,880	75,150	87,160	113,520	183,080

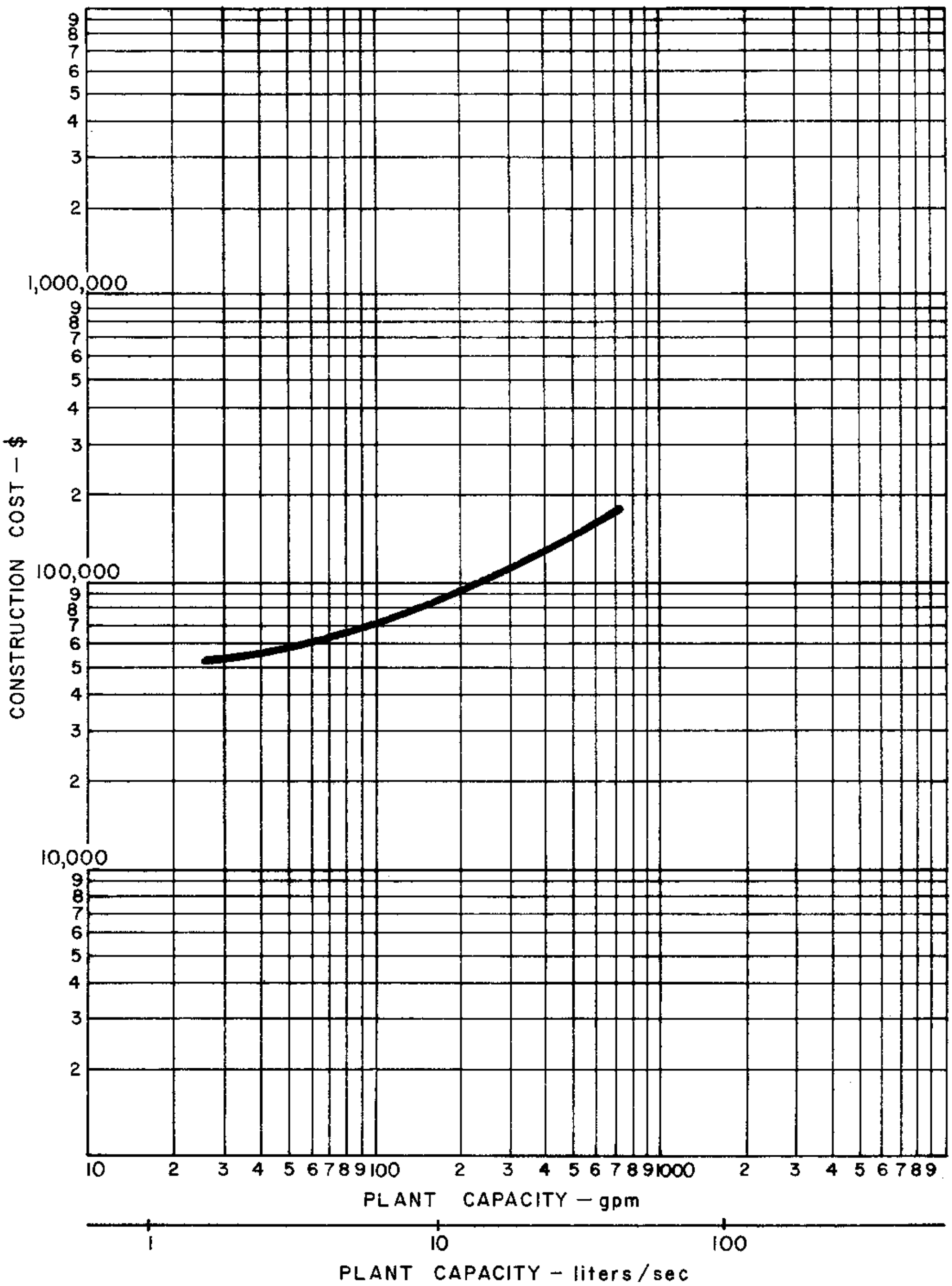


Figure 16. Construction cost for package vacuum diatomite filters.

Table 15

Operation and Maintenance Summary for

Package Vacuum Diatomite Filters

Plant Flow (gpm)	Energy (kw-hr/yr) Building	Energy (kw-hr/yr) Process	Energy (kw-hr/yr) Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
30	26,680	9,670	36,350	$150	730	$8,540
120	31,810	19,300	51,110	350	910	10,980
180	47,200	32,100	79,300	400	1,100	13,780
360	51,300	48,130	99,430	550	1,500	18,530
720	75,900	64,100	140,000	750	2,920	34,150

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

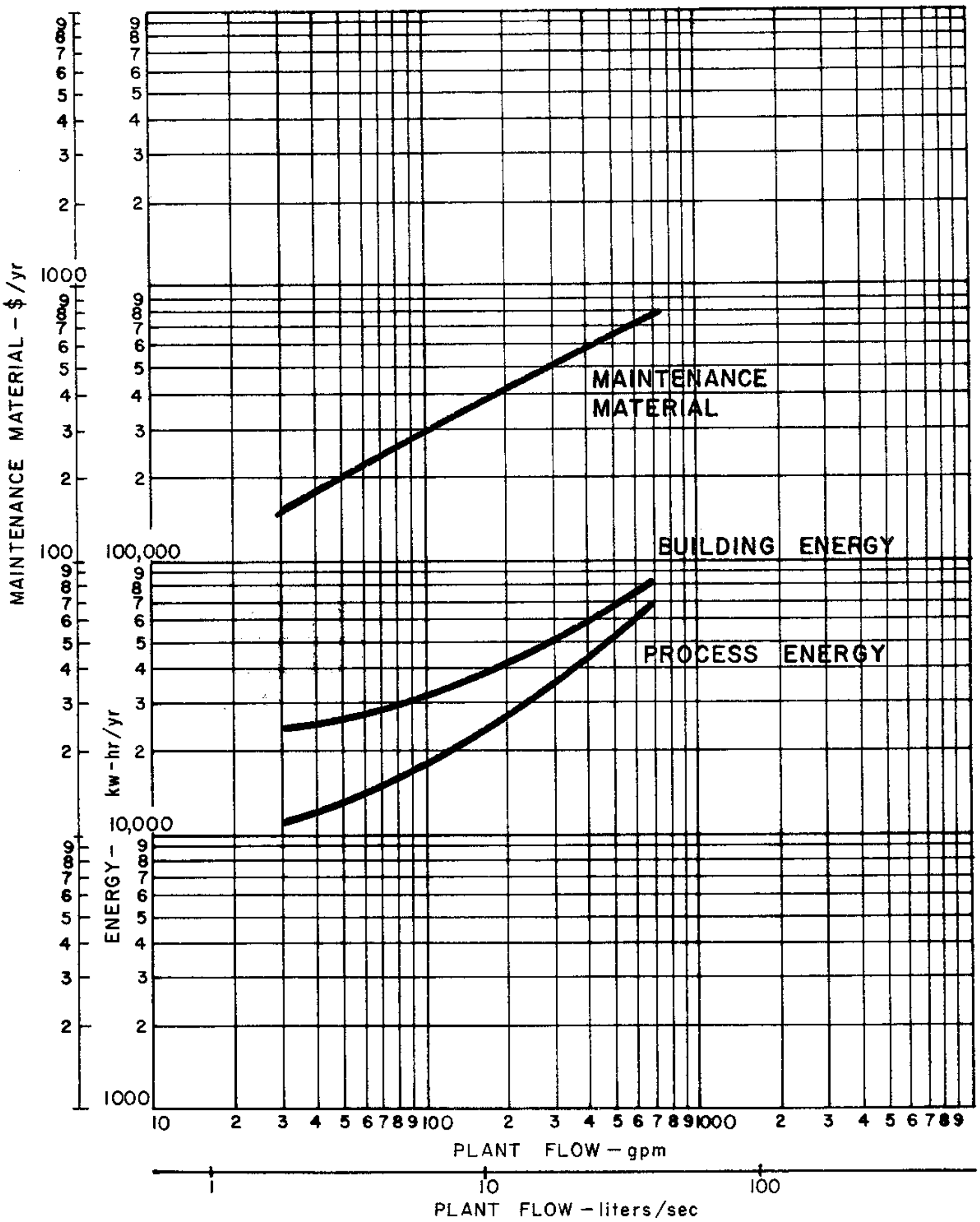


Figure 17. Operation and maintenance requirements for package vacuum diatomite filters - building energy, process energy, and maintenance material.

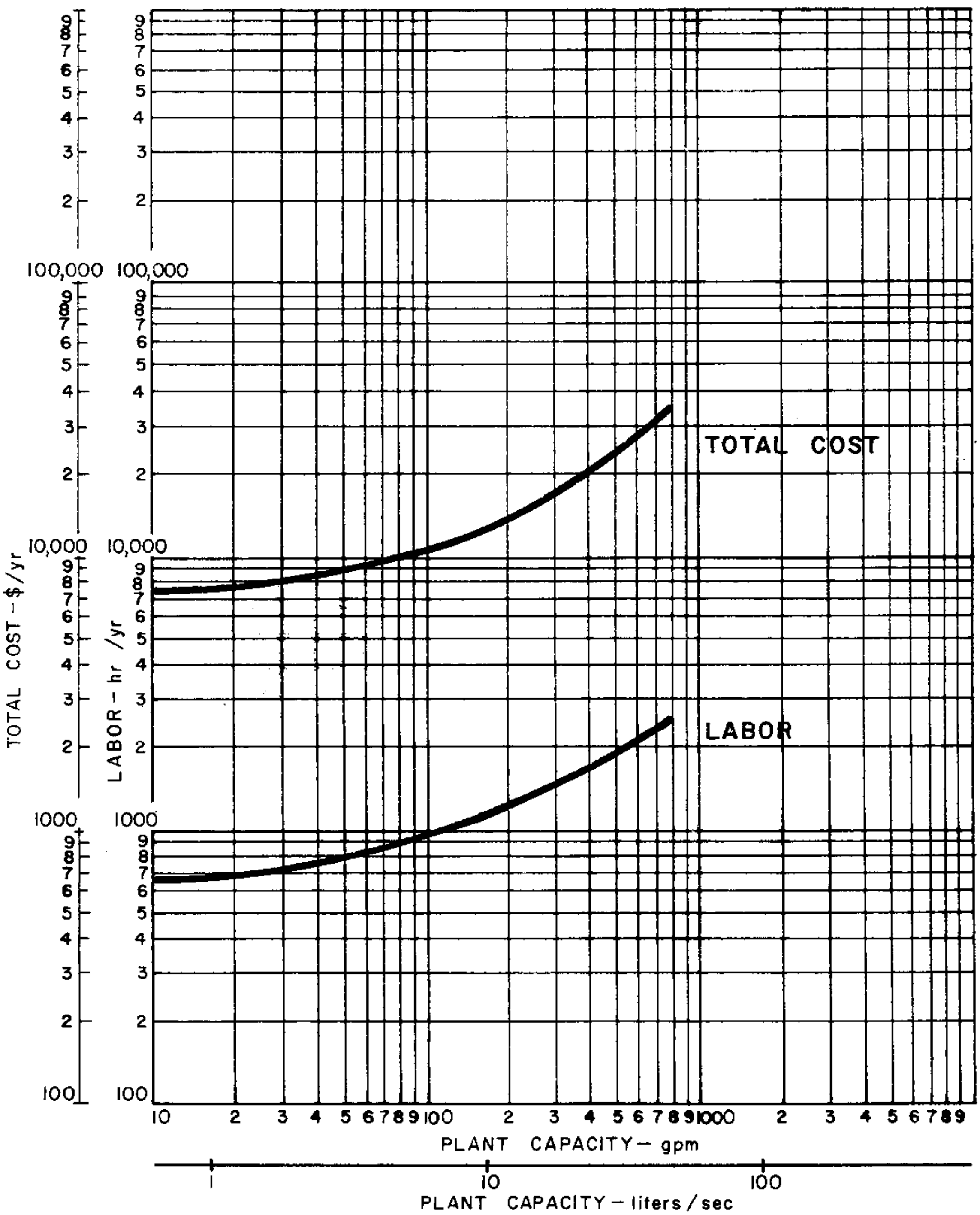


Figure 18. Operation and maintenance requirements for package vacuum diatomite filters - labor and total cost.

Table 16

Conceptual Design for

Package Ultrafiltration Plants

Plant Capacity (gpd)	Membrane Area (Ft^2)	Number of Treatment Modules	Housing Area (Ft^2)
2,500	30	1	100
30,000	424	1	225
100,000	1,431	3	374
150,000	2,120	4	480
250,000	3,604	4	660
500,000	7,155	8	1,360
1,000,000	14,310	16	2,800

cartridges, automatic and manual valves for backwashing and unit isolation, flow meters, pressure gauges, integral backwash pump, and control panel. A separate supply pump is included, as is all interconnecting piping serving plants with multiple units. The costs also include storage tanks and solution pumps for membrane cleaning. Housing is provided for ultrafiltration equipment and supporting appurtenances. Product water storage facilities are not included in the cost estimates.

Construction costs are presented in Table 17 and in Figure 19.

Operation and Maintenance Cost

Process energy requirements were calculated using connected horsepower sizes recommended by manufacturers. Continuous 24-hr/day, 365-day/year operation with one backwash/day of 30 min duration was assumed in the process energy calculations.

Maintenance material requirements are related to replacement of hollow-fiber membrane cartridges once every 4 years, replacement of pump seals, small parts for chemical feed pumps and instruments, and for general facility operation. Membrane cleaning chemical costs are not included.

Labor requirements were developed assuming that the plant operates automatically and that attention is necessary only to provide routine maintenance and occasional membrane cleaning.

Operation and maintenance requirements are summarized in Table 18 and illustrated in Figures 20 and 21.

PACKAGE GRANULAR ACTIVATED CARBON COLUMNS

Construction Cost

Construction costs were developed for factory-assembled, package granular activated carbon columns. The carbon columns were sized on the basis of a 7.5-min detention time, an activated carbon loading rate of 1 gpm/ft^3 of carbon, a bed depth of 5 ft, and a hydraulic loading rate of 5 gpm/ft^2. Conceptual designs for the package activated carbon units are presented in Table 19.

The costs are based on the use of cylindrical, pressurized, downflow steel contactors conforming to the ASME code for pressure vessels designed for a working pressure of 50 psi. Tanks have a skirt base and are furnished with inlet and outlet nozzles, a nozzle-style underdrain system, access manholes, manual ball or butterfly valves, differential pressure gauge, and an initial charge of activated carbon. The units are designed for manual operation. A supply and backwash pump designed for flooded suction application is furnished skid-mounted with the activated carbon columns.

Housing costs are included in the cost estimate. Not included in the cost estimate are supply piping to the carbon column and spent or regenerated activated carbon handling or conveyance systems.

Table 17

Construction Cost for

Package Ultrafiltration Plants

Cost Category	Plant Flow (gpd)						
	2,500	30,000	100,000	150,000	250,000	500,000	1,000,000
Excavation and Sitework	$60	$80	$90	$110	$130	$200	$360
Manufactured Equipment	4,380	20,250	52,500	72,000	104,000	191,000	332,000
Concrete	240	450	680	850	1,100	2,000	4,000
Labor	480	2,150	5,500	7,500	10,750	20,000	31,000
Pipe and Valves, Pump	250	400	750	800	1,100	1,800	3,200
Electrical and Instrumentation	1,260	4,450	10,600	14,350	20,500	38,400	68,000
Housing	3,000	6,750	11,200	14,000	19,800	41,000	84,000
SUBTOTAL	9,670	34,530	81,320	109,610	157,380	294,400	522,560
Miscellaneous and Contingency	1,450	5,180	12,200	16,440	23,610	44,160	78,380
TOTAL COST	11,120	39,710	93,520	126,050	180,990	338,560	600,940

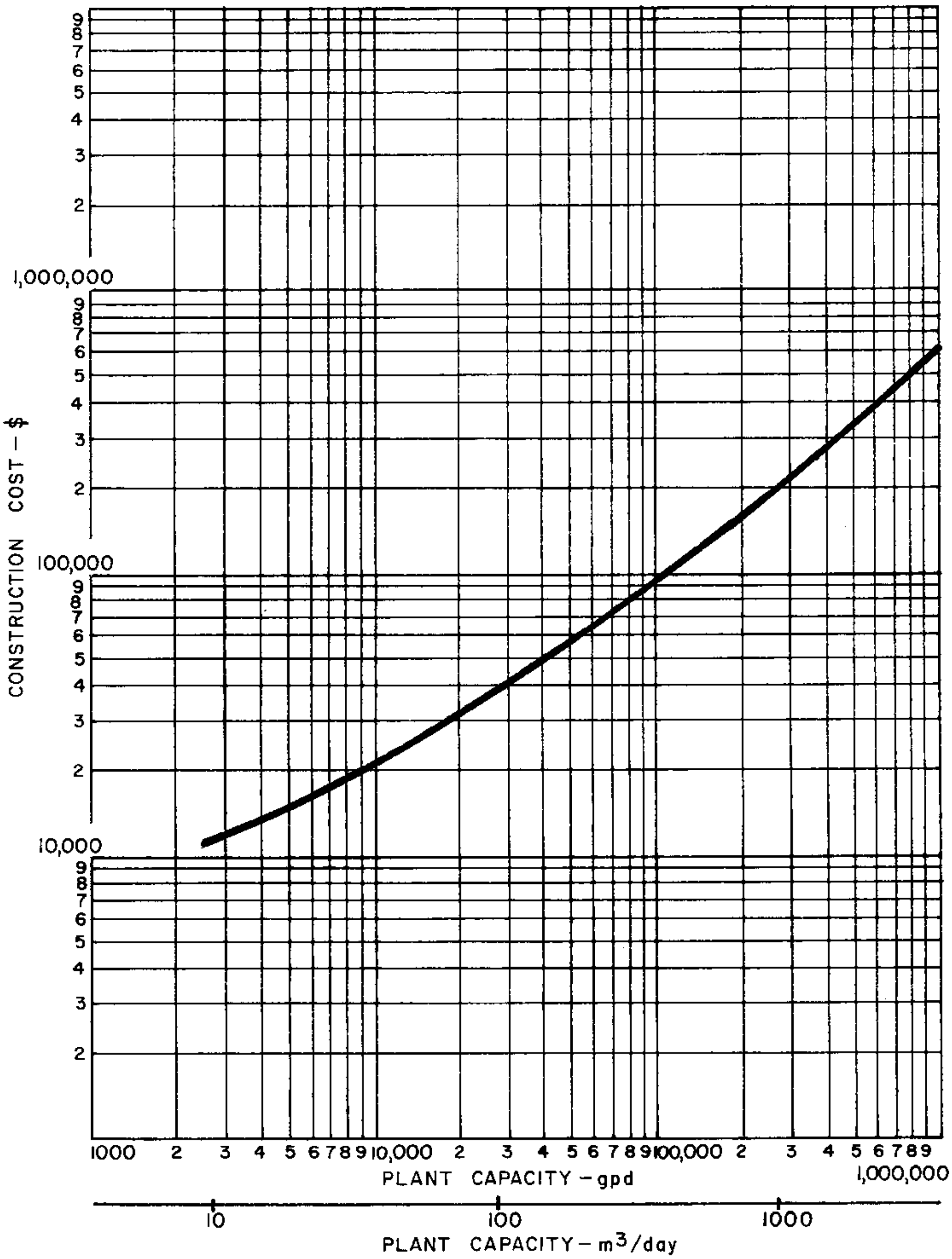


Figure 19. Construction cost for package ultrafiltration plants.

Table 18

Operation and Maintenance Summary for

Package Ultrafiltration Plants

Plant Flow (gpd)	Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
2,500	10,250	1,250	11,500	$200	365	$4,200
30,000	23,090	8,580	31,670	2,000	365	6,600
100,000	38,370	8,990	47,360	7,200	425	12,870
150,000	49,250	8,990	58,240	10,600	450	16,850
250,000	67,720	17,750	85,470	18,000	550	26,060
500,000	139,540	34,570	174,110	36,000	730	48,520
1,000,000	287,280	59,800	347,080	72,000	1,095	93,360

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

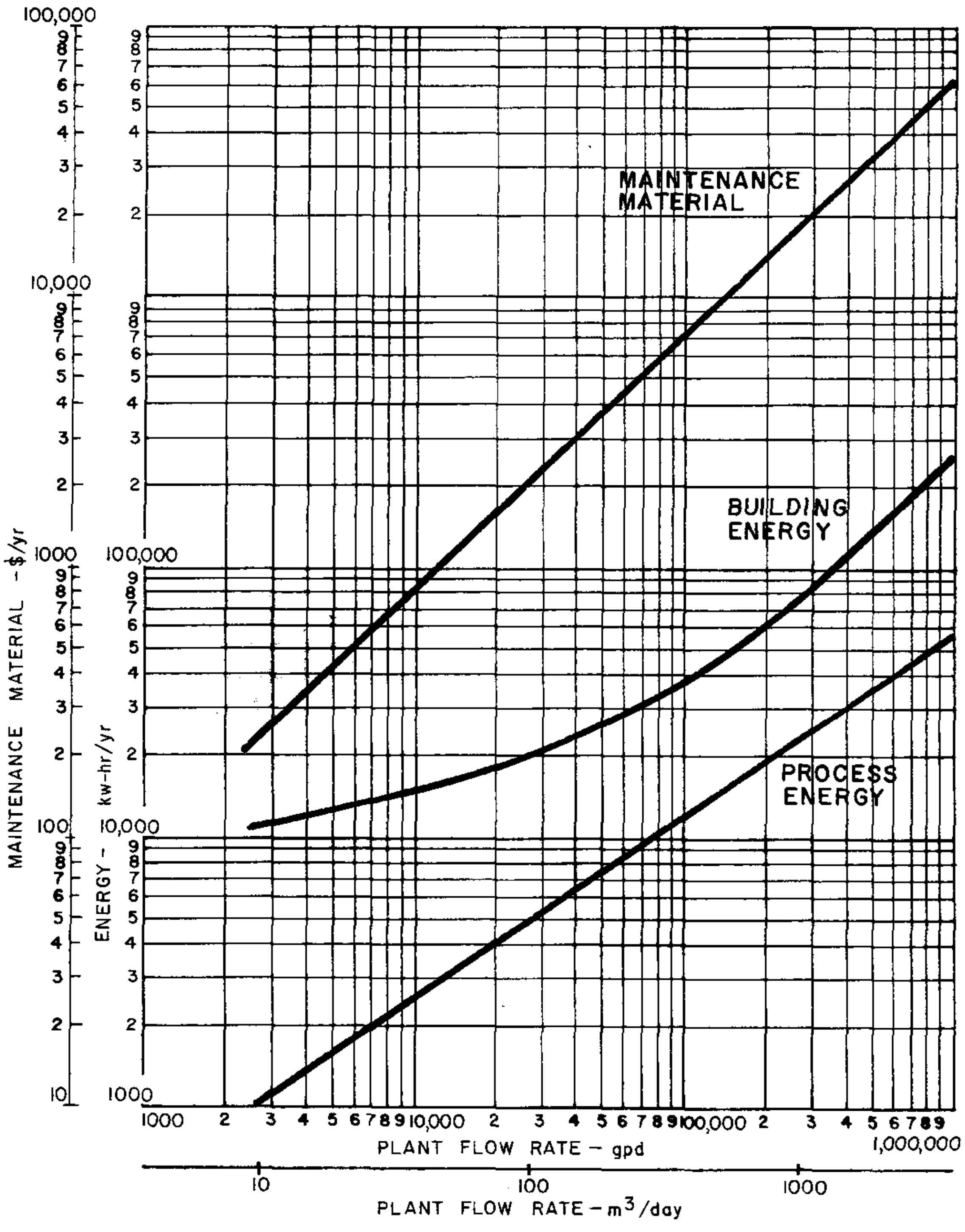


Figure 20. Operation and maintenance requirements for package ultrafiltration plants - building energy, process energy, and maintenance material.

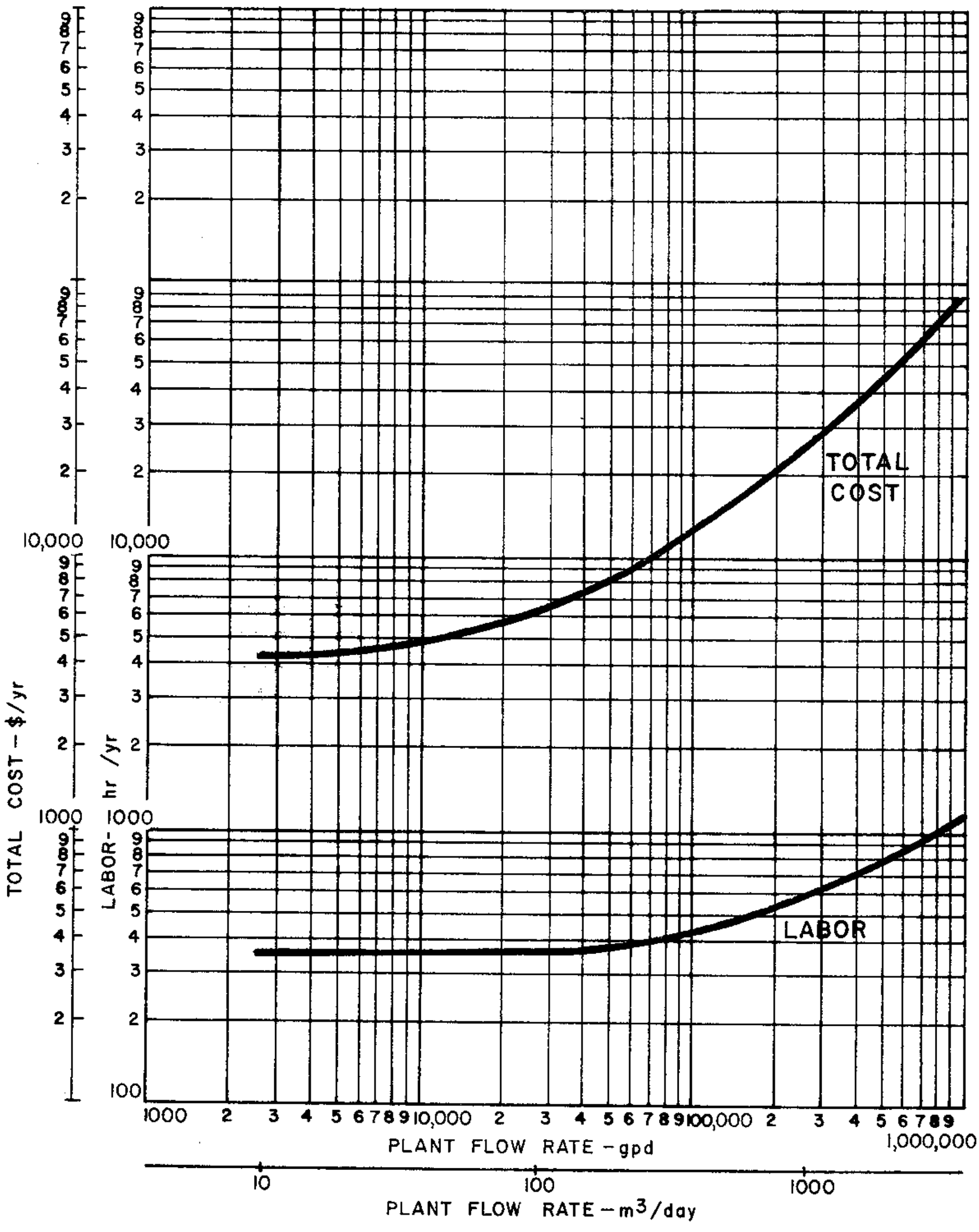


Figure 21. Operation and maintenance requirements for package ultrafiltration plants - labor and total cost.

Table 19

Conceptual Design for

Package Granular Activated Carbon Columns

Plant Flow		Flow Rate	Carbon Columns*			Housing
gpm	gpd	(gpm/ft^2)	No.	Bed Area (ft^2)	Diameter (ft)	Area (ft^2)
1.7	2,500	5.1	1	0.34	0.67	60
17	25,000	5.4	1	3.14	2	150
70	100,000	5.6	1	12.6	4	300
175	250,000	5.1	1	34	6.5	375
350	500,000	5.5	1	64	9	450

*Carbon columns sized to provide 7.5 minutes detention with 5-ft-deep carbon bed at surface loading of 5 gpm/ft^2.

Construction Costs are shown in Table 20 and also in Figure 22.

Operation and Maintenance Cost

Operation and maintenance costs were developed for package granular activated carbon columns from the conceptual designs presented in Table 19. In developing the costs, it was assumed that the carbon columns function as adsorption units and that where required, they are preceded by filtration.

Process energy requirements include both supply and backwash pumping. Building energy requirements are for heating, lighting, and ventilation of the structures.

Maintenance material requirements were estimated from anticipated costs of replacement parts and replenishment of consumable supplies involved in the daily operation of the equipment. Replacement of activated carbon is a major portion of the maintenance material costs. It was assumed that activated carbon would be replaced with virgin or off-site regenerated carbon once per year.

Labor requirements were developed assuming that the facilities operate essentially unattended. Labor requirements involve backwashing the carbon column once per week, performing routine maintenance tasks (such as pump lubrication and occasional replacement of pump seals), and monitoring the performance of the carbon column. No allowance for administrative or for laboratory labor (other than for minimal routine quality assurance testing) is included.

Operation and maintenance requirements are summarized in Table 21 and are shown in Figures 23 and 24.

POTASSIUM PERMANGANATE FEED SYSTEMS

Construction Cost

Construction cost estimates were developed for feed systems using dry, 97-percent pure, potassium permanganate, with on-site mixing of the permanganate solution. Solutions are prepared in a 150-gal tank and fed to the point of application using a dual-head diaphragm pump. A standby metering pump is not included in the cost estimate.

The potassium permanganate feed system would be essentially the same for all water systems with a capacity less than 1 mgd. Such a system would have a construction cost of $7,360, as shown in Table 22.

Operation and Maintenance Cost

At the low feed rates encountered in small water supply systems, operation and maintenance requirements are not a function of the amount of potassium permanganate fed.

Process electrical energy (1,800 kw-hr/year) is required for the

Table 20

Construction Cost for

Package Granular Activated Carbon Columns

Cost Category	Plant Flow 1.7 gpm, 2,500 gpd	17 gpm, 25,000 gpd	70 gpm, 100,000 gpd	175 gpm, 250,000 gpd	350 gpm, 500,000 gpd
Excavation and Site-work	$50	$50	$50	$80	$80
Manufactured Equipment	740	2,900	7,070	14,600	27,100
Concrete	100	250	480	580	700
Labor	1,100	3,900	6,240	9,500	13,000
Pumps, Piping and Valves	500	1,200	4,300	6,400	8,800
Electrical and Instrumentation	600	600	850	1,100	1,300
Housing	5,100	6,910	9,180	10,300	11,400
SUBTOTAL	8,190	15,810	28,170	42,560	62,380
Miscellaneous and Contingency	1,230	2,370	4,230	6,380	9,360
TOTAL COST	9,420	18,180	32,400	48,940	71,740

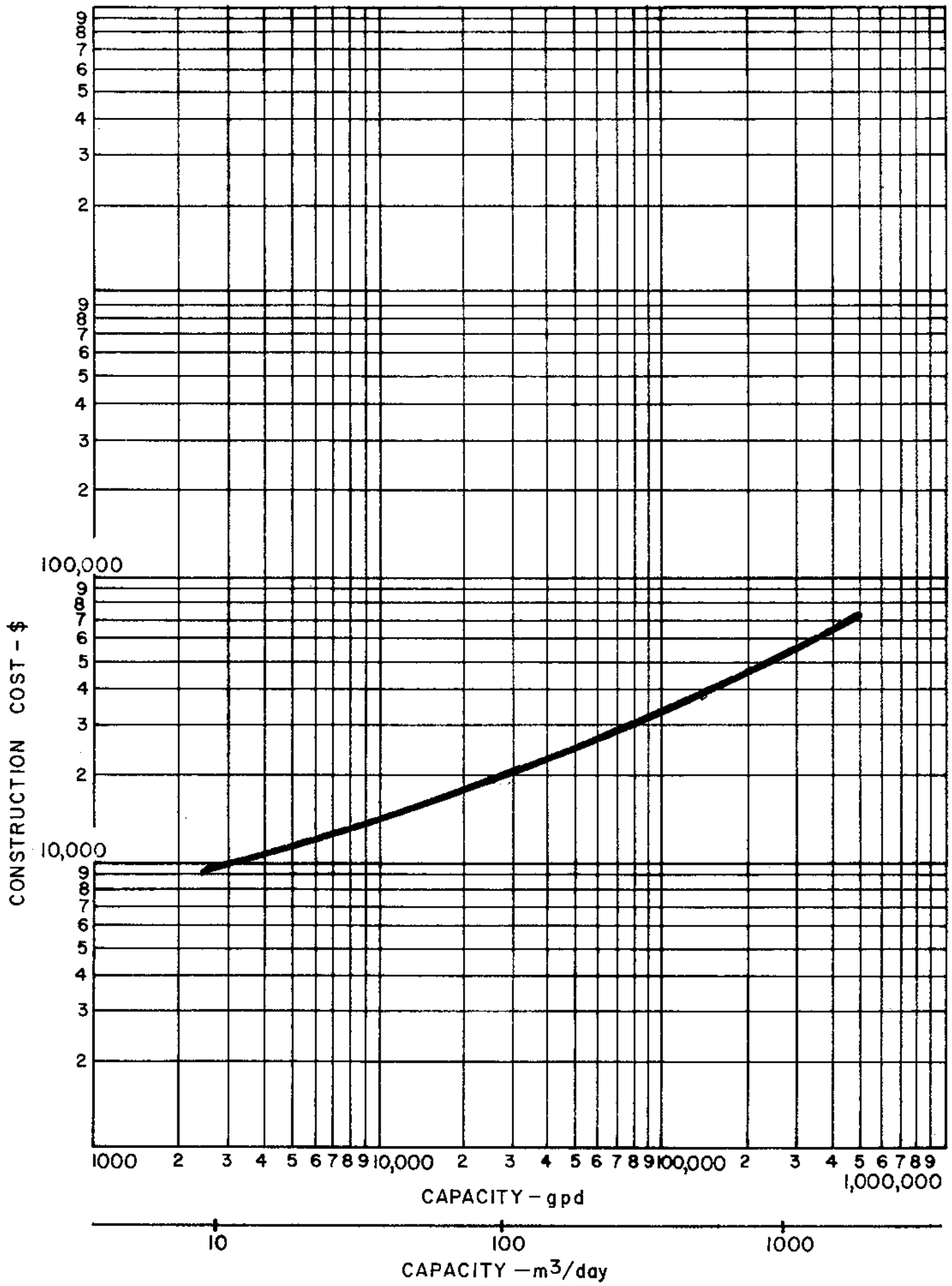


Figure 22. Construction cost for
package granular activated carbon columns.

Table 21

Operation and Maintenance Summary for

Package Granular Activated Carbon Columns

Plant Flow		Energy (kw-hr/yr)			Maintenance	Labor	Total Cost*
gpm	gpd	Building	Process	Total	Material ($/yr)	(hr/yr)	($/yr)
1.7	2,500	6,140	120	6,260	$100	100	$1,290
17	25,000	15,400	1,200	16,600	275	100	1,770
70	100,000	30,800	4,840	35,640	1,000	160	3,670
175	250,000	38,500	9,690	48,190	2,650	210	6,200
350	500,000	46,170	24,210	70,380	4,880	260	9,590

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

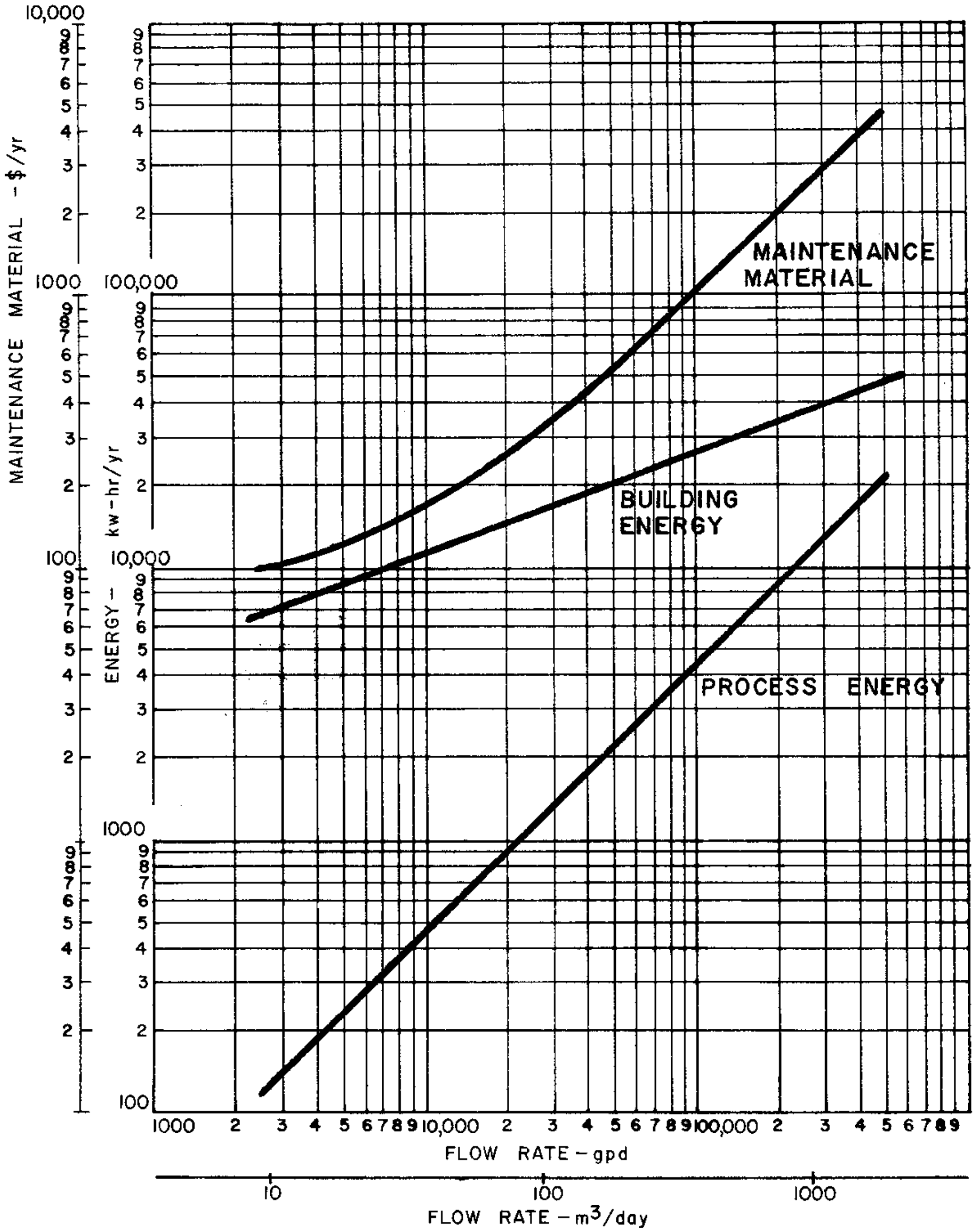


Figure 23. Operation and maintenance requirements for package granular activated carbon columns - building energy, process energy, and maintenance material.

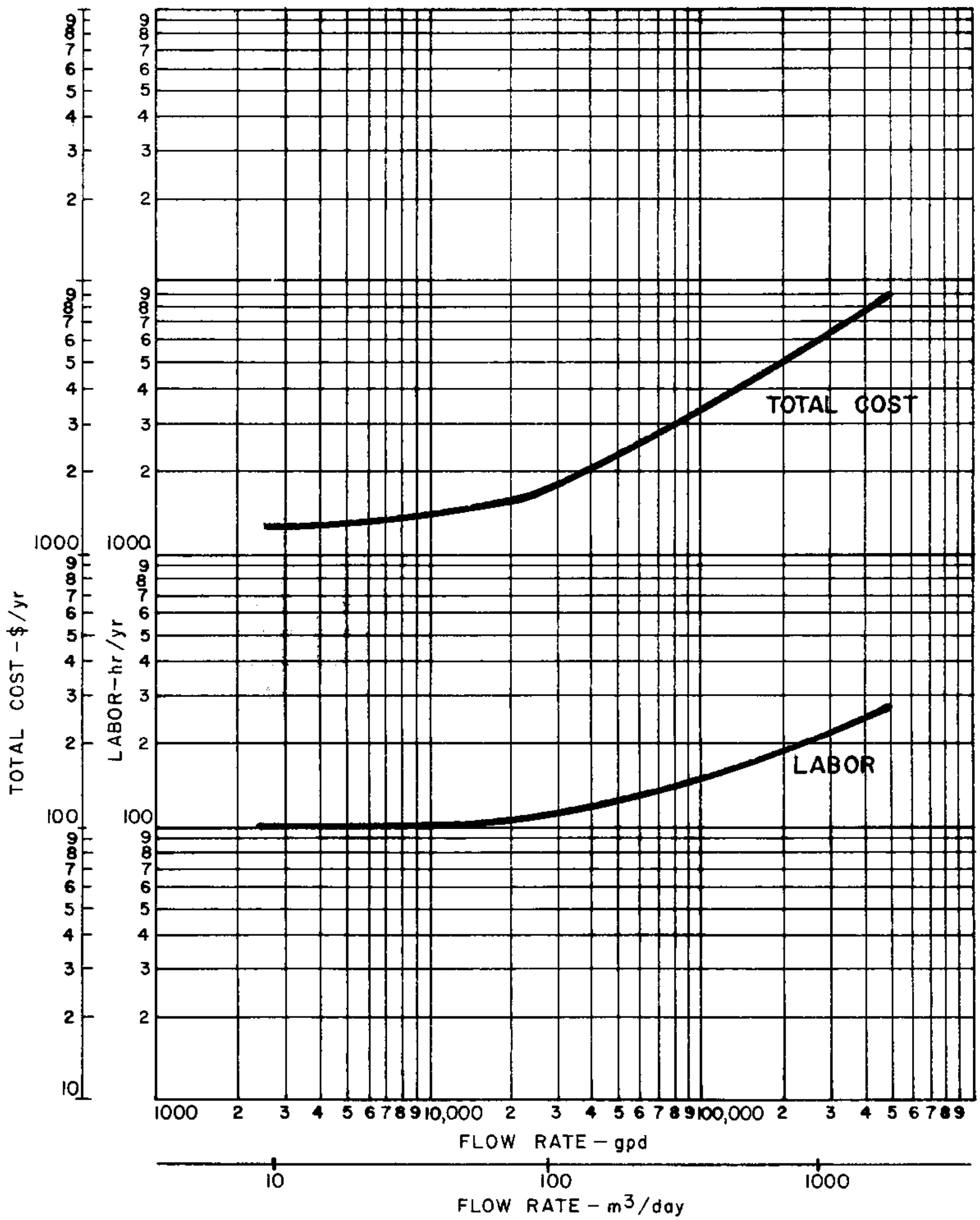


Figure 24. Operation and maintenance requirements for package granular activated carbon columns - labor and total cost.

Table 22

Construction Cost for

Potassium Permanganate Feed Systems

Cost Category	Cost
Manufactured Equipment	$1,380
Pipe and Valves	300
Labor	300
Electrical Equipment and Instrumentation	220
Housing	4,200
SUBTOTAL	6,400
Miscellaneous and Contingency	960
TOTAL	7,360

metering pump and the solution tank mixer. Building energy requirements are 2,050 kw-hr/year, for a total electrical energy requirement of 3,850 kw-hr/year.

Annual maintenance material requirements are for periodic maintenance of the metering pump and pipe and valving. Maintenance material requirements were estimated at $50/year.

Labor requirements are principally for solution preparation and periodic checking and readjustment of the metering pump, as well as for maintenance of the metering pump. Requirements were estimated to be 101 hr/year.

Annual operation and maintenance costs are shown in Table 23.

POLYMER FEED SYSTEMS

Construction Cost

Construction costs are identical for all polymer feed systems with capacities up to 10 lb/day. The manufactured equipment consists of a manufactured feeder-mixer, which contains a hopper for storage of the dry polymer. Dry polymer is fed manually to the hopper tank. The cost estimates were developed for a single system with no backup equipment. The estimated construction cost for a system capable of feeding up to 10 lb/day of polymer is shown in Table 24.

Operation and Maintenance Cost

Process energy requirements (17,300 kw-hr/year) are for the feeder/mixer and for a diaphragm metering pump. Building-related energy for 80 ft^2 is 8,210 kw-hr/year, for a total energy requirement of 25,510 kw-hr/year.

Annual maintenance costs were estimated to be 2 percent of the cost of manufactured equipment and pipe and valves. The annual cost would be $240/year, which does not include the cost of polymer.

Labor requirements are for operation and maintenance of the feeder/mixer and the metering pump, and they are estimated to be 198 hr/year.

Operation and maintenance requirements and costs are shown in Table 25.

POWDERED ACTIVATED CARBON FEED SYSTEMS

Construction Cost

The principal use of powdered activated carbon in small water systems is for taste and odor control, generally on a seasonal basis. Powdered carbon preparation and feed facilities are generally designed to use bagged carbon because of the small quantities involved. A feed slurry is prepared by mixing the carbon with water at a concentration generally not exceeding about 1 lb/gal. The slurry is continuously mixed and applied to the water using a slurry feed pump.

Table 23

Operation and Maintenance Summary for

Potassium Permanganate Feed Systems

Item	Amount
Electrical Energy:	
Process	1,800 kw-hr/yr
Building	2,050 kw-hr/yr
TOTAL	3,850 kw-hr/yr
Maintenance Material	$50/year
Labor	101 hr/yr
TOTAL COST*	$1,180/year

*Calculated using $0.03/kw-hr and $10,00/hr of labor.

Table 24

Construction Cost for

Polymer Feed Systems

Cost Category	Cost
Manufactured Equipment	$11,000
Labor	670
Pipe and Valves	260
Electrical and Instrumentation	1,230
Housing	3,360
SUBTOTAL	16,520
Miscellaneous and Contingency	2,480
TOTAL	19,000

Table 25
Operation and Maintenance Summary for
Polymer Feed Systems

Item	Amount
Electrical Energy:	
Process	17,300 kw-hr/yr
Building	8,210 kw-hr/yr
TOTAL	25,510 kw-hr/yr
Maintenance Material	240/yr
Labor	198 hr/yr
TOTAL COST*	2,990/year

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Construction costs were developed for feed systems capable of applying 1, 5, and 10 lb/hr of powdered activated carbon. Each system consists of two 55-gal slurry preparation tanks using a vacuum bag unloading and slurrying technique, a feed tank with mixer, and a slurry-style feed pump along with all associated piping and valving adjacent to the equipment. Although housing is required, it was assumed that carbon feed facilities will be used in conjunction with package complete treatment plants, for which the required housing includes adequate space for the powdered carbon feed facilities.

Construction costs are presented in Table 26 and Figure 25.

Operation and Maintenance Cost

Process energy requirements are for operation of the vacuum bag unloading and slurrying system, slurry mixer, and slurry feed pump. Continuous operation on a yearly basis was assumed with 1 hr/day downtime to maintain equipment, flush the feed pump, and allow for backwashing of the plant filter.

Maintenance materials are related to slurry pump replacement parts, replacement vacuum dust bags, and other small parts associated with the feed assembly. Labor requirements are for preparation of the carbon slurry and for maintenance of the equipment.

Operation and maintenance requirements are listed in Table 27 and shown in Figures 26 and 27.

CHLORINE FEED SYSTEMS

Construction Cost

Feed of small quantities of chlorine may be either by direct-feed gas chlorination or by feeding a sodium hypochlorite solution. Hypochlorite feed is generally more economical at low feed rates, but operating labor is higher for hypochlorite solution feed than it is for direct-gas feed systems.

Direct-Feed Gas Chlorination--

Chlorine gas is fed from a 150-lb cylinder through a small chlorinator located either directly on the cylinder or on an adjacent wall. Chlorine gas is transferred under vacuum from the chlorinator to an eductor, which is located at or near the point of application. The educator generates the vacuum using a high-pressure water supply. This high-pressure water supply is generally created by withdrawing a portion of the water from the main supply line, passing it through a small booster pump, and then injecting it back into the main supply line. The advantage of using the booster pump is the ability to convey chlorine under a vacuum, and the disadvantage is the need for electricity, the booster pump, and additional piping and valving.

An alternative approach to the use of the booster pump is to feed chlorine gas under pressure directly to the point of application. This approach

Table 26

Construction Cost for

Powdered Activated Carbon Feed Systems

Cost Category	Feed System Capacity (lb/hr)		
	1	5	10
Manufactured Equipment	$2,250	2,970	3,420
Labor	320	410	440
Electrical and Instrumentation	340	360	400
SUBTOTAL	2,910	3,740	4,260
Miscellaneous and Contingency	440	560	640
TOTAL COST	3,350	4,300	4,900

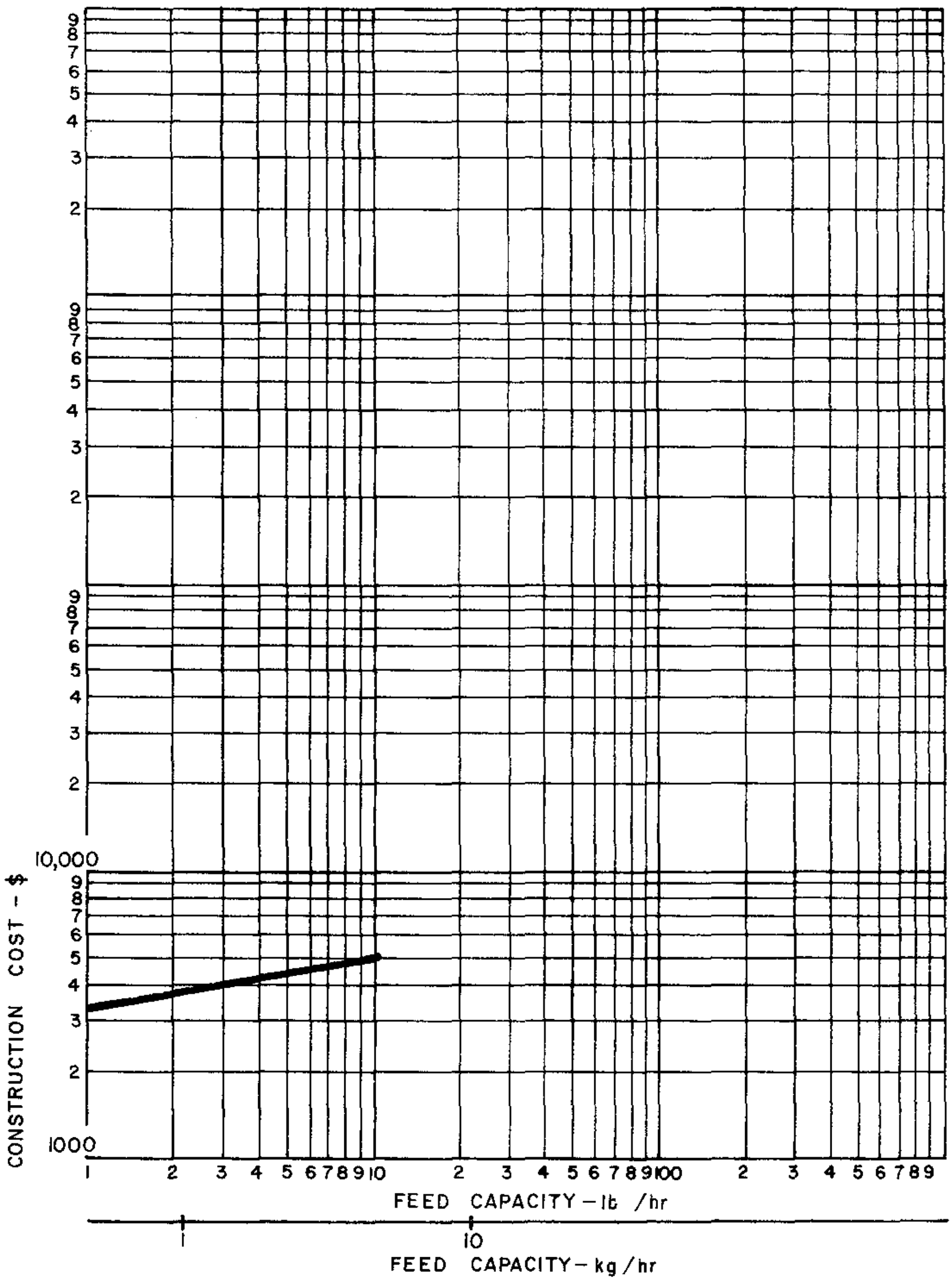


Figure 25. Construction cost for
powdered activated carbon feed systems.

Table 27

Operation and Maintenance Summary for

Powdered Activated Carbon Feed Systems

Feed System Capacity (lb/hr)	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1	2,100	$50	200	$2,110
5	2,640	80	365	3,810
10	3,700	120	550	5,730

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

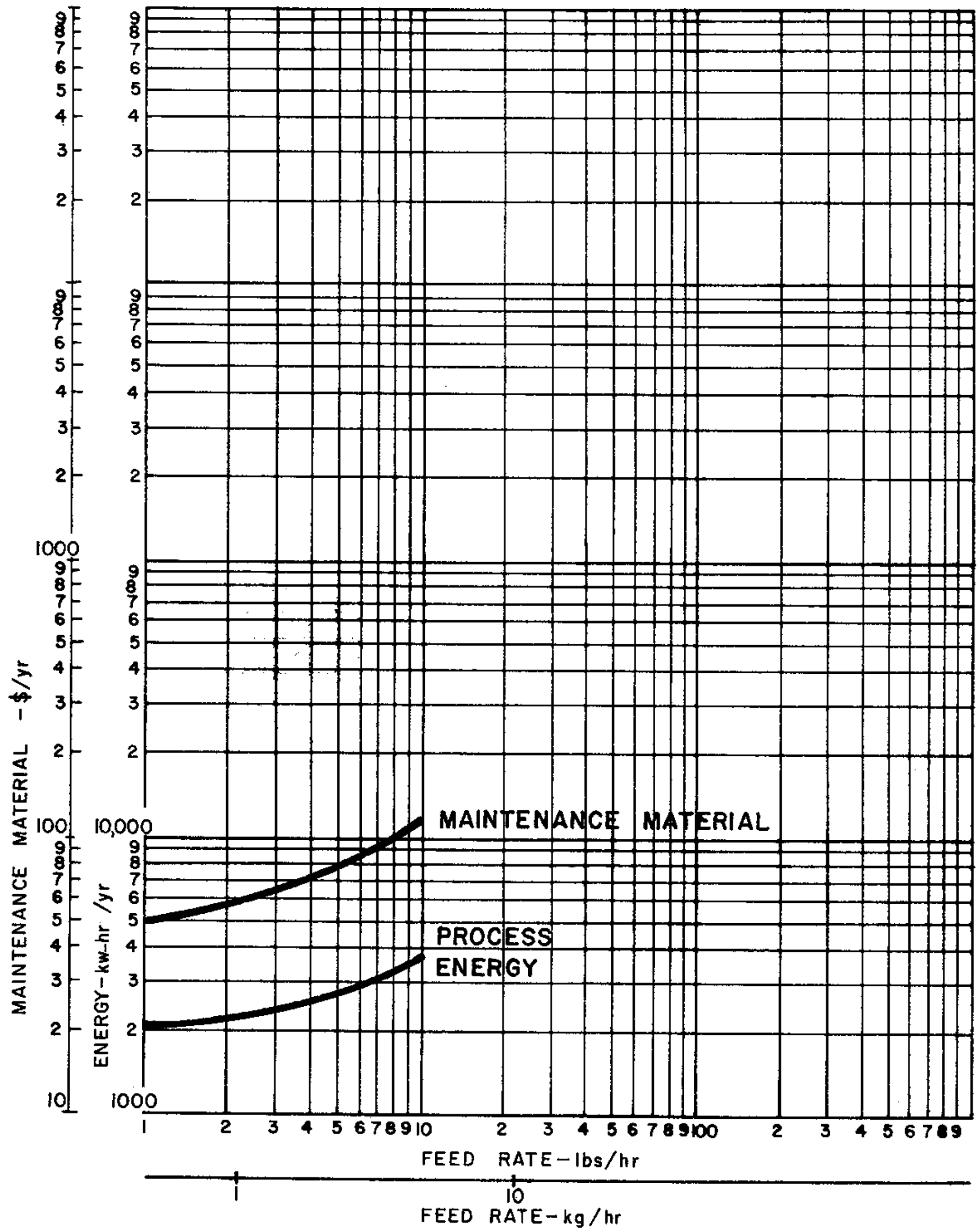


Figure 26. Operation and maintenance requirements for powdered activated carbon feed systems - process energy and maintenance material

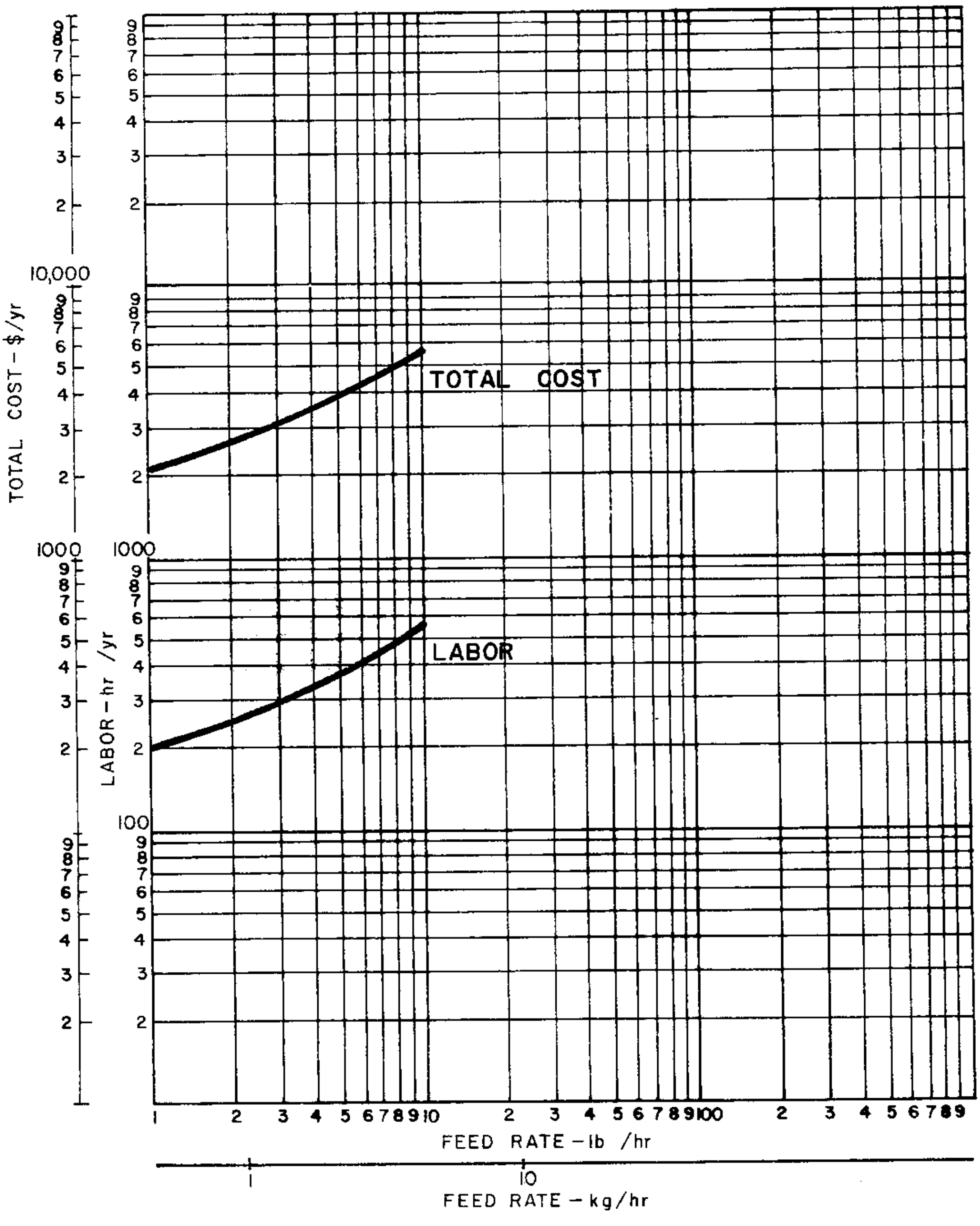


Figure 27. Operation and maintenance requirements for powdered activated carbon feed systems - labor and total cost

is generally not recommended because of the safety hazard involved in conveying chlorine under pressure. The advantage of feeding chlorine gas under pressure is that cylinder pressure operates the system and no electrical power is required.

The estimated costs for a gaseous chlorine feed system using a vacuum transport and booster pump are constant for delivery rates up to 100 lb/day of chlorine. Construction costs are shown in Table 28.

Sodium Hypochlorite Solution Feed--

Sodium hypochlorite solutions are prepared in a day tank and then pumped by a diaphragm metering pump to the point of application. Use of a metering pump allows injection into a pumped supply pipeline or application to a gravity flow. Automatic proportioning may be desirable, but it is not included in the cost estimates. Costs would be constant for flows between 2,500 gpd and 1 mgd. Construction costs are shown in Table 29.

Operation and Maintenance Costs

Direct-Feed Gas Chlorination--

In general, operation and maintenance costs are independent of flow. Process energy requirements are for the booster pump only and would be about 1,630 kw-hr/year. Building energy requirements for a 25-ft^2 building would be 2,560 kw-hr/year. Maintenance material requirements would only be for miscellaneous repair of valving, electrical switches, and other equipment, and it would be about $40/year. Labor requirements are for periodic checking of equipment, with an average requirement of 1/2 hr/day, or 183 hr/year.

Operation and maintenance requirements are shown in Table 30.

Sodium Hypochlorite Solution Feed--

As with direct-feed gas chlorination, operation and maintenance requirements are independent of flow. Process energy requirements are for the diaphragm metering pump and are 570 kw-hr/year. Building energy requirements for a 25-ft^2 building would be 2,560 kw-hr/year. Maintenance material would be only for minor component repair and would be $20/year.

Labor is required for periodic mixing of the sodium hypochlorite solution as well as for checking of the equipment. Requirements are difficult to estimate because the chlorination station may be remote and transit time may be extensive. Based on a labor requirement of 1 hr/day, the annual requirement would be 365 hr/year.

Operation and maintenance requirements are shown in Table 31.

OZONE GENERATION SYSTEMS AND CONTACT CHAMBERS

Construction Cost

Small ozone generators are available for use with either air or pure

Table 28

Construction Cost for

Direct-Feed Gas Chlorination

Cost Category	Cost
Manufactured Equipment	$1,300
Labor	300
Pipe and Valves	100
Electrical	200
Housing (25 ft^2)	1,850
SUBTOTAL	3,750
Miscellaneous and Contingency	560
TOTAL	4,310

Table 29

Construction Cost for

Sodium Hypochlorite Solution Feed

Cost Category	Cost
Manufactured Equipment	$1,100
Labor	300
Pipe and Valves	300
Electrical Equipment and Instrumentation	200
Labor	300
Housing (25 ft^2)	1,850
SUBTOTAL	4,050
Miscellaneous and Contingency	610
TOTAL	4,660

Table 30

Operation and Maintenance Summary for Direct-Feed Gas Chlorination

Item	Amount
Electrical Energy:	
Process	1,630 kw-hr/yr
Building	2,560 kw-hr/yr
TOTAL	4,190 kw-hr/yr
Maintenance Material	$40/yr
Labor	183 hr/yr
TOTAL COST*	$2,000/yr

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 31

Operation and Maintenance Summary for Sodium Hypochlorite Solution Feed

Item	Amount
Electrical Energy:	
Process	570 kw-hr/yr
Building	2,560 kw-hr/yr
TOTAL	3,130 kw-hr/yr
Maintenance Material	$20/yr
Labor	365 hr/yr
TOTAL COST*	$3,760/yr

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

oxygen feed. Normally, air feed would be used for small generation rates, as pure oxygen storage is not economical. However, an ozonator operated on pure oxygen feed would have approximately double the generating capacity of the same ozonator on air feed. Significantly less energy is also required when pure oxygen feed is used.

Construction costs were developed for air-feed ozone generating systems with capacities between 0.5 and 10 lb/day. The costs include the ozonator, dissolution equipment, and all required electrical equipment and instrumentation. Ozone contactor costs must be added separately because they are a function of flow treated and contact time. A separate curve is included for the ozone contactor. Costs for the ozone generation system are shown in Table 32 and Figure 28.

Ozone contactors for small systems are best constructed of PVC pipe standing on end, or FRP tanks. The contact chamber should be approximately 18-ft high with a water depth of 16-ft; it should provide a detention time of 10 to 15 min. Costs were developed for the 18-ft-high FRP contactors located out-of-doors. Dissolution equipment is included with the generation system costs, and it is not included with the contactor. Contactor costs are shown in Table 33 and also in Figure 29.

Operation and Maintenance Cost

Electrical energy is required for building, heating, lighting, and ventilation, as well as for process energy for ozone generation. Process energy for ozonation is based on a usage of 15 kw-hr/lb of ozone for the smallest system, decreasing to 11 kw-hr/lb of ozone for the largest system.

Maintenance material requirements are for periodic equipment repair and replacement of parts. Based on manufacturers' recommendations, an annual maintenance material requirement of 1 percent of the manufactured equipment cost was utilized.

Labor requirements for for periodic cleaning of the ozone generation apparatus, maintenance of the oxygen generation equipment, annual maintenance of the contact basin, and day-to-day operation of the generation equipment.

Operation and maintenance requirements are summarized in Table 34 and are shown in Figures 30 and 31.

CHLORINE DIOXIDE GENERATING AND FEED SYSTEMS

Construction Cost

Chlorine dioxide may be generated in small quantities by mixing a sodium chlorite solution with an acidified sodium hypochlorite solution. Mixing of the solutions takes place in a PVC chamber filled with procelain Raschig Rings, with the chlorine dioxide generation occurring in the chamber following mixing. A required pH of 4 and sufficient chemicals for the reaction to go to completion will result when equal parts of a 1-percent sodium hypochlorite solution, a 25-percent sulfuric acid solution, and a 2.4-percent sodium

Table 32

Construction Cost for
Ozone Generation Systems

Cost Category	Ozone Generation Capacity (lb/day)		
	0.5	5.0	10.0
Manufactured Equipment	$11,540	$19,880	$28,530
Labor	1,860	3,300	4,840
Housing	6,000	6,000	6,000
SUBTOTAL	19,400	29,180	39,370
Miscellaneous and Contingency	2,910	4,380	5,910
TOTAL	22,310	33,560	45,280

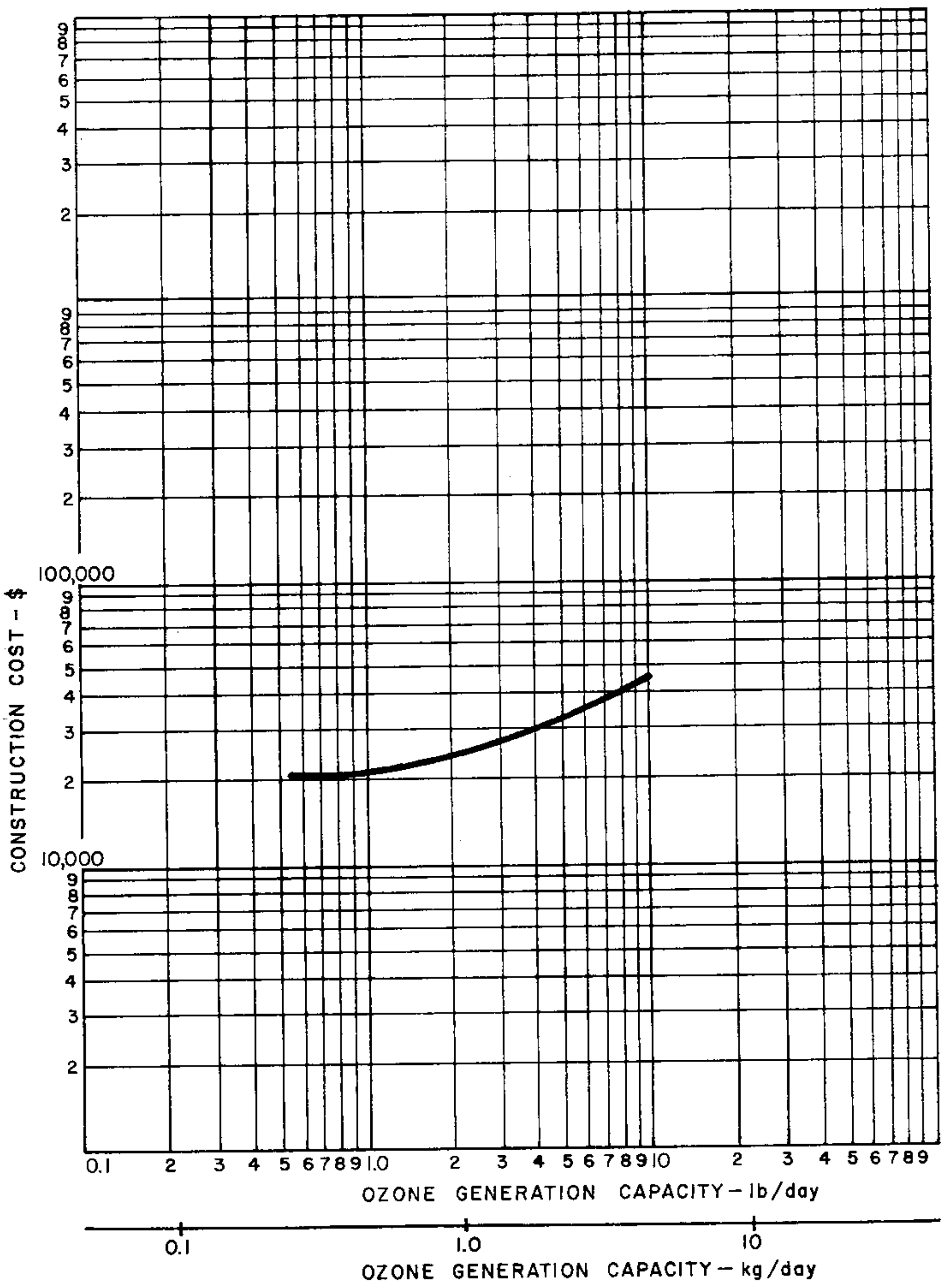


Figure 28. Construction Cost for Ozone Generation Systems.

Table 33

Construction Cost for

Ozone Contact Chambers

Cost Category	Contactor Volume (gal)				
	850	2,350	5,290	8,480	13,540
Manufactured Equipment	$ 690	$ 1,270	$ 3,160	$ 6,960	$ 8,640
Concrete	20	50	100	140	190
Steel	10	20	40	50	70
Labor	170	280	470	610	760
SUBTOTAL	890	1,620	3,770	7,760	9,660
Miscellaneous and Contingency	130	240	570	1,160	1,450
TOTAL	1,020	1,860	4,340	8,920	11,110

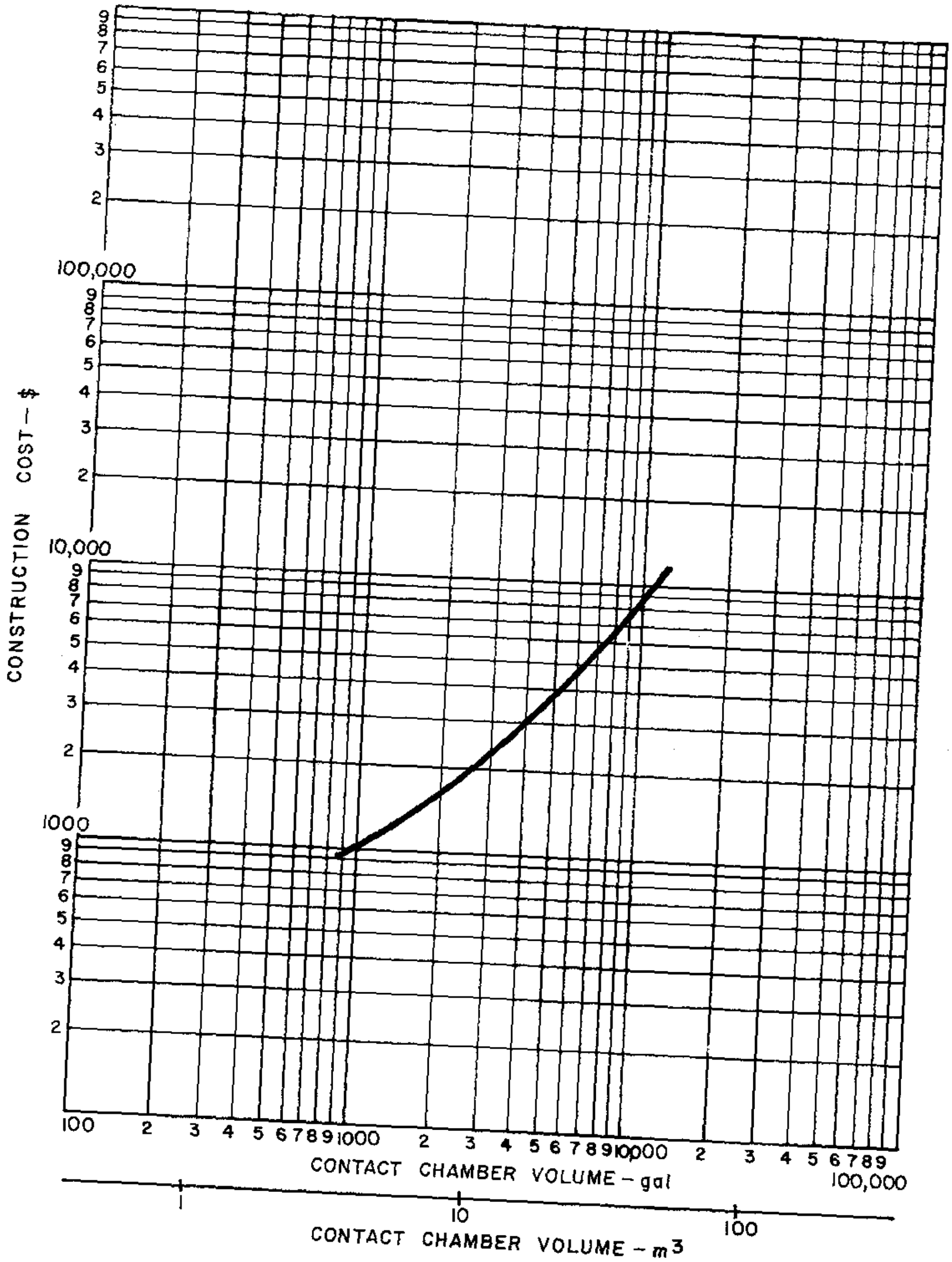


Figure 29. Construction cost for ozone contact chambers.

Table 34

Operation and Maintenance Summary for Ozone Generation Systems

Ozone Generation Rate (lb/day)	Electrical Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total* Cost ($/yr)
0.5	6,570	2,560	9,130	$ 120	370	$ 4,090
5.0	6,570	21,900	28,470	200	550	6,550
10.0	6,570	40,150	46,720	290	550	7,190

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

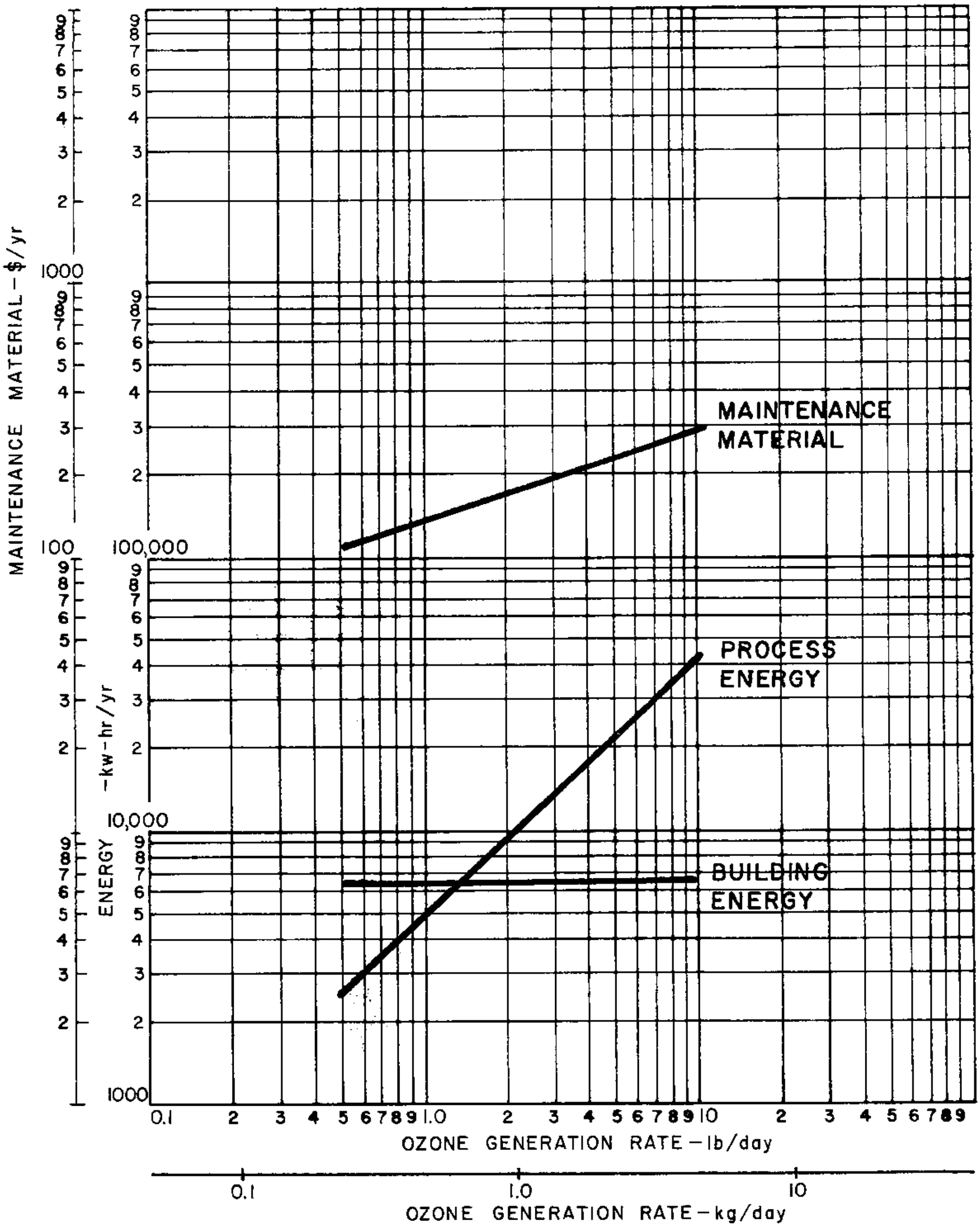


Figure 30. Operation and maintenance requirements for ozone generation systems - building energy, process energy, and maintenance material.

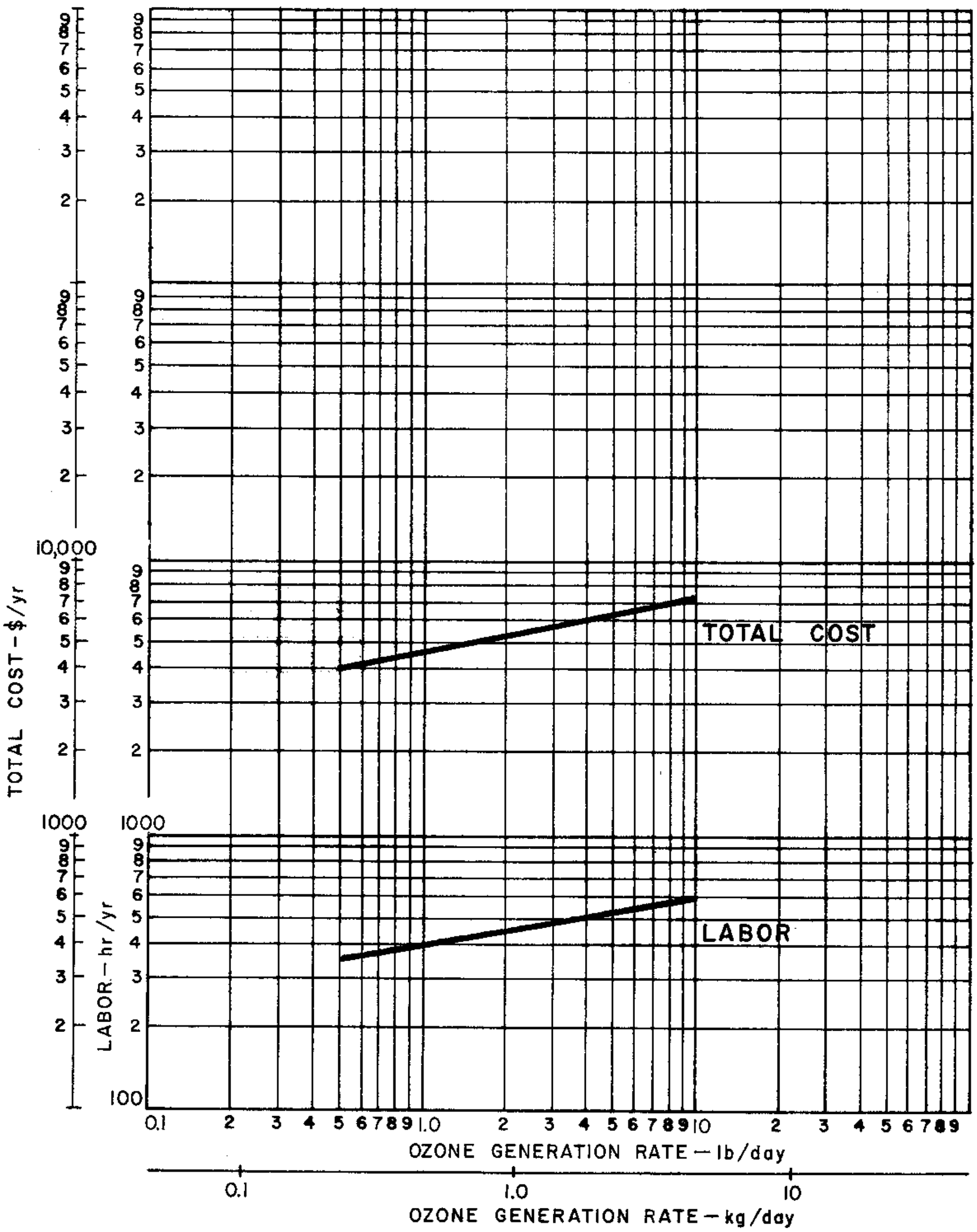


Figure 31. Operation and maintenance requirements for ozone generation systems - labor and total cost.

chlorite solution are mixed.

Construction costs are independent of generating capacity, up to about 50 lb of chlorine dioxide/day. Cost estimates were made based on use of a dual-head diaphragm pump for the sodium hypochlorite and sulfuric acid solutions, and a separate diaphragm pump for the sodium chlorite. The chlorine dioxide generator was sized for a detention time of approximately 0.2 min. Estimated construction costs are shown in Table 35.

Operation and Maintenance Cost

Generally, operation and maintenance costs are independent of the quantity of chlorine dioxide generated. Process energy requirements, which are for the metering pumps and mixer for the sodium chlorite solution, would be 1,240 kw-hr/year. Building energy requirements for 40 ft^2 would be 4,100 kw-hr/year. Total energy requirements are therefore 5,340 kw-hr/year. Maintenance material requirements would only be for minor equipment repair, amounting to $100/year.

Labor is required for preparation of the three required solutions and periodic maintenance of the equipment. The annual labor requirement is estimated to be 365 hr/year. Operation and maintenance requirements are shown in Table 36.

ULTRAVIOLET LIGHT DISINFECTION

Construction Cost

Ultraviolet light may be utilized to sterilize water, provided that the turbidity is very low. The ultraviolet rays, which are generated by a mercury lamp, sterilize by penetrating the microbial cell wall and reacting with the cell contents, a process that is complete within a few seconds. The mercury lamp is contained in a quartz glass sleeve, and the water to be disinfected is passed through a tubular chamber surrounding the quartz glass sleeve. The principal advantage of this process is that no chemicals are added and the chemical quality of the water is not changed. The principal disadvantage is the lack of any residual disinfectant.

Construction costs were developed for single and multiple ultraviolet sterilizing units ranging in capacity from 10 to 780 gpm. The units are available from a number of manufacturers and are furnished in a modular form requiring only piping and electrical connections. The units are extremely compact, and a 780-gpm module would occupy an area of less than 24 ft^2. The costs include the manufactured units and the related costs of piping, electrical equipment, and equipment installation, and a building to house the equipment.

Construction costs are shown in Table 37 and also in Figure 32.

Operation and Maintenance Cost

Process energy is for the mercury lamp. Continuous 24-hr/day operation

Table 35

Construction Cost for

Chlorine Dioxide Generating and Feed Systems

Cost Category	Cost
Manufactured Equipment	$4,050
Labor	600
Pipe and Valves	500
Electrical Equipment and Instrumentation	400
Housing (40 ft^2)	2,860
SUBTOTAL	8,410
Miscellaneous and Contingency	1,260
TOTAL	9,670

Table 36

Operation and Maintenance Summary for

Chlorine Dioxide Generating and Feed Systems

Item	Amount
Electrical Energy:	
Process	1,240 kw-hr/yr
Building	4,100 kw-hr/yr
TOTAL	5,340 kw-hr/yr
Maintenance Material	$100/yr
Labor	365 hr/yr
TOTAL COST*	$3,910/yr

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 37

Construction Cost for

Ultraviolet Light Disinfection

Cost Category	Plant Capacity (gpm) 10	20	130	260	520	780
Excavation and Sitework	$60	$60	$60	$60	$80	$110
Manufactured Equipment	700	1,150	3,900	7,550	15,100	22,650
Concrete	250	250	250	250	280	300
Labor	110	170	250	300	400	500
Pipe and Valves	60	150	350	450	750	1,000
Electrical and Instrumentation	430	430	430	430	480	480
Housing	1,500	1,500	1,500	1,500	1,800	2,000
SUBTOTAL	3,110	3,710	6,740	10,540	18,890	27,040
Miscellaneous and Contingency	470	560	1,010	1,580	2,830	4,060
TOTAL	3,580	4,270	7,750	12,120	21,720	31,100

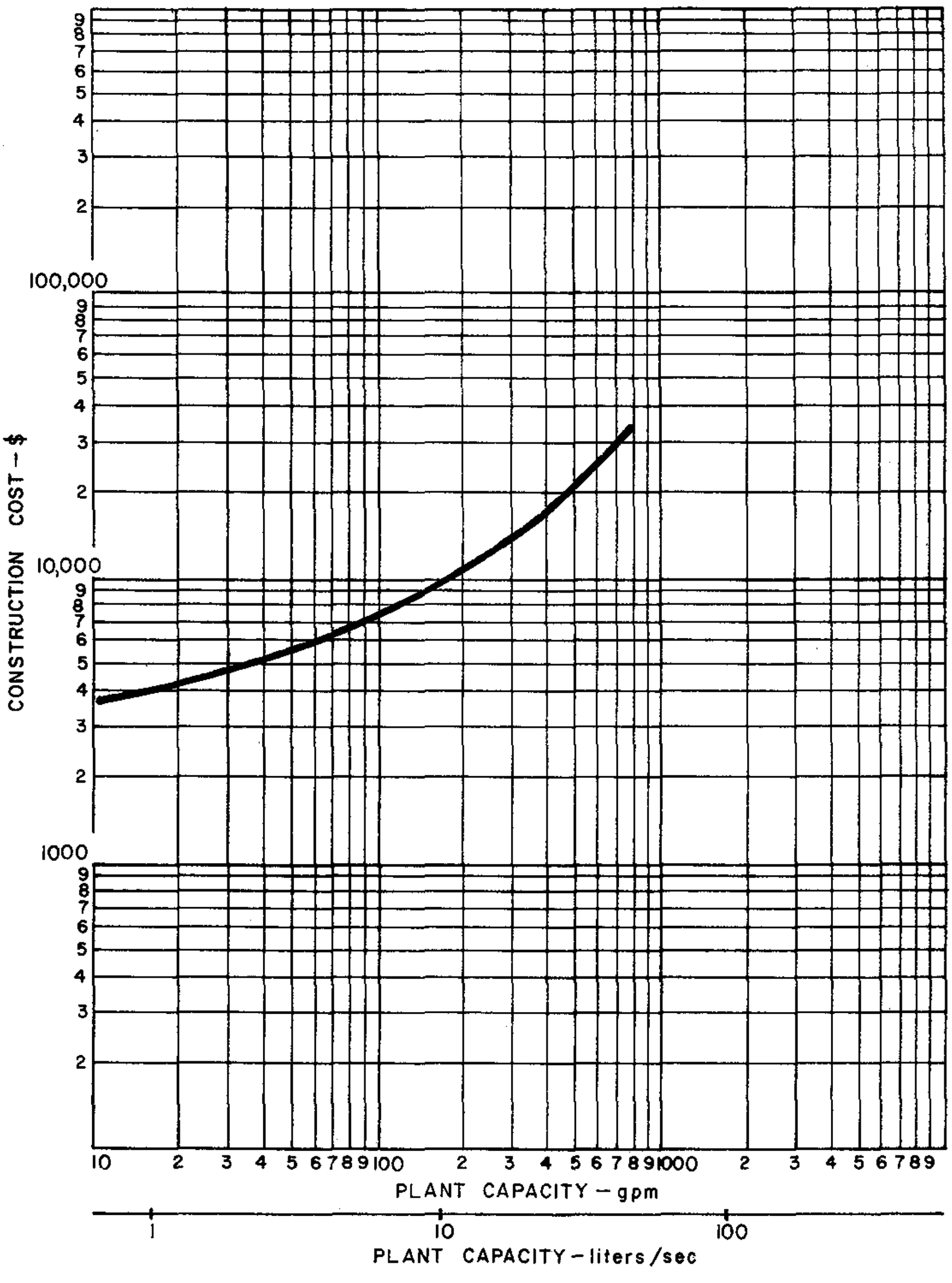


Figure 32. Construction cost for ultraviolet light disinfection.

was assumed, with only occasional shutdown to clean cells and replace weak ultraviolet lamps. Building energy is for heating, lighting, and ventilation.

Maintenance materials are related to the replacement cost of the ultraviolet lamps, which are generally replaced after operating continuously for about 8,000 hr.

Labor requirements are related to occasional cleaning of the quartz sleeves and periodic replacement of the ultraviolet lights.

Operation and maintenance requirements are summarized in Table 38 and also presented in Figures 33 and 34.

REVERSE OSMOSIS

Construction Cost

Reverse osmosis utilizes membranes to remove a high percentage of almost all inorganic ions, turbidity, bacteria, and viruses. Most organic matter is also removed, with the exception of several materials, including most halogenated and low-molecular-weight compounds.

Construction costs were developed for complete reverse osmosis plants in the size ranges from 2,500 gpd to 1 mgd. Commercial units are available in sizes up to about 5,000 gpd for the membrane elements and up to 30,000 gpd for the reverse osmosis modules (pressure vessels). Therefore, large-scale plants are composed of many smaller, parallel modules. Components taken into account in the construction cost estimates include housing, structural steel and miscellaneous metalwork, tanks, piping, valves, pumps, reverse osmosis membrane elements and pressure vessels, flow meters, cartridge filters, acid and polyphosphate feed equipment, and also cleaning equipment. The cost curves are based on the use of either spiral-wound or hollow fine-fiber reverse osmosis membranes.

The efficiency of the membrane elements in reverse osmosis systems may be impaired by scaling (because of slightly soluble or insoluble compounds) or by fouling (because of the deposition of colloidal or suspended materials). Because of this possibility, a very important consideration in the design of a reverse osmosis system is the provision of adequate pretreatment to protect the membrane from excessive scaling and fouling and to avoid frequent cleaning requirements. In the development of the cost curves, adequate pretreatment was assumed to precede the reverse osmosis process, but costs for pretreatment are not included in the estimates.

The construction cost curve applies to waters with a total dissolved solids (TDS) concentration ranging up to about 10,000 mg/l. Other considerations, such as calcium sulfate and silica concentrations and also the desired water recovery, affect cost more than the influent TDS concentration. The temperature of the feedwater is assumed to be between 65° and 95° F, and the pH of the feedwater is adjusted to about 5.5 to 6.0 before the reverse osmosis process. A single-pass treatment system (only one pass through the membrane) is assumed, with an operating pressure of 400 to 450 psi. The

Table 38

Operation and Maintenance Summary for

Ultraviolet Light Disinfection

Plant Flow Rate (gpm)	Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
10	10,260	440	10,700	$100	24	$660
20	10,260	880	11,140	140	24	710
130	10,260	5,260	15,520	600	24	1,310
260	10,260	10,510	20,770	1,120	30	2,040
520	12,310	21,020	33,330	2,250	36	3,610
780	13,340	31,540	44,880	3,300	42	5,070

*Calculated using $0.03/kw-hr and $10.00/hr labor.

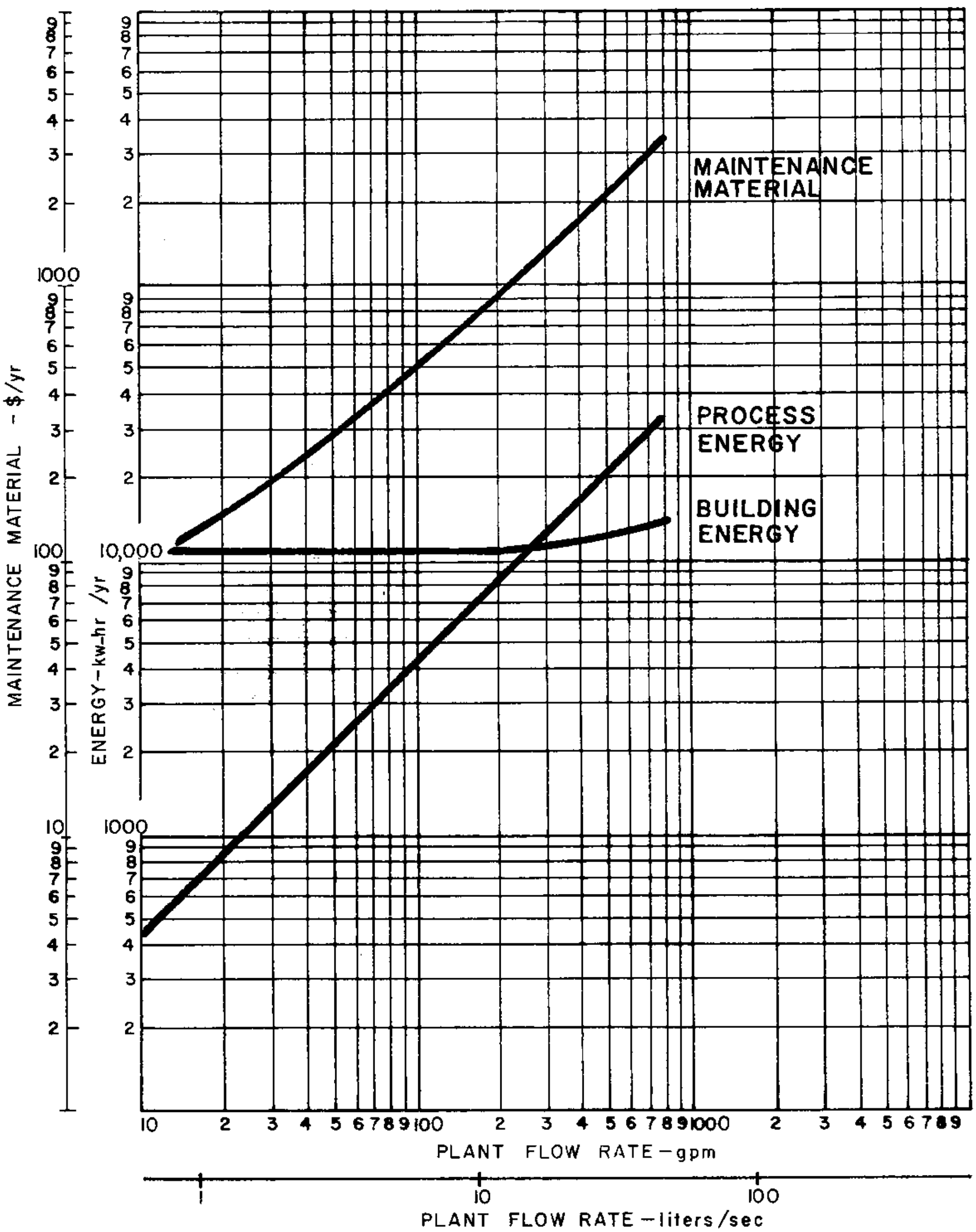


Figure 33. Operation and maintenance requirements for ultraviolet light disinfection - building energy, process energy, and maintenance material.

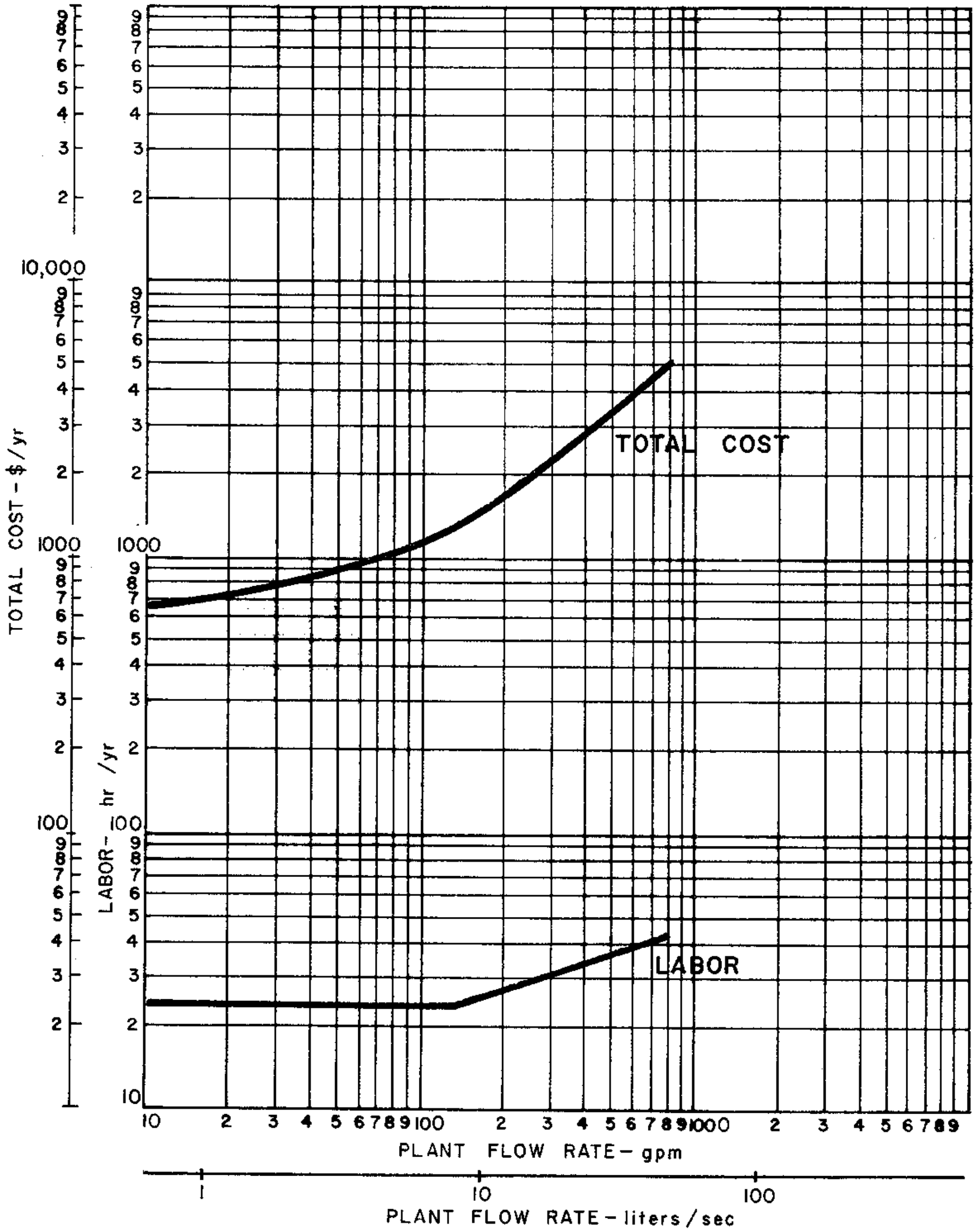


Figure 34. Operation and maintenance requirements for ultraviolet light disinfection - labor and total cost.

assumed water recoveries for different flow ranges are as follows:

Flow Range	Water Recovery (%)
2,500 - 10,000 gpd	60
10,000 - 100,000 gpd	70
100,000 gpd - 1.0 mgd	75

Brine disposal costs are not included in the estimates. Construction cost estimates are presented in Table 39 and also in Figure 35.

Operation and Maintenance Cost

Electrical energy usage is included for the high-pressure feedwater pumps, based on an operating pressure of 450 psi and on the water recoveries listed in the construction cost write-up. For other pumps and chemical feed equipment, an energy usage of 10 percent of the usage for the high-pressure pumps was assumed . Electrical energy for lighting, heating, and ventilating was calculated, based on an estimated floor area required for complete housing of the reverse osmosis equipment.

The largest maintenance material requirement is for membrane replacement; a membrane life of 3 years was used in the cost estimates. Other maintenance material requirements are for replacement of cartridge filters, for membrane cleaning chemicals, and for materials needed for periodic repair of pumps, motors, and electrical control equipment. Costs for pretreatment chemicals, such as acid and polyphosphate, are not included in the estimates. The chemicals utilized and the dosages required will show great variability between different water supplies and should be determined from pilot plant testing.

Labor requirements are for cleaning and replacing membranes, replacing cartridge filters, maintaining the high-pressure and other pumps, preparing treatment chemicals and determining proper dosages, maintaining chemical feed equipment, and monitoring performance of the reverse osmosis membranes. Membrane cleaning was assumed to occur monthly. In estimating labor requirements, a minimum of about 1.5 hr/day of labor was assumed for the smallest plant.

Operation and maintenance requirements are summarized in Table 40 and illustrated in Figures 36 and 37.

PRESSURE ION EXCHANGE SOFTENING

Construction Cost

Cation exchange resins can be utilized for the removal of hardness, barium, trivalent chromium, lead, manganese, mercury, and radium. Construction costs were developed for pressure ion exchange softening systems using the conceptual information presented in Table 41. The contact vessels were fabricated steel, with a baked phenolic lining added after fabrication and constructed for 100 psi working pressure. The depth of resin was 6 ft,

Table 39

Construction Cost for

Reverse Osmosis

Cost Category	Plant Capacity (gpd)			
	2,500	10,000	100,000	1,000,000
Manufactured Equipment	$ 3,710	$11,140	$81,050	$ 474,210
Labor	770	2,210	16,080	70,420
Electrical and Instrumentation	4,190	4,710	10,680	65,740
Housing	2,680	4,070	6,430	64,260
SUBTOTAL	11,350	22,130	114,240	674,630
Miscellaneous and Contingency	1,700	3,320	17,140	101,190
TOTAL	13,050	25,450	131,380	775,820

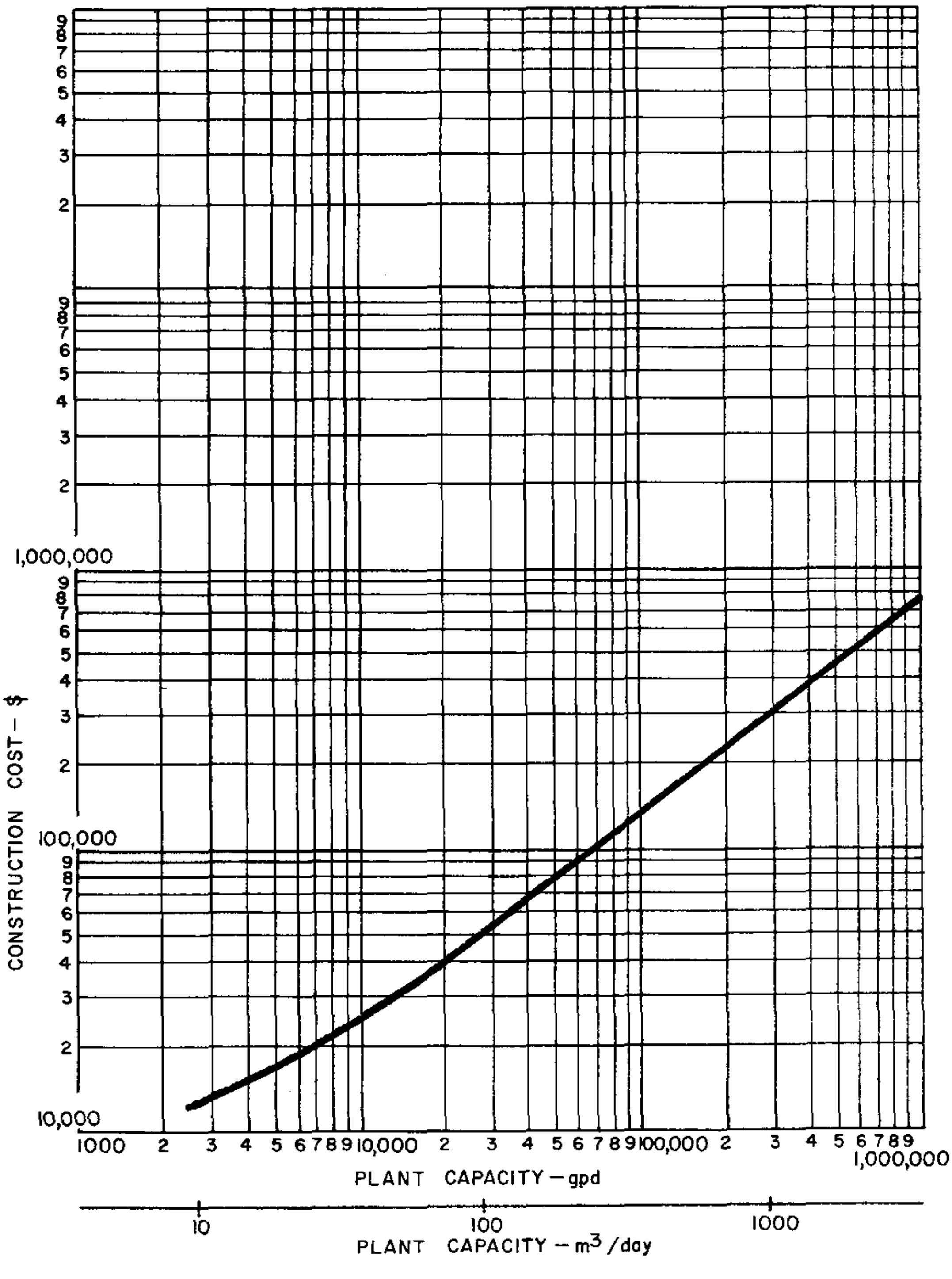


Figure 35. Construction cost for reverse osmosis.

Table 40

Operation and Maintenance Summary for

Reverse Osmosis

Plant Capacity (gpd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
2,500	7,000	8,030	15,030	$250	510	$5,800
10,000	10,500	28,100	38,600	970	710	9,230
100,000	15,400	260,980	276,380	9,730	1,320	31,220
1,000,000	105,400	2,409,000	2,514,400	97,280	1,840	191,110

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

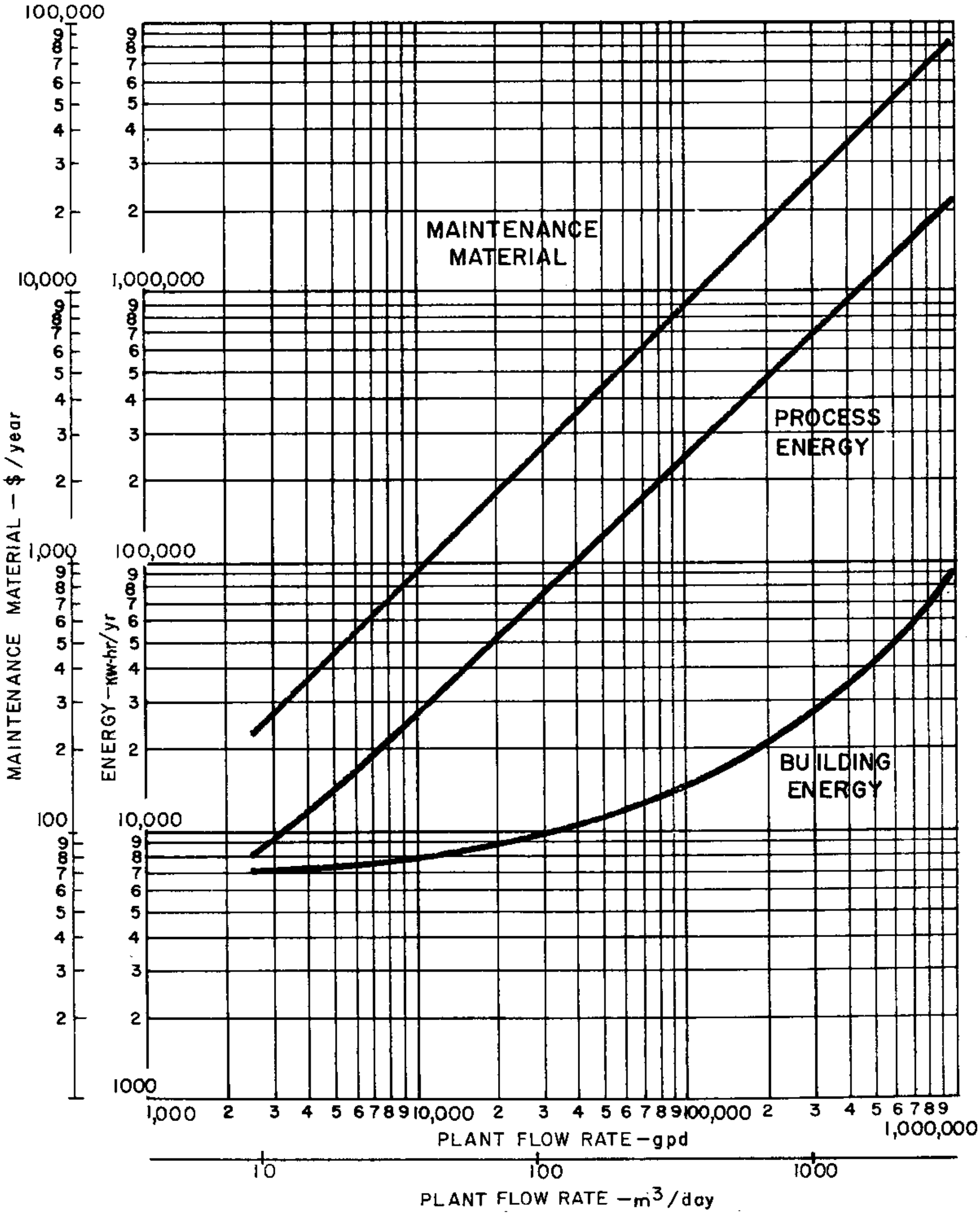


Figure 36. Operation and maintenance requirements for reverse osmosis - building energy, process energy, and maintenance material.

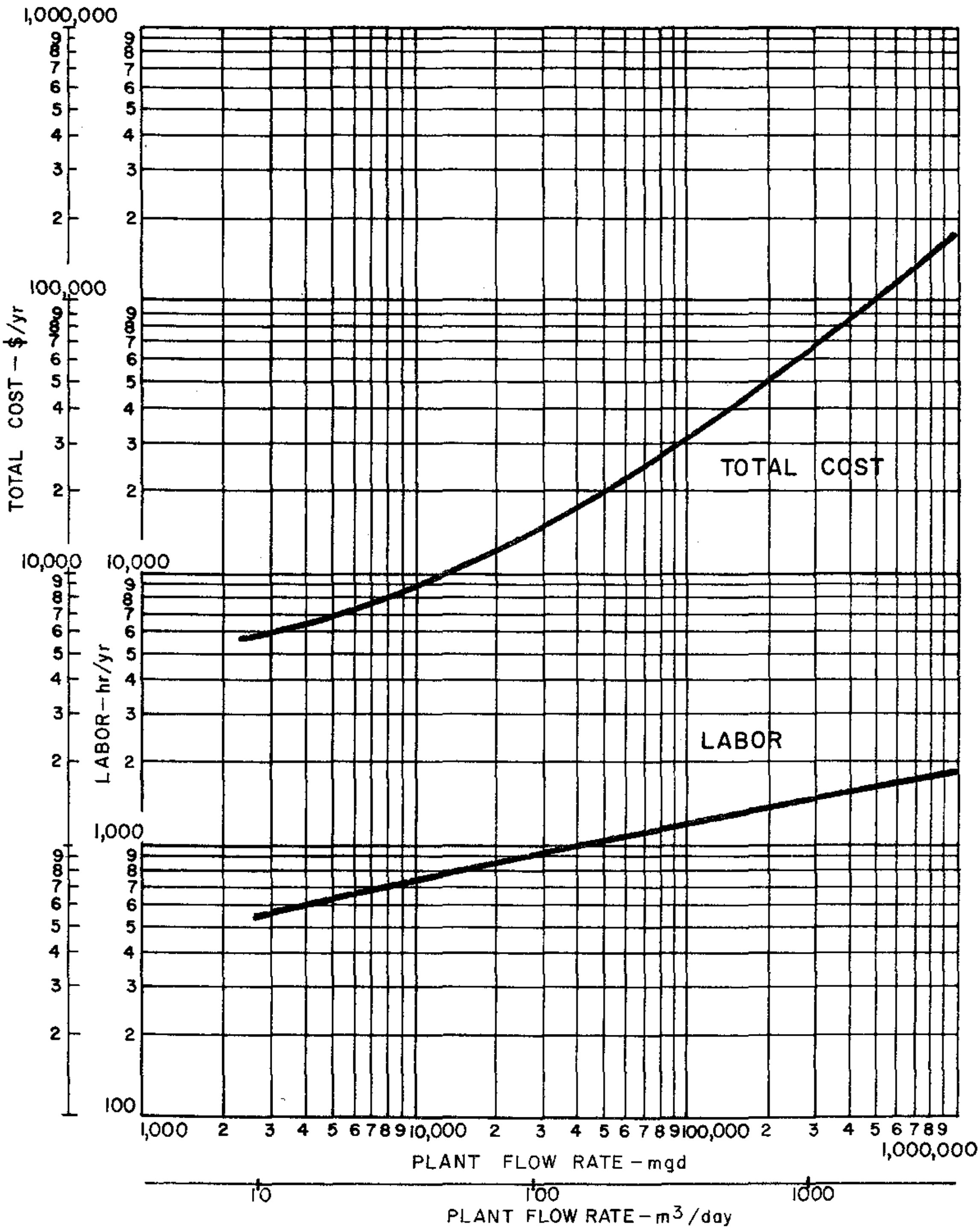


Figure 37. Operation and maintenance requirements for reverse osmosis - labor and total cost.

Table 41

Conceptual Design for

Pressure Ion Exchange Softening

Plant Capacity (gpd)	Number of Contactors	Diameter of Contactors (ft)	Housing (ft^2)	Total Salt Storage/Brining Capacity (ft^3)
70,000	2	2	132	110
280,000	2	4	210	435
440,000	2	5	255	680
630,000	2	6	304	975
860,000	2	7	357	1,330

and the contact vessel was designed to allow for up to 80-percent media expansion during backwash.

Facilities were sized based on an exchange capacity of 20 kilograins/ft^3 and a hardness reduction of 300 mg/l. Regeneration facilities were sized on the basis of 150 bed volumes treated before regeneration and a regenerant requirement of 0.275 lb of sodium chloride per kilograin of exchange capacity. The total regeneration time required is 50 min. Of this time, 10 min is for backwash, 20 min is regeneration brine contact time (brining and displacement rinse), and 20 min is a fast rinse at 1.5 gpm/ft^3. Feedwater was assumed to be of sufficient clarity to require backwashing only for resin reclassification. Backwash pumping facilities and resin installation are included in the construction cost. In-place resin costs of \$45.00/ft^3 were utilized.

Regeneration facilities include two salt storage/brining basins, which are open, reinforced concrete structures constructed with the top foot above ground level. Saturated brine withdrawal from the salt storage/brining basins is 25 percent brine by weight. A salt storage of 4 days of normal use was provided in the storage/brining basins. Pumping facilities were included to pump from the brining tanks to the contact vessels. An eductor is utilized to add sufficient water to dilute the brine to a 10-percent concentration as it is being transferred from the salt storage/brining tank to the contact vessel. No facilities are included in the construction cost for spent brine disposal.

Construction costs for pressure ion exchange softening are presented in Figure 38 and summarized in Table 42.

Operation and Maintenance Cost

Electrical requirements are for regenerant pumping, rinse pumping, backwash pumping, and building heating, lighting, and ventilation. Backwash pumping was based on a 10-min wash period at 8 gpm/ft^2. Regenerant pumping was based on a regenerant rate of 0.7 gal/min/ft^3 of resin and a regeneration time of 20 min. Fast-rinse pumping was based on a 20-min rinse at a rate of 30 gal/ft^3 of media. All pumping was assumed to be against a 25 foot TDH. Feed water pumping requirements are not included.

Maintenance material costs for periodic repair and replacement of components were estimated based on 1-percent of the construction cost. Resin replacement costs are for resin lost annually by physical attrition as well as loss of capacity as a result of chemical fouling. A 3-percent annual loss of resin capacity because of physical and chemical causes is typical for cation resins. To account for this loss of resin and the required replacement every 8 to 10 years, an annual cost equivalent to 13 percent of the resin cost is also included in the maintenance material. No cost is included for sodium chloride regenerant.

Labor requirements are for operation and maintenance of the ion exchange vessels and the pumping facilities. Hours were estimated based on comparable size pressure filtration plants that operate automatically. Labor requirements are also included for a periodic media addition and replacement of the

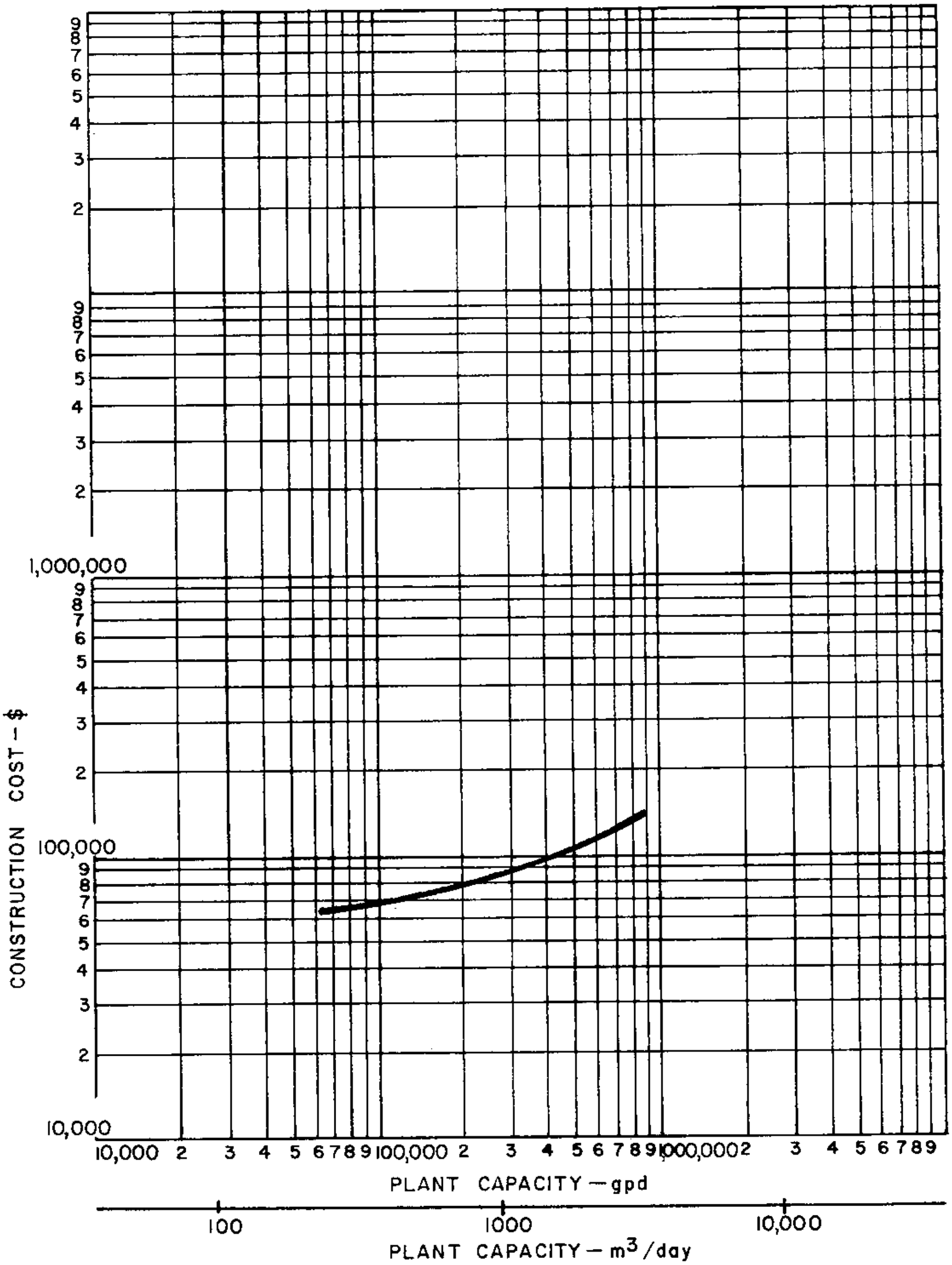


Figure 38. Construction cost for pressure ion exchange softening.

Table 42

Construction Cost for

Pressure Ion Exchange Softening

Cost Category	Plant Capacity (gpd) 70,000	280,000	440,000	630,000	860,000
Excavation and Sitework	$320	$640	$800	$960	$1,120
Manufactured Equipment:					
Equipment	11,360	16,000	18,580	21,160	25,420
Resin	1,700	6,790	10,600	15,270	20,780
Concrete	700	1,400	1,750	2,100	2,450
Steel	1,080	2,170	2,710	3,250	3,800
Labor	5,220	7,430	8,800	9,980	12,080
Pipe and Valves	9,550	12,340	13,500	15,260	18,250
Electrical and Instrumentation	18,390	21,600	23,070	23,720	24,360
Housing	7,600	8,900	9,800	10,700	11,600
SUBTOTAL	55,920	77,270	89,610	102,400	119,860
Miscellaneous and Contingency	8,390	11,590	13,440	15,360	17,980
TOTAL	64,310	88,860	103,050	117,760	137,840

media every 8 to 10 years.

No costs are included for spent brine disposal. Operation and maintenance costs are presented in Figures 39 and 40 and summarized in Table 43.

PRESSURE ION EXCHANGE NITRATE REMOVAL

Construction Cost

Strongly basic anion exchange resins may be used for the removal of nitrates, and also sulfates, fluorides, and some forms of organic and inorganic mercury. When a strongly basic anion exchanger is operated on the chloride form, the sulfate is selectively removed over nitrate, and the nitrate is selectively removed over fluoride. Therefore, the larger the nitrate-to-sulfate ratio, the greater is the nitrate removal capacity of the resin. Generally, fluoride removal by anion exchange resins is not considered practical because of the low capacity.

Costs were developed for treatment of a water supply with the following anion content: Nitrate = 100 mg/l, sulfate = 80 mg/l, other anions = 120 mg/l. The assumed nitrate capacity for the strongly basic anion exchange resin operated on the chloride form was 7 kilograins of nitrate/ft^3, when operated to nitrate breakthrough. It is important to note that other water supplies with different quality may have significantly different exchange capacities, depending generally on the nitrate-to-sulfate ratio.

A sodium chloride regenerant was utilized, with a regenerant requirement of 15 lb/ft^3 of resin. A total regeneration time of 54 min was utilized. Backwash required 10 min, the brine contact and displacement rinse 24 min, and the fast rinse an additional 20 min.

Construction costs were developed for pressure anion exchange systems using the conceptual information in Table 44. Contact vessels were fabricated steel, with a 100-psi working pressure and a baked phenolic lining. A 6-ft bed depth was utilized, although tanks were sized for up to 80-percent resin expansion during backwash. A gravel layer between the resin and the underdrains was not utilized.

Regeneration facilities include two salt storage/brining basins, which are open, reinforced concrete structures, constructed with the top foot above ground level. A salt storage capacity of 4 days was provided. A saturated 26-percent brine is pumped from these storage basins to the contact vessel using an eductor to dilute the brine to 10 percent concentration as it is being transferred.

Brine, transfer, and backwash pumping facilities are included in the cost estimate. However, costs for spent regenerant disposal are not included in the cost estimate. Construction costs are presented in Table 45 and in Figure 41.

Operation and Maintenance Cost

Electrical energy costs are for backwash pumping, rinse pumping, re-

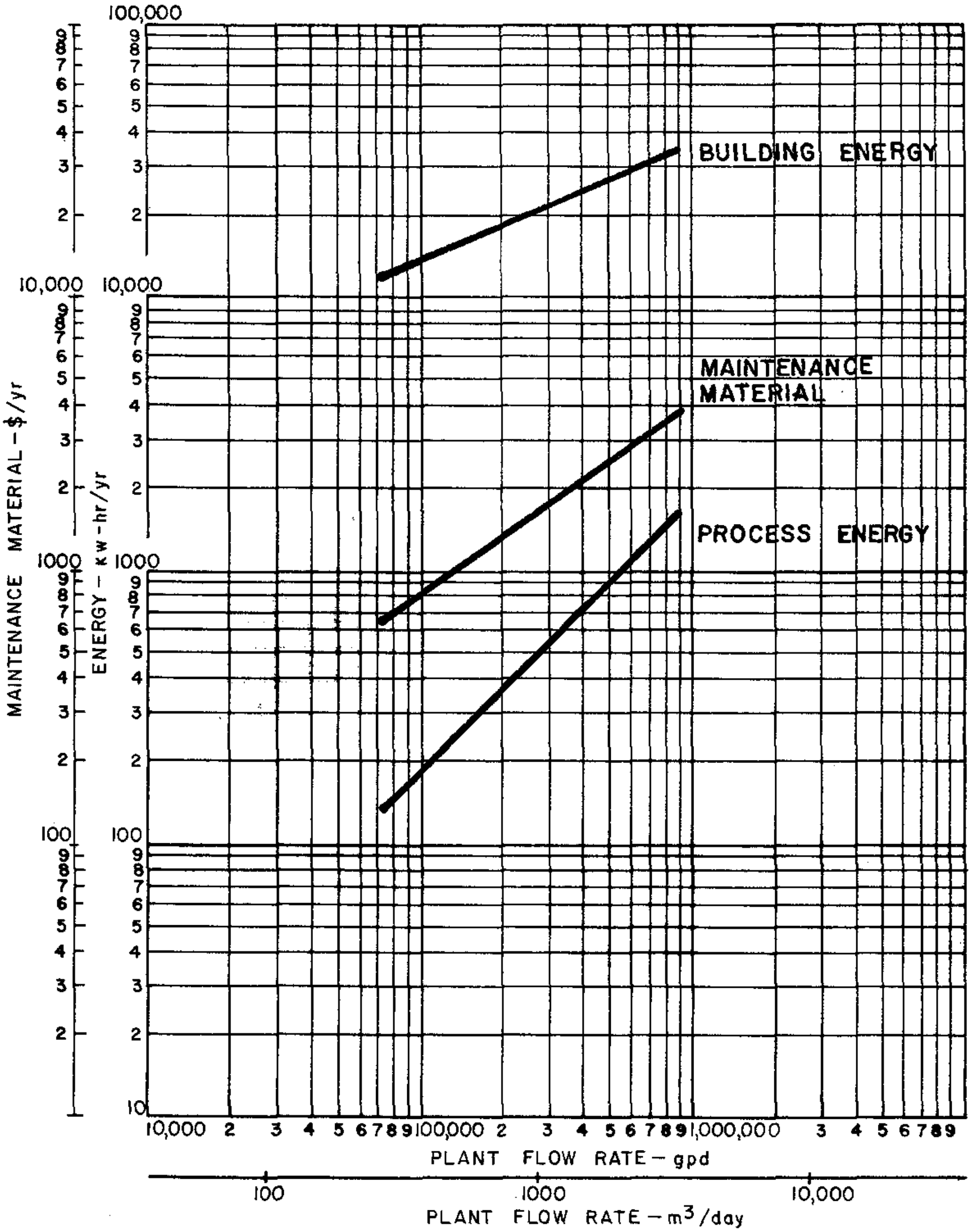


Figure 39. Operation and maintenance requirements for pressure ion exchange softening - building energy, process energy, and maintenance material.

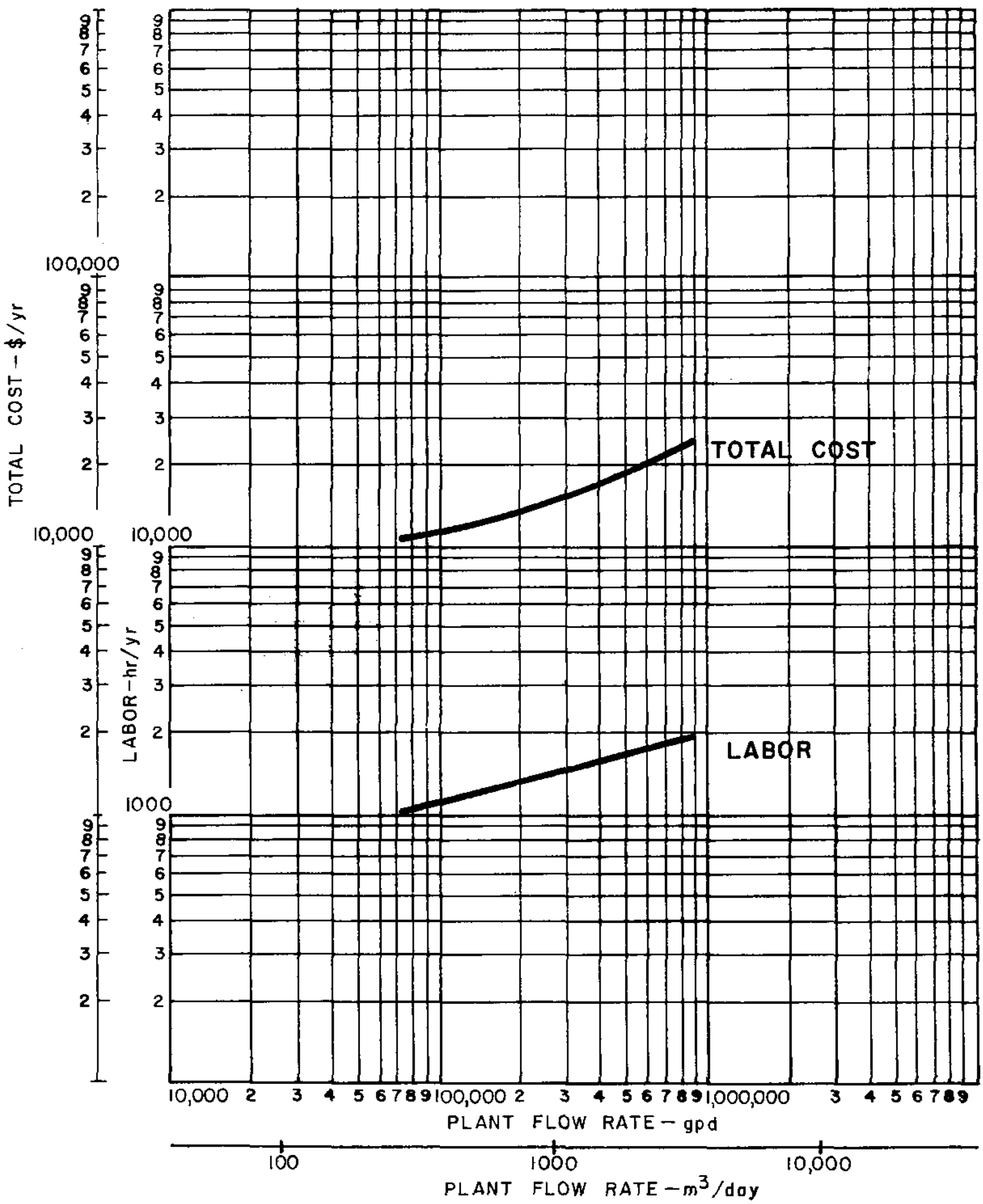


Figure 40. Operation and maintenance requirements for pressure ion exchange softening - labor and total cost.

Table 43

Operation and Maintenance Summary for

Pressure Ion Exchange Softening

Plant Flow Rate (gpd)	Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
70,000	13,540	140	13,680	$700	1,000	$11,110
280,000	21,550	550	22,100	1,600	1,400	16,260
440,000	26,160	870	27,030	2,260	1,550	18,570
630,000	31,190	1,250	32,440	3,030	1,710	21,100
860,000	36,630	1,700	38,330	3,960	1,900	24,110

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 44

Conceptual Design for

Pressure Ion Exchange Nitrate Removal

Plant Capacity (gpd)	Number of Contactors	Diameter of Contactors (ft)	Housing ft^2
70,000	2	2	132
270,000	2	4	210
425,000	2	5	255
610,000	2	6	304
830,000	2	7	357

Table 45

Construction Cost for

Pressure Ion Exchange Nitrate Removal

Cost Category	Plant Capacity (gpd) 70,000	270,000	425,000	610,000	830,000
Excavation and Sitework:	$50	$110	$140	$170	$200
Manufactured Equipment					
Equipment	11,860	16,500	19,090	21,660	25,920
Media	5,460	21,860	34,160	49,200	66,960
Concrete	280	490	550	740	880
Steel	420	680	950	1,110	1,300
Labor	4,770	5,990	6,880	7,590	9,250
Pipe and Valves	9,650	12,440	13,600	15,360	18,350
Electrical and Instrumentation	18,390	21,460	23,070	23,720	24,360
Housing	7,600	8,900	9,800	10,700	11,600
SUBTOTAL	58,480	88,430	108,240	130,250	158,820
Miscellaneous and Contingency	8,770	13,260	16,240	19,540	23,820
TOTAL	67,250	101,690	124,480	149,790	182,640

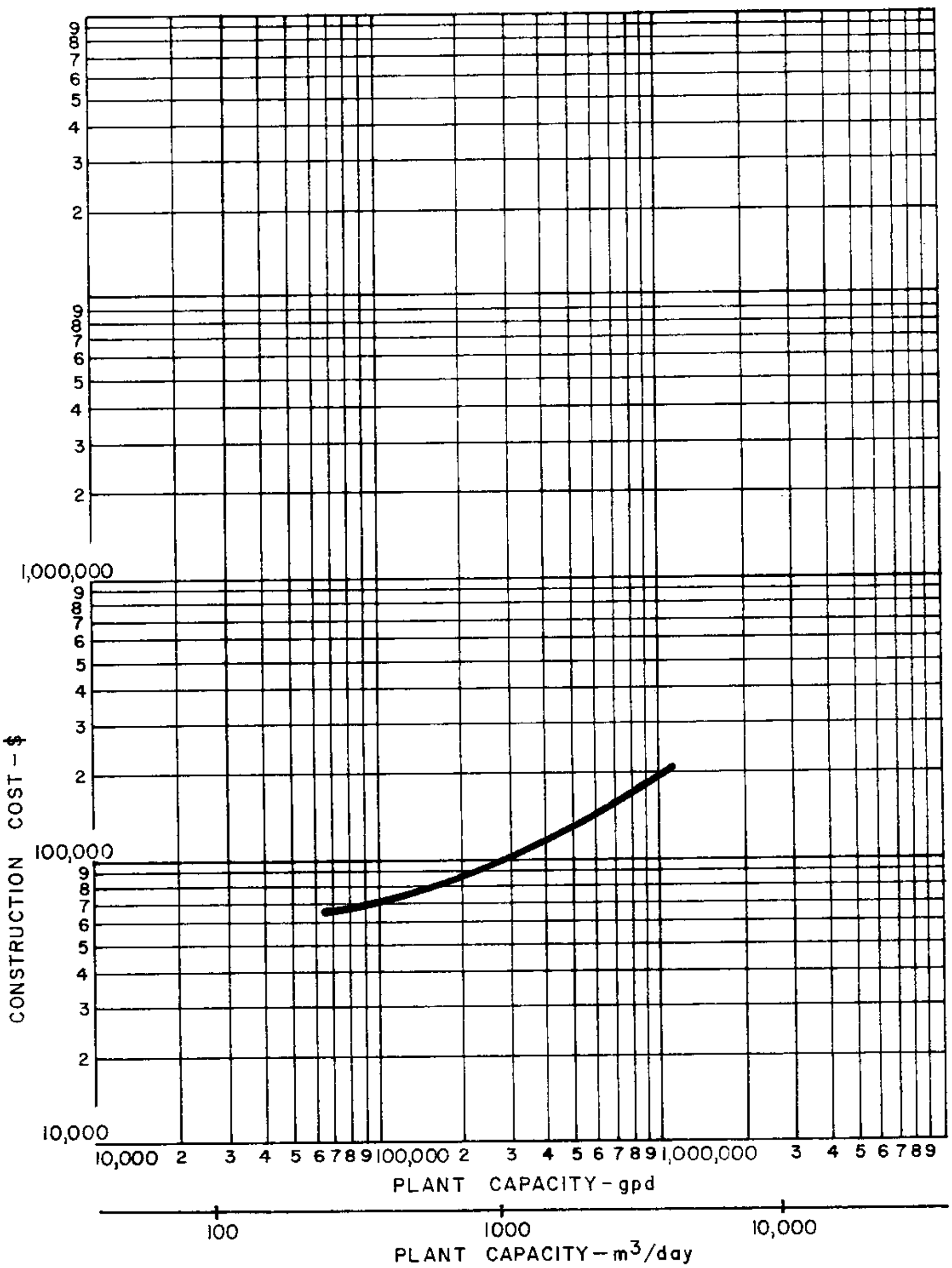


Figure 41. Construction cost for pressure ion exchange nitrate removal.

generant pumping, and building heating, lighting, and ventilation. Backwash pumping was based on a 10-min wash at 3 gpm/ft^2. Regenerant pumping was based on a rate of 6 gpm/ft^2 of resin for 24 min, and fast-rinse pumping was based on a rate of 8 gpm/ft^2 for 20 min. All pumping was assumed to be against a 25-foot TDH. Feed water pumping requirements are not included.

Maintenance material costs for periodic repair and replacement of components were estimated based on 1-percent of the construction cost plus the cost of resin replacement. Resin replacement costs are for resin lost annually by physical attrition as well as loss of capacity as a result of chemical fouling. As anion resin is typically replaced every 3 to 5 years, a 25-percent annual resin replacement was included to account for resin fouling and resin loss. Regenerant costs are not included in the maintenance material cost.

Labor requirements are for operation and maintenance of ion exchange vessels and the pumping facilities. Hours were estimated based on filtration plants and filter pumping facilities of comparable size. Labor requirements are also included for periodic media addition and replacement of the media every 4 years. No costs are included for spent brine disposal.

Operation and maintenance curves are presented in Figures 42 and 43 and are summarized in Table 46.

ACTIVATED ALUMINA FLUORIDE REMOVAL

Construction Cost

Water supplies with fluoride concentrations up to 10 mg/l and higher can be effectively treated by contact with activated alumina. Fluoride reductions to less than 0.5 mg/l can generally be achieved with activated alumina, and blending can then be utilized to meet the desired fluoride concentration. Treatment is generally selective for fluoride and arsenic, although small amounts of other anions often are removed. Regeneration of the activated alumina with caustic removes both exchanged fluoride and arsenic.

Facilities were sized based on a fluoride exchange capacity of 0.6-percent by weight, or 0.25 lb/ft^3 of activated alumina, and a fluoride reduction from 3 to 0.5 mg/l. Operation was assumed to be a pH 5.5, although higher pH values may be used with a resulting lower exchange capacity. Regeneration facilities were sized on the basis of batch rather than continuous regeneration because of the significant savings in regeneration chemicals that results from using batch regeneration. Regeneration was assumed to consist of 1-hr contacts with 0.1 N sodium hydroxide for fluoride removal from the alumina, followed by a one-half-hour contact with 0.05 N sulfuric acid for neutralization. In-place resin costs of $\$13.86/ft^3$ were utilized. Feed water was assumed to be sufficiently low in suspended solids so that backwashing was not necessary; thus backwashing facilities are not included.

Construction costs were developed for pressure systems using the conceptual information presented in Table 47. The contact vessels are fabricated steel with a baked phenolic lining; they are constructed for a 100-psi

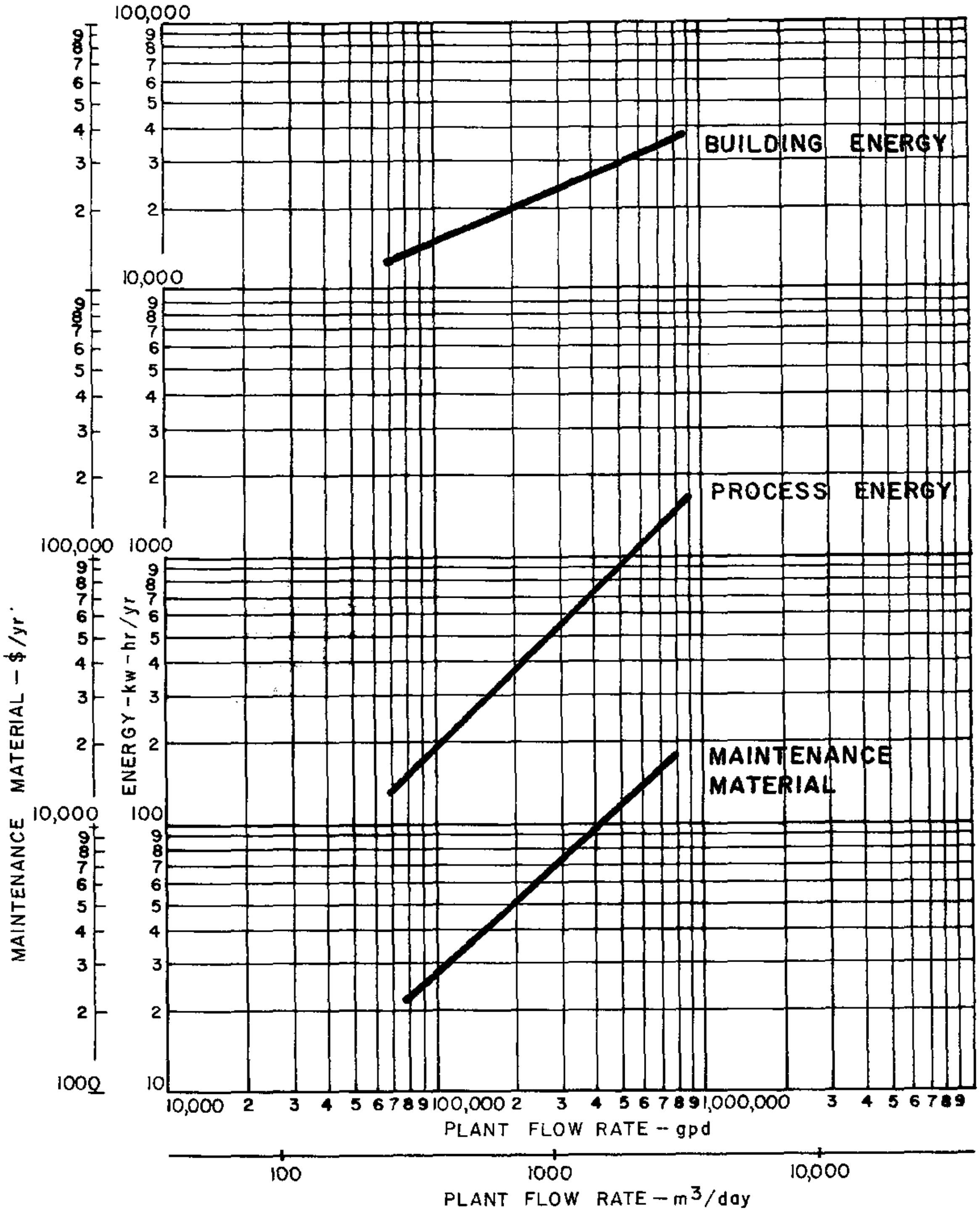


Figure 42. Operation and maintenance requirements for pressure ion exchange nitrate removal - building energy, process energy, and maintenance material.

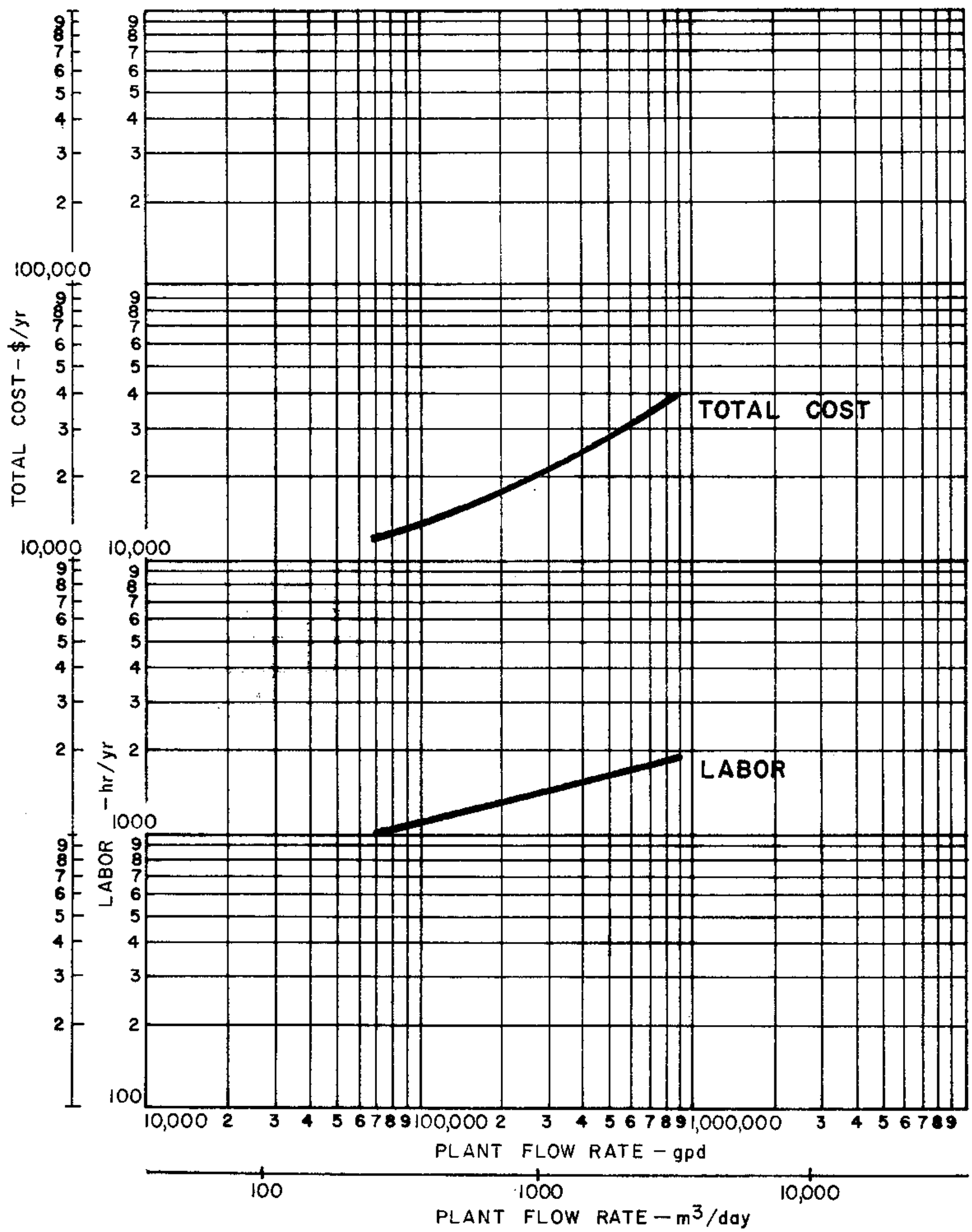


Figure 43. Operation and maintenance for pressure ion exchange nitrate removal - labor and total cost.

Table 46

Operation and Maintenance Summary for
Pressure Ion Exchange Nitrate Removal

Plant Flow Rate (gpd)	Electrical Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
70,000	13,540	126	13,666	$1,890	1,000	$12,300
270,000	21,550	510	22,060	6,340	1,400	21,000
425,000	26,160	790	26,950	9,660	1,550	25,970
610,000	31,190	1,140	32,330	13,710	1,700	31,680
830,000	36,630	1,550	38,180	18,520	1,900	38,670

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 47

Conceptual Design for

Activated Alumina Fluoride Removal

Plant Capacity (gpd)	Number of Contactors	Diameter of Contactors (ft)	Housing (ft^2)
12,700	2	1	70
25,000	2	1	74
100,000	2	2	109
400,000	2	4	160
640,000	2	5	273
910,000	2	6	322

working pressure. The depth of resin was 10 ft, and the contact vessel was designed for 80-percent media expansion during backwash. A gravel layer between underdrains and media was not included.

Regeneration storage facilities were sized for 30 days of storage. Sodium hydroxide required for regeneration was assumed to be purchased as a solid and mixed to the required concentration at the plant. Sulfuric acid was assumed to be purchased in the concentrated form and then diluted at the plant. Metering pumps were included for transfer of caustic and sulfuric acid from the dilution tanks to the exhausted contactor.

All facilities were assumed to be located indoors. Construction costs are presented in detail in Table 48 and are also shown in Figure 44.

Operation and Maintenance Cost

Electrical energy costs are for regenerant pumping, and building heating, ventilation, and lighting. The latter requirements constitute the majority of the energy requirements, and use of an outdoor installation would have a very significant impact on energy requirements. Process energy is only for regenerant pumping, and it is extremely small. Feed water pumping requirements are not included.

Maintenance material costs are for periodic repair and replacement of components and were estimated on the basis of 1-percent of the construction cost. An activated alumina replacement cost was also included in maintenance material at an annual rate of 10-percent. Regenerant costs are not included in the maintenance material costs.

Labor requirements are principally for regenerant preparation and regeneration of the activated alumina. Labor requirements also include periodic media addition to make up losses and occasional replacement.

Operation and maintenance curves are presented in Figures 45 and 46 and are summarized in Table 49.

BONE CHAR FLUORIDE REMOVAL

Construction Cost

Bone char has a high natural calcium content, which makes it useful for the removal of both fluoride and arsenic compounds. After removal of the fluoride from the water by the bone char, the fluoride can be removed from the bone char by exposing the char to a weak caustic solution. A principal disadvantage of bone char is the nearly irreversible reaction of arsenic with the bone char, which will rapidly deplete the capacity if high arsenic-content waters are being treated. When arsenic is present, activated alumina would be preferred to bone char as a removal method.

Construction cost estimates were developed for 8-ft-deep beds of bone char contained in fabricated steel contact vessels. The vessels were constructed for a working pressure of 100 psi, and they allowed 100-percent media

Table 48

Construction Cost for

Activated Alumina Fluoride Removal

Cost Category	Plant Capacity (gpd) 12,700	25,000	100,000	400,000	640,000	910,000
Manufactured Equipment:						
Equipment	$3,480	$3,500	$12,160	$17,600	$21,240	$24,760
Media	130	260	1,060	4,240	6,620	9,530
Labor	3,070	4,650	6,670	8,730	10,620	13,520
Pipe and Valves	7,120	8,900	11,320	15,370	18,430	19,570
Electrical and Instrumentation	18,350	18,350	18,820	21,950	23,570	23,770
Housing	2,650	2,800	4,000	7,100	12,350	15,000
SUBTOTAL	34,800	38,460	54,030	74,990	92,830	106,150
Miscellaneous and Contingency	5,220	5,770	8,100	11,250	13,920	15,920
TOTAL	40,020	44,230	62,130	86,240	106,750	122,070

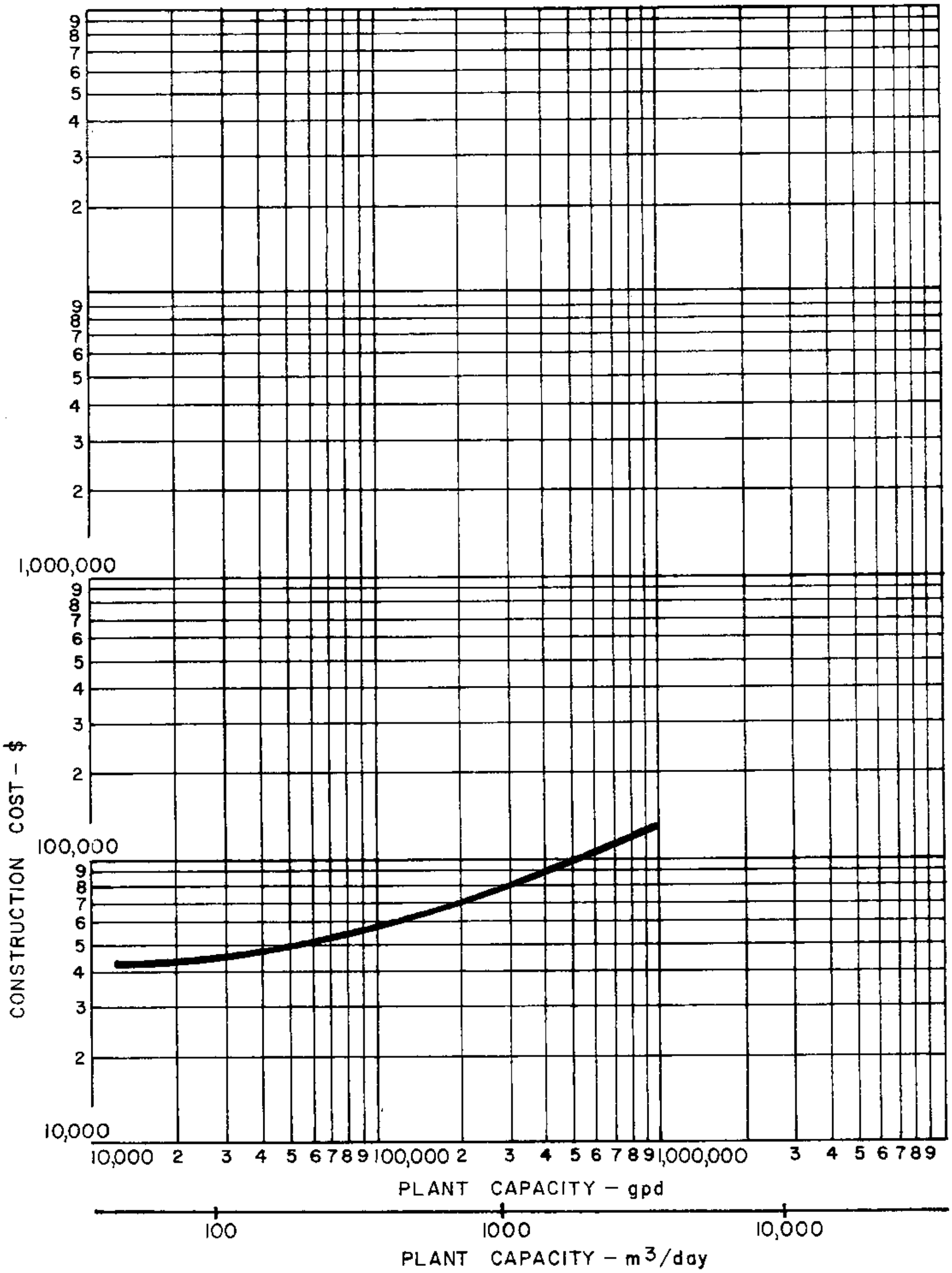


Figure 44. Construction cost for activated alumina fluoride removal.

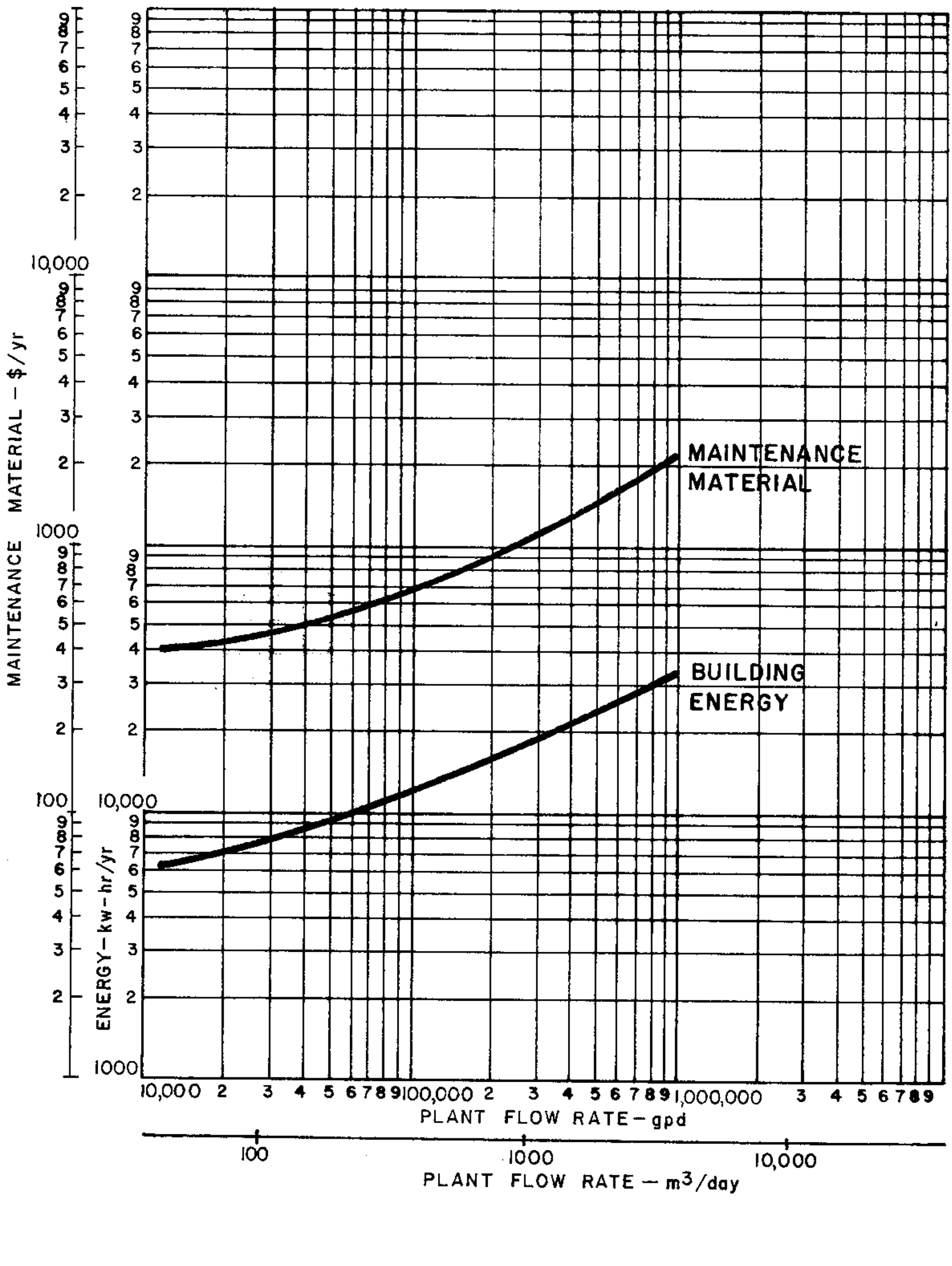


Figure 45. Operation and maintenance requirements for activated alumina fluoride removal - building energy, and maintenance material

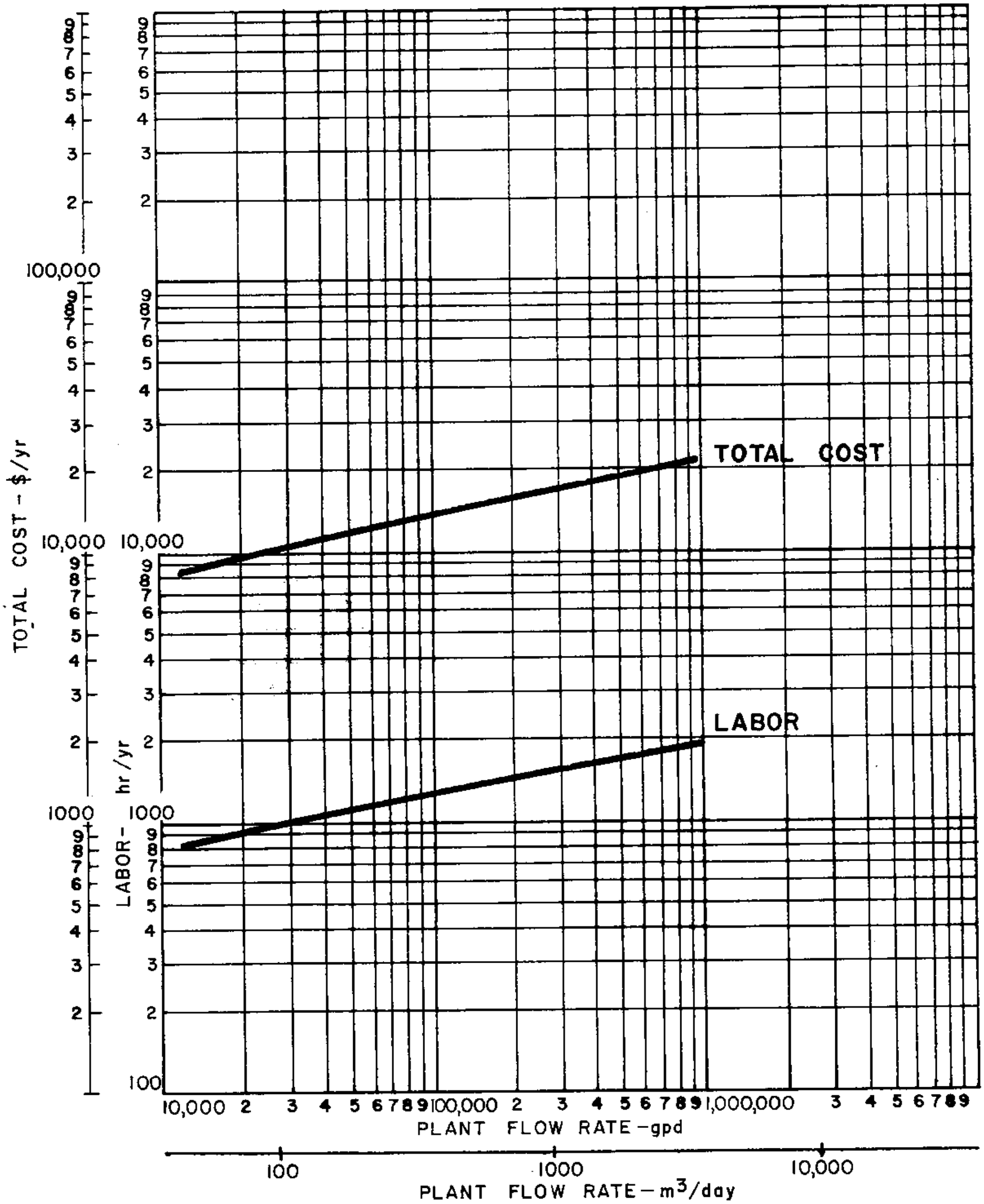


Figure 46. Operation and maintenance requirements for activated alumina fluoride removal - labor and total cost.

Table 49

Operation and Maintenance Summary for

Activated Alumina Fluoride Removal

Plant Flow Rate (gpd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
12,700	7,180	-	7,180	$410	800	$8,630
25,000	7,590	-	7,590	470	1,000	10,700
100,000	11,180	-	11,180	630	1,400	14,970
400,000	16,420	-	16,420	1,290	1,550	17,280
640,000	28,010	10	28,020	1,730	1,700	19,570
910,000	33,040	20	33,060	2,170	1,900	22,160

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

expansion during backwash. The bone char was assumed to have an exchange capacity of 200 g of fluoride/ft^3. Regeneration of spent bone char is accomplished using a dilute sodium hydroxide solution for regeneration of the bone char and a weak sodium bicarbonate solution for neutralization of remaining sodium hydroxide before a unit is returned to service. Regeneration requirements were based on a removal of 2.5 mg/l of fluoride, a sodium hydroxide use of 6.2 lb/ft^3 per regeneration, and a sodium bicarbonate use of 2.5 lb/ft^3 of resin per regeneration. Both the sodium hydroxide and the sodium bicarbonate were assumed to be purchased in the solid form and dissolved into a dilute solution at the plant site. All equipment and chemical storage was assumed to be completely enclosed.

Construction costs are presented in Table 50 and also in Figure 47.

Operation and Maintenance Cost

Process energy is relatively small and is only for regenerant pumping. The building energy constitutes most of the energy required, and use of an outdoor installation would have a very significant impact on energy requirements. If backwash is required, process energy requirements will increase significantly. Feed water pumping requirements are not included.

Maintenance material costs are for periodic repair and replacement of components; they were estimated on the basis of 1-percent of the construction cost. A bone char replacement cost was also included in maintenance material at an annual rate of 15-percent. Regenerant costs are not included in the maintenance material costs.

Labor requirements are principally for regenerant preparation and regeneration of the bone char. Labor requirements also include periodic bone char addition to make up for losses and occasional replacement.

Operation and maintenance curves are presented in Figures 48 and 49 and are summarized in Table 51.

PACKAGE RAW WATER PUMPING FACILITIES

Construction Cost

Construction cost estimates were developed for raw water pumping facilities with capacities ranging between 20 and 700 gpm. Costs were based on the use of premanufactured package pump stations using duplex submersible pumps contained in a 20-ft deep steel pump sump. The pump sump is supported on a concrete anchor slab at the bottom of the excavation. The pumping facilities are located adjacent to a stream or lake, and water enters by gravity flow.

The costs also include manifold piping within the sump, sump intake line valve, pump check valves, and electrical controls. Excluded are costs of a raw water intake structure and transmission lines between water source and pump sump and to the treatment facilities. Costs of these items are excluded because specific site conditions will result in significant variations in requirements and cost. No housing for the pumping facilities is required.

Table 50

Construction Cost for

Bone Char Fluoride Removal

Cost Category	Plant Capacity (gpd)					
	16,300	65,000	260,000	407,000	585,000	800,000
Manufactured Equipment:						
Equipment	$8,820	$15,880	$23,850	$28,800	$34,150	$41,710
Media	250	1,000	4,020	6,280	9,020	12,320
Labor	5,620	8,460	12,010	14,440	16,890	20,930
Pipe and Valves	8,150	10,530	11,590	15,660	18,800	19,380
Electrical and Instrumentation	18,220	18,220	19,200	22,850	23,790	23,790
Housing	7,100	8,070	14,100	19,200	25,000	28,500
SUBTOTAL	48,160	62,160	84,770	107,230	127,650	146,630
Miscellaneous and Contingency	7,220	9,320	12,720	16,080	19,150	21,990
TOTAL	55,380	71,480	97,490	123,310	146,800	168,620

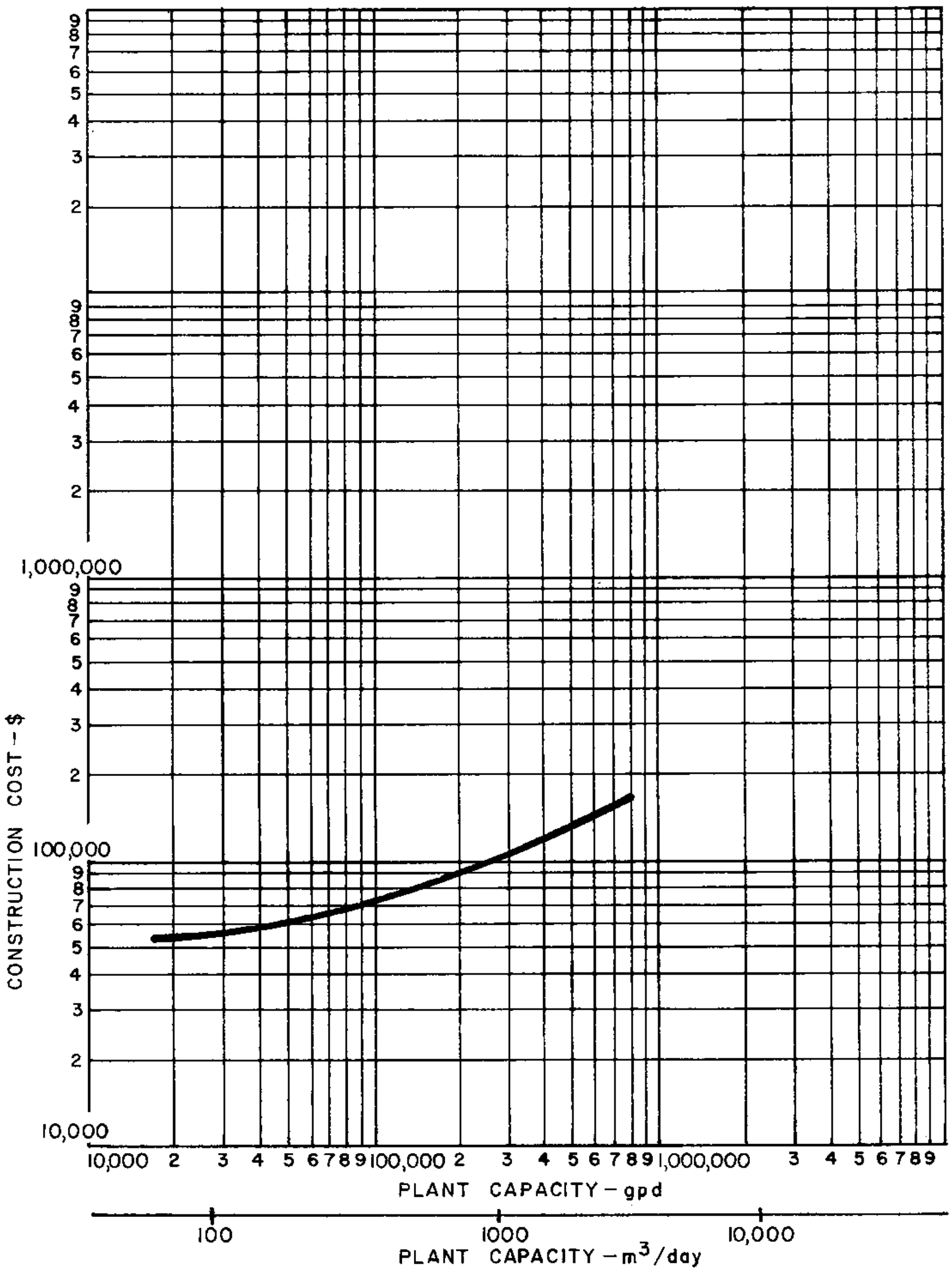


Figure 47. Construction cost for bone char fluoride removal.

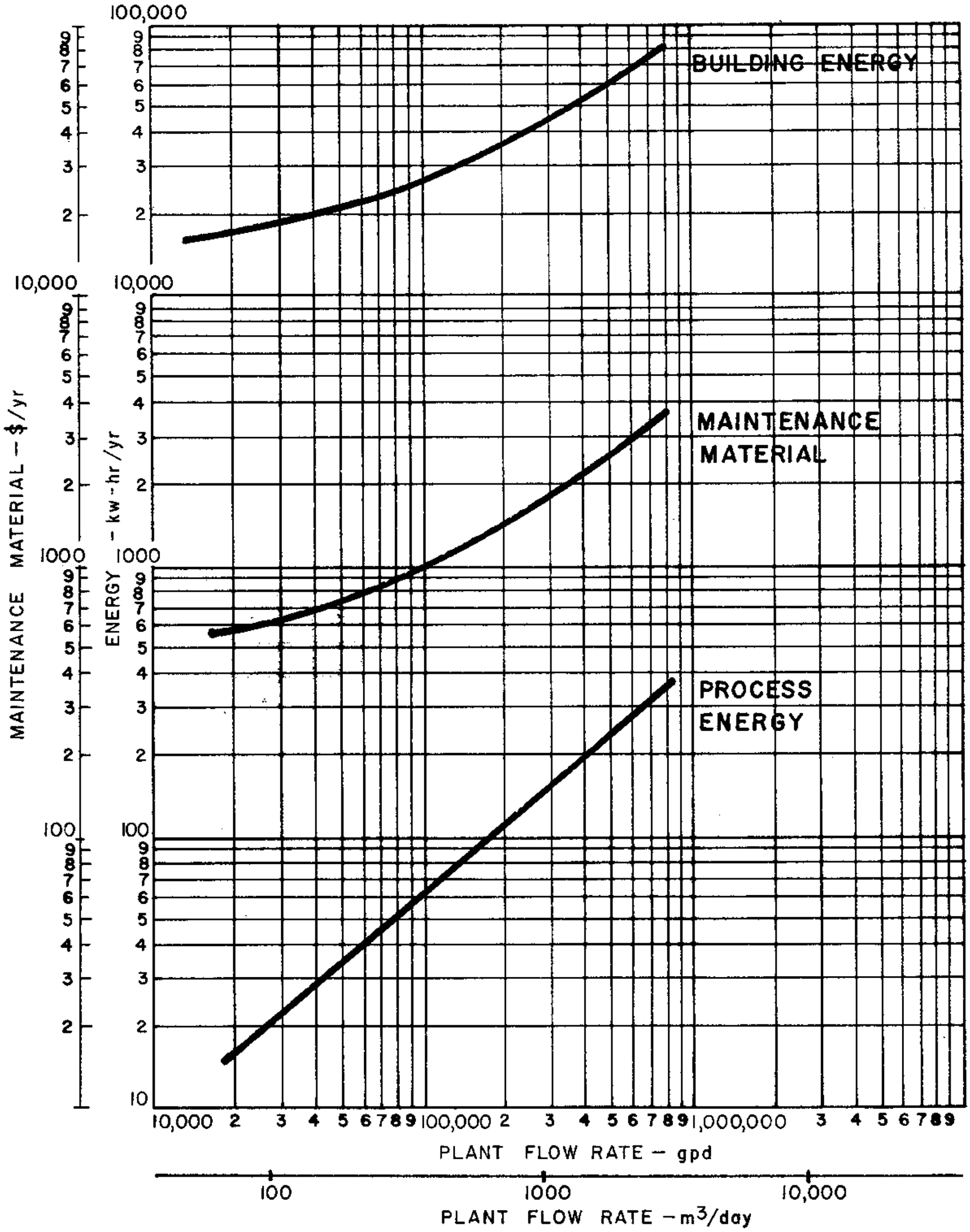


Figure 48. Operation and maintenance requirements for bone char fluoride removal - building energy, process energy, and maintenance material.

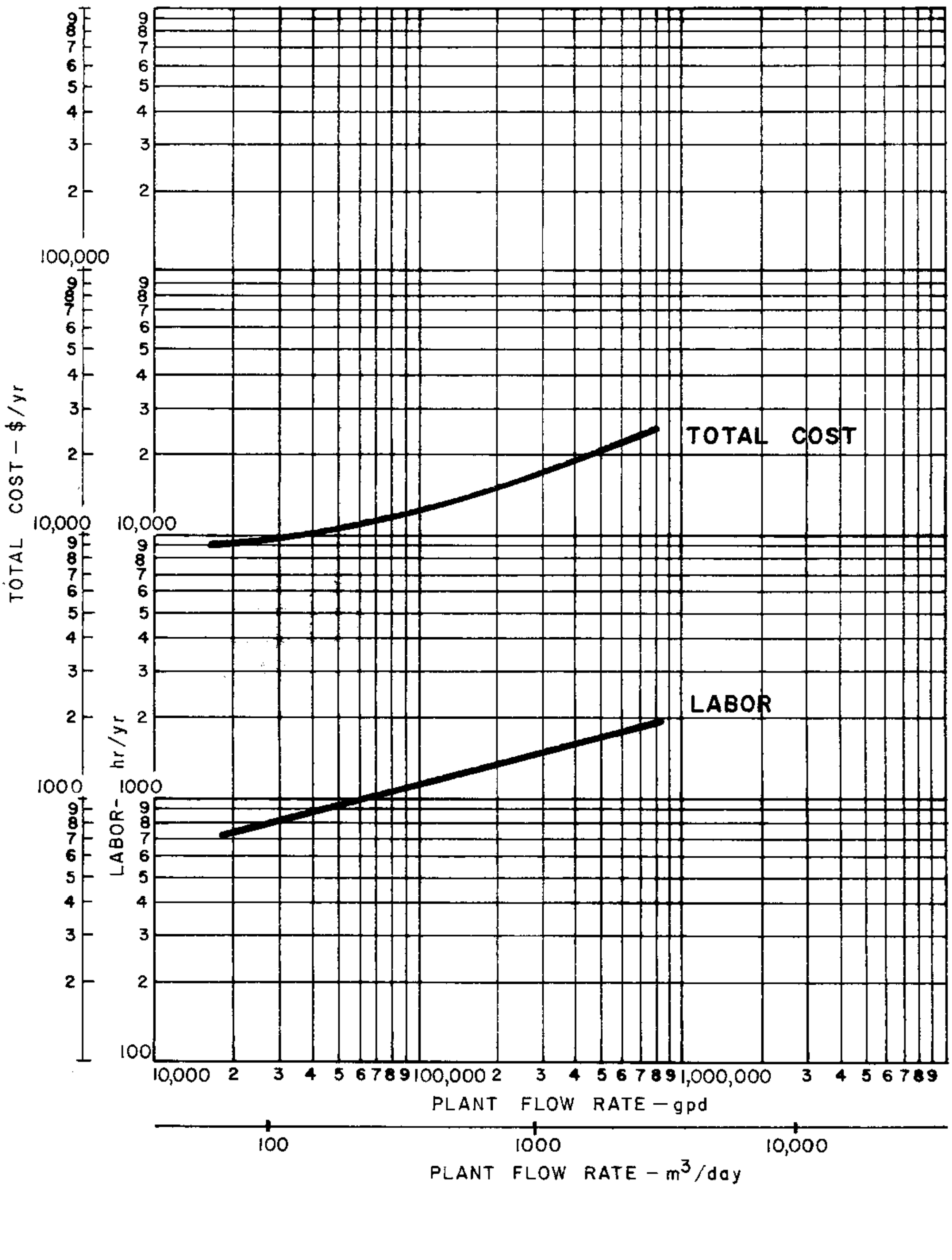


Figure 49. Operation and maintenance requirements for bone char fluoride removal - labor and total cost.

Table 51

Operation and Maintenance Summary for

Bone Char Fluoride Removal

Plant Flow Rate (gpd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
16,300	19,490	20	19,510	$590	800	$9,180
65,000	22,160	30	22,190	870	1,000	11,540
260,000	39,190	120	39,310	1,580	1,400	16,760
407,000	53,660	190	53,850	2,180	1,550	19,300
585,000	69,970	270	70,240	2,820	1,700	21,930
800,000	82,080	380	82,460	3,540	1,900	25,010

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Estimated construction costs are shown in Table 52 for facilities capable of pumping against a head of 50 ft. The costs are graphically presented in Figure 50.

Operation and Maintenance Cost

Process electrical energy requirements are for continuous, 24-hr/day operation of raw water pumps at a TDH of 50 ft. Power requirements were based on a pumping efficiency of 80-percent and a motor efficiency of 90-percent. Since the facilities are not housed, no energy for heating, lighting, and ventilating is required.

Maintenance material requirements for submersible pumps and other pumping facility equipment were estimated at approximately 1-percent of equipment cost, according to manufacturers' recommendations.

Labor requirements are for general maintenance of pumping station equipment. Maintenance requirements for the totally sealed submersible pumps are minimal.

Operation and maintenance requirements are summarized in Table 53 and illustrated in Figures 51 and 52.

PACKAGE HIGH-SERVICE PUMPING STATIONS

Construction Cost

Package finished water pumping stations may be suitable for use with certain small systems. Such stations are capable of handling a wide variation in flow caused by fluctuating system demand while maintaining a relatively uniform system pressure. Costs were developed for single units ranging in size from 30 to 1,100 gpm to match expected maximum system hourly demands from plants producing 2,500 to 500,000 gpd.

Pumping stations utilize two end suction centrifugal pumps for capacities smaller than 400 gpm. Three such pumps are used to handle flows in excess of 400 gpm. The pumping stations are prepackaged and contain pumps, pressure sensing and flow control valves, and control electrical equipment and instrumentation. Pumps were selected to provide a maximum output pressure of 70 psi. The units are designed for flooded suction applications and are to be used with above-grade storage tanks or clearwells.

No allowance for housing costs were included, since spatial requirements are minimal, and adequate floor area within treatment plant structures is generally available.

Figure 53 and Table 54 present construction costs for package high-service pumping stations.

Operation and Maintenance Cost

Pumping units were selected to handle peak hourly flows and utilize a

Table 52

Construction Cost for

Package Raw Water Pumping Facilities

Cost Category	Pumping Capacity at TDH of 50 ft (gpm)				
	20	100	350	500	700
Excavation and Sitework	$820	$970	$1,300	$1,500	$1,700
Manufactured Equipment	4,760	7,770	10,700	11,950	14,000
Concrete	250	400	900	1,100	1,600
Labor	2,700	2,800	3,100	3,700	4,600
Pipe and Valves	1,000	1,200	1,500	1,600	1,800
Electrical and Instrumentation	500	500	600	700	800
SUBTOTAL	10,030	13,640	18,100	20,550	24,500
Miscellaneous and Contingency	1,500	2,050	2,720	3,080	3,680
TOTAL	11,530	15,690	20,820	23,630	28,180

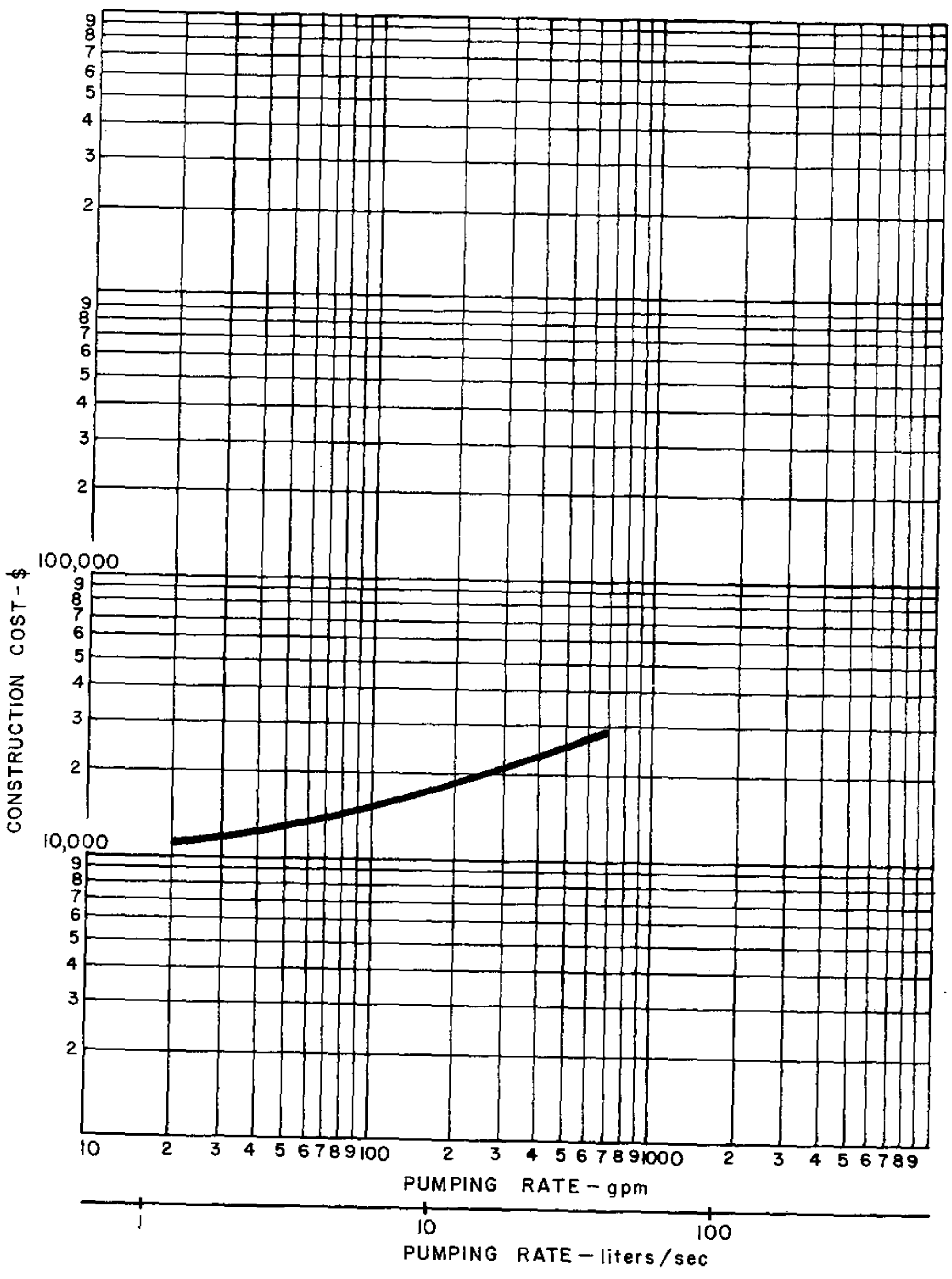


Figure 50. Construction cost for package raw water pumping facilities.

Table 53

Operation and Maintenance Summary for

Package Raw Water Pumping Facilities*

Pumping Capacity (gpm)	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost+ ($/yr)
20	2,320	$50	50	$620
100	11,620	80	60	1,030
350	40,700	110	80	2,130
500	58,000	120	100	2,860
700	81,300	140	120	3,780

*Continuous 24-hr/day, 365-day/year operation.

+Calculated using $0.03/kw-hr and $10.00/hr of labor.

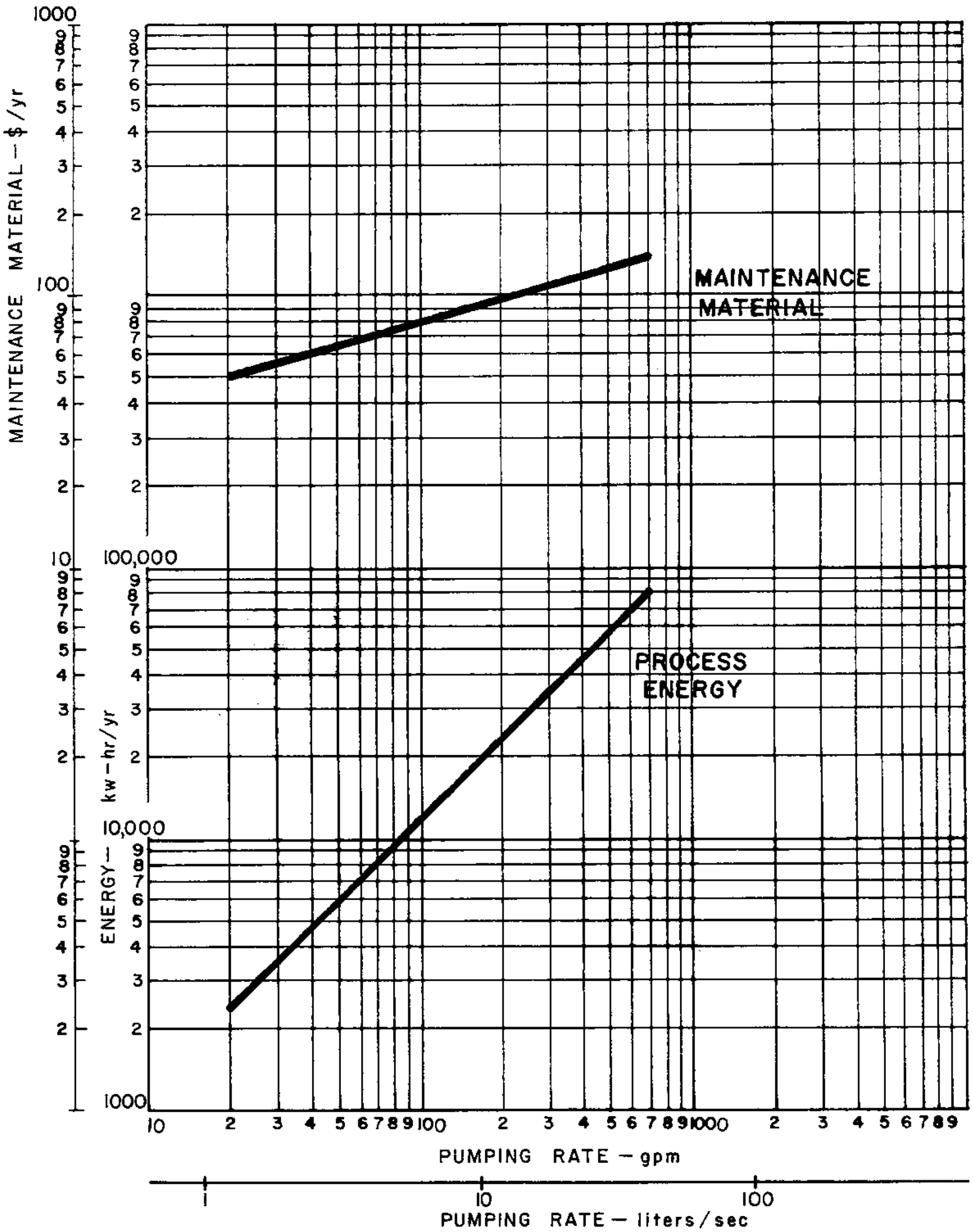


Figure 51. Operation and maintenance requirements for package raw water pumping facilities - process energy, and maintenance material.

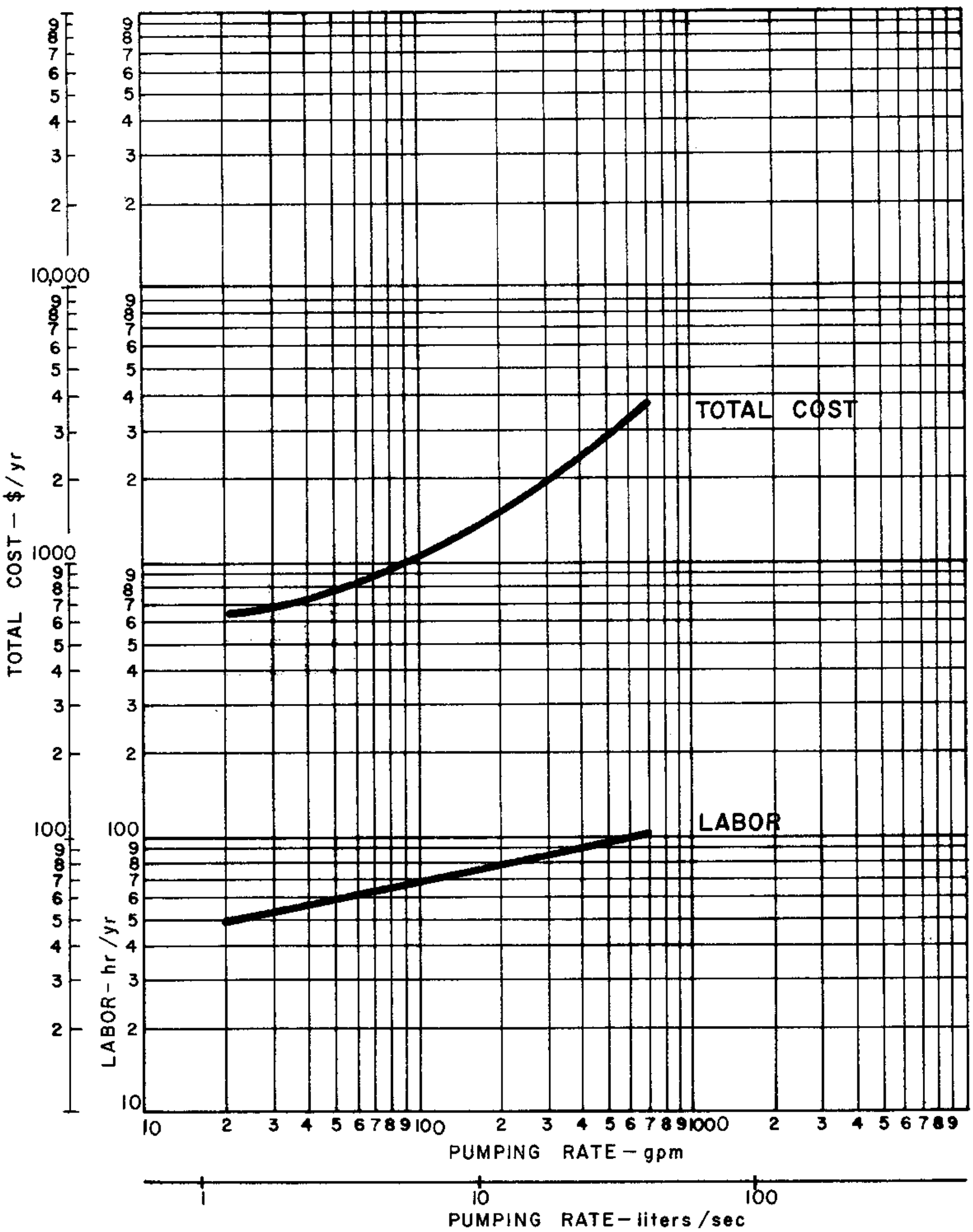


Figure 52. Operation and maintenance requirements for package raw water pumping facilities - labor and total cost.

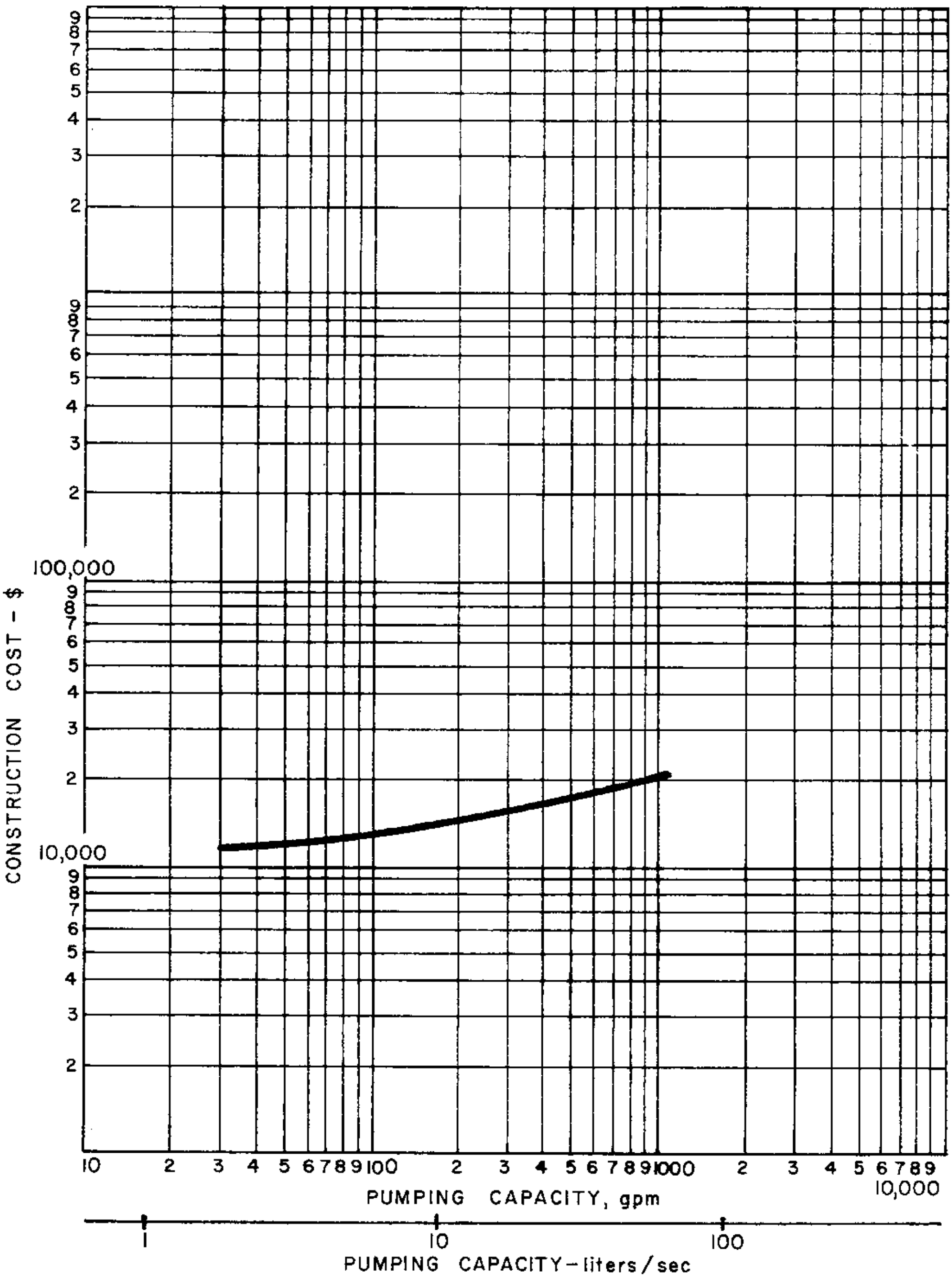


Figure 53. Construction cost for package high-service pumping stations.

Table 54

Construction Cost for

Package High Service Pumping Stations

Cost Category	Pumping Capacity				
	30	70	250	500	1,100
Manufactured Equipment	$7,500	$8,000	$9,500	$12,300	$15,000
Labor	1,130	1,200	1,430	1,850	2,250
Pipe & Valves	450	550	700	800	1,000
Electrical and Instrumentation	250	250	280	400	530
SUBTOTAL	9,330	10,000	11,910	15,350	18,780
Miscellaneous and Contingency	1,400	1,500	1,790	2,300	2,820
TOTAL COST	10,730	11,500	13,700	17,650	21,600

two- or three-pump system with a lead pump and one or two main pumps. In all systems, continuous 24-hr operation of the lead pump and 8-hr operation of the main pump was assumed to determine energy usage. Pumping costs were computed based on supplying the indicated flows at 70 psi discharge pressure.

Maintenance material costs are related to replacement costs for seals and other miscellaneous small parts. Labor requirements consist of pump seal lubrication, calibration of pressure control devices, and occasional seal replacement.

Operation and maintenance requirements for package high-service pumping stations are listed in Table 55 and illustrated in Figures 54 and 55.

STEEL BACKWASH/CLEARWELL TANKS

Construction Cost

Construction costs were developed for backwash water/clearwell storage tanks with capacities ranging from 500 to 30,000 gal. Conceptual design information related to tank dimensions is presented in Table 56. Tanks are either shop fabricated (5,000 gal and less) or field erected; they are 3/16 in. steel plate in all cases and are painted inside and outside. Tanks are supported on a concrete pad and are covered. All sizes of tanks are furnished with inlet/outlet, drain, vent and overflow nozzles, and handrails around top access hatch and on ladders. Tanks larger than 5,000 gal are equipped with an additional 24-in. manway in the side of the tank.

Construction costs are presented in Table 57 and also in Figure 56.

SLUDGE HAULING TO LANDFILL

Construction Cost

Sludge may be conveyed to landfill in a liquid form using tank trucks or in a dewatered form using dump trucks. Separate cost estimates were made for each form of hauling, based on agency ownership of the trucks and a truck usage of 8 hr/day. When other than daylight operation is possible and/or local requirements on route utilization allow operation over a 24-hr day, a substantial savings in capital expenditure will occur. Serious consideration should be given to operation over time periods greater than 8-hr/day. If such operation is possible, the costs presented must be adjusted to reflect the higher daily usage rate.

These criteria utilized to develop costs for liquid and dewatered sludge hauling are presented in Table 58.

Liquid Sludge--

Costs were developed for hauling liquid sludge with volumes ranging from 25,000 to 15 million gal/year for one-way distances between 5 and 40 miles. All estimates were for use of a 5,500-gal tanker truck, except for the smallest haul volume of 25,000 gal/year, which is based on use of a 1,200 gal

Table 55

Operation and Maintenance Summary for

Package High-Service Pumping Stations

Flow Rate (gpm)	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
30	3,930	$ 30	104	$ 1,190
70	11,040	30	104	1,400
250	42,940	40	130	2,630
500	106,730	50	130	4,550
1,100	212,850	90	143	7,910

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

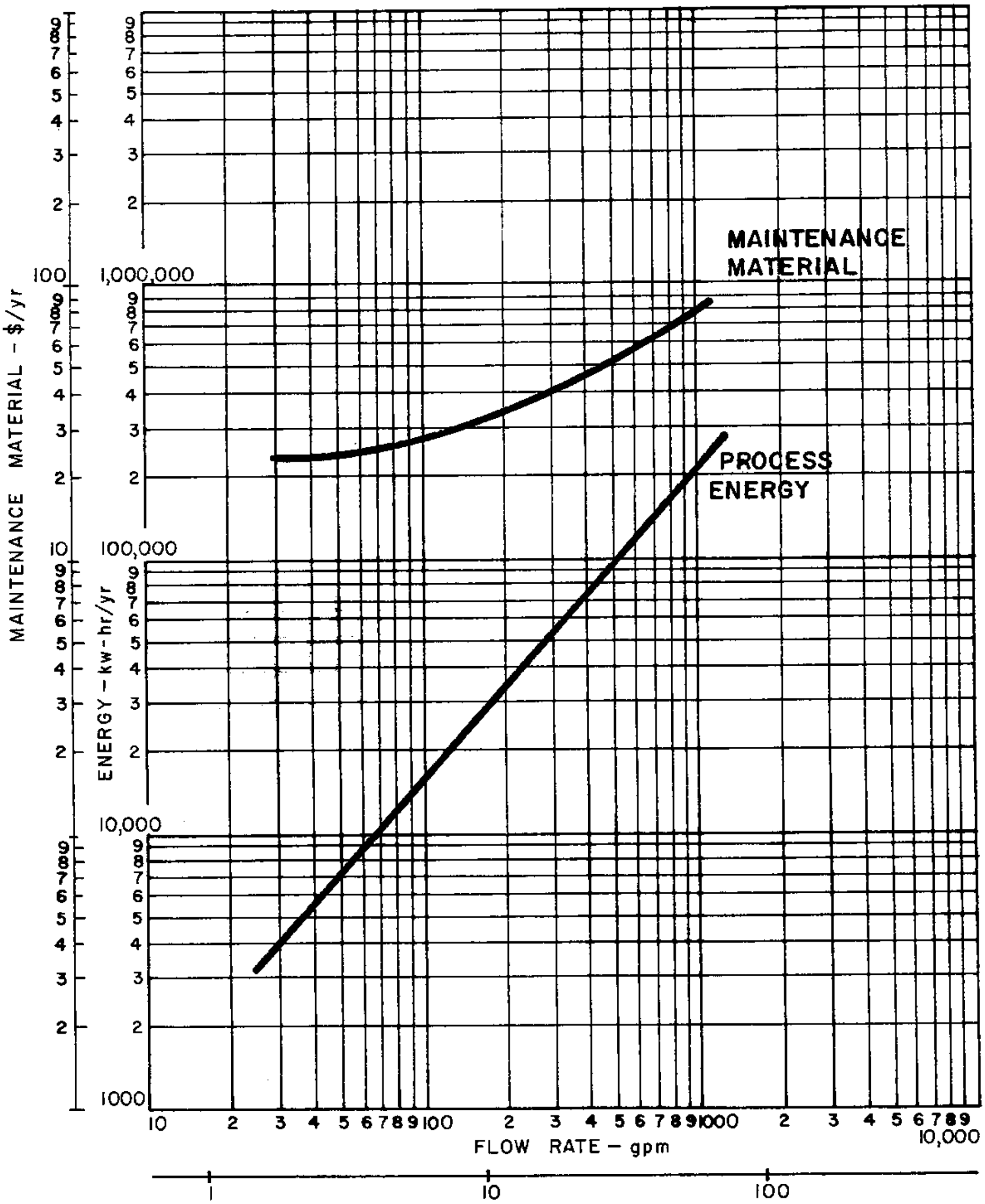


Figure 54. Operation and maintenance requirements for package high-service pumping stations - process energy and maintenance material.

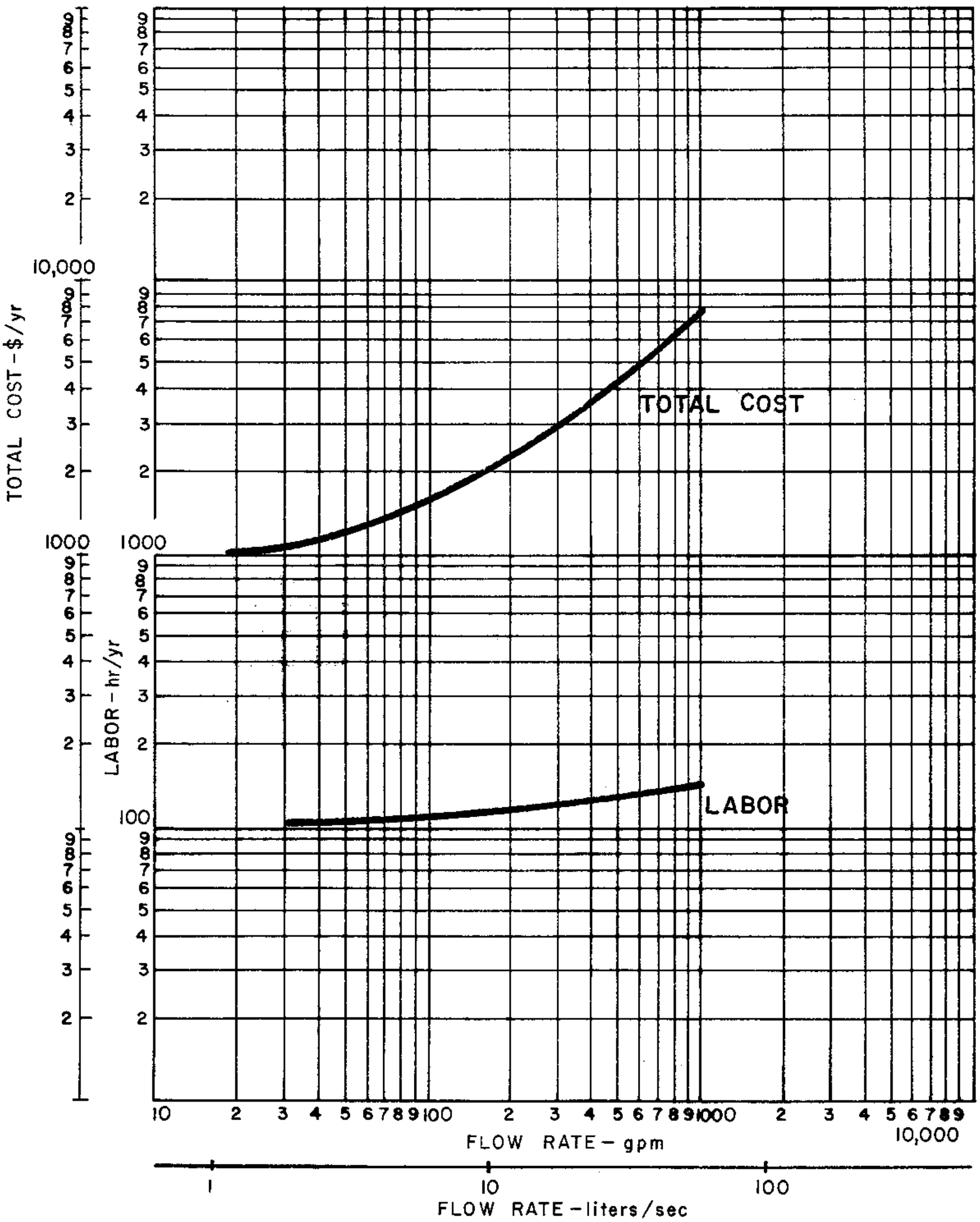


Figure 55. Operation and maintenance requirements for package high-service pumping stations - labor and total cost.

Table 56

Conceptual Design for

Steel Backwash/Clearwell Tanks*

Storage Volume (gal)	Tank Dimensions (ft)	
	Diameter	Height
500+	4	5
2,500	7	8
5,000	8.5	12
10,000‡	12	12
15,000	13	15
30,000	16	20

* Tanks are fabricated of 3/16-in. steel plate and painted inside and out. Tanks are covered.

+ Tanks smaller than 5,000 gallons are shop fabricated. Larger tanks are field erected.

‡ Tanks larger than 5,000 gallons are equipped with access manway in side and roof and caged access ladder. All tanks have inlet/outlet, overflow, and vent-pipe connections.

Table 57

Construction Cost for

Steel Backwash/Clearwell Tanks

Cost Category	Storage Volume (gal)					
	500	2,500	5,000	10,000	15,000	30,000
Excavation and Sitework	$20	$50	$100	$130	$200	$250
Concrete	50	140	180	320	370	520
Steel Tankage	1,200	3,200	5,300	8,100	10,500	19,000
Labor	100	300	400	500	2,800	4,500
SUBTOTAL	1,370	3,690	5,980	9,050	13,870	24,270
Miscellaneous and Contingency	210	550	900	1,360	2,080	3,640
TOTAL COST	1,580	4,240	6,880	10,410	15,950	27,910

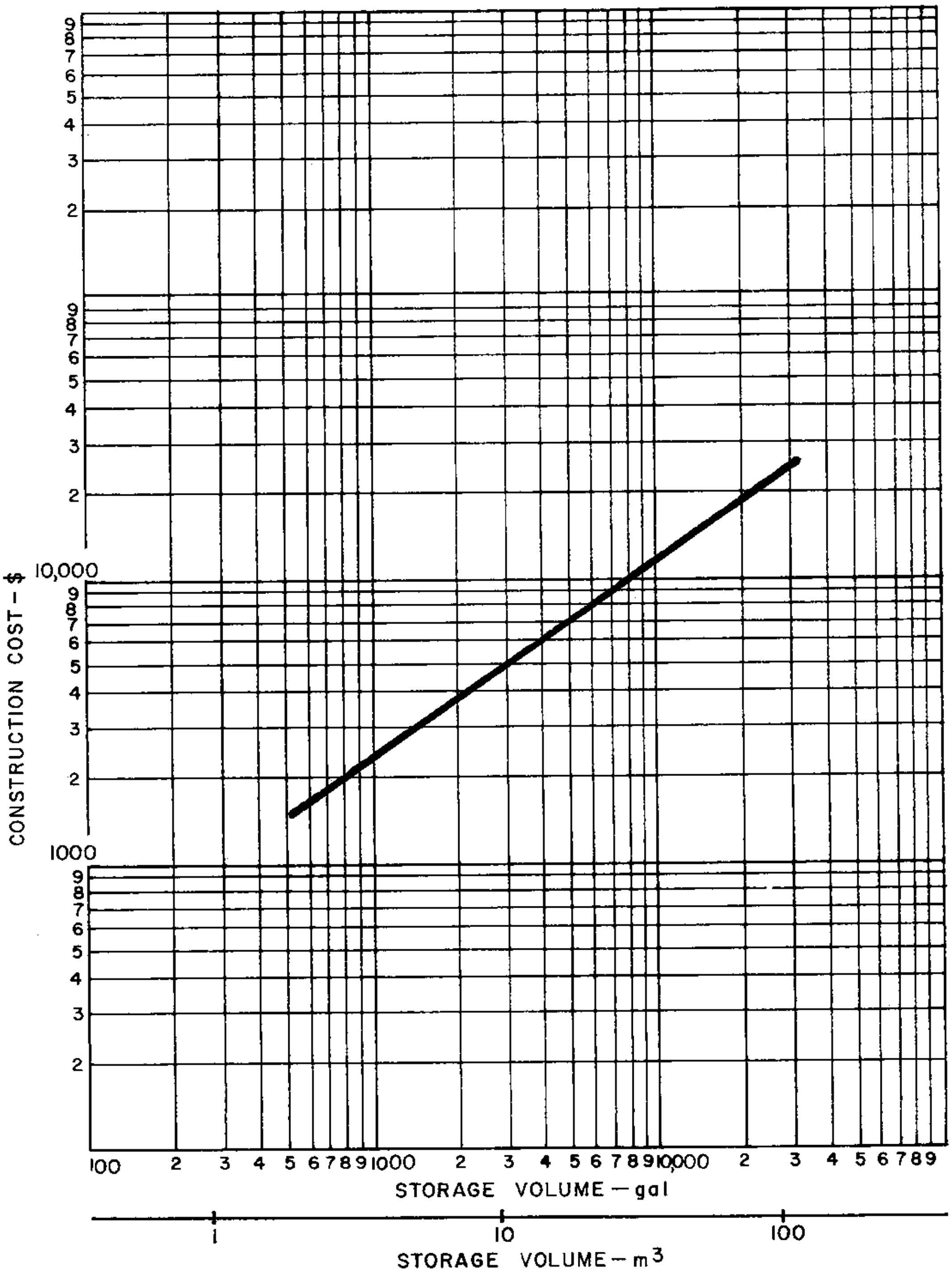


Figure 56. Construction cost for steel backwash/clearwell tanks.

Table 58

Criteria for Liquid and Dewatered Sludge Hauling*

Sludge Type	Truck Capacity	Fuel	Capital Cost	Mileage (mpg)	Fuel Cost ($/gal)	Operator Cost ($/hr)	Operation+ Cost ($/mile)
Liquid	1,200 gal	Gas	$28,750	4.5	$0.55	$15.00	$0.219
	5,500 gal	Diesel	63,240	3.5	0.45	15.00	0.328
Dewatered	10 yd^3	Gas	28,750	4.5	0.55	15.00	0.219
	30 yd^3	Diesel	57,490	3.5	0.45	15.00	0.328

*The following transport cycling criteria were also utilized: Loading time, 20 min/truck; unloading time, 15 min/truck; speed, 25 mph for 1st 20 miles on one-way distance and 35 mph for all miles thereafter.

+Operation Cost excludes operator and fuel cost.

tanker truck. Loading facilities include a truck loading enclosure and appropriate piping and valving to allow loading in a maximum time of 20 min. Sludge pumping facilities are not included in these costs, as separate curves are provided for chemical sludge pumping. The number of trucks required and the initial costs are shown in Table 59; initial costs are also shown in Figure 57.

Dewatered Sludge--

Costs were also developed for hauling dewatered sludge with volumes between 100 and 50,000 yd^3/year, over one-way distances between 5 and 40 miles. Where loading facilities are utilized, the facilities include a sludge conveyor, a hopper capable of holding 1.5 truckloads of sludge, and an enclosure for the sludge hopper. When more than one hopper was required, multiple conveyors and enclosures were utilized. Initial costs for loading facilities and trucks are shown in Table 60 and Figure 58.

Operation and Maintenance Cost

Energy requirements for sludge hauling are for truck fuel. The type of fuel used, the fuel cost, and mileage estimates utilized for various truck configurations that were used in the estimates are shown in Table 58. Process energy for sludge pumping at the treatment facility is not included, and the cost curves for chemical sludge pumping should be utilized if pumping is required.

Maintenance costs for the trucks were calculated on the basis of $/mile traveled, using the per-mile costs included in Table 58. The maintenance costs do not include fuel. Labor requirements are for the truck operators. A loading time of 20 min and an unloading time of 15 min were utilized, and it was assumed that the truck operator would be responsible for each.

Operation and maintenance requirements for liquid sludge hauling are summarized in Table 61 and are shown in Figures 59 and 60. Dewatered sludge hauling operation and maintenance costs are summarized in Table 62 and are presented in Figures 61 and 62.

SLUDGE DISPOSAL TO SANITARY SEWERS

Annual Cost

Sludge disposal to sanitary sewers usually enhances sedimentation in the wastewater treatment facility, but also creates a problem as a result of the additional quantity of sludge that must be treated and ultimately disposed. The cost for disposal of water treatment plant sludges to wastewater facilities varies widely, depending on the concentration of the water treatment plant sludge, the wastewater quality, and the degree of treatment provided by the wastewater facility.

To estimate the cost of treating sludge from a water treatment plant, a charge of $100/million gal of wastewater was used. The wastewater composition used was assumed to have a BOD of 225 mg/l and TSS of 275 mg/l. The

Table 59

Initial Cost for

Liquid Sludge Hauling

Annual Volume of Sludge Hauled (gal/yr)	One Way Haul Distance (Miles)	Number of Trucks Required*	Initial Cost of Trucks	Construction Cost of Loading Facilities	Total Initial Cost
25,000	5	1	$ 28,750	$ 7,500	$ 36,250
	20	1	28,750	7,500	36,250
	40	1	28,750	7,500	36,250
250,000	5	1	63,240	12,500	75,740
	20	1	63,240	12,500	75,740
	40	1	63,240	12,500	75,740
1,500,000	5	1	63,240	15,500	75,740
	20	1	63,240	15,500	75,740
	40	1	63,240	15,500	75,740
5,000,000	5	1	63,240	15,500	75,740
	20	1	63,240	15,500	75,740
	40	2	126,480	31,000	157,480
15,000,000	5	2	126,480	31,000	157,480
	20	3	189,720	46,500	236,220
	40	4	252,960	62,000	314,960

*All trucks are 5,500 gallon capacity except for the 1,200-gal trucks used to haul 25,000 gal/year.

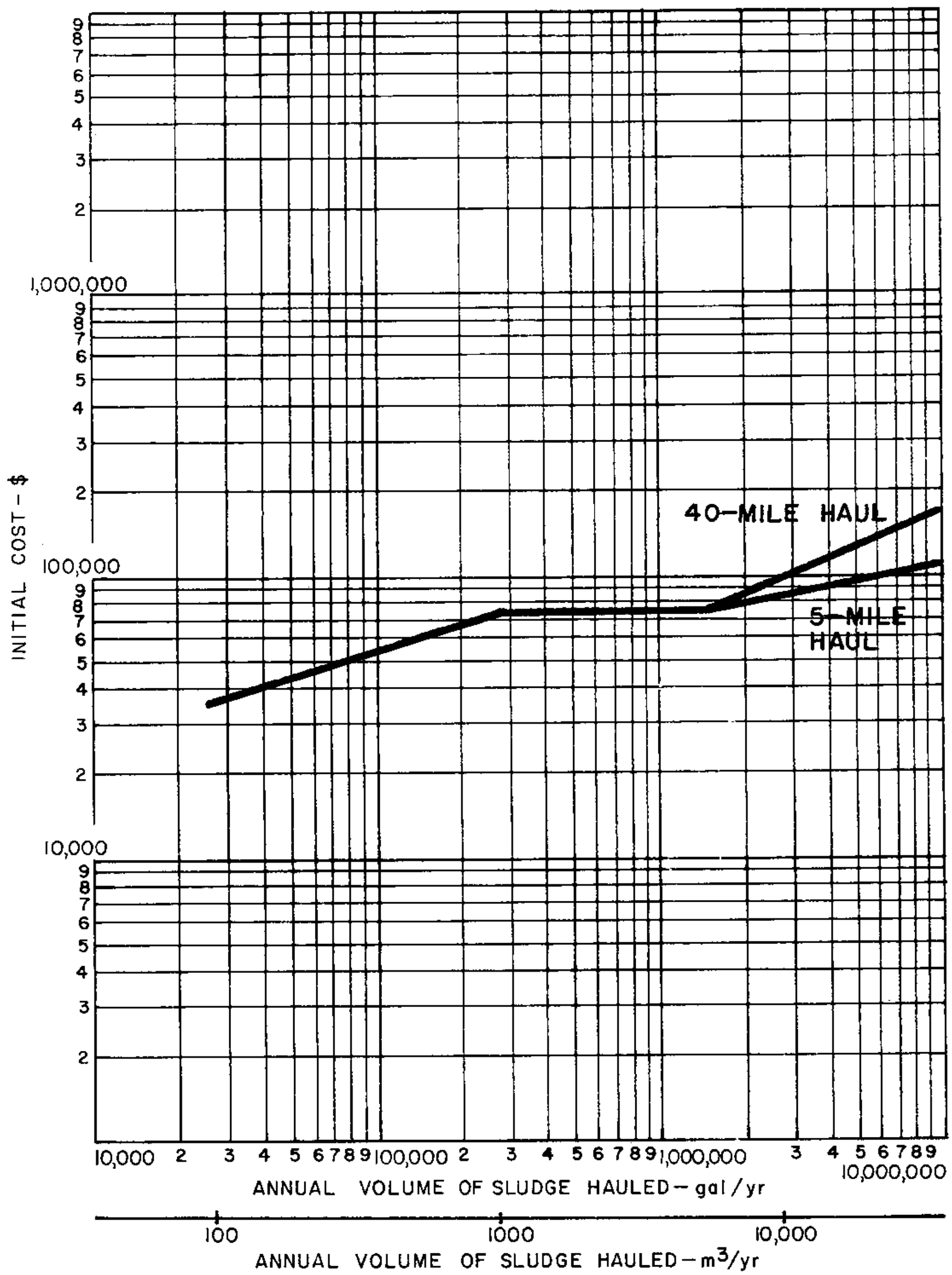


Figure 57. Initial cost for
liquid sludge hauling at 5- and 40-mile haul distances.

Table 60

Initial Cost for

Dewatered Sludge Hauling

Annual Volume of Sludge Hauled (yd^3/yr)	One Way Haul Distance (Miles)	Number of Trucks	Size of Trucks (yd^3)	Initial Cost of Trucks	Construction Cost of Loading Facilities	Total Initial Cost
100	5	1	10	$28,750	$0	$28,750
	20	1	10	28,750	0	28,750
	40	1	10	28,750	0	28,750
1,000	5	1	10	28,750	15,900	44,650
	20	1	10	28,750	15,900	44,650
	40	1	10	28,750	15,900	44,650
10,000	5	1	30	57,490	32,800	90,290
	20	1	30	57,490	32,800	90,290
	40	1	30	57,490	32,800	90,290
50,000	5	1	30	57,490	32,800	90,290
	20	2	30	114,980	32,800	147,780
	40	3	30	172,470	32,800	205,270

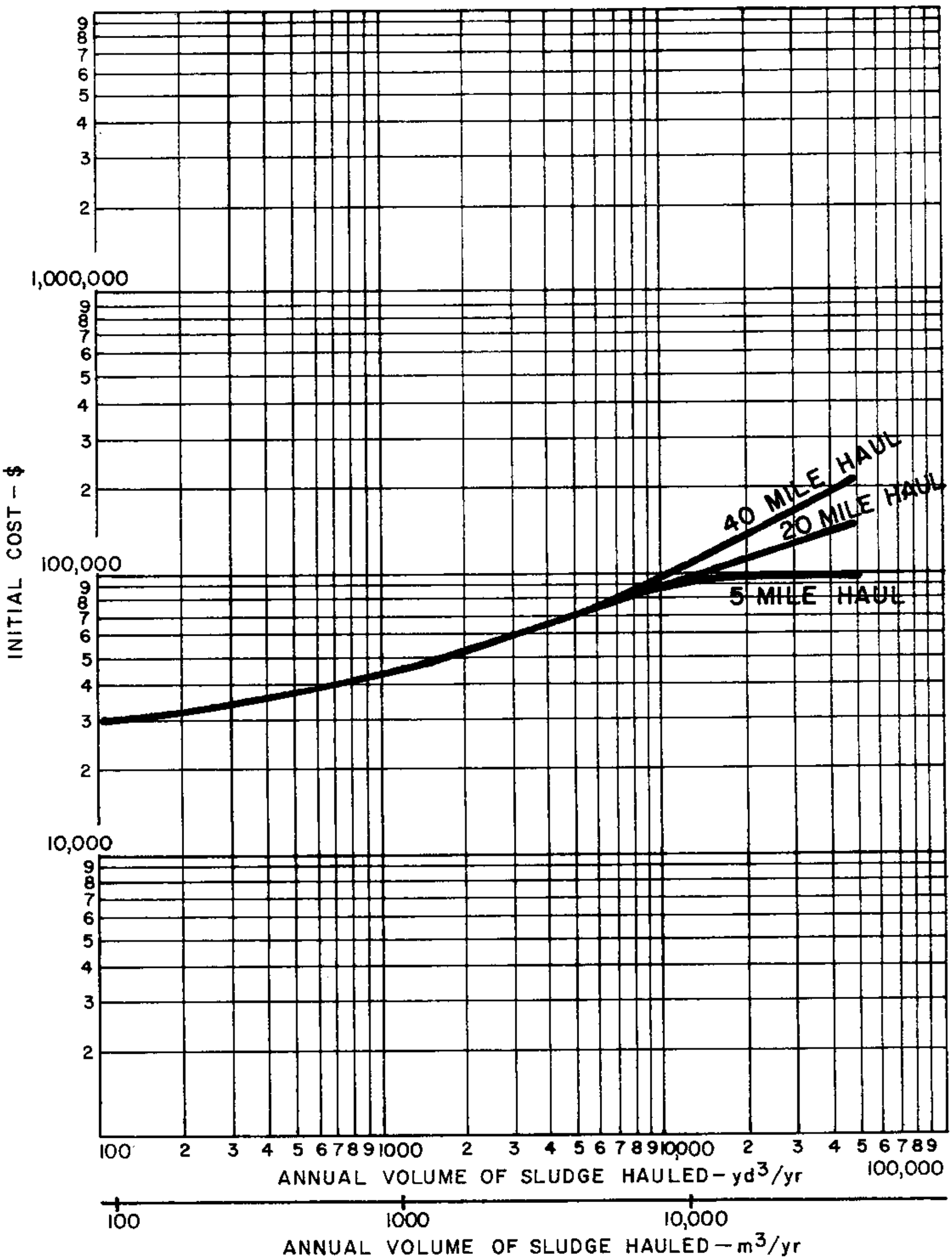


Figure 58. Initial cost for
dewatered sludge hauling at 5-, 20-, and 40-mile haul distances.

Table 61

Operation and Maintenance Summary for

Liquid Sludge Hauling

Annual Volume of Sludge Hauled (gal/yr)	One Way Haul Distance (miles)	Fuel (gal/yr)	Maintenance ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
25,000	5	50	$50	30	$ 530
	20	190	180	50	1,030
	40	370	360	130	2,510
250,000	5	130	150	40	810
	20	520	600	90	2,180
	40	1,040	1,190	130	3,610
1,500,000	5	700	750	260	4,970
	20	2,600	2,980	540	12,250
	40	5,200	5,980	790	20,170
5,000,000	5	2,600	2,980	1,045	19,830
	20	10,400	11,940	2,140	48,720
	40	20,800	23,850	3,160	80,610
15,000,000	5	7,800	8,960	3,140	59,570
	20	31,200	35,670	6,410	145,860
	40	62,300	71,570	9,490	241,960

*Calculated using #0.45/gal and $15.00/hr of labor.

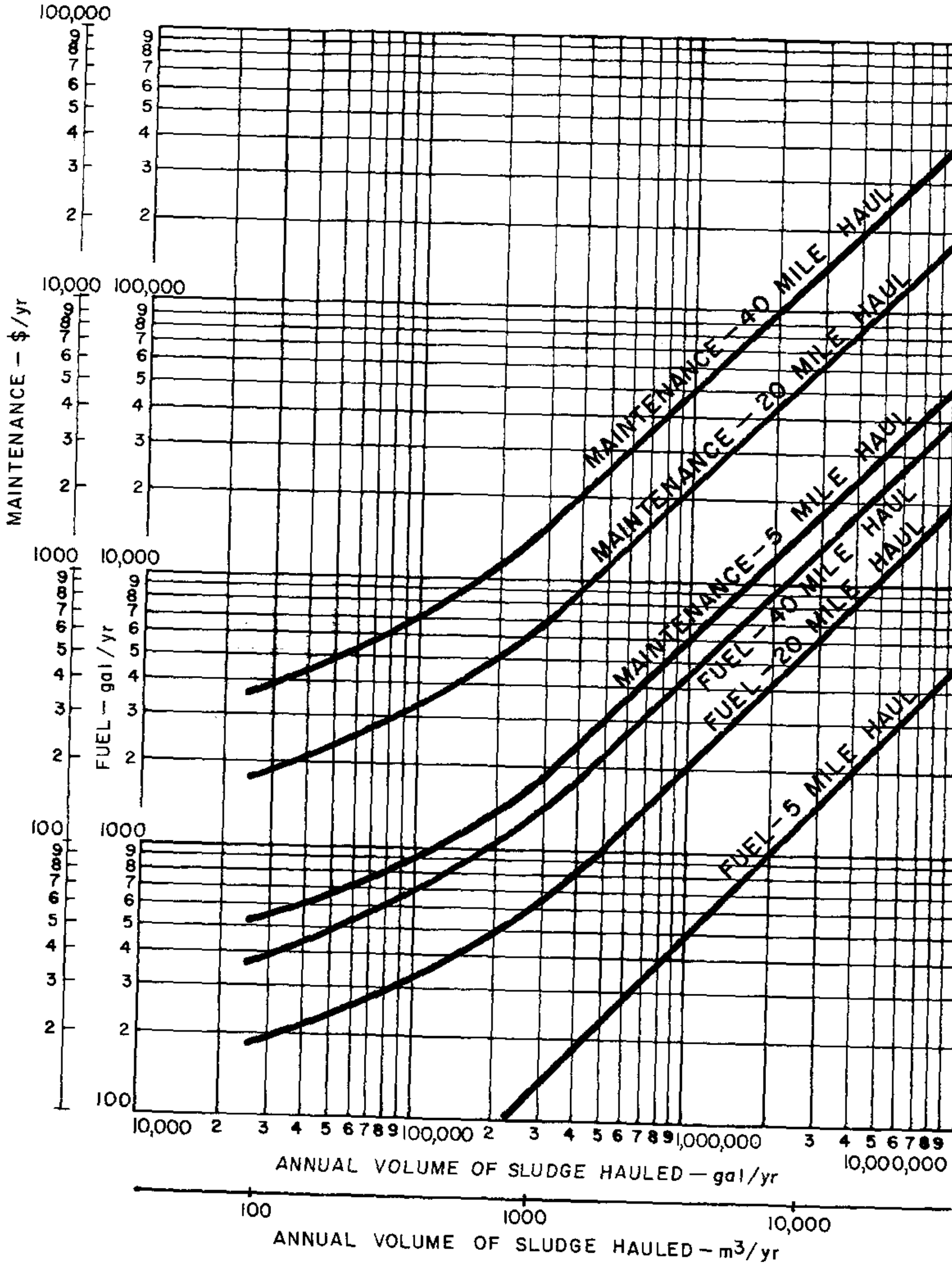


Figure 59. Operation and maintenance requirements for liquid sludge hauling - maintenance material and fuel needed for 5-, 20-, and 40-mile haul distances.

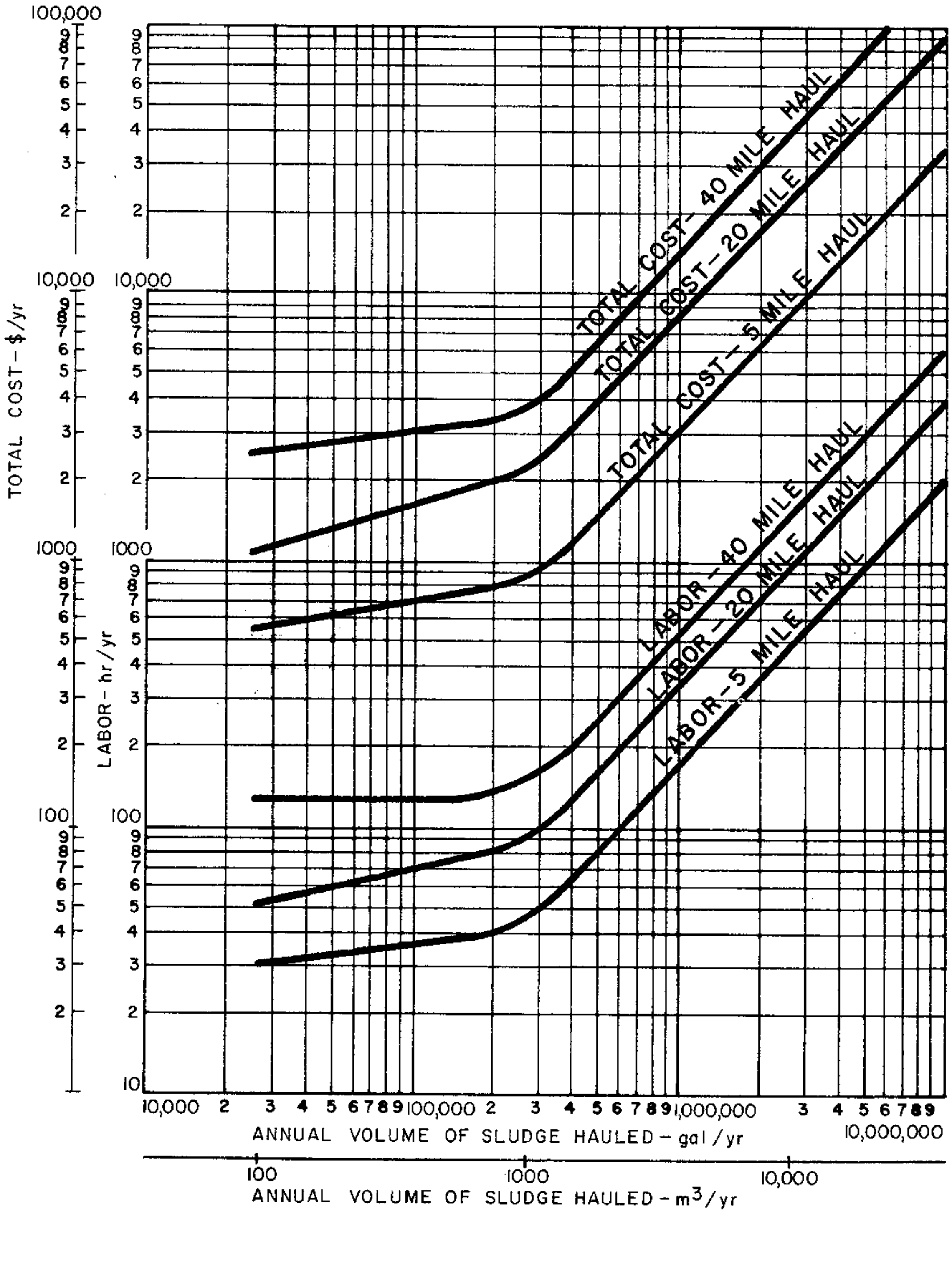


Figure 60. Operation and maintenance requirements for liquid sludge hauling - labor and total cost for 5-, 20-, and 40-mile haul distances.

Table 62

Operation and Maintenance Summary for

Dewatered Sludge Hauling

Annual Volume of Sludge Hauled (yd^3)	One Way Haul Distance (miles)	Fuel (gal/yr)	Maintenance ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
100	5	22	$22	12	$ 210
	20	88	88	24	490
	40	170	175	35	790
1,000	5	220	220	120	2,140
	20	890	880	240	4,970
	40	1,700	1,750	350	7,940
10,000	5	1,000	1,090	380	7,240
	20	3,800	4,370	780	17,780
	40	7,600	8,740	1,200	20,160
50,000	5	4,900	5,470	1,900	36,180
	20	19,100	21,870	3,900	88,970
	40	38,000	43,740	5,800	147,840

*Calculated using $0.03/kw-hr and $15.00/hr of labor.

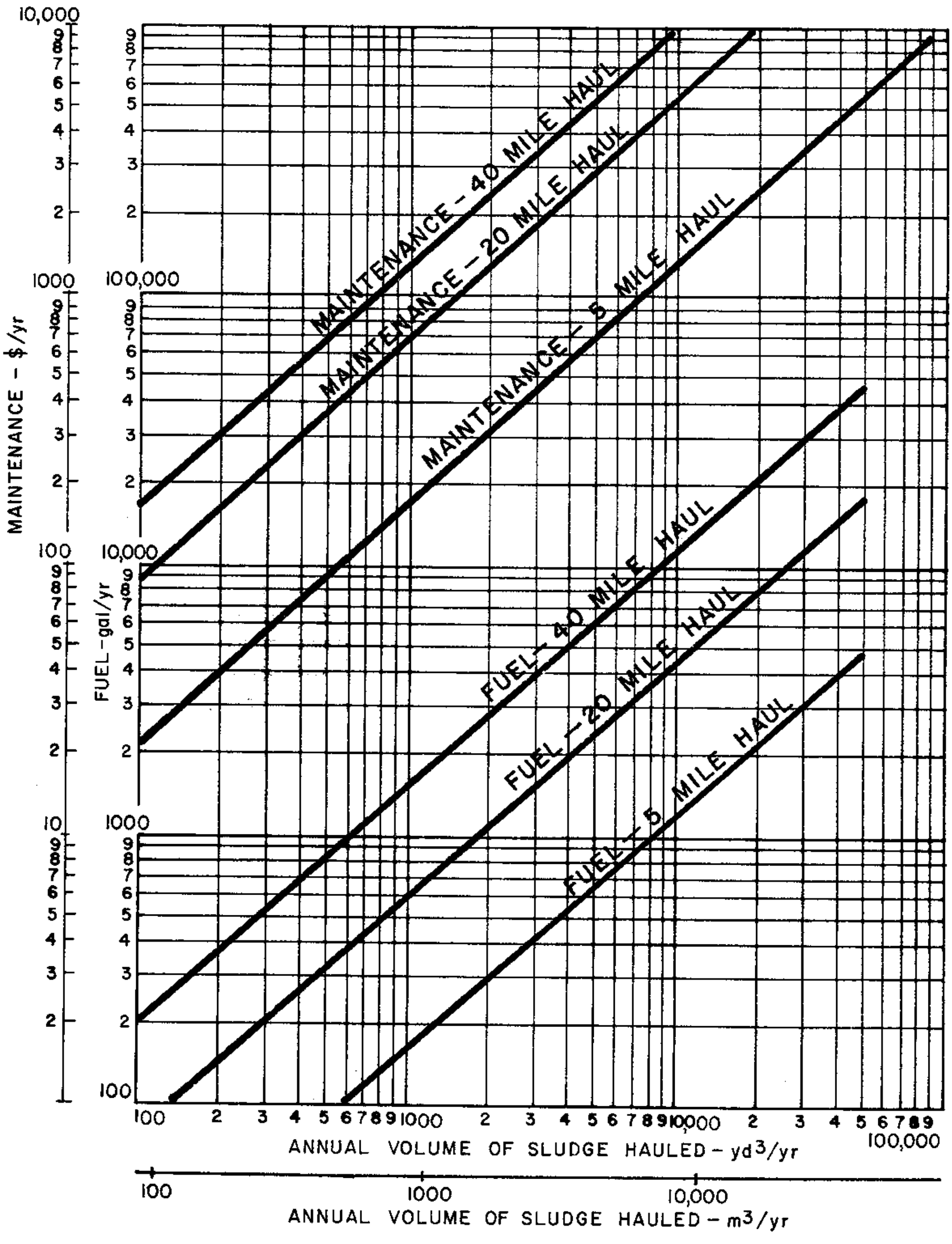


Figure 61. Operation and maintenance requirements for dewatered sludge hauling - maintenance material and fuel needed for 5-, 20-, and 40-mile haul distances.

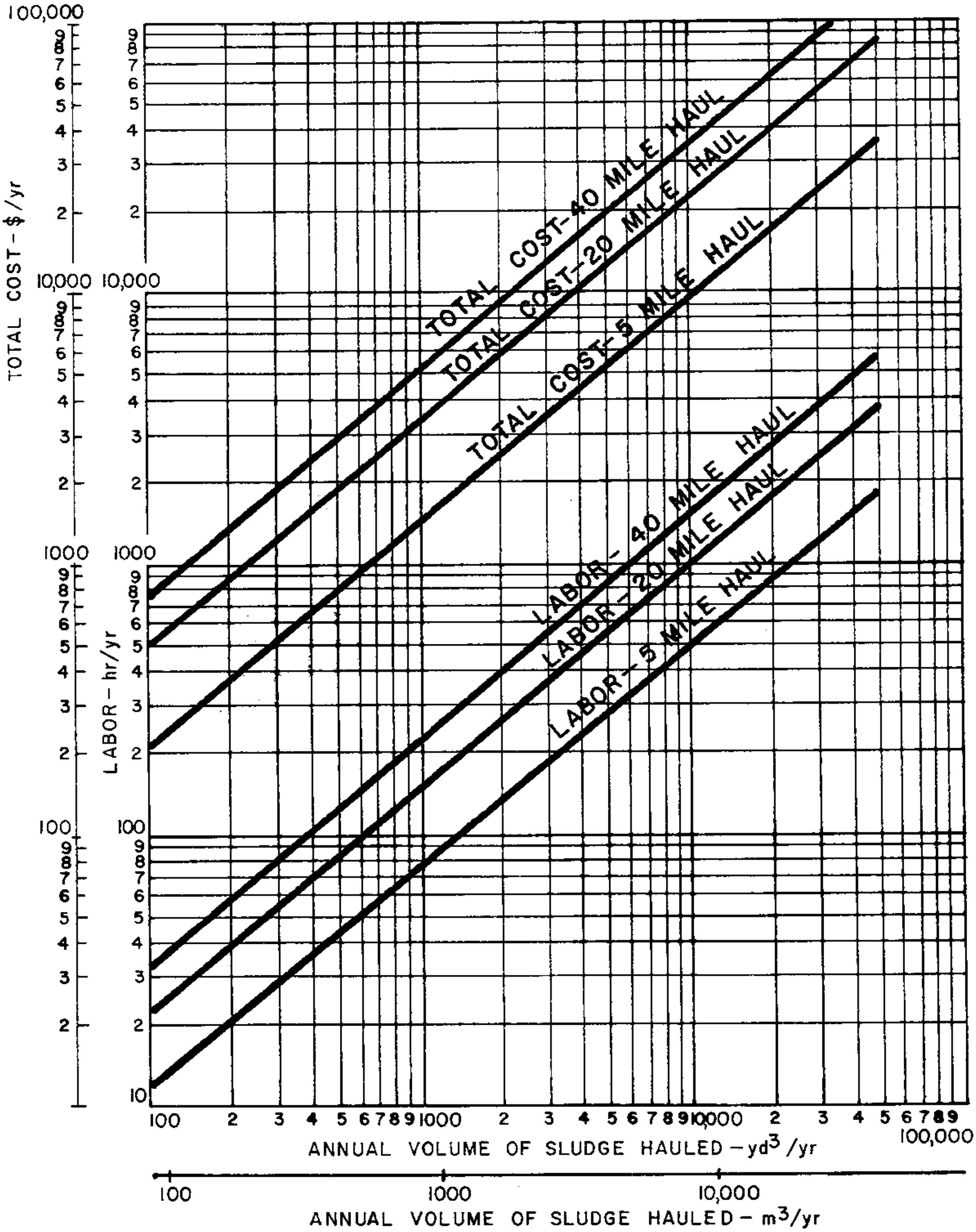


Figure 62. Operation and maintenance requirements for dewatered sludge hauling - labor and total cost for 5-, 20-, and 40-mile haul distances.

$100 charge was allocated as follows: 34-percent to flow, 33-percent to BOD, and 33-percent to suspended solids, which is equivalent to $85/million gal of flow, $0.044/lb of BOD, and $0.036/lb of suspended solids. Table 63 presents the annual cost of discharging water treatment sludges with BOD values of 50 mg/l, at various flow rates and suspended solids concentrations, to this wastewater system. Costs are not significantly influenced by higher BOD values, even up to 150 mg/l. Other factors that should be considered in determining the feasibility and cost of sewer discharge are the availability of trunk sewer capacity and the cost of using this capacity.

SLUDGE DEWATERING LAGOONS

Construction Cost

A popular and economical technique for handling waste sludge from small treatment plants is a sludge lagoon. Waste sludge, and often filter backwash water, is discharged to the lagoon for clarification and storage. Generally more than one lagoon is provided to allow time for the sludge in the lagoon that is out of service to dewater sufficiently to permit removal.

Construction costs were estimated for unlined, earthen basins fully excavated to a depth of 7-ft. Lagoons were assumed to have a 2-ft freeboard, and all dike materials are assumed to be obtained from the excavation. A dike side slope of 3:1 was assumed. Lagoons are provided with an inlet flow-distributing structure to minimize disturbance of settled sludge. An outlet structure to skim clarified water is also provided. Conceptual designs used to estimate costs are presented in Table 64.

Construction costs are presented in Table 65 and in Figure 63. The costs are shown as a function of effective storage volume, which is the volume of the lagoon minus freeboard volume. The costs exclude those for land.

Operation and Maintenance Cost

Operation and maintenance requirements are primarily associated with sludge removal from the lagoons. Where climatic conditions are favorable and lagoons allow percolation of entrained water, sludge will dewater sufficiently so that it can be removed by mechanical means.

Operation and maintenance requirements are presented for removing sludge with a front-end loader and hauling it in dump trucks to a disposal site within 1 mile of the lagoon. Sludge is assumed to be removed from a lagoon on the average of once every 2 years. Energy requirements are for diesel fuel used in the removal and transport of sludge. Maintenance material is for periodic lagoon grading, restoration of dikes, and roadway maintenance. Labor requirements are for sludge removal and transport, and for facility maintenance.

Operation and maintenance requirements are summarized in Table 66 and are shown in Figures 64 and 65.

Table 63

Annual Cost for

Sludge Disposal to Sanitary Sewers

Sludge Volume (gpd)	Suspended Solids Concentration (mg/1)			
	1,000	5,000	10,000	50,000
50	$ 3	$ 12	$ 23	$110
250	15	60	110	550
500	30	120	230	1,100
2,500	150	590	1,130	5,510
5,000	300	1,170	2,270	--
25,000	1,470	5,850	--	--

Note: Costs are based on a wastewater treatment charge of $100/million gal for a wastewater with a BOD of 225 mg/1 and a suspended solids concentration of 275 mg/1. The $100/million gal charge was allocated as follows: 34-percent to flow, 33-percent to BOD, and 33-percent to suspended solids.

Table 64

Conceptual Design for

Sludge Dewatering Lagoons

Effective Storage Volume (ft^3)	Lagoon Dimensions (ft)	
	Length	Width
1,500	30	30
3,500	40	40
5,000	60	35
17,000	150	40
30,000	180	50

Table 65

Construction Cost for

Sludge Dewatering Lagoons

Cost Category	Effective Lagoon Volume (ft^3)				
	1,500	3,500	5,000	17,000	30,000
Excavation and Sitework	$ 500	$ 650	$ 700	$ 1,300	$ 2,000
Concrete	300	300	300	350	600
Pipe and Valves	600	600	600	750	900
Labor	400	550	650	1,000	1,800
SUBTOTAL	1,800	2,100	2,250	3,400	5,300
Miscellaneous and Contingency	270	320	340	510	800
TOTAL COST	2,070	2,420	2,590	3,910	6,100

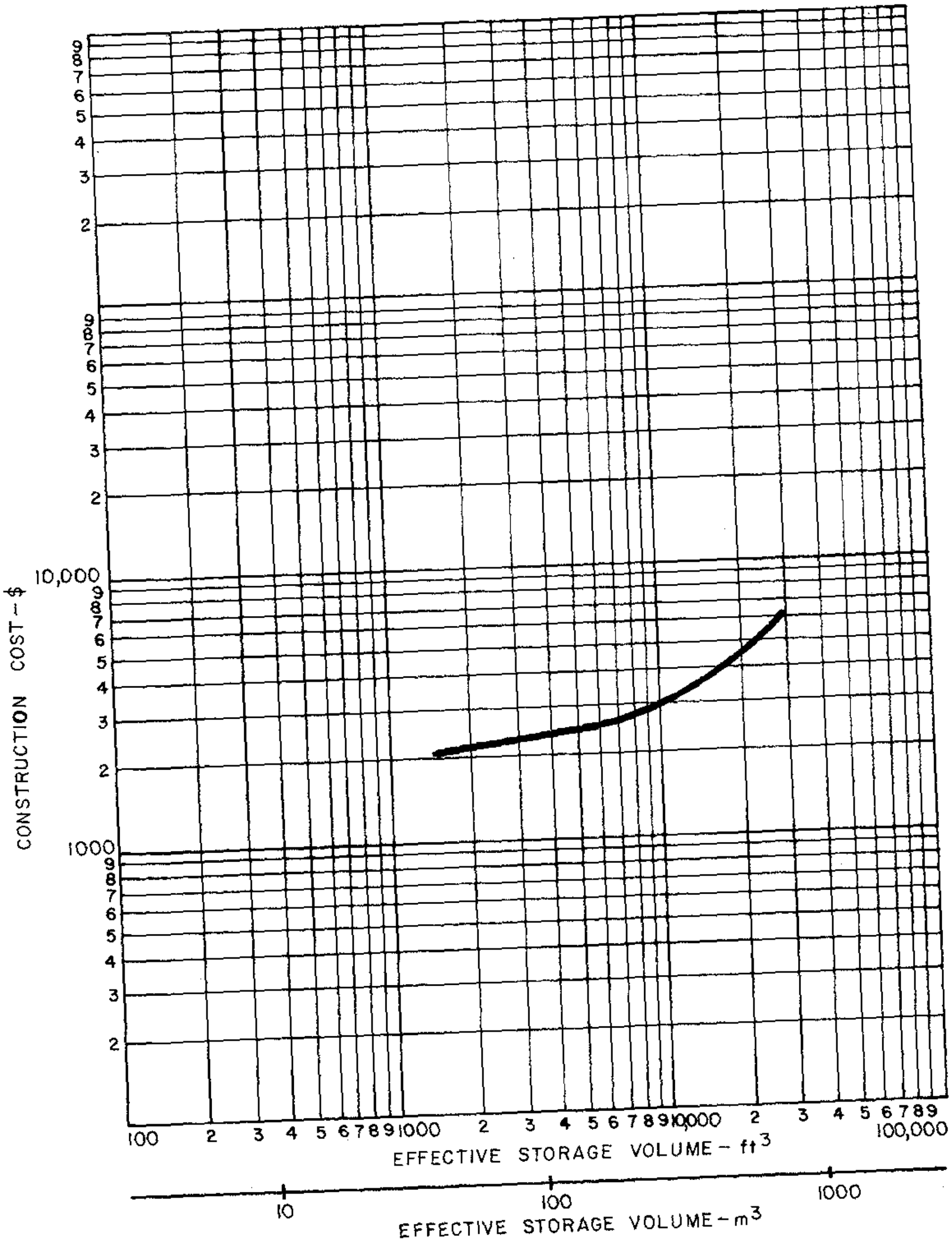


Figure 63. Construction cost for sludge dewatering lagoons.

Table 66

Operation and Maintenance Summary for

Sludge Dewatering Lagoons

Volume of Sludge Removed* (ft^3/yr)	Diesel Fuel (gal/yr)+	Maintenance Material ($/yr)‡	Labor (hr/yr)	Total Cost# ($/yr)
750	10	$50	16	$210
1,750	22	60	18	250
2,500	30	65	24	320
8,500	110	70	80	920
15,000	190	75	140	1,560

*Assumes a sludge density of 70 lb/ft^3 and a sludge solids concentration of 17 to 20-percent.

+No. 2 diesel fuel used for loader and dump truck.

‡Exclusive of removal equipment maintenance.

#Calculated using a diesel fuel cost of $0.45/gal and $10.00/hr of labor.

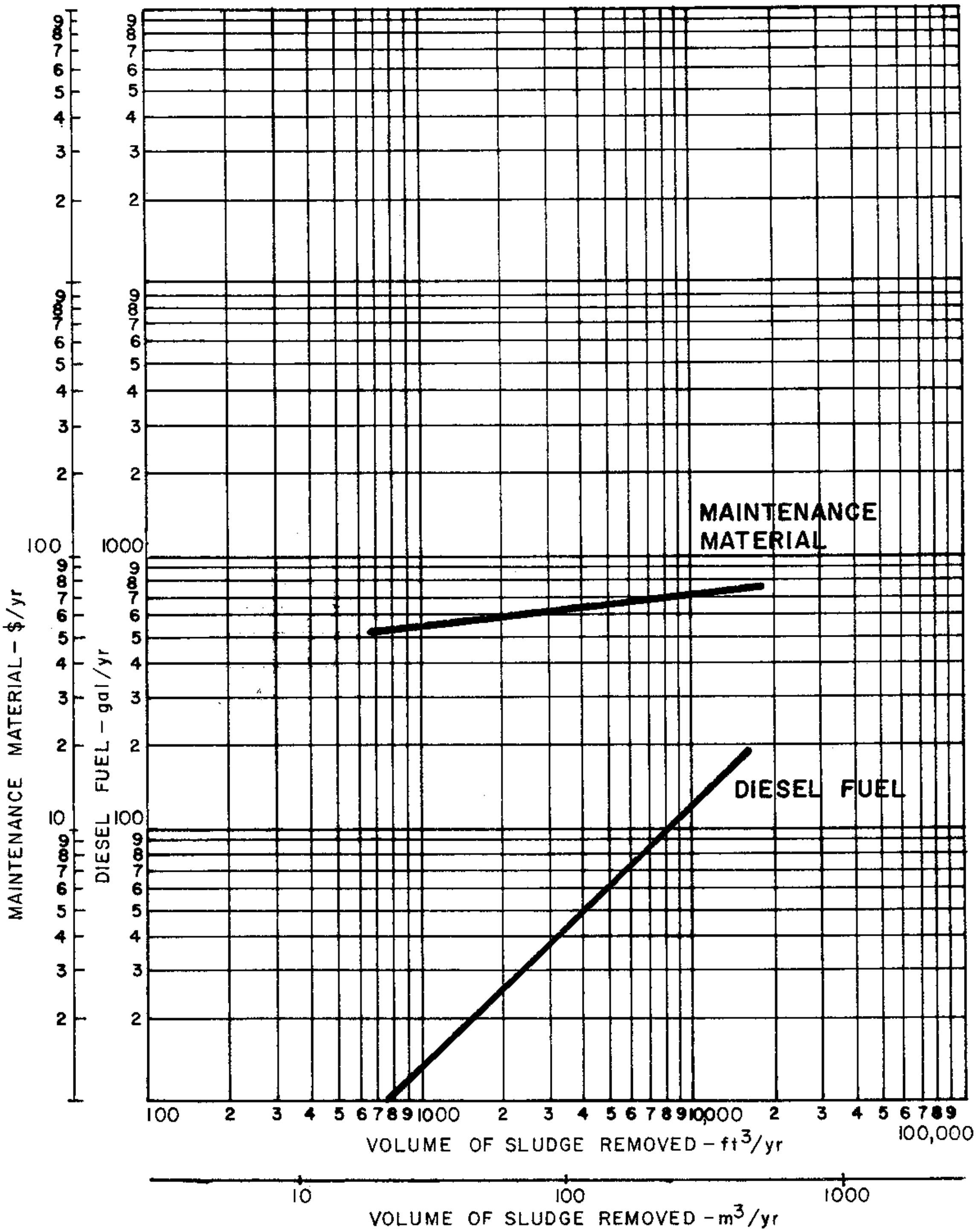


Figure 64. Operation and maintenance requirements for sludge dewatering lagoons - maintenance material and diesel fuel.

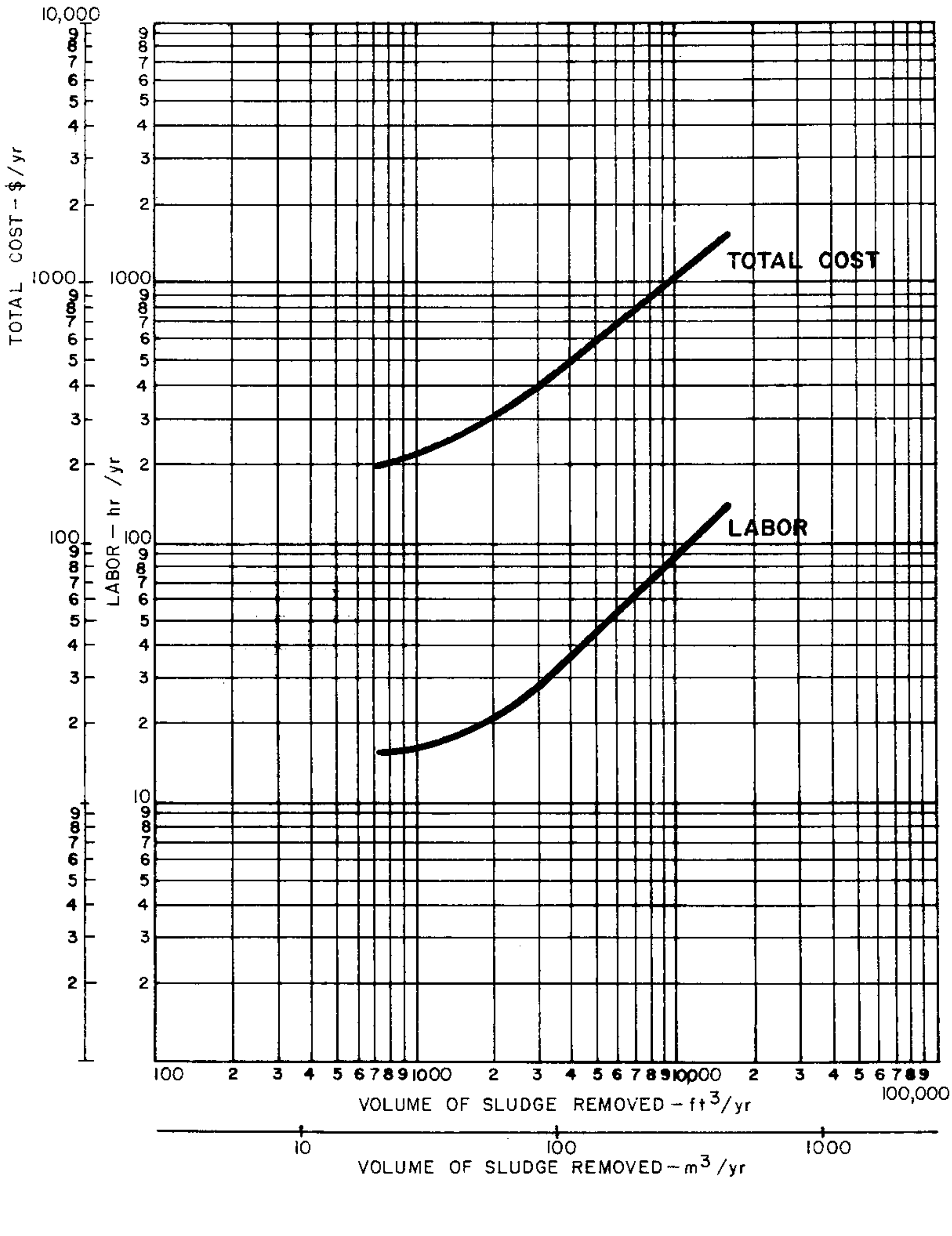


Figure 65. Operation and maintenance requirements for sludge dewatering lagoons - labor and total cost.

SAND DRYING BEDS

Construction Cost

Cost estimates were made for uncovered and unlined sand drying beds using the conceptual designs presented in Table 67. The beds were assumed to be divided into two cells, each totally contained by a concrete curb wall. The curb wall design will permit access by a small tractor with a front-end loader for the removal of sludge. Water that percolates downward into the sand bed is removed by a perforated pipe underdrain system placed beneath 18 in. of graded sand and gravel. The beds are provided with a central sludge distribution box, complete with removable baffles and associated supply piping to the end of the bed.

Table 68 presents estimated construction costs, which are also illustrated in Figure 66.

Operation and Maintenance Cost

Energy requirements are for a small, diesel-powered tractor with front-end loader, which is used to remove dried sludge from the beds and to perform grading and sand replacement before the next sludge application. A fuel consumption of 0.5 gal per hour for the loader and 20 bed cleanings per year were assumed to determine fuel requirements. It was assumed that dried sludge would be loaded onto a truck and hauled from the plant site, although no allowance was made for truck fuel consumption. Separate curves are provided in this report for dewatered sludge hauling.

Maintenance material requirements are for replacement of sand lost during bed cleaning. A loss of 1/2 in. of sand per cleaning was assumed. Labor requirements were based on operating installations and on computations of anticipated time to perform cleaning and bed preparation.

Figures 67 and 68 present operation and maintenance requirements, which are also summarized in Table 69.

Table 67

Conceptual Design for

Sand Drying Beds

Total Bed Area (ft^2)	Number of Cells*	Dimensions of Cell+ (ft)		Sand Media Depth‡ (ft)
		Length	Width	
200	2	10	10	2
500	2	16	16	2
800	2	20	20	2

*Application of sludge alternated between two cells to allow for drying, sludge removal, and bed prep.

+Each cell is contained by 2-ft-high concrete ring wall.

‡Graded sand and gravel over perforated pipe collection system.

Table 68

Construction Cost for

Sand Drying Beds

Cost Category	Bed Area (ft^2)		
	200	500	800
Excavation and Sitework	$100	$170	$200
Concrete and Media	550	1,200	1,800
Steel	140	160	180
Labor	600	800	950
Pipe and Valves	420	960	1,450
SUBTOTAL	1,810	3,290	4,580
Miscellaneous and Contingency	270	490	690
TOTAL	2,080	3,780	5,270

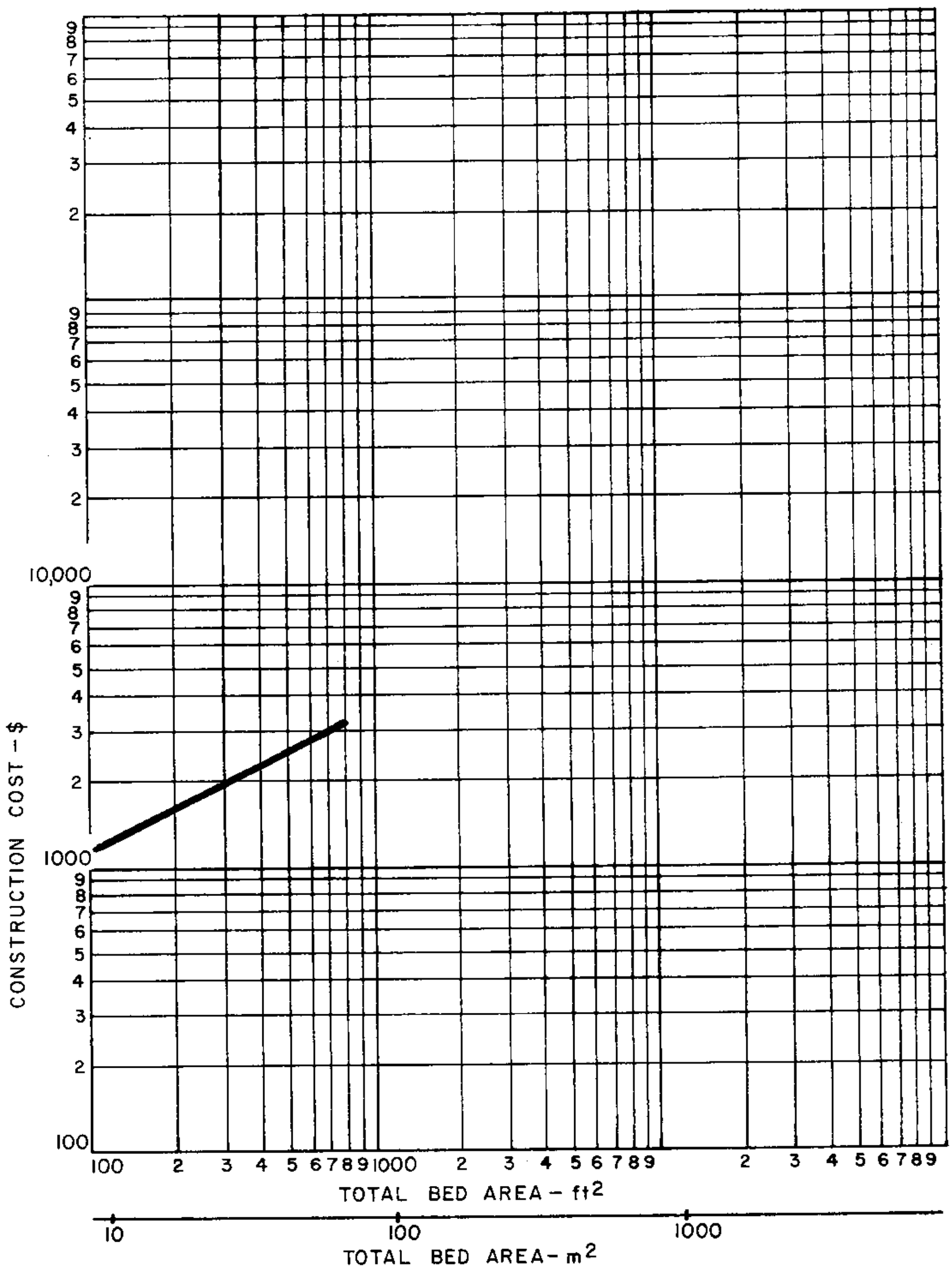


Figure 66. Construction cost for
sand drying beds.

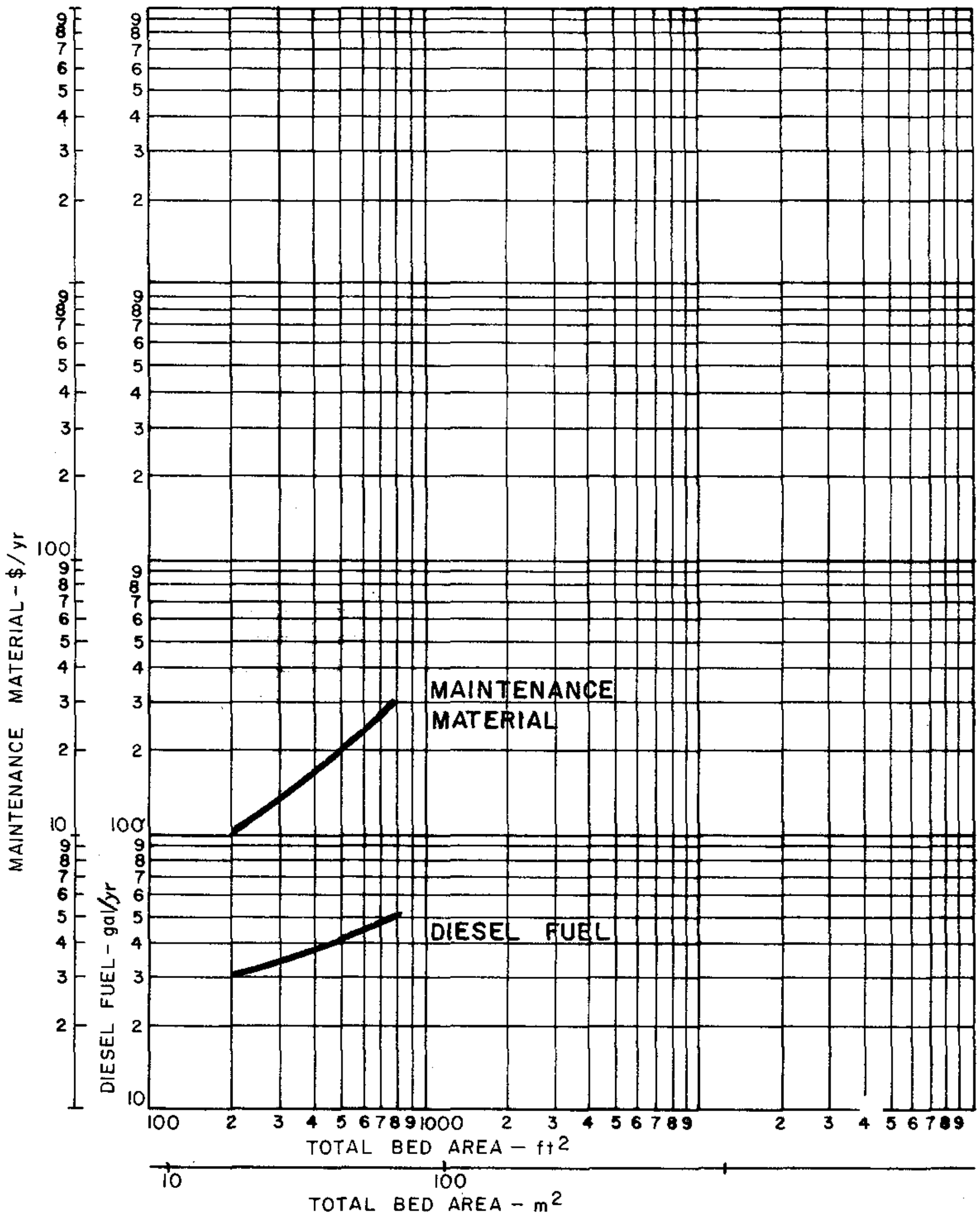


Figure 67. Operation and maintenance requirements for sand drying beds - maintenance material and diesel fuel.

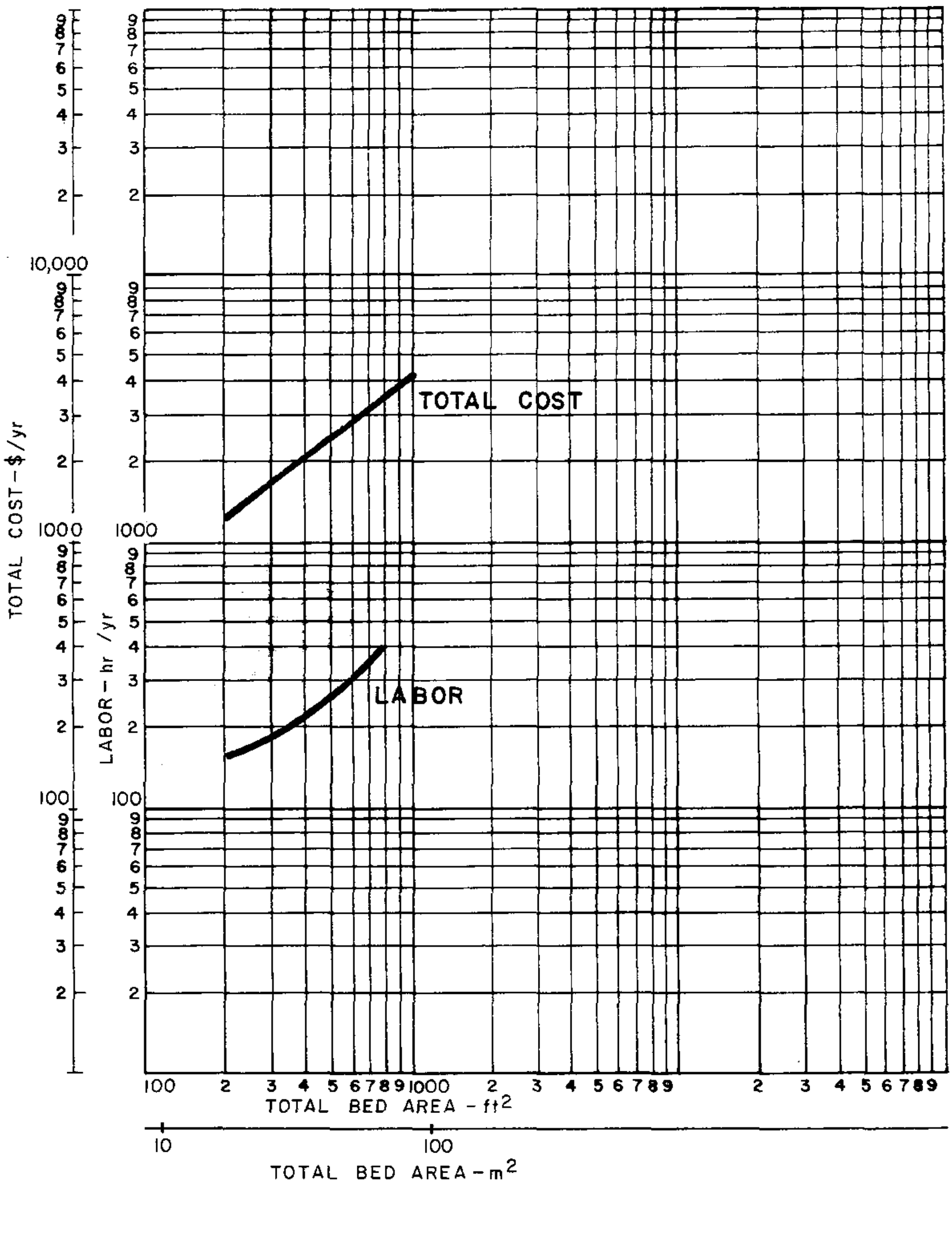


Figure 68. Operation and maintenance requirements for sand drying beds - labor and total cost.

Table 69

Operation and Maintenance Summary for

Sand Drying Beds

Total Sand Drying Bed Area (ft^2)	Diesel Fuel (gal/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total cost* ($/yr)
200	30	$ 10	160	$ 1,620
500	40	20	250	2,540
800	50	30	400	4,050

*Calculated using $0.45/gal of diesel fuel and $10.00/hr of labor.

SECTION 3

EXAMPLE CALCULATION FOR A 350-gpm PACKAGE COMPLETE TREATMENT PLANT

This example demonstrates the use of the curves included in this volume to develop the cost of a 350-gpm package complete treatment facility, including sludge handling facilities. In this example, the plant design capacity is 350 gpm, but the facility is only operating at 70-percent of capacity, or 245 gpm.

The design criteria and operating conditions for the complete facility are shown in Table 70. As shown, the complete facility consists of a package raw water pumping station, a package complete treatment plant, a steel backwash/clearwell tank, package high-service pumping, and sludge dewatering lagoons. The unit processes and design criteria that are presented in Table 70 represent a hypothetical situation and should not be considered to be applicable to all treatment plants of this general capacity.

The total of the construction costs for the individual unit processes shown in Table 70 yield a subtotal cost that is the basis for a number of special costs more appropriately related to the subtotal of construction cost than to the construction cost of each individual unit process. These special costs include: (1) special sitework, landscaping, roads, and interface piping between processes, (2) special subsurface considerations, and (3) standby power. The special costs vary widely, depending on the site, the design engineer's preference, and regulatory agency requirements. Addition of these special costs to the aggregate cost of the unit processes gives the total construction cost.

To arrive at the total capital cost, the following costs must be added to the total construction cost: (1) general contractor's overhead and profit, (2) engineering, (3) land, (4) legal, fiscal and administrative costs, and (5) interest during construction. Curves for these costs, with the exception of engineering and land, are presented in Figures 69 to 73. A curve for engineering cost is not included as the cost will vary widely, depending on the need for preliminary studies, time delays, the size and complexity of the project, and any construction related inspection and engineering design activities.

Table 71 presents a calculation of total annual cost and cost per 1,000 gal treated. This calculation involves a number of variables such as amortization rate and period, labor rate (including fringes and benefits),

Table 70

Design Criteria and Cost Calculation for a

350-gpm Package Complete Treatment Plant

System and Design Criteria	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Fuel (gal/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
Package Raw Water Pumping Facilities	500 gpm	$ 23,280	245 gpm	28,460	0	$110	73
Package Complete Treatment Plant - 5 gpm/ft^2	350 gpm	183,690	245 gpm	160,230	0	1,630	2,940
Steel Backwash/Clearwell Tank	100,000 gal	84,430	-	0	0	0	0
Package High-Service Pumping Station	500 gpm	16,570	245 gpm	44,330	0	40	123
Sludge Dewatering Lagoon	15,000 ft^3	3,720	12,000 ft^3/yr	0	155	70	118
Subtotal	--	311,690	--	233,020	155	1,850	3,254
Sitework, Interface Piping, Roads @ 5%	--	15,590	--	--	--	--	--
Surface Considerations	--	0	--	--	--	--	--
Standby Power	--	0	--	--	--	--	--
Total Construction Cost	--	327,280	--	--	--	--	--
General Contractor's Overhead and Profit	--	39,270	--	--	--	--	--
Subtotal	--	366,550	--	--	--	--	--
Engineering @ 10%	--	36,660	--	--	--	--	--
Subtotal	--	403,210	--	--	--	--	--
Land, 0.45 acres @ $2,000/acre	--	900	--	--	--	--	--
Legal, Fiscal and Administrative Services	--	10,080	--	--	--	--	--
Interest during Construction (7%)	--	10,680	--	--	--	--	--
Total Capital Cost	--	$424,870	--	--	--	--	--

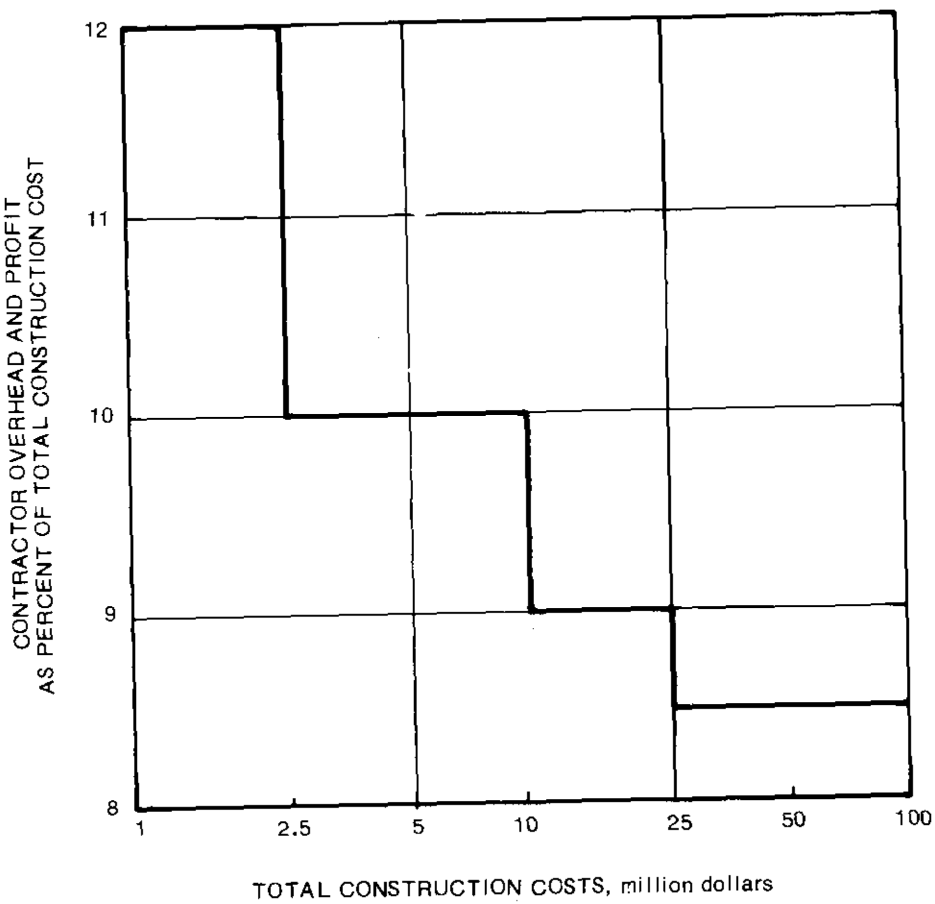


Figure 69. General contractor's overhead and fee percentage versus total construction cost.

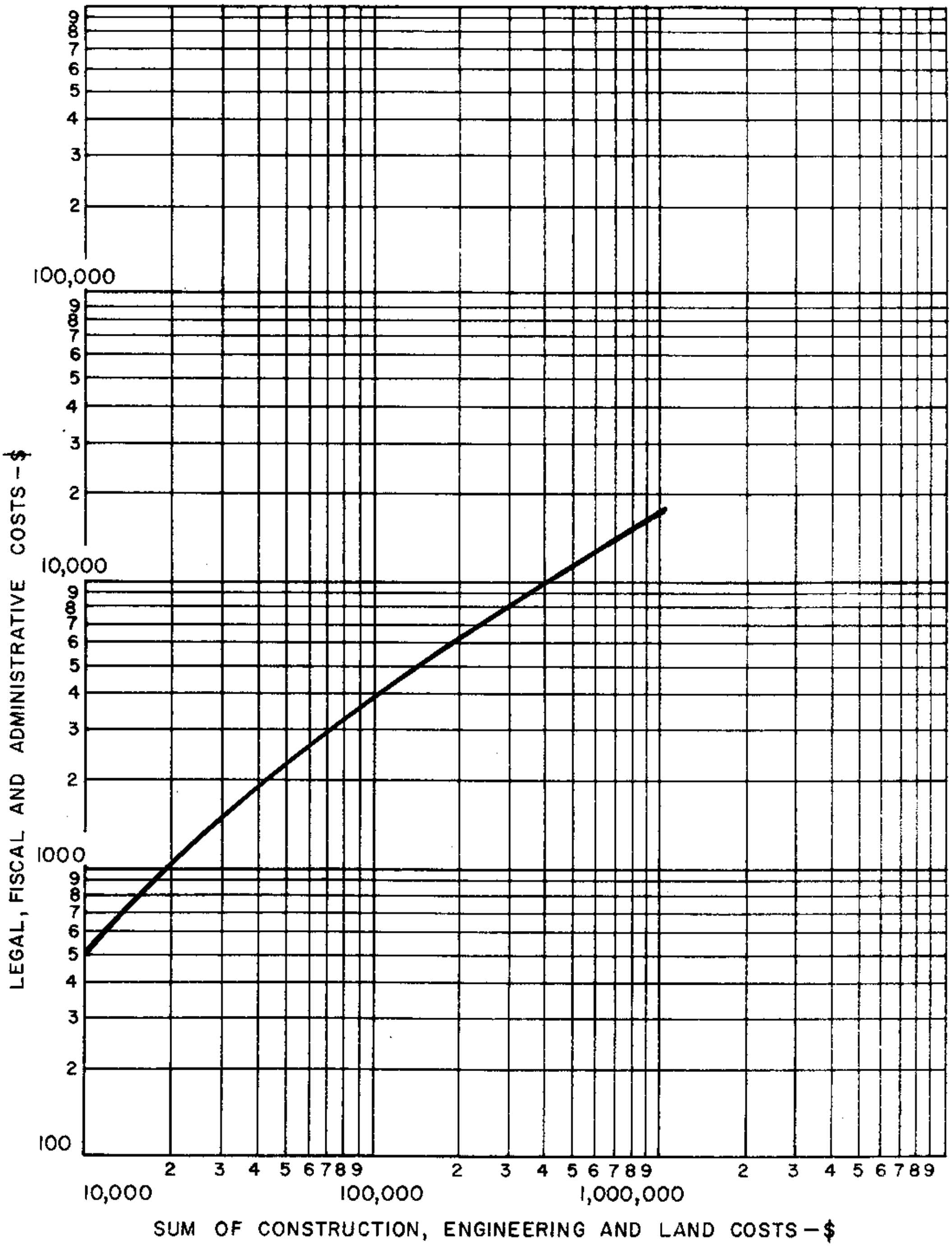


Figure 70. Legal, fiscal, and administrative costs for projects less than $1 million.

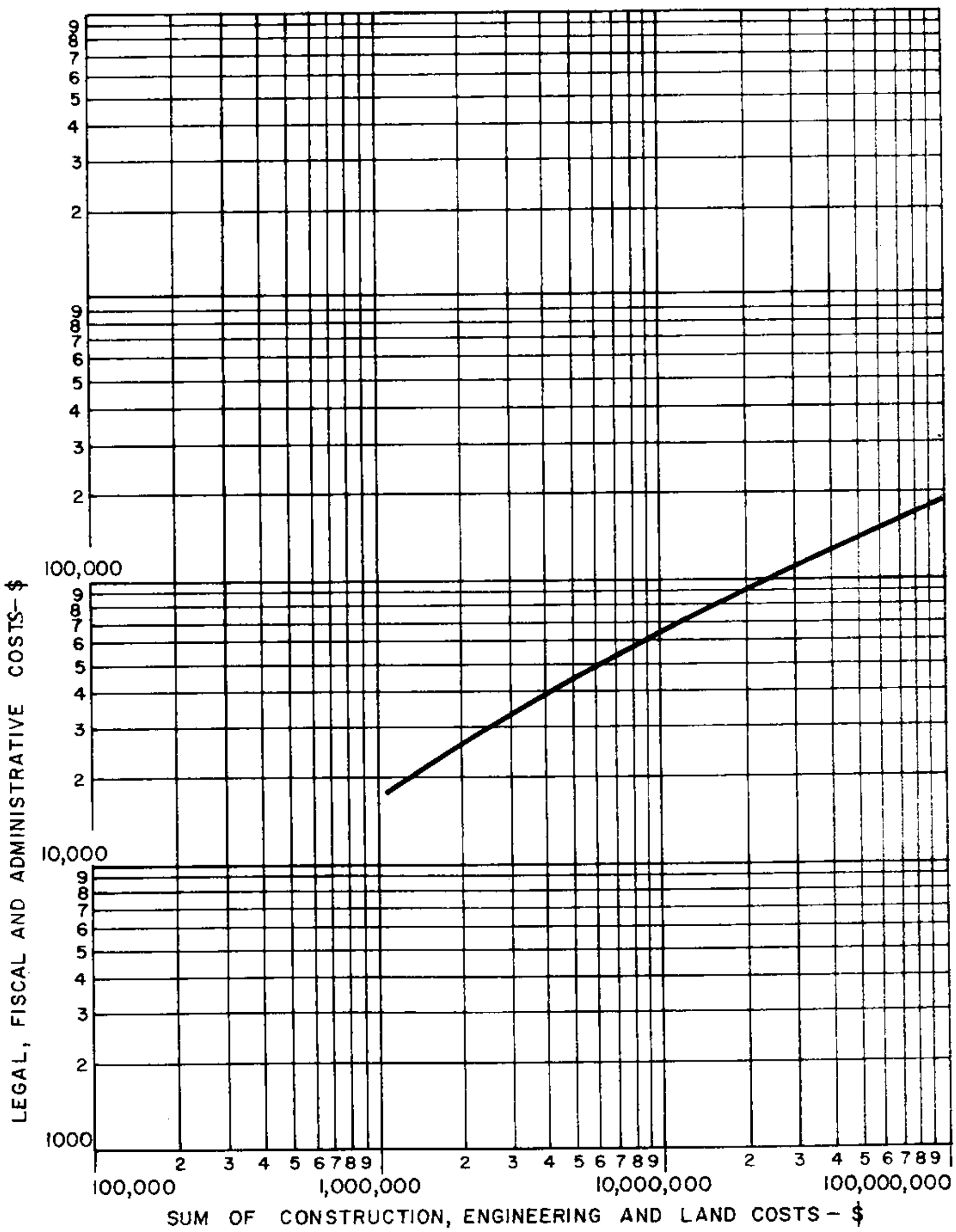


Figure 71. Legal, fiscal, and administrative costs for projects greater than $1 million.

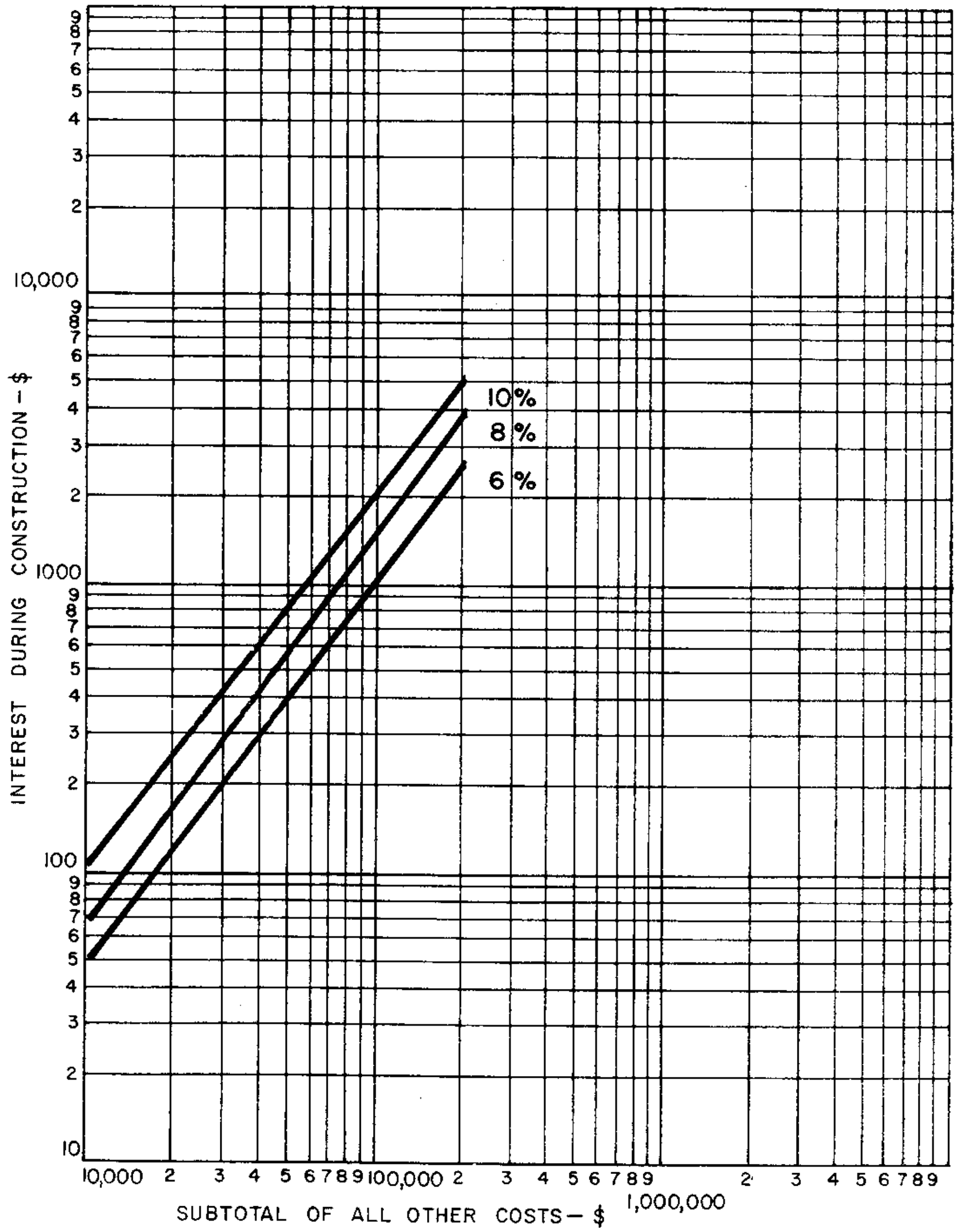


Figure 72. Interest during construction for projects less than $200,000.

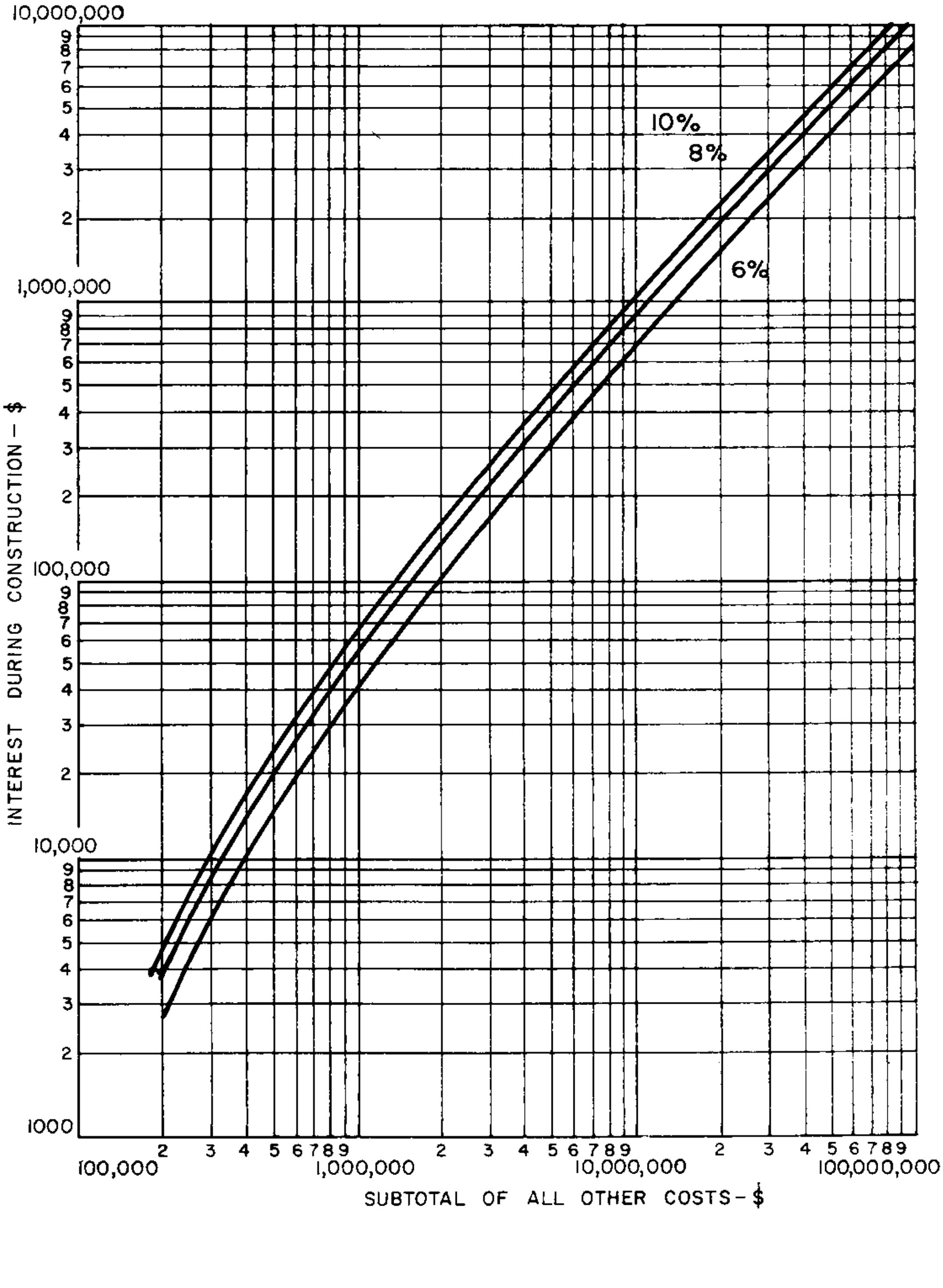


Figure 73. Interest during construction for projects greater than $200,000.

Table 71

Annual Cost for A 350-gpm Package Complete Treatment Plant

Item	Total Annual Costs
Amortized Capital @ 7%, 20 yr	$40,100
Labor, 3,254 hr @ $10/hr (Total Labor Costs Including Fringes and Benefits)	32,540
Electricity, 233,017 kw-hr @ $0.03	6,990
Fuel, 155 gal @ $0.45	70
Maintenance Material	1,850
Chemicals, Alum, 11 tons/yr @ $70/ton Polymer, 274 lb/yr @ $2/lb Chlorine, 1.6 tons/yr @ $300/ton	1,810
TOTAL ANNUAL COST*	83,360

$$\text{*Cents/1,000 gal treated} = \frac{\$83,360/\text{yr } (100)}{352.8 \times 365} = 64.73¢/1,000 \text{ gal treated}$$

electrical rates, and natural gas rates. The variables used in Table 71 are representative of U.S. averages, but they may vary significantly among geographical areas.

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16. ABSTRACT

This report discusses unit processes and combinations of unit processes that are capable of removing contaminants included in the National Interim Primary Drinking Water Regulations. Construction and operation and maintenance cost curves are presented for 99 unit processes that are considered to be especially applicable to contaminant removal. The report is divided into four volumes. Volume 1 is a summary volume. Volume 2 presents cost curves applicable to large water supply systems with treatment capacities between 1 and 200 mgd, as well as information on virus and asbestos removal. Volume 3 includes cost curves applicable to flows of 2,500 gpd to 1 mgd. And Volume 4 is a computer program user's manual for the curves included in the report. For each unit process included in this report, conceptual designs were formulated, and construction costs were then developed using the conceptual designs. The construction cost curves were checked for accuracy by a second consulting engineering firm, Zurheide-Herrmann, Inc., using cost-estimating techniques similar to those used by general contractors in preparing their bids. Operation and maintenance requirements were determined individually for three categories: Energy, maintenance material, and labor. Energy requirements for the building and the process are presented separately. Costs are in October 1978 dollars.

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