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Research and Development

# Package Water Treatment Plants

## Volume 2. A Cost Evaluation

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# PACKAGE WATER TREATMENT PLANTS

## Volume 2. A Cost Evaluation

by

Richard G. Stevie
Robert M. Clark

Drinking Water Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

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Project Officer

Robert M. Clark
Drinking Water Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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# FOREWORD

The 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 interplay among its components require a concentrated and integrated attack on the problem.

Research and development is that 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 (1) to prevent, treat, and manage wastewater, solid and hazardous waste, and pollutant discharges from municipal and community sources, (2) to preserve and treat public drinking water supplies, and (3) to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is a product of that research and is a most vital communications link between the researcher and the user community.

One of the major problems facing the U. S. Environmental Protection Agency in meeting the requirements of the Safe Drinking Water Act is helping small and rural water systems in achieving compliance. This report presents results from a study on the cost and performance characteristics of self-contained package water treatment plants. These data should be useful in assisting small and rural systems in providing high quality drinking water.

Francis T. Mayo,
Director
Municipal Environmental Research
Laboratory

## ABSTRACT

Many small and rural water systems have both cost and quality problems. Their unit costs tend to be higher because of the small number of connections they service. As shown by the Community Water Supply Survey of 1969, many small systems have trouble meeting minimal drinking water standards. These problems are likely to be compounded in the future as drinking water standards are raised. The cost of building a conventional water treatment plant to provide higher quality water for a small community may be prohibitive. A possible alternative to a conventional water treatment plant is a package water treatment plant. These plants are self-contained units that can be installed for minimum cost.

Results from a study of 36 package plants in Kentucky, West Virginia, and Tennessee show that treatment plants can provide water that meets the turbidity requirement of the National Interim Primary Drinking Water Standards. However, as with all treatment plants, proper operation is required. These plants, contrary to some manufacturers' claims, are not totally automatic but require supervision. Nevertheless, when properly maintained and operated, they can provide water that meets the Safe Drinking Water Act's MCLs at a cost less than that associated with conventional treatment.

The results of this study indicate two aspects. Scale economies exist in package treatment plants under 1 mgd. The average flow rate for the municipal systems in this study was found to be slightly less than 0.2 mgd, implying that the average plant will be able to achieve the scale economies that potentially exist with this technology.

Therefore, based on this study, it is felt that package plants can be used in a cost effective manner to meet the turbidity requirements of the Safe Drinking Water Act, and still not impose an enormous burden on the utility's budget.

This report (Volume 2) present the results of a cost evaluation study for package water treatment plants. Volume 1 discusses the performance of package plants with minimal cost evaluation.

This report was submitted in fulfillment of Contract GS-05S-10458. This report covers the period June 1977 to June 1979, and work was completed as of June 1979.

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## TABLES

## METRIC CONVERSION TABLE

| English Units | Metric Equivalents |
|---|---|
| 1 foot | 0.305 meters |
| 1 mile | 1.61 kilometers |
| 1 sq mi | 2.59 sq kilometers |
| 1 mil gal | 3.79 thou cu meters |
| 1 $/mil gal | 0.26 $/thou cu meters |

## ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of the following individuals: Dr. Gary Logsdon, Messrs. Walter Feige, Daniel Guttman, Jeffrey Adams, and Michael Laugle of the Drinking Water Research Division, Municipal Environmental Research Laboratory, USEPA, and Mr. Carl Schneider of PEDCO, Incorporated, Cincinnati, Ohio.

The authors would like to extend a special acknowledgement to Mr. Larry Gray and and Mr. Steve Cordle for their encouragement and support throughout all phases of this study.

INTRODUCTION

Many studies have attempted to evaluate the costs associated with conventional water treatment plant design and operation.[1,2,3] Evidence from these studies indicates that significant economies of scale exist in construction as well as in day-to-day operation. The large expenditures required to construct and maintain such a treatment system can place an immense burden on small water utilities. Package water treatment plants have been suggested as an alternative to conventional technologies, but little is known about their costs and performance. This report evaluates the cost-effectiveness of operating package treatment plants. It is hoped that the information provided in this report will aid water utility managers.

The following section contains a description of the data collected during the study and a discussion of cost allocation procedures utilized. In additional sections: a descriptive analysis of the data is provided; empirical methodology is presented, which involves identifying the relationships to be estimated; factors affecting the cost of water supply are identified; empirical results are presented and interpreted; and, a comparative analysis of conventional and package treatment plant technologies is made.

# PACKAGE PLANT DATA ANALYSIS

## PACKAGE PLANTS

Package water treatment plants are prefabricated treatment systems requiring minimal on-site construction. Necessary installation procedures involve assembly of prefabricated parts, a hook-up to an existing pipe network, and the construction of a building to house the plant. Table 1 lists the types of plants visited, and Table 2 specifies their location.

The package plants studied were categorized as being either municipal or recreational in nature. Municipal plants generally serve a stable population and are operated year-round, while recreational plants serve a transient population and tend to be operated sporadically.

## COST AND QUALITY DATA

Data were collected in two major areas: quality and cost. Quality data reflect the capability of package plants to purify source water in order to meet drinking water standards. Cost data can be used to evaluate the cost effectiveness of this type of treatment technology.

Quality information gathered for both raw and finished water included alkalinity, hardness, pH, temperature, turbidity, coliforms, and inorganic chemicals. Information on other selected quality variables was also collected, such as the type of water source (ground, spring, free-flowing surface, or impounded surface), level of nitrate, fluoride, free chlorine residual, and trihalomethanes; and the input concentration of certain chemicals: alum, polyelectrolyte, soda ash, and lime. Based on quality data, the ability to meet the drinking water standards can be determined. Appendix A, Tables A-1 and A-2, list the quality data for both municipal and recreational plants.

Cost and operational information was collected on numerous aspects of individual package plants as well as for the utility as a whole. Data forms used in the study are contained in Appendix B. Utility costs were separated into four major components: acquisition, treatment, distribution, and support services. The first three represent functional areas related to the physical operation of the plant. Acquisition includes all operating and capital (depreciation plus interest) costs incurred in collecting water for delivery to the treatment plant. Treatment costs include operating and capital costs associated with the purification of source water by the package plant, and distribution expenditures involve

Table 1. TYPES OF PLANTS STUDIED

| Sites | Manufacturer | Model | Capacity |
|---|---|---|---|
| 5 | Neptune Microfloc | WB-27 | 20 gpm |
| 1 | Permutit | | 48 gpm |
| 6 | Neptune Microfloc | SB-82 | 60 gpm |
| 1 | Intermountain Systems | 60TS/PF-IF | 60 gpm |
| 3 | Neptune Microfloc | WB-133 | 100 gpm |
| 7 | Neptune Microfloc | AQ-40 | 200 gpm |
| 1 | Hungerford & Terry | L-28 | 200 gpm |
| 1 | Permutit | | 200 gpm |
| 5 | Neptune Microfloc | AQ-70 | 350 gpm |
| 3 | Neptune Microfloc | AQ-112 | 560 gpm |
| 2 | Neptune Microfloc | AQ-180 | 900 gpm |
| 1 | Neptune Microfloc | Concrete | 1000 gpm |

Table 2. LOCATIONS OF PLANTS STUDIED

I. MUNICIPAL PLANTS

Alderson, W. Va.
Anawalt, W. Va.
Bonde Croft Utility District, Sparta, Tenn.
Carrollton Utilities, Carrollton, Ky.
Coal River PSD, Racine, W. Va.
Franklin, W. Va.
Greenup, Ky.
Hambrick PSD, Hendricks, W. Va.
Marrowbone Plant, Regina, Ky.
Mountain Top PSD, Mount Storm, W. Va.
Mowbray Utility Dist., Soddy Daisy, Tenn.
Nettie-Levisay PSD, Nettie, W. Va.
Preston County PSD, Reedsville, W. Va.
Richwood, W. Va.
Russell Springs, Ky.
Stanton, Ky.
Thomas, W. Va.
Union, W. Va.
Winfield, W. Va.

II. RECREATIONAL PLANTS

Apple Valley Resort, Jamestown, Ky. (private)
Big Bone State Park, Union, Ky. (state)
Canaan Valley State Park, Davis, W. Va. (state)
Carr Fork Lake, Irishman Creek Rec. Area, Sassafras, Ky. (USCE)*
Dewey Lake, Prestonburg, Ky. (USCE)
East Lynn Lake, East Fork Rec. Area, East Lynn, W. Va. (USCE)
East Lynn Lake, Utility Bldg., East Lynn, W. Va. (USCE)
Fishtrap Lake, Shelbiana, Ky. (SCE)
Green River Reservoir, Holmes Bend Rec. Area, Campbellsville, Ky. (USCE)
J. Percy Priest Reservoir, Cook Rec. Area, Nashville, Tenn. (USCE)
J. Percy Priest Reservoir, Fate Sanders Rec. Area, Nashville, Tenn. (USCE)
J. Percy Priest Reservoir, Poole Knobs Rec. Area, Nashville, Tenn. (USCE)
J. Percy Priest Reservoir, Seven Points Rec. Area, Nashville, Tenn. (USCE)
Natural Bridge State Park, Slade, Ky. (state)
Norris Dam State Park, Norris, Tenn. (state)
Smith County Rest Area (Interstate 40, Tenn. (state)
Snowshoe Ski Resort, Slaty Fork, W. Va. (private)

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*USCE stands for U. S. Army Corps of Engineers.

all costs incurred in delivery of the finished or treated drinking water to the consumer. The fourth component, support services, is related to the overall utility management function. Support service costs include activities, such as billing, supervision, accounting, and general items, not directly related to any of the other three components. In addition, subelement operating costs (chemical, payroll, and power) were collected for each component. These are isolated for analysis as to their individual impact on operating expenditures as well as their productive input into the operation of a utility. In general, the data collected in this study had to be allocated to each component, since the original cost records do not conform to this categorization. In many cases, this allocation was based upon a proportion suggested by the utility manager.

Package water treatment plant costs were also collected according to the four major categories. As with the total utility costs each catagory was subdivided into chemical, payroll, and power costs. Capital costs were categorized according to installation, building, and the package plant itself and also aggregated into total cost. Installation capital expense includes the depreciation and interest spent to make the plant operational; building capital expense involves the annualized construction cost of a building to house the package plant; and package plant capital is the annualized purchase price of the plant. Many of the utilities did not depreciate their facilities, therefore, a depreciation schedule was constructed, based on a 20-yr life and a 5 percent interest rate. An interest rate of 5 percent was used to reflect histrocial costs not current or incremental costs. Appendix C tables C-1 and C-2 contains all information generated (-2 indicates missing data).

Not all of the utilities were established in the same year, and not every utility had current expenditures available. Therefore, capital and operating costs were adjusted to a common base, using regional consumer price indices, for 1977. The inflation factors for each utility are listed in Table C-3. Cost figures in tables C-1 and C-2 have already been adjusted for inflation.

## DESCRIPTIVE ANALYSIS OF DATA

In this section a descriptive analysis of the collected data is performed at two levels. An aggregate analysis of data at the utility level has been made as well as a more detailed analysis of the package plants themselves.

### UTILITY DATA ANALYSIS

Figures 1, 2, and 3 show the relationship between O&M (operation and maintenance costs), depreciation, and interest expenses for municipal, recreational (which do not operate year-round), and the combined utilities. It is obvious that for these small utilities, having an average flow rate of .115 MGD (.195 MGD for municipal plants and 0.35 MGD for recreational plants when operating), capital cost is a very important factor.

Figures 4 to 6 show the allocation of operating cost to acquisition, treatment, transmission, and distribution based on the latest year of information. In general, acquisition costs are lowest, while treatment costs are highest. These costs result from the chemical, power, and labor costs associated with operating the treatment plant.

Figures 7 to 9 show the allocation of capital. Distribution capital expenditures are highest in municipal utilities, but treatment capital is highest in recreational utilities. Municipal utilities tend to have elaborate distribution systems with a larger number of service connections than do recreational systems. Figures 10 to 12 present average yearly expenditures for labor, chemicals and power. Labor cost is the predominant factor, ranging from 67% to 71% of the total cost of chemicals, power, and labor.

### PACKAGE TREATMENT PLANT DATA

The following analysis is directed toward the treatment function specifically. Figures 13 to 15 show the average operating and maintenance cost, depreciation, and interest for the treatment function. Capital dominates treatment costs. As might be expected, total treatment is more expensive for municipal than for recreational plants.

As shown in figures 16 to 18, the treatment capital costs have been subdivided into the average construction costs for the plant itself, the building to house the plant, and the installation cost. Housing is the greatest portion of capital cost, amounting to over 40% of the treatment plant construction cost. The purchase price of the prefabricated plant is significant, but the building to house the plant remains the most important cost item, and is also the factor which can be best controlled by the utility manager. If a utility were to construct the building itself, some costs might be cut from total treatment expenditures.

Figures 19 to 21 show the treatment, labor, chemical and power cost elements. Labor cost dominates, representing 50% to 65% of the total chemical, power, and payroll expense. Treatment labor expense comprises almost 50% of the total utility payroll. The degree of labor time apportioned to the treatment function can affect the level of quality. This is analyzed more closely in the empirical work to follow. In general, from the quality analysis, it was evident that with more time devoted to the operation of the treatment plant a higher quality of water was produced.

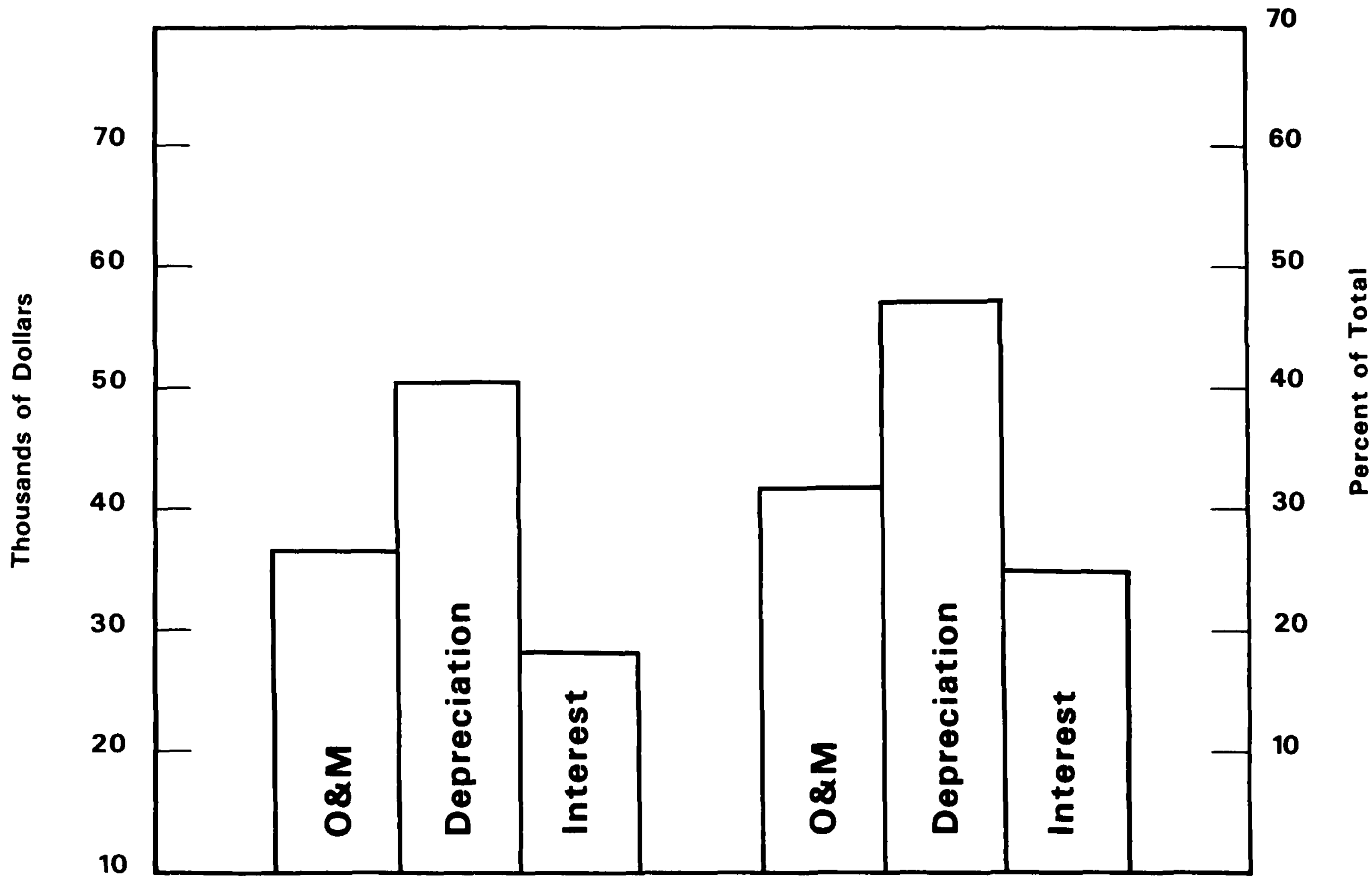


**Figure 1. Operating and Capital Costs for Municipal Utilities**

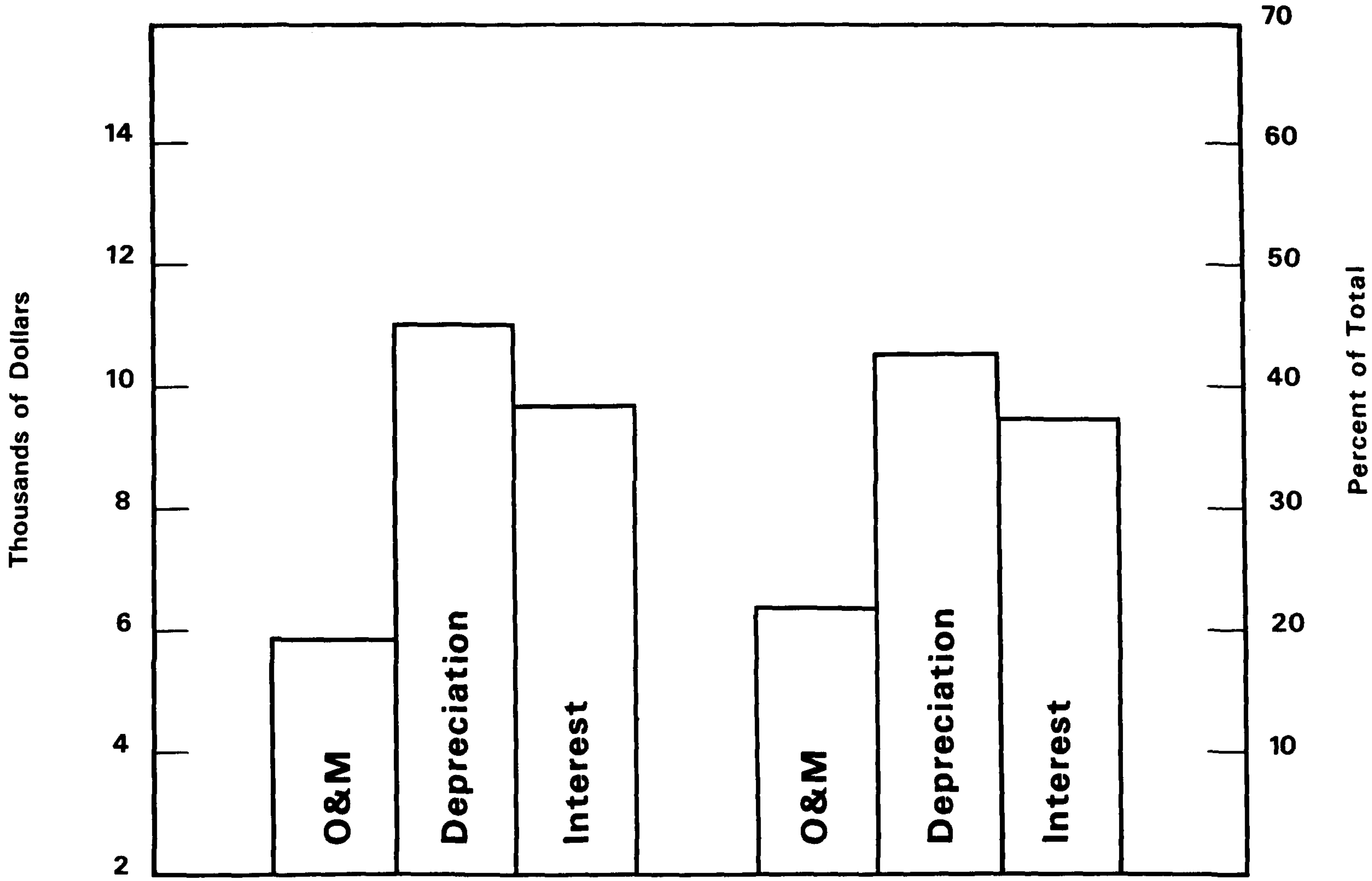


Figure 2. Operating and Capital Costs for Recreational Utilities

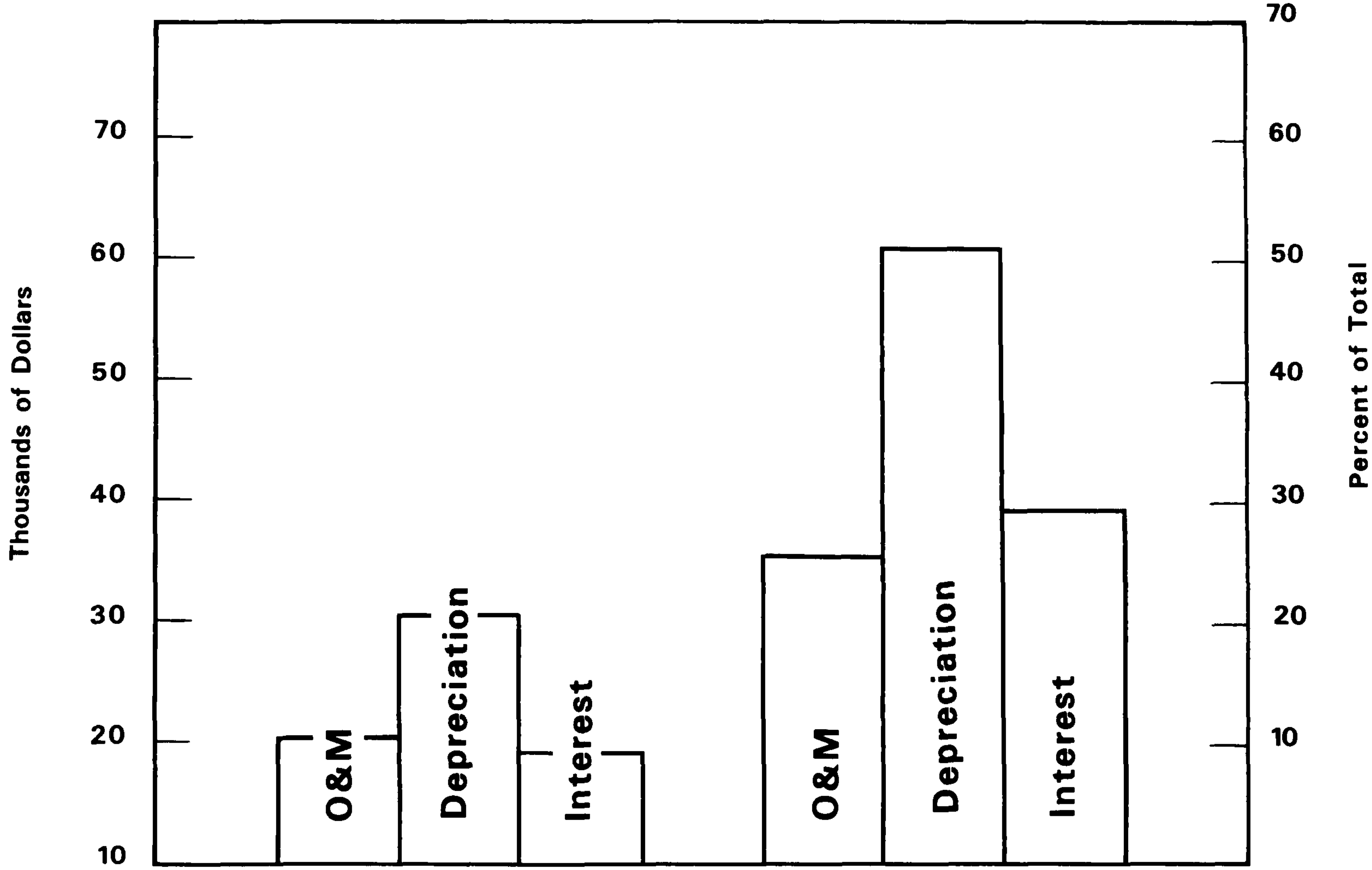


Figure 3. Operating and Capital Costs for Combined Data Set

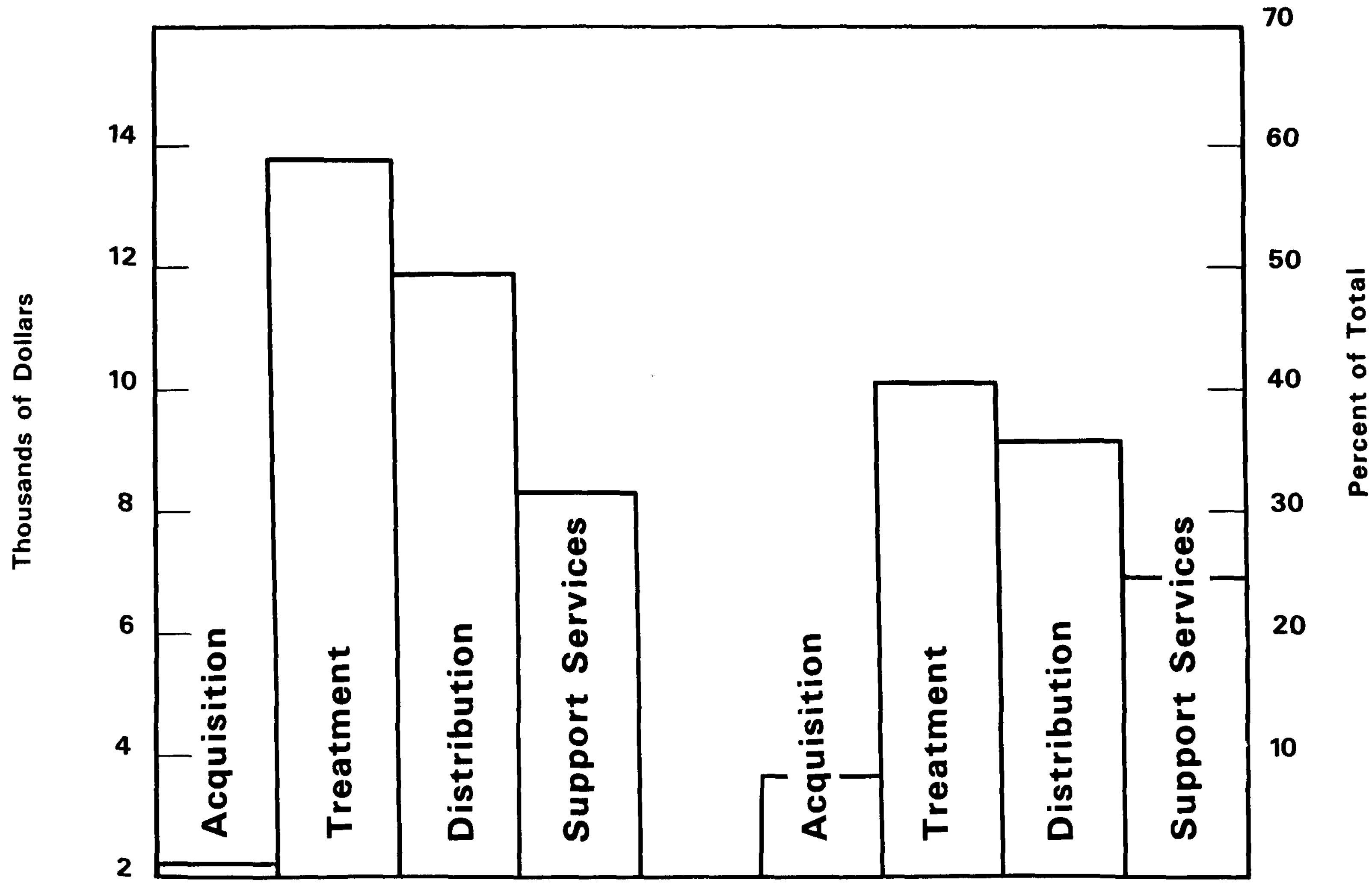


Figure 4. Operating Cost Functions for Municipal Utilities

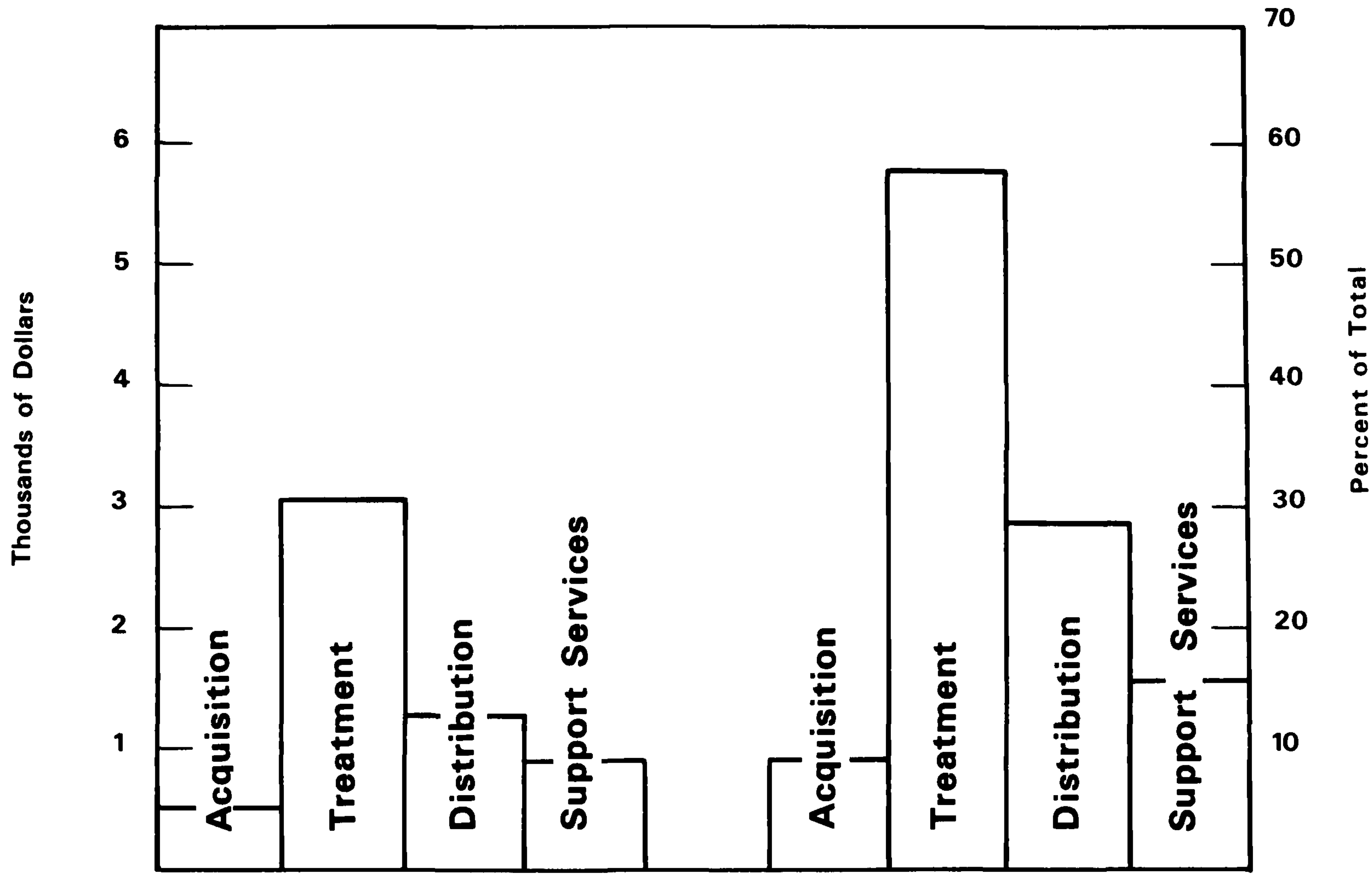


**Figure 5. Operating Cost Functions for Recreational Utilities**

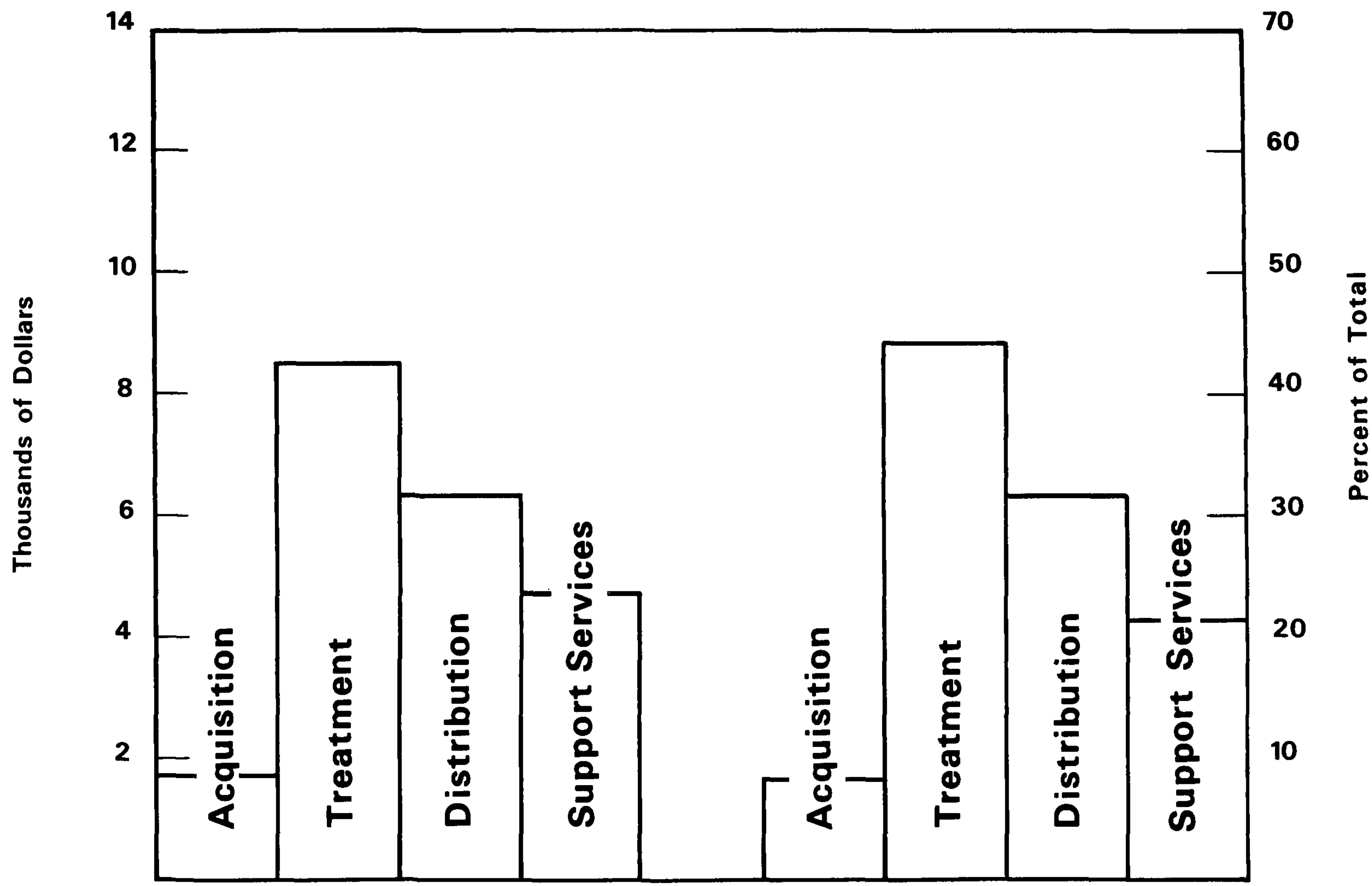


Figure 6. Operating Cost Functions for Combined Data Set

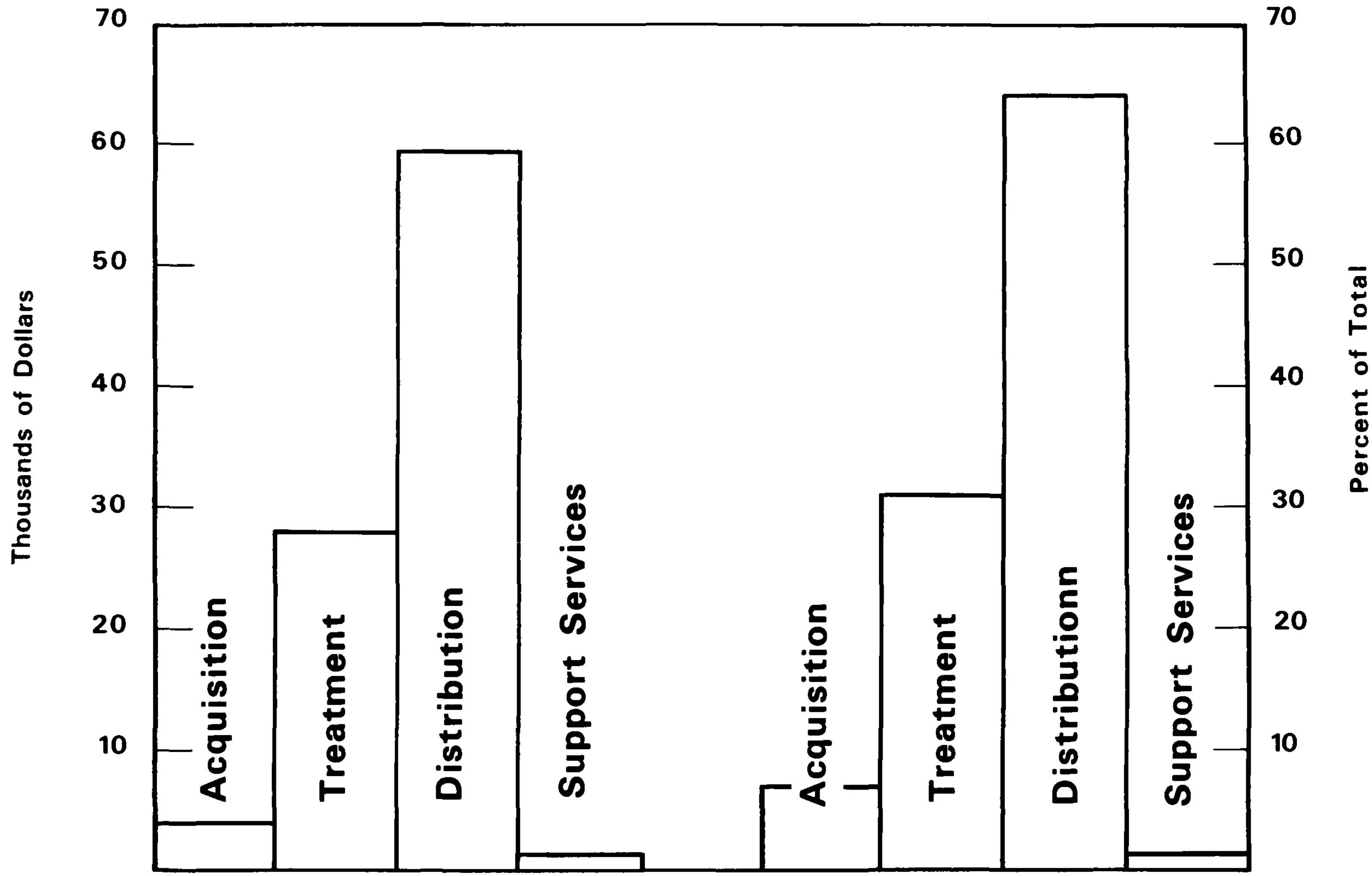


**Figure 7. Capital Cost Functions for Municipal Utilities**

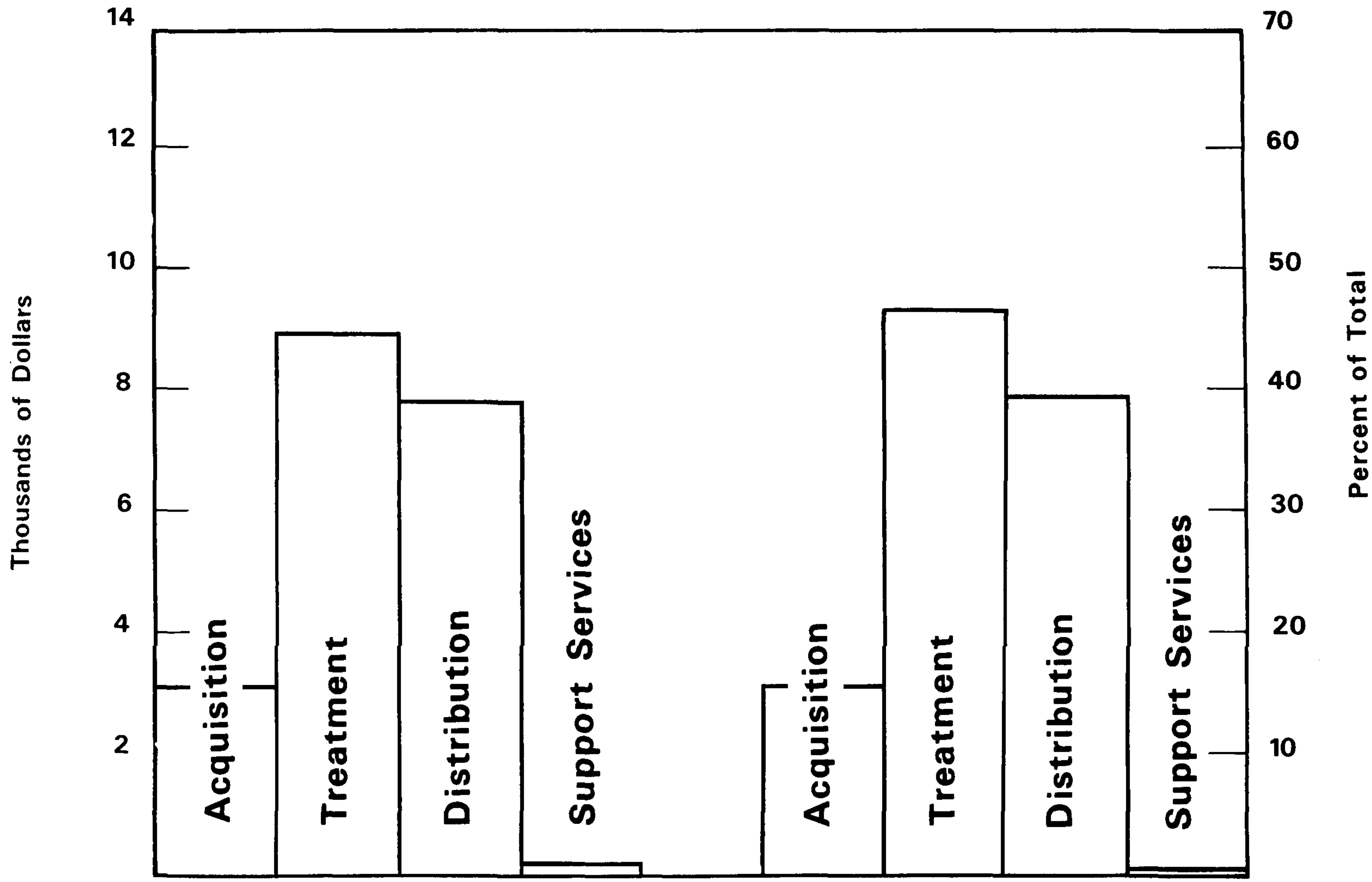


**Figure 8. Capital Cost Functions for Recreational Utilities**

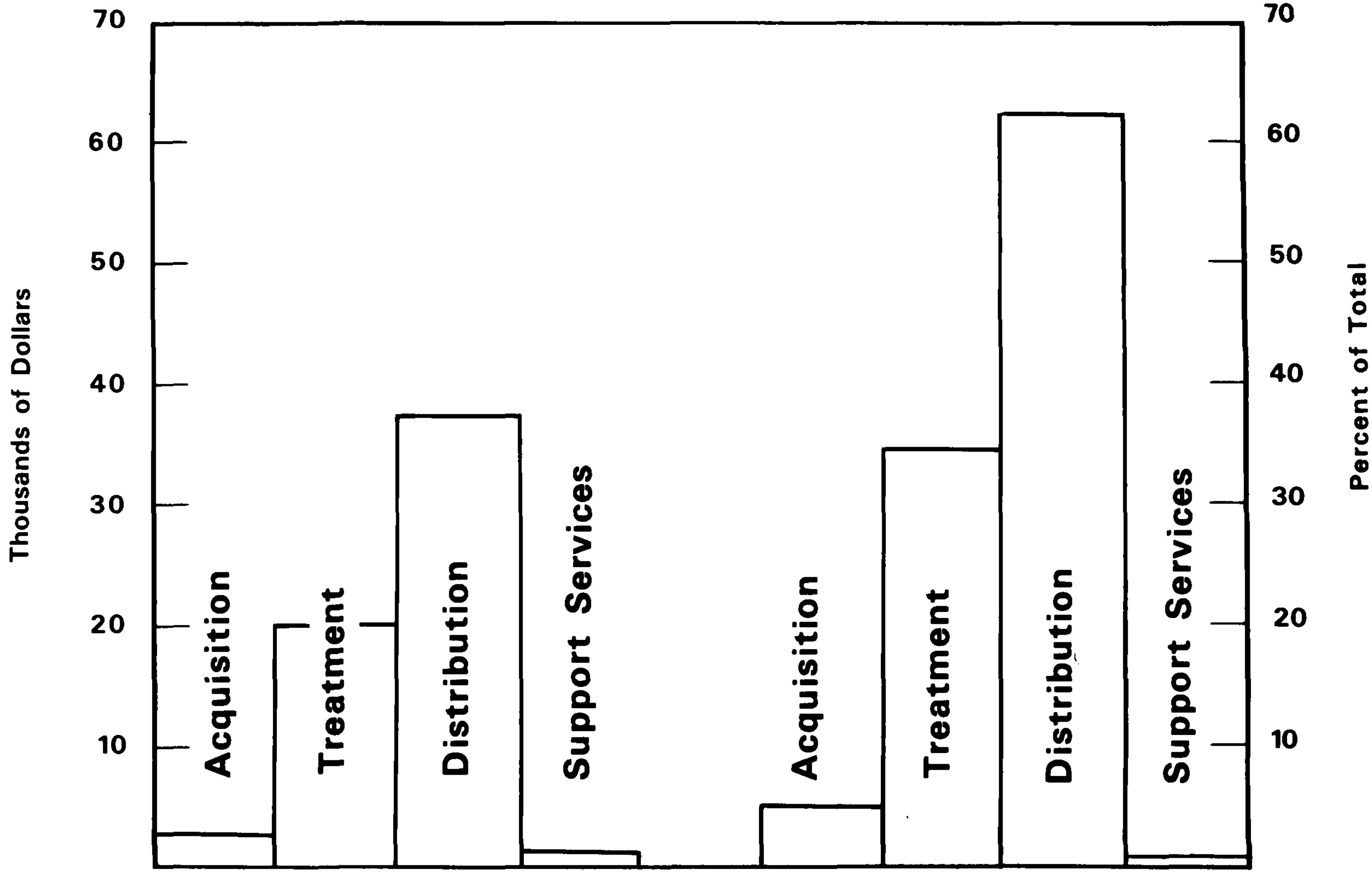


Figure 9. Capital Cost Functions for Combined Data Set

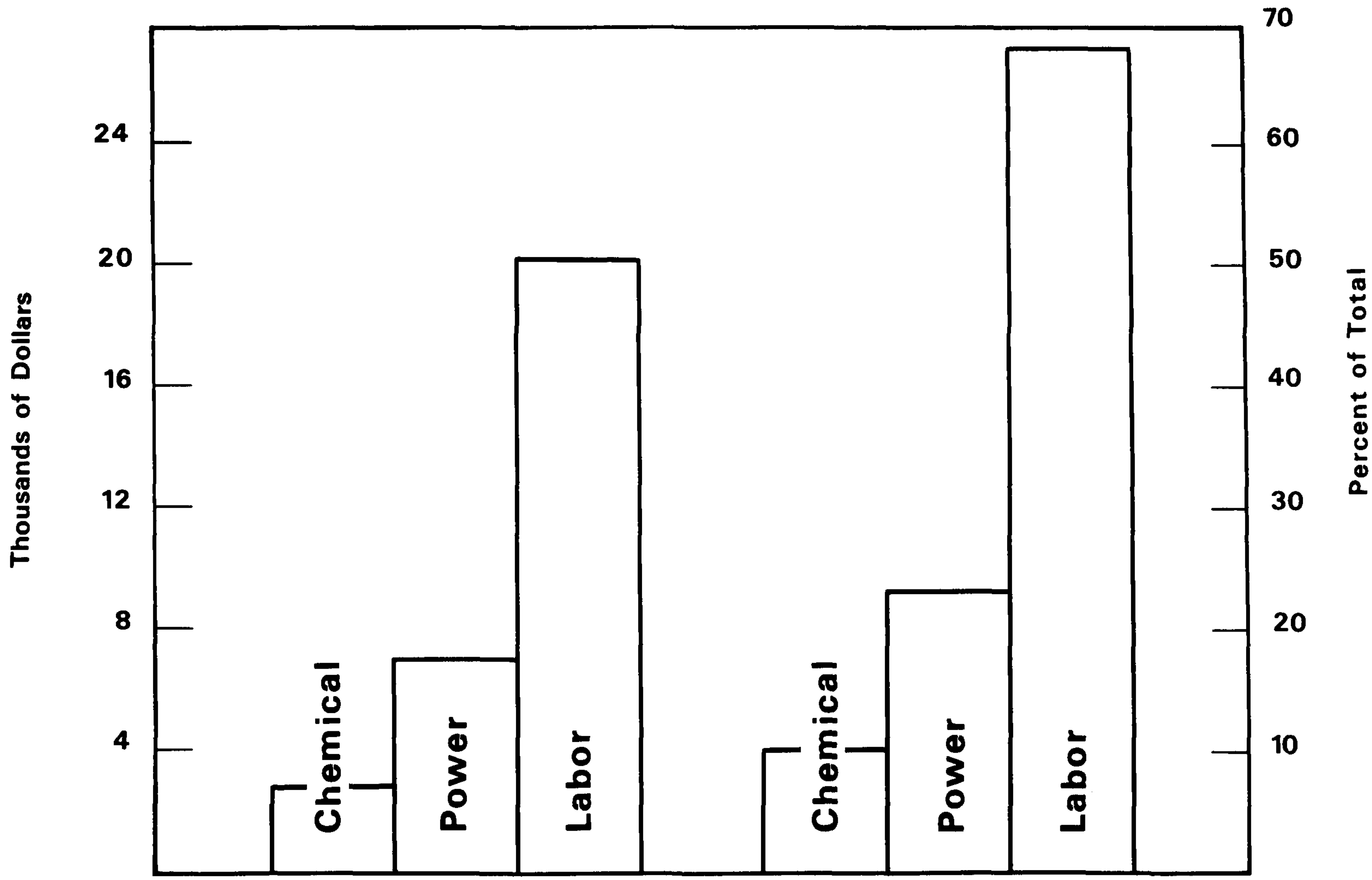


**Figure 10. Principle Operating Cost Components for Municipal Utilities**

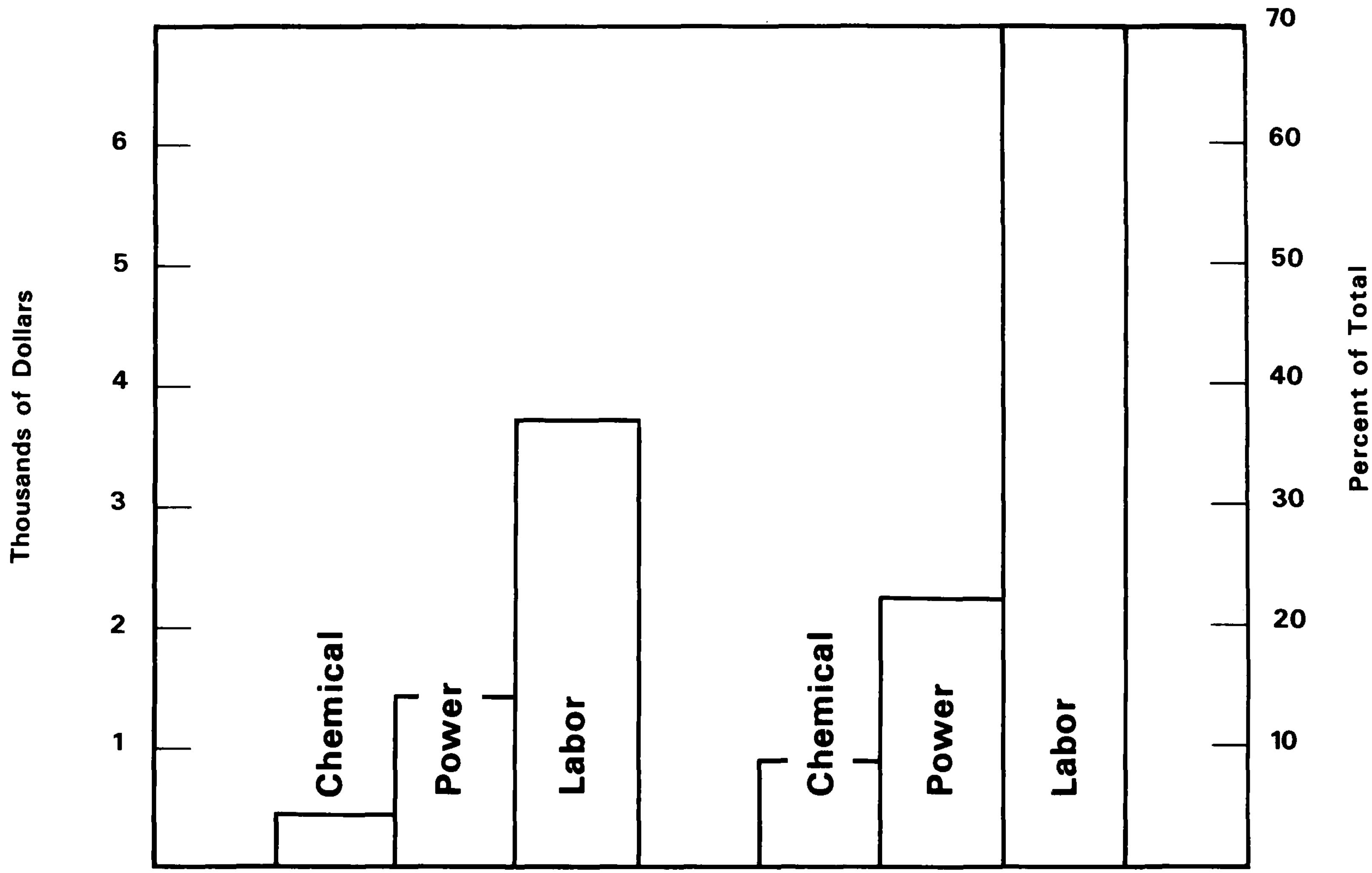


Figure 11. Principle Operating Cost Components for Recreational Utilities

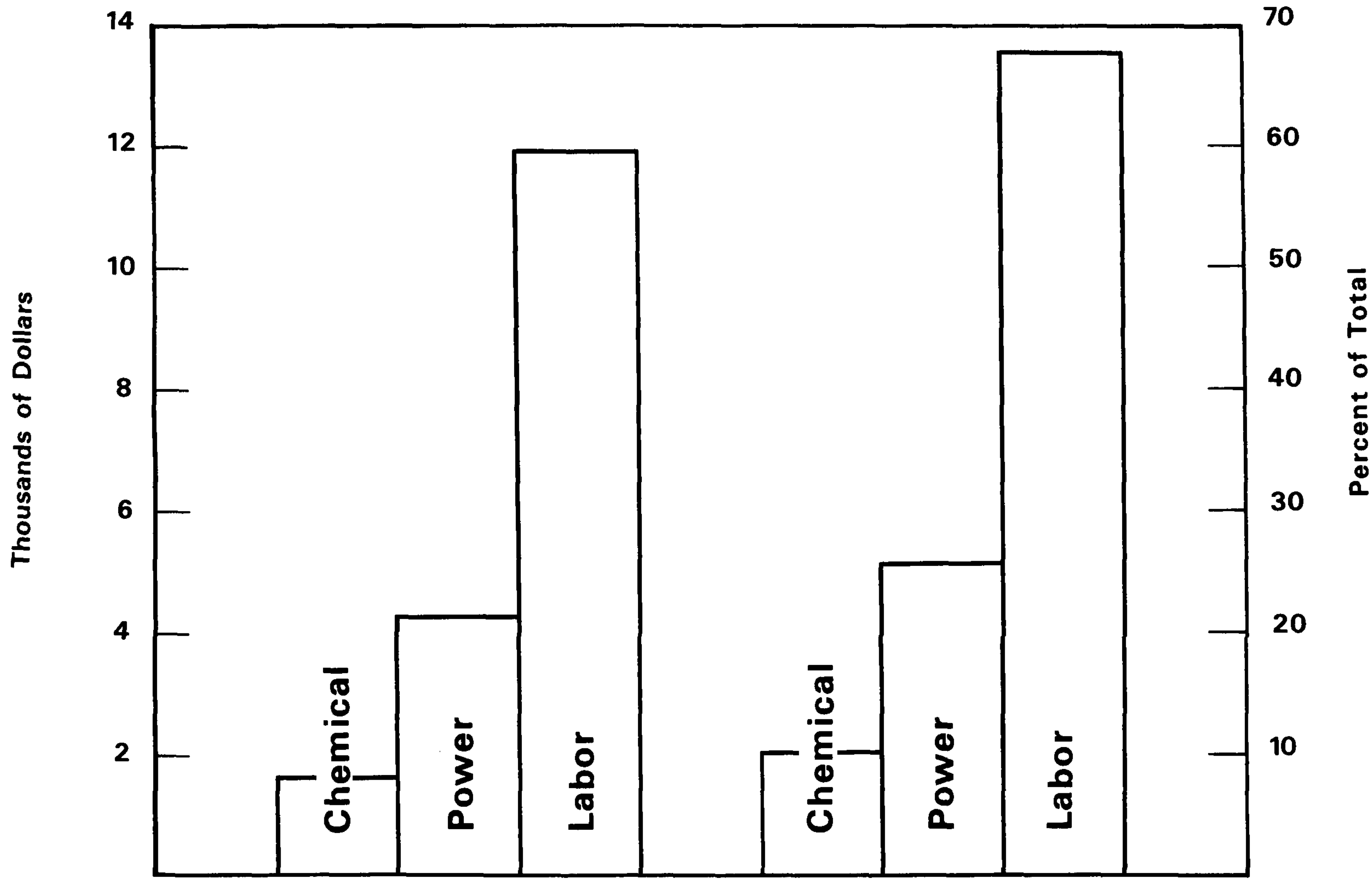


Figure 12. Principle Operating Cost Components for Combined Data Set

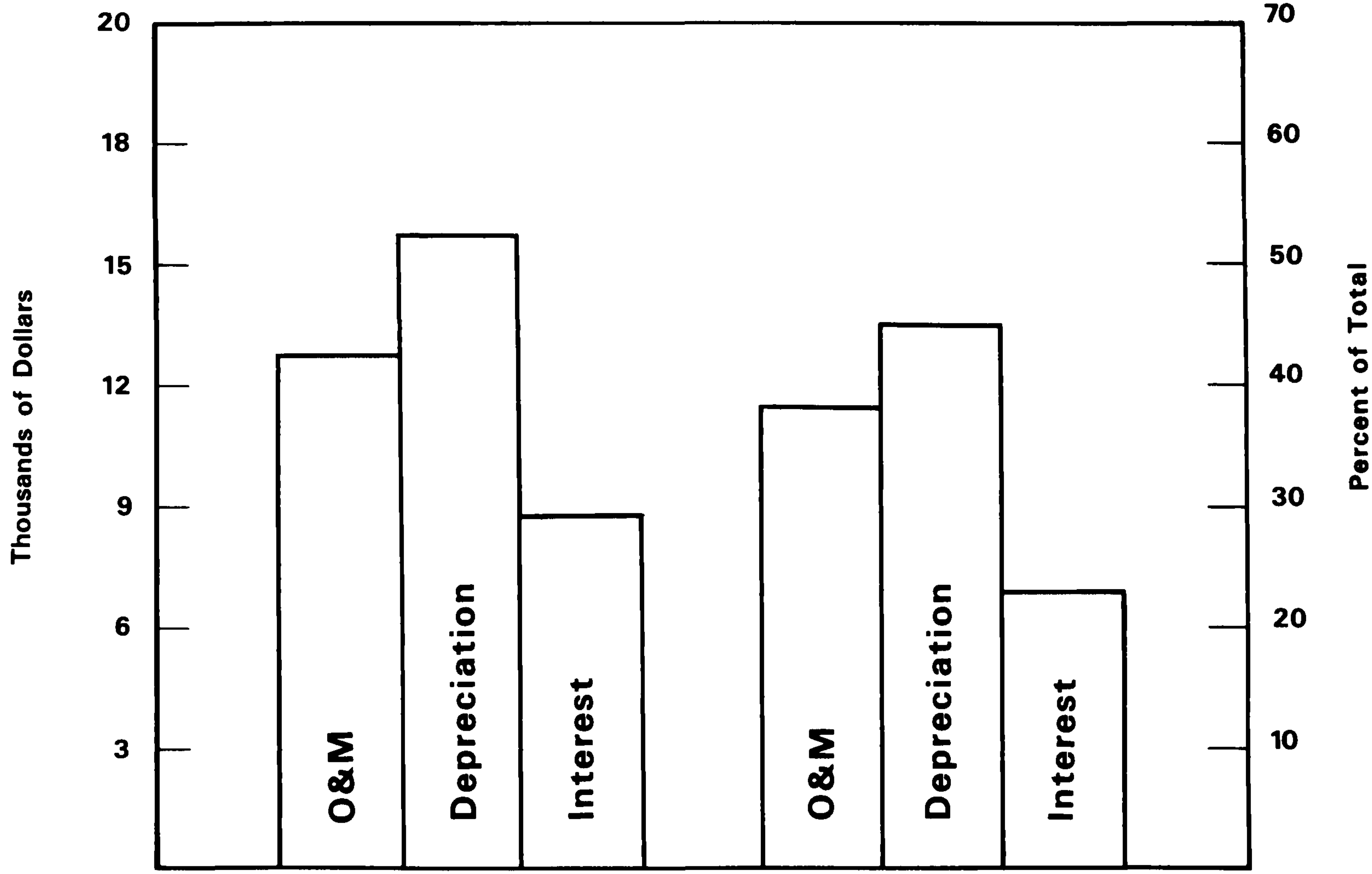


Figure 13. Municipal Package Plants Operating and Capital Cost

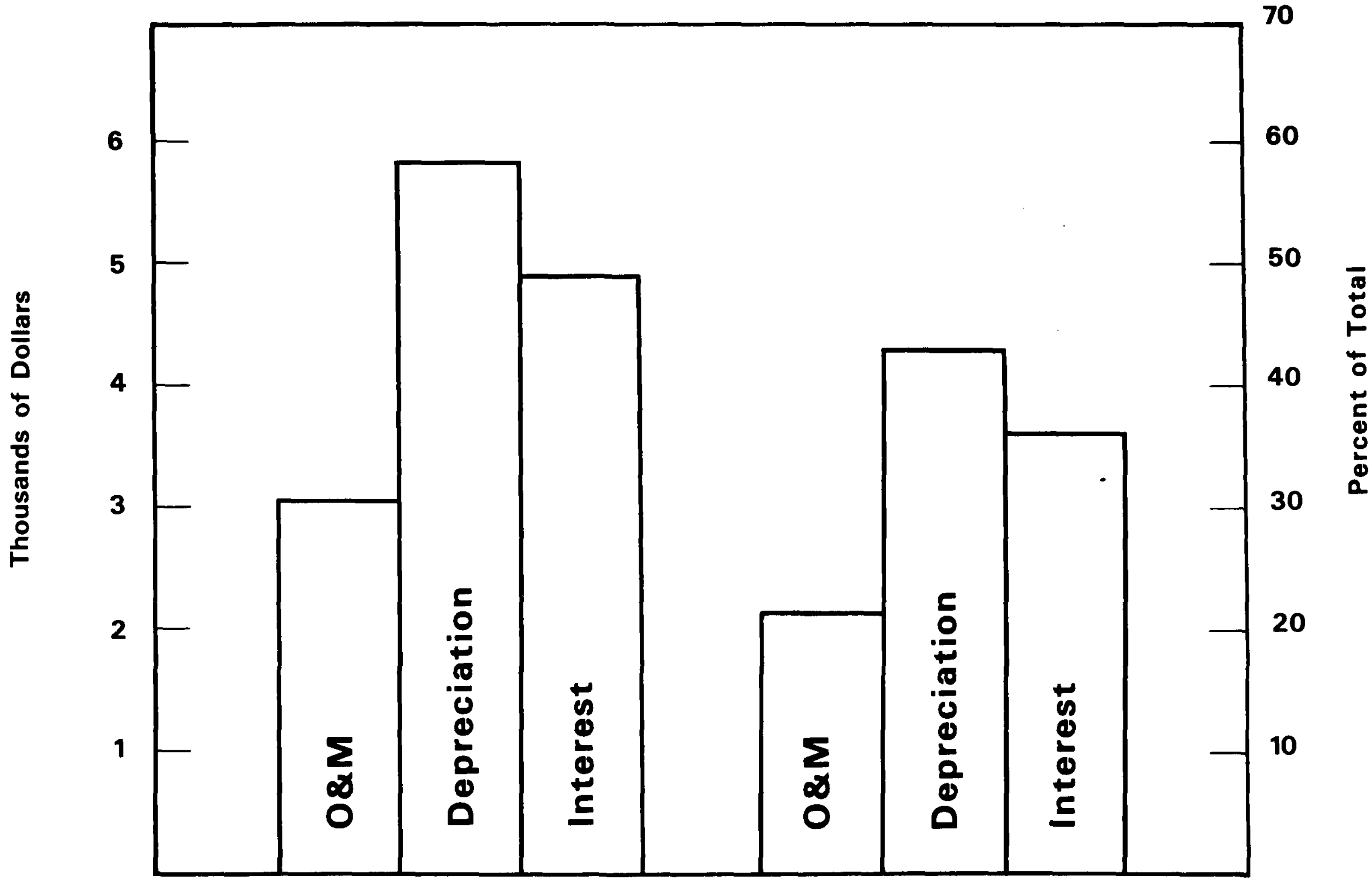


**Figure 14. Recreational Package Plants Operating and Capital Cost**

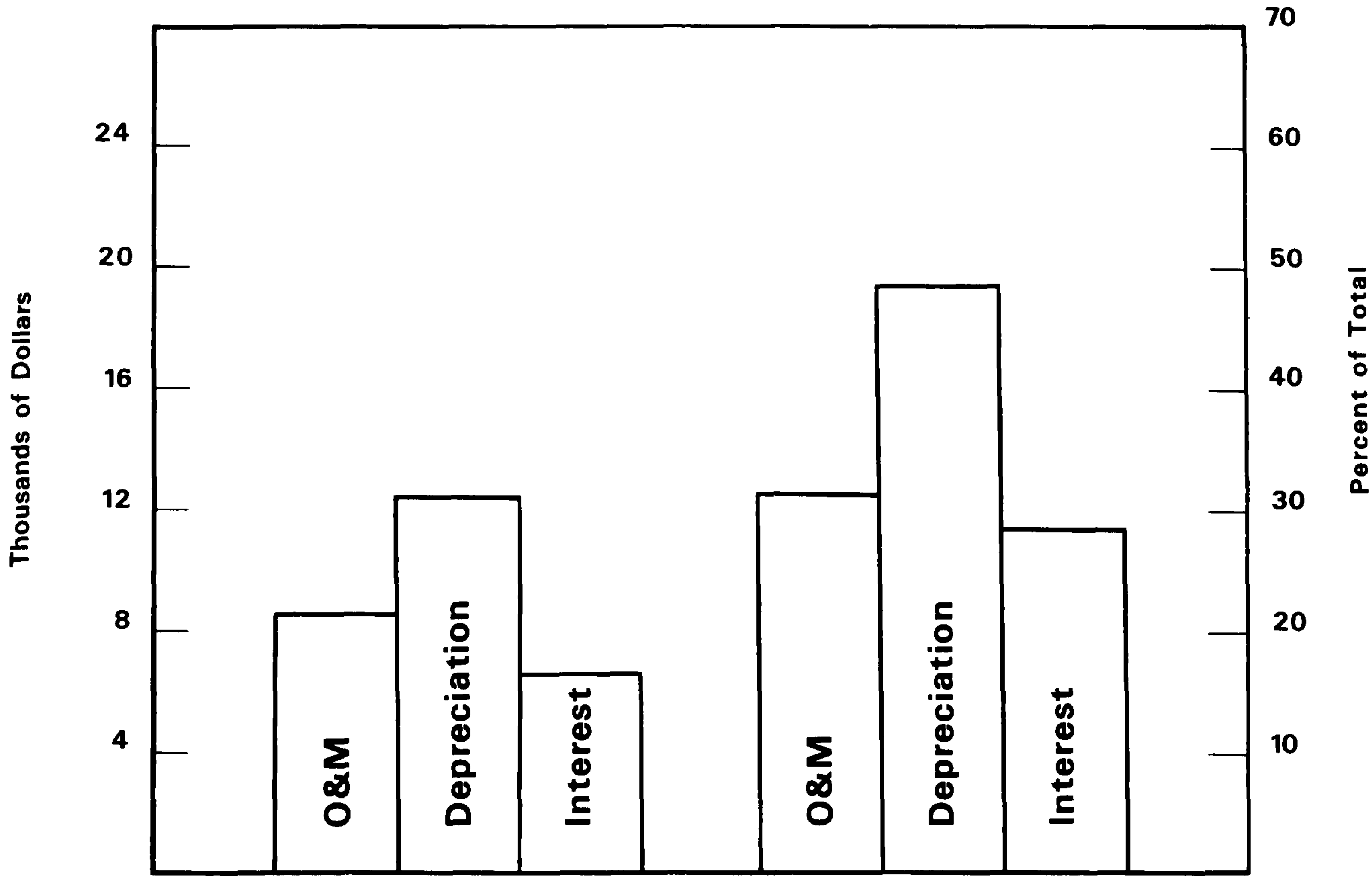


Figure 15. Combined Package Plants Operating and Capital Cost

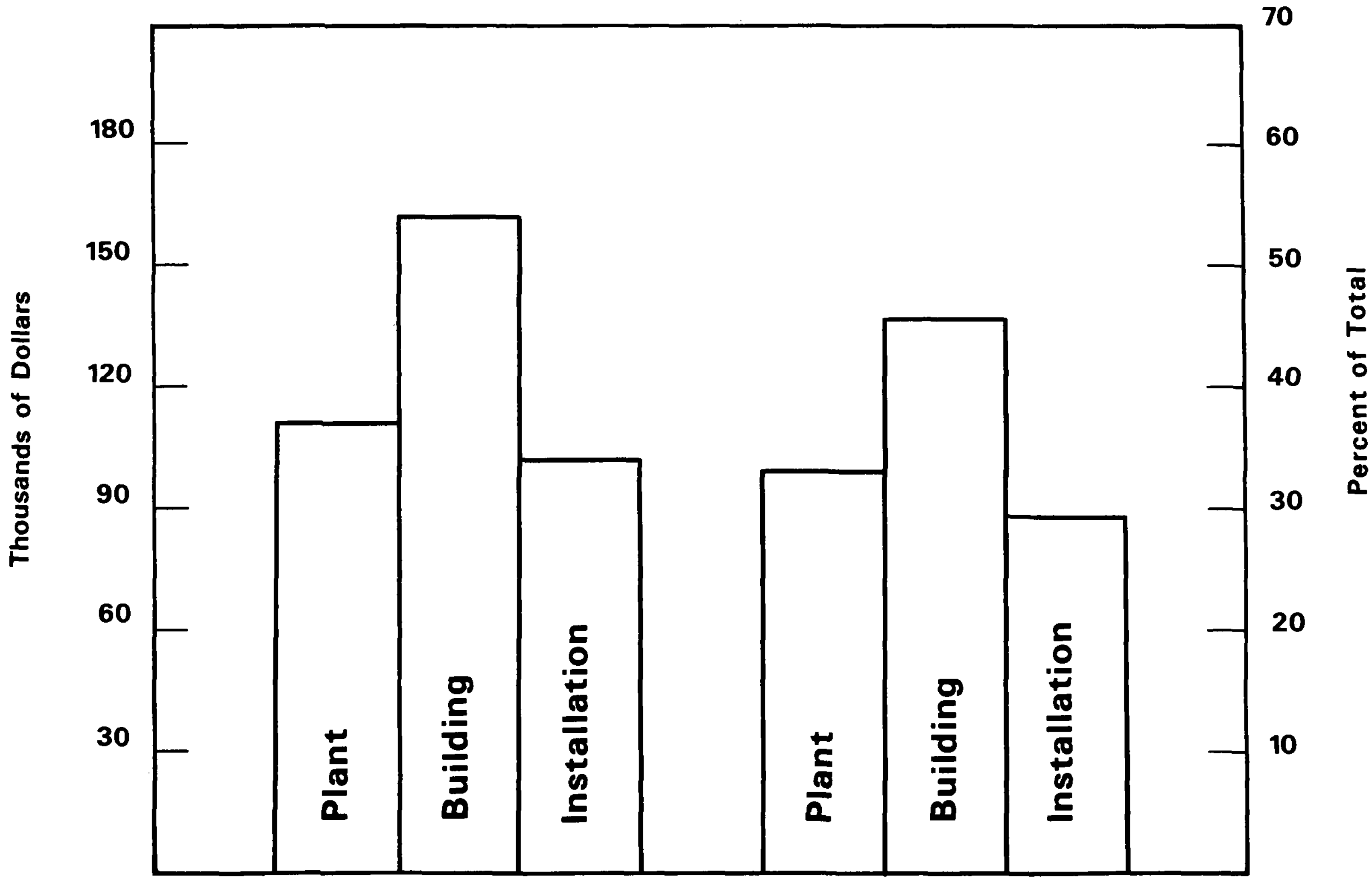


Figure 16. Municipal Package Plant Construction Cost Components

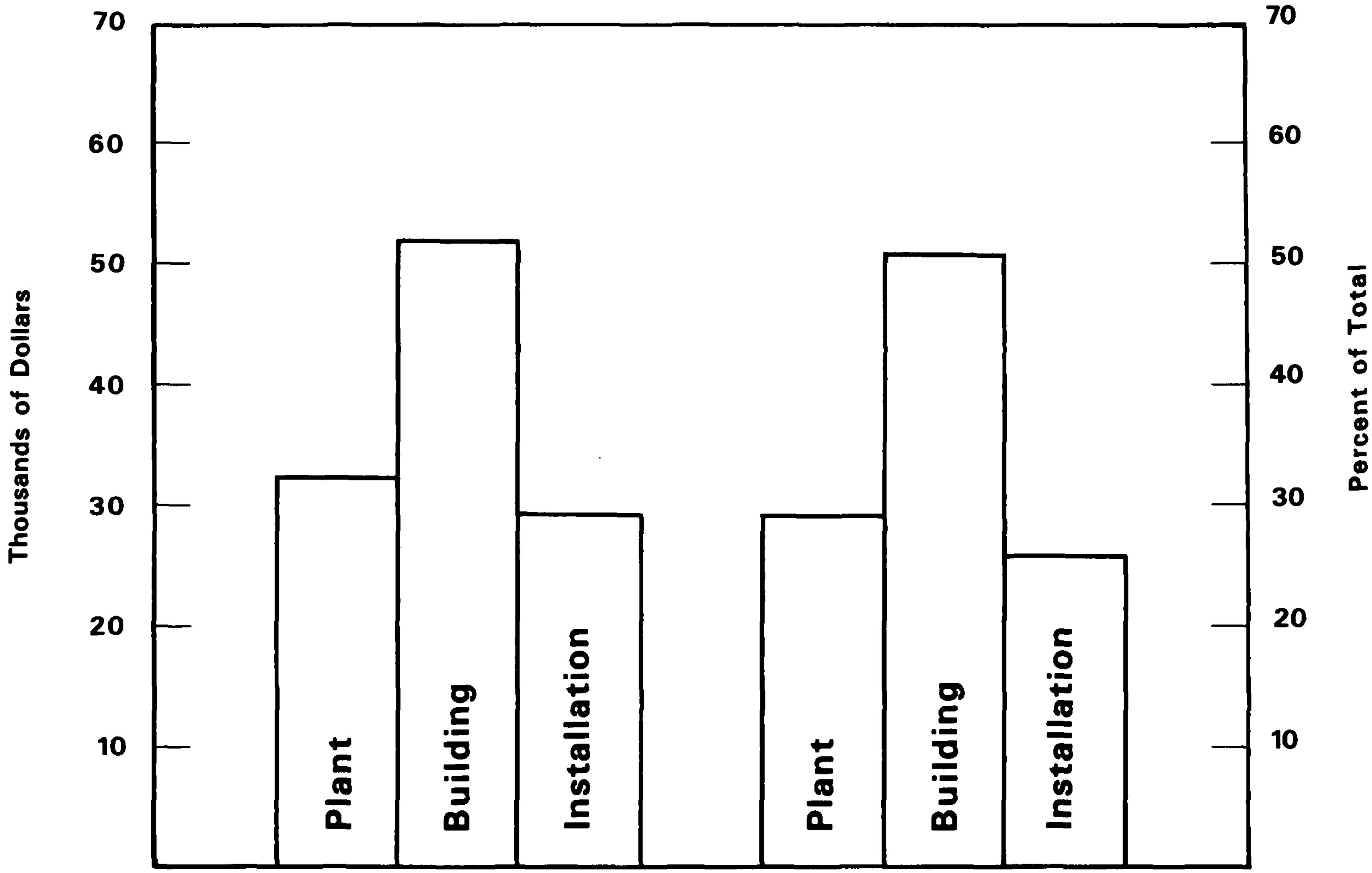


Figure 17. Recreational Package Plant Construction Cost Components

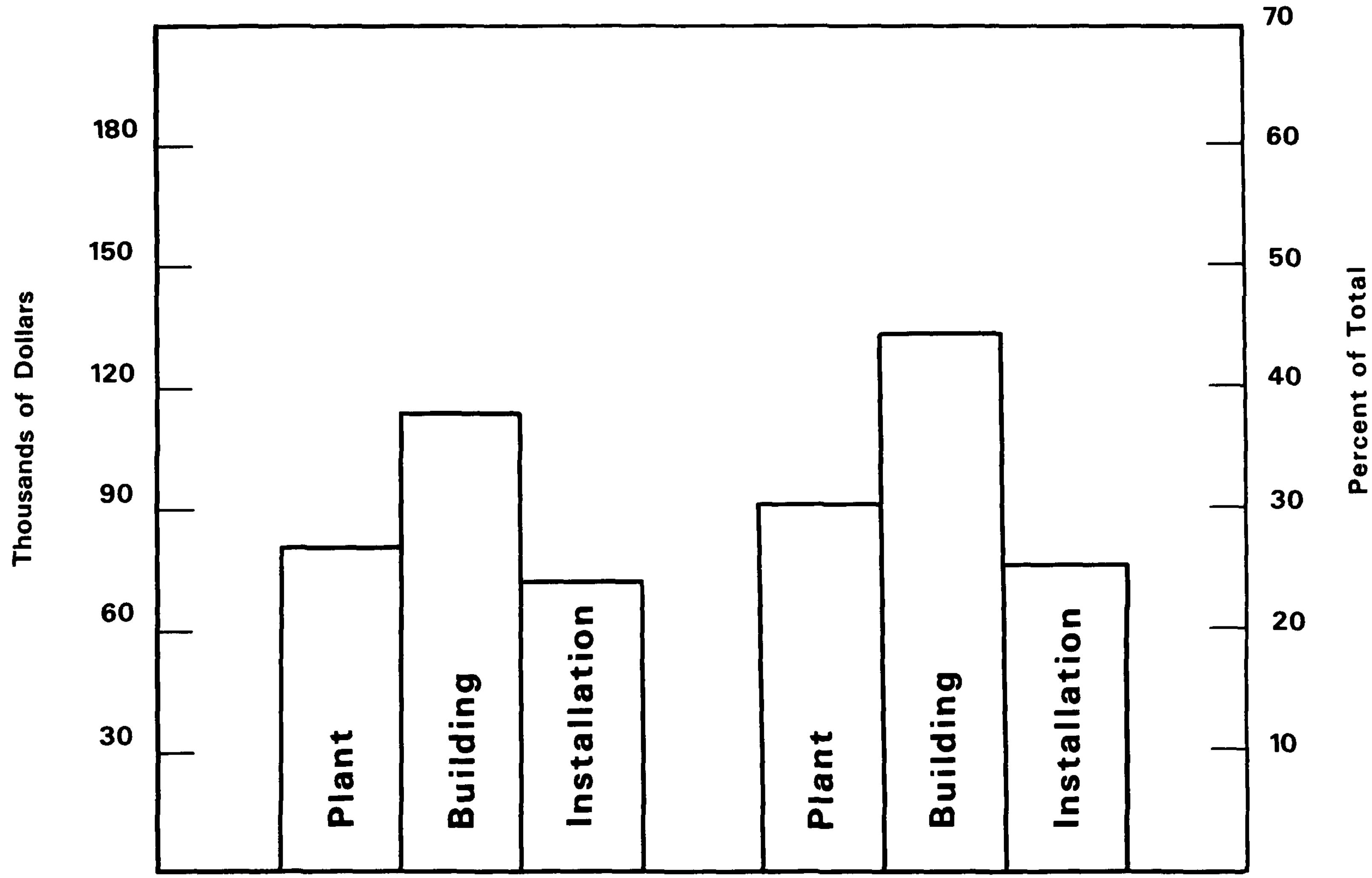


Figure 18— Combined Package Plant Construction Cost Components

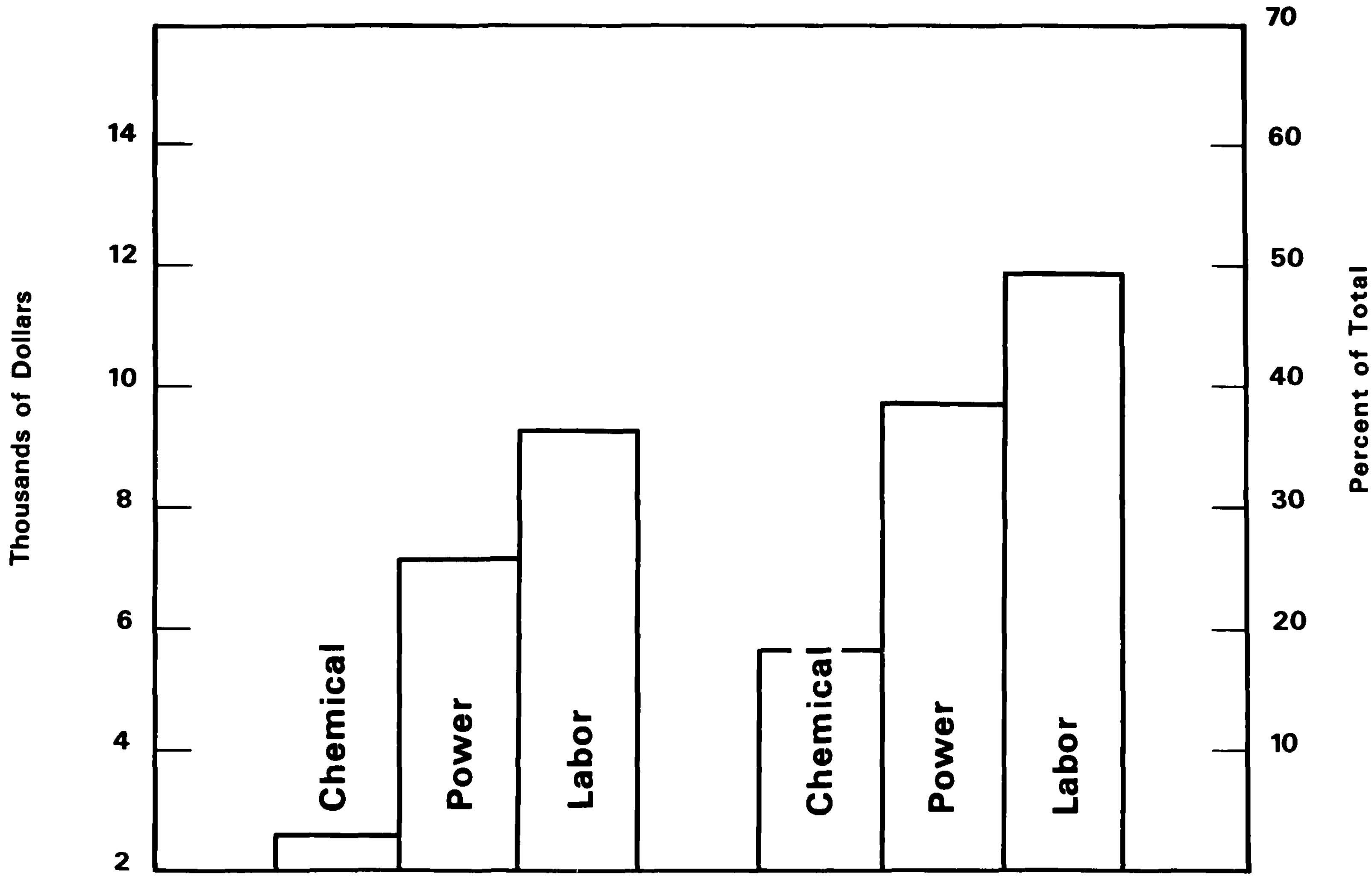


Figure 19. Municipal Package Plants Operating Cost Elements

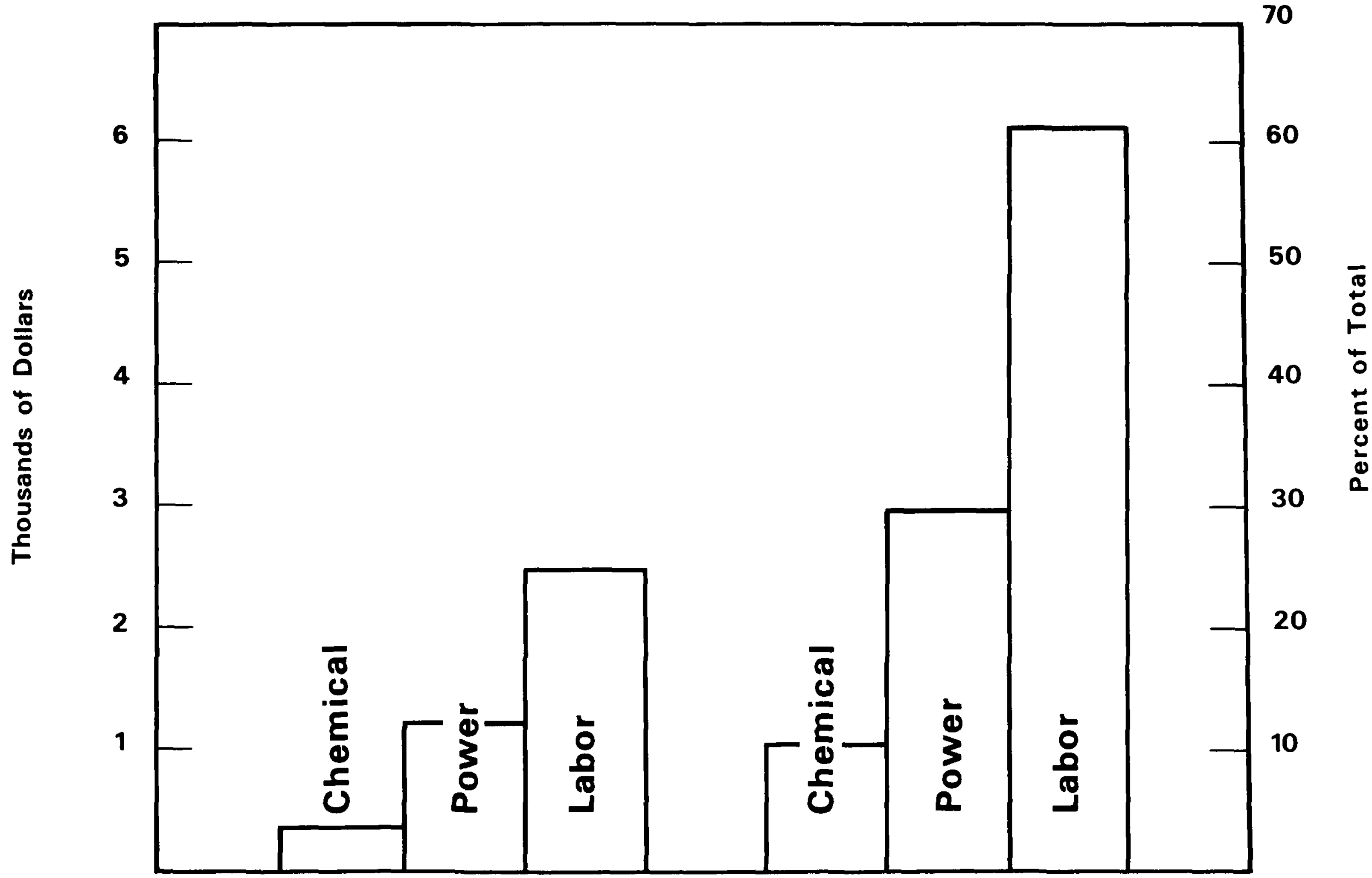


Figure 20. Recreational Package Treatment Plants Operating Cost Elements

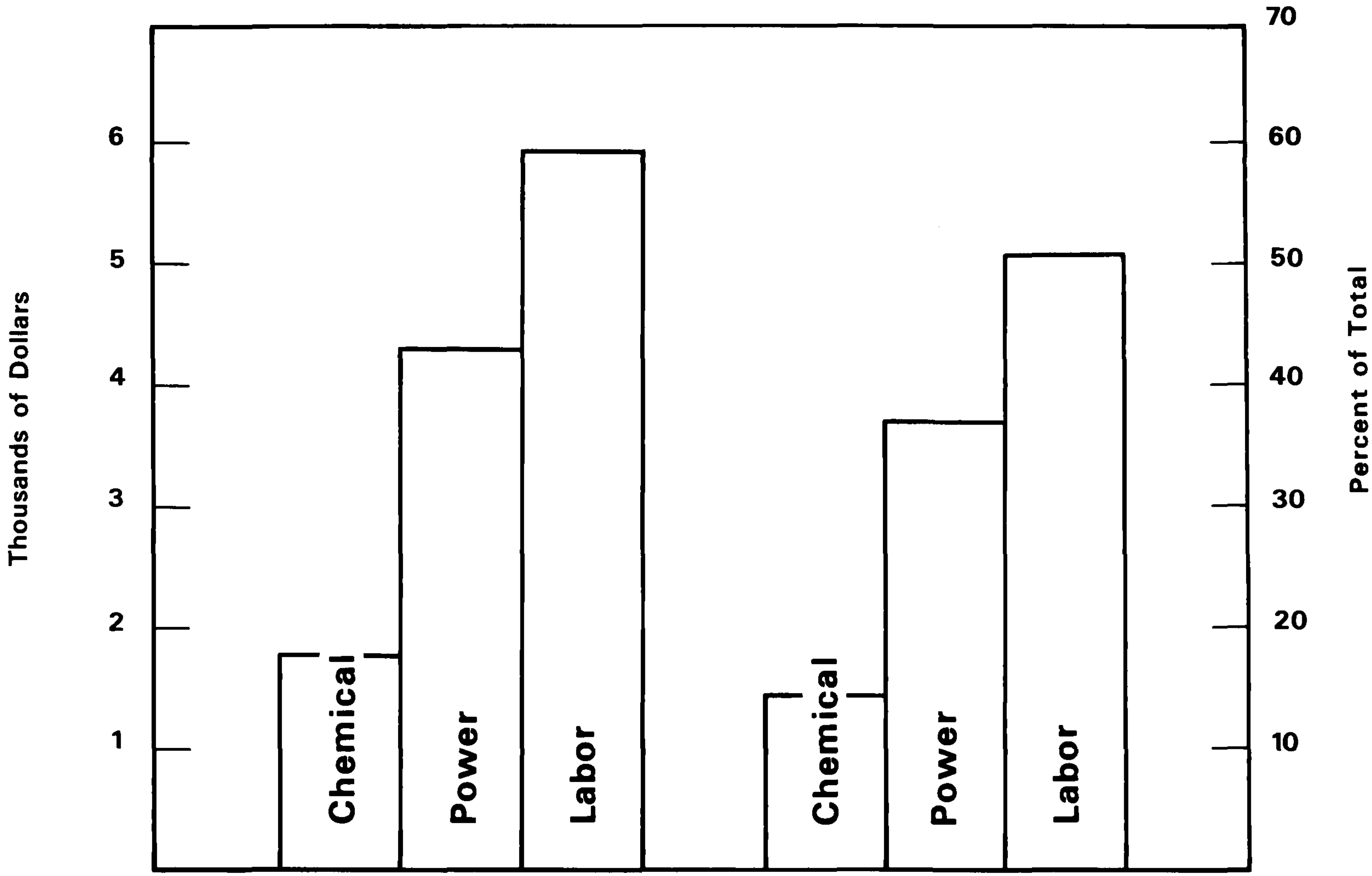


Figure 21. Combined Package Plant Operating Cost Elements

## EMPIRICAL METHODOLOGY

Many approaches have been used to examine the cost structure of an industry or firm. Two are discussed by Johnston[4] in his book on statistical estimation of cost functions. According to Johnston, cost curves can be analyzed on the basis of accounting records or through the use of key explanatory variables. Cost curve estimation based on accounting records reflects the production relationships involved. The use of explanatory variables attempts to provide information on the relation between cost and selected factors which theoretically affect cost. This study utilizes both approaches. Accounting data were collected from municipal and recreational water utilities which use package water treatment plants, but most empirical relationships developed in this report are for predictive as well as explanatory purposes.

### DISCUSSION OF METHODOLOGY

Major predictive relationships were developed to estimate costs based upon design capacity or flow in the form of a power function, as follows:

$$C = AQ^{b} \qquad (1)$$

where Q = design capacity or flow, million gallons/year;

C = total cost, \$/year;

b = cost elasticity; and

A = constant.

Separate equations were estimated for the municipal, recreational, and combined data sets. The combined data set does not necessarily reflect the actual proportion of municipal to recreational facilities in the population. But some indication of the general relationships in the total population can be determined from this data set. Results from the individual data sets are more applicable for some predictive purposes.

### PRODUCTION FUNCTIONS

Production function relationships cannot be explicitly estimated, because the usage of each input factor was not collected except for the chemical input ratios. Therefore, the general trade-off among inputs cannot be determined, but some indication of the substitutability among the inputs can be determined by examination of the costs. The following production function was hypothesized:

$$Q = f(L, P, Q, K) \tag{2}$$

where $L$ = labor units, man-hours;

$P$ = power units, kwh;

$K$ = design capacity, MG/yr;

$Q$ = revenue-producing water, MG/yr.

As a variant on equation 2, total cost can be expressed as:

$$TC = g(Q) = g^1 (L, P, C, K) \tag{3}$$

A linear form of equation 3 is as follows:

$$TC = A + wL + mP + nC + rK \tag{4}$$

where $TC$ = total cost in \$/yr;

$w$ = wage rate in \$/hr;

$m$ = unit power cost in \$/kwh;

$n$ = unit chemical cost in \$/lb;

$r$ = capital or capacity cost in \$/unit of capacity;

$A$ = constant.

Equation 4 represents the sum of each cost input. Multiplying both sides of equation 4 by $Q/Q = 1$ yields:

$$TC = \frac{wL}{Q} Q + \frac{mP}{Q} Q + \frac{nC}{Q} Q + \frac{rK}{Q} Q \tag{5}$$

Each of these ratios represents the unit costs of labor, power, chemicals, and capacity, and each contains the input ratios implicitly even though they cannot be evaluated separately. In addition, each term in equation 5 refers to the share of total expenditures incurred by that input. Because of the separable nature of the equations, estimates may be made on the individual segments and combined to create equation 5.

A multiplicative variant of equation 3 may also be formed as follows:

$$TC = B(L^1)^{\alpha}(P^1)^{\beta}(C^1)^{\gamma}(K^1)^{\delta}Q^{\eta} \qquad (6)$$

where $L^1 = \frac{wL}{Q}$

$P^1 = \frac{mP}{Q}$

$C^1 = \frac{nC}{Q}$

$K^1 = \frac{rK}{Q}$

$B$ = constant

$\alpha$, $\beta$, $\gamma$, $\delta$, $\eta$, = cost elasticities

Equation 6 combines all of the relevant inputs into one equation for ease of estimation. Empirical analysis of equation 6 will yield information on the existence of scale economies and substitutability of inputs.

Chemical Cost Relationships

The relationship between finished water quality and chemical costs is of particular interest. Using the approaches discussed earlier, it is possible to formulate a chemical cost equation as follows:

$$CH = \eta\ (A, PL, S, LM, Q) \qquad (7)$$

where CH = total chemical cost, \$/year;

A = alum, mg/L;

PL = polyelectrolyte, mg/L;

S = soda ash, mg/L;

LM = lime, mg/L; and

Q = revenue-producing water, million liters/yr.

Equation 7 expresses chemical cost as a function of its input.

A more appropriate method for evaluating raw water quality would be to examine the relation of chemical costs and total treatment cost to selected dummy variables.

For example:

$$CH = f\ (Q, X\phi) \qquad (8)$$

where $X\phi$ = (0 for unprotected raw water source
(1 for protected raw water source

An unprotected source is defined as free-flowing or impounded surface water while a protected source is ground or spring water.

# EMPIRICAL RESULTS

This section provides the empirical estimates of the relationships discussed previously. Results, categorized into three segments, are reported for each data set: municipal, recreational, and combined. The first segment presents the results for predictive relationships, while the second segment provides empirical results for the production equations.

## PREDICTIVE RELATIONSHIPS

Individual cost equations for each component of the entire water utility -- acquisition, treatment, distribution, and support services -- were estimated as a function of revenue/producing water. The O&M equations are presented for each data set in Table 3. For treatment and total O&M, recreational utilities have lower cost elasticities than do municipal plants. This should be expected, since recreational plants operate at a lower average flow and for only part of the year. Thus, greater operating economies may be gained by recreational plants through expanding output than can be gained by municipal plants, which have already achieved economies of scale. In general, the results indicate that operating economies exist in all components as well as total O&M for utilities that use package treatment plants.

Table 4 contains results for the total costs including capital for each major component as well as for total system cost. Municipal cost elasticities again exceed the recreational cost elasticity estimates, as might be expected. Results in these tables also indicate that significant economies prevail for total operating cost, depreciation and interest, and total annual cost as a function of revenue-producing water. These results imply that as output rises, economies of scale in capital and operation drive unit costs down.

Table 5 provides the empirical results from construction cost equations for each data set. Total construction cost is regressed against treated water. These construction costs are for the total utility and the complete package treatment plant (includes equipment, building, and installation cost). As can be seen from the table, significant scale economies also exist in construction. Figures 22 and 23 depict unit construction costs and O&M costs with respect to plant size for package treatment plants and for a total utility. These data are from the municipal data set.

Table 3. UTILITY O&M COSTS BY MAJOR COST COMPONENTS ($C = aQ^b$)*

| | Municipal Utilities | | | Recreational Utilities | | | Combined Data Set | | |
|---|---|---|---|---|---|---|---|---|---|
| | a | b | $R^2$ | a | b* | $R^2$ | a | b | $R^2$ |
| Acquisition | 79.277 | .716 (.155) | .620 | NS | NS | -- | 209.863 | .399 (.103) | .350 |
| Treatment | 297.526 | .886 (.182) | .627 | 2326.181 | .218 (.078) | .374 | 2044.530 | .394 (.054) | .646 |
| Distribution | 232.204 | .930 (.182) | .668 | NS | NS | -- | 425.354 | .724 (.116) | .583 |
| Support Services | 129.195 | .914 (.488) | .212 | NS | NS | -- | 329.308 | .614 (.134) | .430 |
| Total O&M | 895.620 | .862 (.209) | .567 | 4073.134 | .222 (.092) | .307 | 3661.697 | .475 (.059) | .696 |

* C = Cost in \$/yr; Q = revenue-producing water in mil gal/yr; a, b = constants (values in parentheses are standard errors).

Table 4. TOTAL COST EQUATIONS (O&M AND CAPITAL) BY MAJOR COMPONENT ($C = aQ^b$)*

| | Municipal Utilities | | | Recreational Utilities | | | Combined Data Set | | |
|---|---|---|---|---|---|---|---|---|---|
| | a | b | $R^2$ | a | b | $R^2$ | a | b | $R^2$ |
| Acquisition | 432.272 | .588* (.315) | .208 | NS | NS | -- | 1460.734 | .213 (.102) | .143 |
| Treatment | 3492.074 | .549 (.159) | .499 | 10030.984 | .132 (.070) | .264 | 9556.807 | .278 (.043) | .639 |
| Distribution | 2863.769 | .713 (.344) | .264 | NS | NS | -- | 4817.522 | .537 (.094) | .575 |
| Support Services | 468.746 | .608 (.374) | .249 | NS | NS | -- | 342.561 | .627 (.132) | .520 |
| Total O&M | 895.620 | .862 (.209) | .567 | 4073.134 | .222 (.092) | .307 | 3661.697 | .475 (.059) | .696 |
| Total Capital | 36761.633 | .151 (.098) | .122 | 12761.614 | .241 (.114) | .240 | 16006.113 | .329 (.064) | .443 |
| Total Cost | 7775.787 | .645 (.196) | .454 | 19054.451 | .118 (.101 | .089 | 17753.803 | .408 (.057) | .653 |

* C = Cost in dollars/yr; Q = revenue-producing water in mil gal/yr; a,b = constants. All values in parentheses are standard errors.

Table 5. CONSTRUCTION COSTS FOR PACKAGE PLANTS AND TOTAL SYSTEM ($C = aQ^b$)

| Data Set | Total | a | b | $R^2$ |
|---|---|---|---|---|
| Municipal | | | | |
| | Total | 35018.788 | .610 (.256) | .251 |
| | Treatment | 12890.141 | .616 (.150) | .498 |
| Recreational | | | | |
| | Total | 17835.462 | .684 (.165) | .552 |
| | Treatment | 8470.095 | .730 (.194) | .520 |
| Combined | | | | |
| | Total | 14289.31 | .773 (.090) | .692 |
| | Treatment | 10739.717 | .653 (.064) | .762 |

C = total cost; Q = mil gal water treated/yr; a,b = constants.

(Values in parentheses are standard errors.)

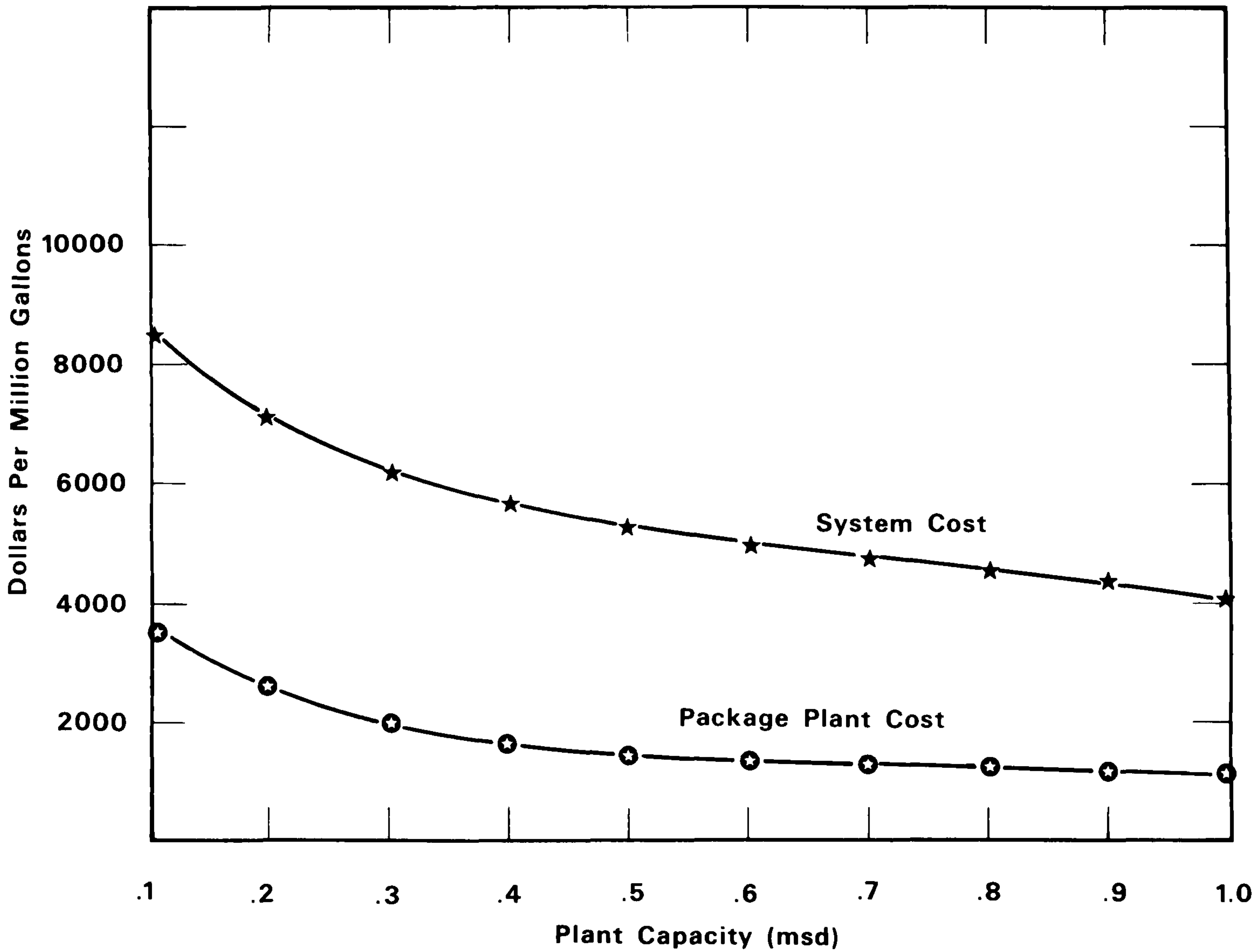


Figure 22. Total Unit Construction Costs for System and Package Plants (Municipal Utilities)

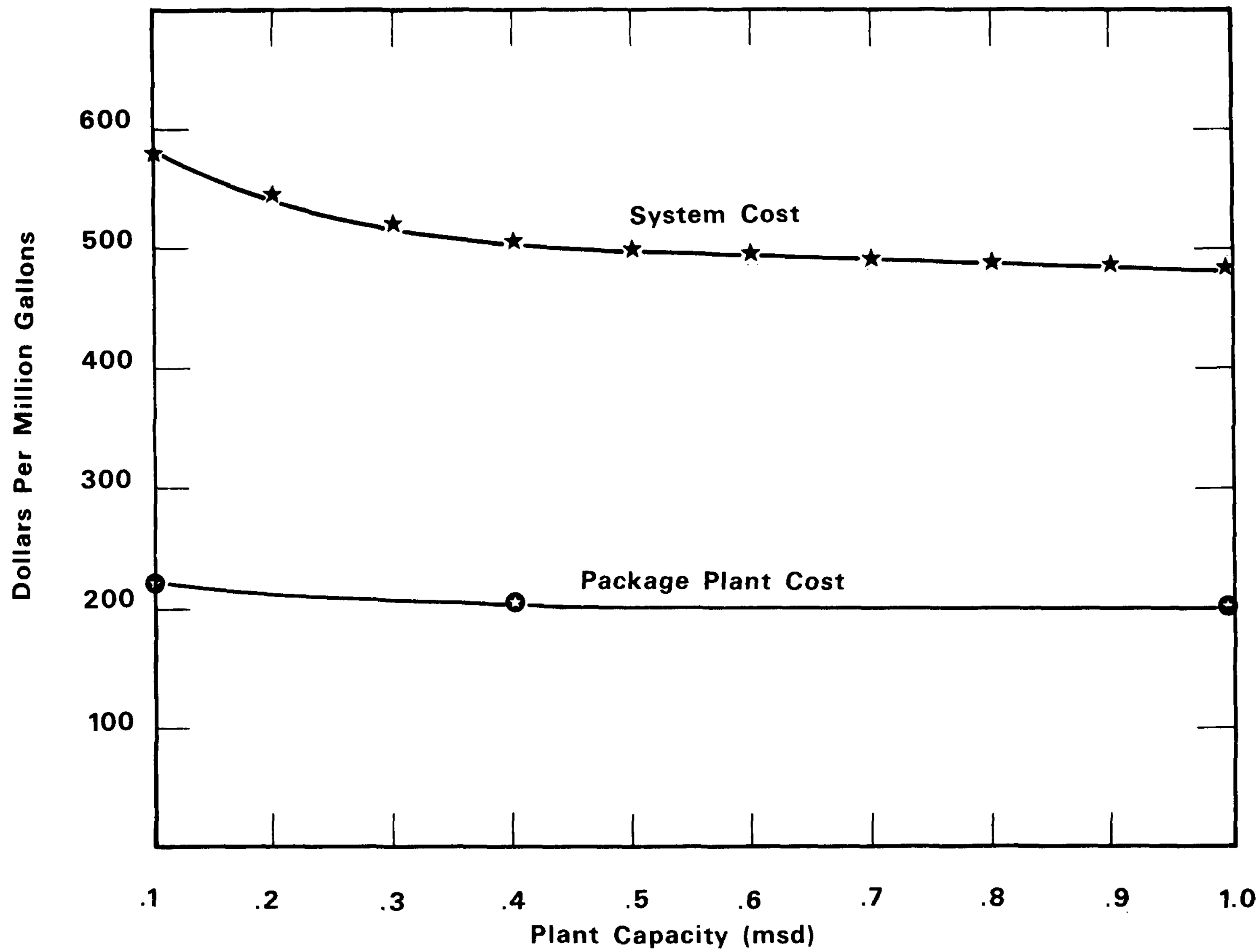


Figure 23. Total Unit O&M Cost for System and Package Plant (70% of capacity)

QUASI-PRODUCTION FUNCTIONS

Equation 9 provides a variation of equation 6 discussed in the previous section. Since no productivity or production function relationships can be generated due to the sparsity of data, an attempt was made to examine the cost tradeoffs inherent in utilities using package treatment plants. This analysis is conducted only for total treatment operating costs. The estimated operating and maintenance cost equation is:

$$TOC = 3.561\ \underset{(.038)}{Q^{.980}}\ \underset{(.038)}{L^{.612}}\ \underset{(.025)}{C^{.160}}\ \underset{(.049)}{E^{.179}} \qquad (R^2 = .994) \qquad (9)$$

where:

TOC = total annual treatment operating cost in \$/yr;

Q = revenue-producing water, million gallons/yr;

L = payroll expense per million gallons;

C = chemical expense per million gallons; and

E = power expense per million gallons.

From this equation, it is obvious the payroll costs are a significant factor in operating the package plant. To further examine the degree of this impact, a set of relationships can be derived based on equation 9.

The total differential of equation 9 yields:

$$\begin{aligned} dTOC &= 3.490\ Q^{-.020}\ L^{.612}\ C^{.160}\ E^{.179}\ dQ \\ &+ 2.179\ Q^{.980}\ L^{-.388}\ C^{.160}\ E^{.179}\ dL \\ &+ .570\ Q^{.980}\ L^{.612}\ C^{-.840}\ E^{.179}\ dC \\ &+ .637\ Q^{.980}\ L^{.612}\ C^{.160}\ E^{-.821}\ dE \end{aligned} \qquad (10)$$

Setting dTOC, dQ, and dE = 0 yields:

$$\begin{aligned} 0 = {} & 2.179\ Q^{.980}\ L^{-.388}\ C^{.160}\ E^{.179}\ dL \\ & + .570\ Q^{.980}\ L^{.612}\ C^{-.840}\ E^{.179}\ dC \end{aligned} \qquad (11)$$

Solving for $\frac{dL}{dC}$ gives:

$$\frac{dL}{dC} = - \frac{.570\ Q^{.980}\ L^{.612}\ C^{-.840}\ E^{.179}}{2.179\ Q^{.980}\ L^{-.388}\ C^{.160}\ E^{.179}} = -0.262\ \frac{L}{C} \tag{12}$$

Multiplying by $\frac{C}{L}$ to get a cost elasticity yields:

$$\frac{dL}{dC}\ \frac{C}{L} = \xi_{LC} = -.262 \tag{13}$$

Equation 13 implies that a 1% increase in chemical costs must be accompanied by a .262% decrease in payroll costs in order to keep costs constant. Other trade-off elasticities generated from equation 9 are provided in Table 6. These relationships do not reflect the trade-offs from large changes in the variables, but rather the variations in the neighborhood of a point.

Table 6. SUBSTITUTION ELASTICITIES AMONG Q, L, C, AND E

| | $\xi_{YX}$ | | | |
|---|---|---|---|---|
| X \ Y | Q | L | C | E |
| Q | -- | -1.602 | -6.123 | -5.479 |
| L | -.624 | -- | -3.817 | -3.421 |
| C | -.163 | -.262 | -- | - .895 |
| E | -.183 | -.292 | -1.118 | -- |

The most important factor influencing operating cost outside of Q is payroll cost. If payroll costs increase by 1%, chemical cost must decrease 3.817% or energy cost must decrease 3.421%. Thus, the level of labor activity devoted to operating and maintenance of the package plant is very important.

Chemical cost equations were developed for the combined data set as follows:

Combined Chemical Costs

$$CH = 55.037\ \underset{(.054)}{Q^{.661}}\ \underset{(.071)}{AL^{.349}} \qquad (R^2 = .860) \qquad (14)$$

where CH = total chemical cost, \$/year;

Q = revenue-producing water, million gallons/year; and

AL = alum, mg/L.

Other relationships were developed between chemical cost or total treatment operating cost and selected dummy variables on source type, turbidity standards, and drinking water standards.

Relationships were developed for chemical and total treatment O&M costs, versus water source, meeting the turbidity standards and meeting the other drinking water standards. These significant equations are as follows:

Combined Cost

$$CH = 105.109\ \underset{(.075)}{Q^{.660}}\ 1.458^{X} \qquad (R^2 = .754) \qquad (15)$$

$$CH = 125.336\ \underset{(.042)}{Q^{.589}}\ 1.486^{T} \qquad (R^2 = .756) \qquad (16)$$

$$TOM = 1939.140\ \underset{(.042)}{Q^{402}}\ 1.203^{S} \qquad (R^2 = .781) \qquad (17)$$

where TOM = total treatment O&M, \$/year;

$$X = \begin{cases} 1 & \text{if unprotected raw water source} \\ 0 & \text{if protected raw water source} \end{cases}$$

$$T = \begin{cases} 1 & \text{if turbidity standard met} \\ 0 & \text{if turbidity standard not met} \end{cases}$$

$$S = \begin{cases} 1 & \text{if drinking water standards met} \\ 0 & \text{if drinking water standards not met.} \end{cases}$$

A protected source is defined as ground water or spring water while an unprotected source is a surface source or impoundment. These results indicate that if a standard is met or if the source is unprotected, more treatment expense is incurred at each level of output.

## COST COMPARISON AND CONCLUSIONS

This report presents results from a study of 36 selected water utilities that use package treatment plants. The study was conducted in order to evaluate the cost-effectiveness of package treatment plants in treating drinking water. The following section provides a comparative analysis to the cost of conventional treatment and the general conclusions are contained in the final section.

### COMPARATIVE COST ANALYSIS

Package water treatment plants can produce water for small communities that will meet the requirements of the Interim Regulations. However, the cost of this new technology must be compared to that for conventional treatment. Data on the cost of conventional treatment plants are not generally available for plants of the size less than one mgd, prohibiting extrapolation of cost estimates for conventional treatment into that range. It is equally difficult to estimate costs for plants greater than one mgd. Therefore, both systems were compared at the one mgd level.

Reference to figures 22 and 23 in the previous section shows the relevant unit operating and construction costs for municipal treatment plants and total utility cost. These figures indicate that economies of scale and operation are achievable for package plants built and operated in a range less than or equal to one mgd. Therefore, for the average municipal plant size, slightly greater than .5 mgd in this data set, significant scale economies can be attained.

Figure 24 shows total construction cost of a package plant and the entire treatment system versus plant capacity in mgd. Figure 25 shows the annualized cost of treatment and total utility cost versus revenue producing water in mil gal/yr.

The construction cost for 1 mgd plant with settling has been estimated[7] at $1,124,000 (see Table 7). Total construction cost for 1 mgd package plant (includes plant, building, and installation), using the equation for municipal treatment plant from Figure 24, is $488,236. Therefore, based on construction cost alone, a package plant is significantly less expensive then conventional treatment.

Total operation and maintenance cost for both technologies can also be estimated. Using a previously developed equation for treatment O&M from a study of small utilities,[8] annual operating cost is estimated at $62,571.42 for conventional treatment. The equations from Table 3 estimate annual operating costs for package plants as $40,408.55.

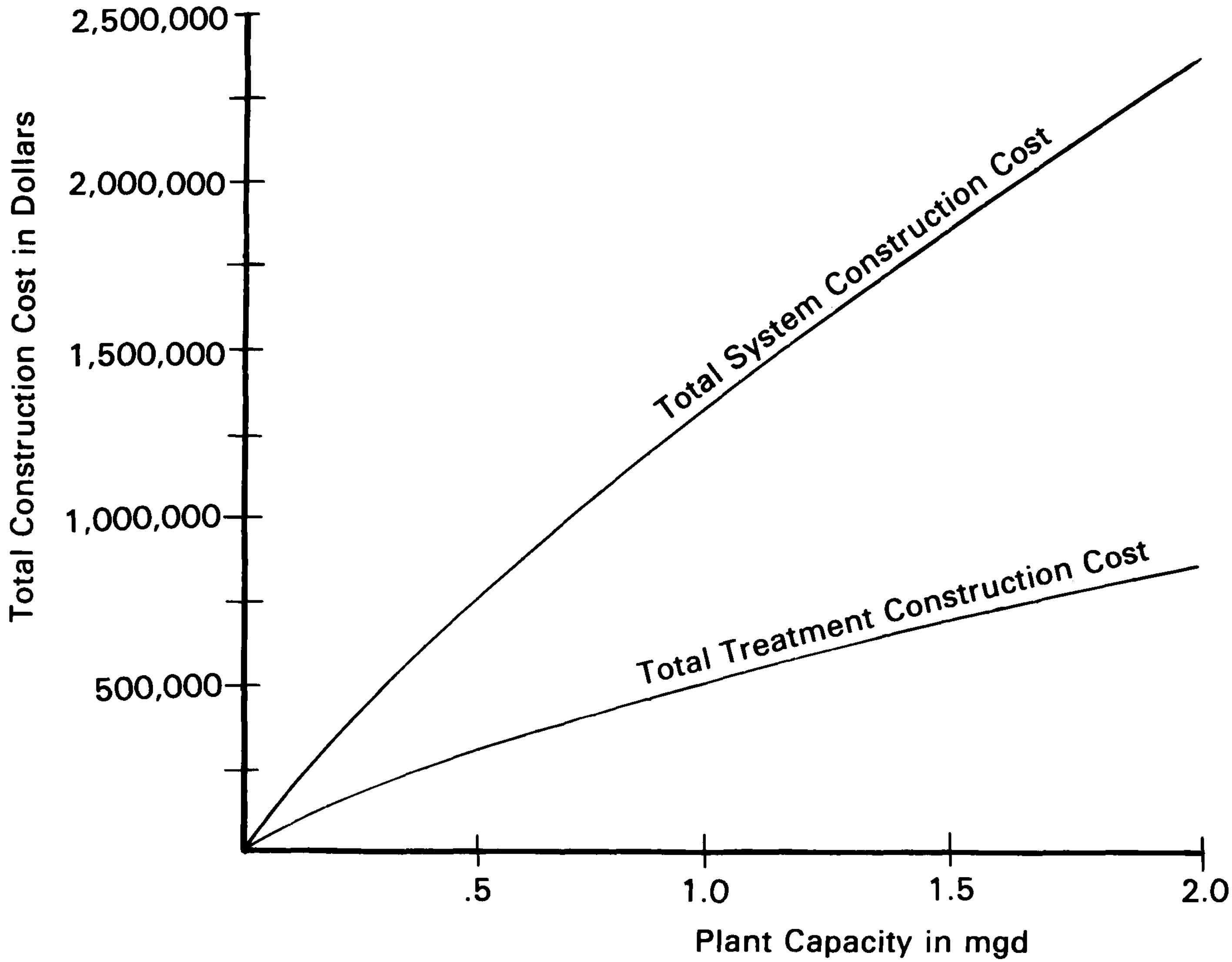


**Figure 24. Total Construction Cost Versus Plant Capacity**

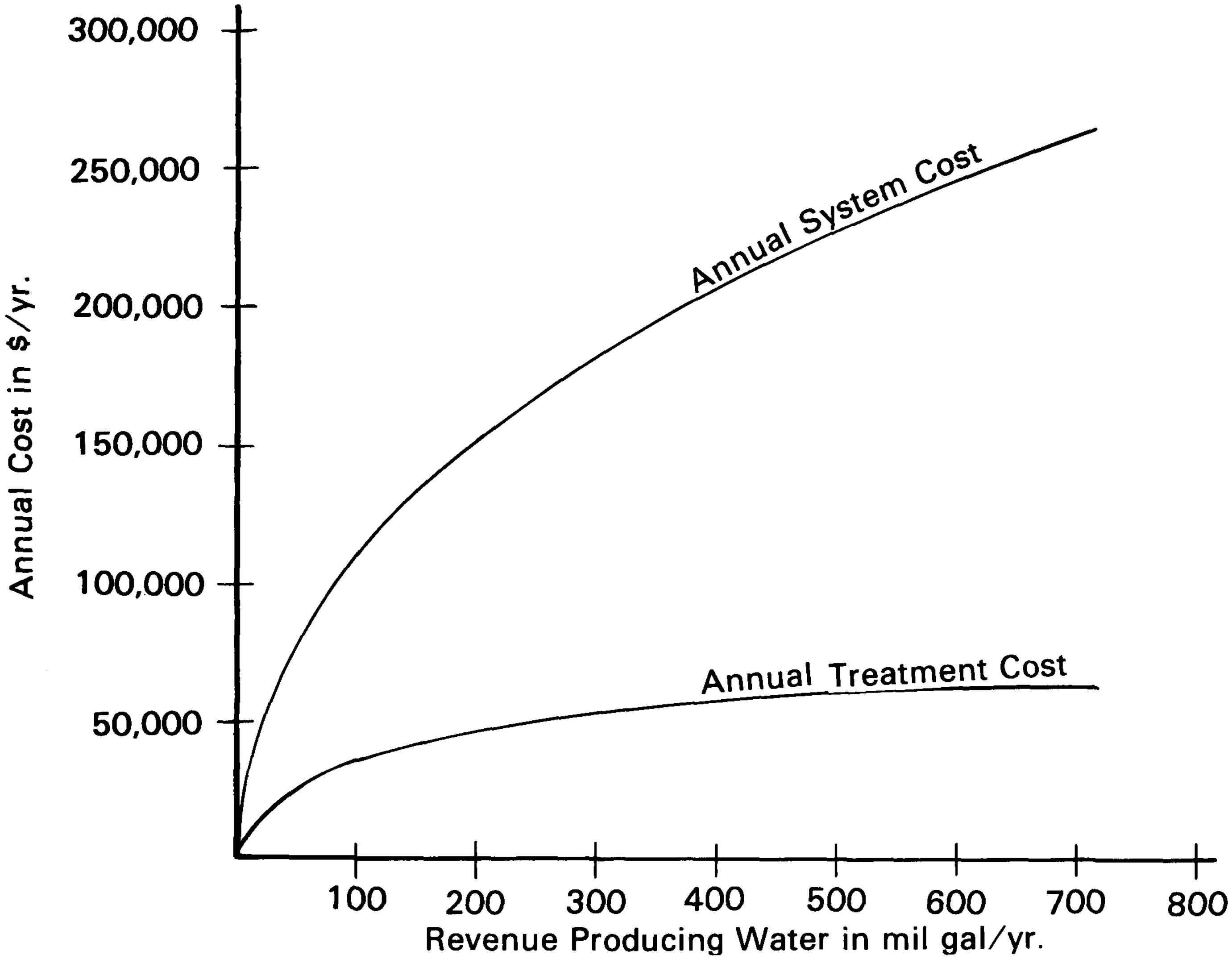


**Figure 25. Annual Cost Versus Revenue Producing Water**

Table 7. COMPARATIVE COST ANALYSIS FOR 1 MGD PLANT[7]

| Cost Estimate | Conventional | Package |
|---|---|---|
| Construction cost | $1,124,000.00 | $488,236.00 |
| Annual treatment, operation, and maintenance cost | $ 62,571.42 | $ 40,408.55 |

Therefore, package plants not only can produce water for small communities that will meet the turbidity requirements of the National regulations, but also reduce the cost impact on small systems unable to achieve scale economies with conventional treatment.

## CONCLUSIONS

Compliance with the requirements of the Safe Drinking Water Act may seriously impact the budgets of small communities But it is the intent of the Act to provide adequate water quality to the small as well as the large utilities. As a result, this analysis was conducted to examine the viability of using package treatment plants to meet the drinking water standards.

The results of this study indicate two aspects. Scale economies exist in package treatment plants under 1 mgd. The average flow rate for the municipal systems in this study was found to be slightly less than 0.2 mgd, implying that the average plant will be able to achieve the scale economies that potentially exist with this technology.

As shown in Table 7, construction and operating costs are lower for the package treatment technology than for conventional treatment processes of the 1 mgd level. Utilities can lower their construction cost by performing some of the installation and building work themselves. This opportunity gives the manager a great deal of flexibility in controlling construction costs.

Therefore, based on this study, it is felt that package plants can be used in a cost effective manner to meet the turbidity requirements of the Safe Drinking Water Act, and still not impose an enormous burden on the utility's budget.

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8. Unpublished report on small utilities, Environmental Protection Agency, Municipal Environmental Research Laboratory, Water Supply Research Division, Table 17.

# APPENDIX A

## QUALITY DATA

Table A-1. MUNICIPAL PLANTS

| Plant No. | Type of Plant | Capacity gpd | Plant Output gpd | Water Source | Alkalinity, mg/ℓ | | Hardness, mg/ℓ | | pH | | Temperature, °F | | $NO_3$(as N), mg/ℓ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Raw | Finished | Raw | Finished | Raw | Finished | Raw | Finished | Finished |
| 1 | AQ 40 | 288,000 | 97,000 | Im | 36 | 70 | 60 | 62 | 7.1 | 7.8 | 73 | 73 | < 0.01 |
| 2 | (2)WB 133 | 288,000 | 98,500 | Gr | 180 | 180 | 180 | 184 | 7.3 | 7.3 | 55 | 55 | 0.18 |
| 3 | AQ 40 | 288,000 | 75,000 | Gr | 257 | 261 | 390 | 400 | 7.1 | 7.2 | 56 | 57 | 3.30 |
| 4 | AQ 70 | 504,000 | 147,350 | Ff | 55 | 59 | 78 | 88 | 7.9 | 7.6 | 70 | 71 | 0.40 |
| 5 | AQ 40 | 288,000 | 105,500 | Im | 100 | 113 | 64 | 62 | 7.8 | 7.9 | 59 | 59 | 0.13 |
| 6 | Concrete | 1,440,000 | 860,000 | Ff | 4 | 12 | 12 | 10 | 6.6 | 7.2 | 58 | 60 | 0.22 |
| 7 | AQ 180 | 1,296,000 | 364,000 | Gr | 358 | 159 | 448 | 124 | 7.0 | 8.5 | 57 | 61 | 4.1 |
| 8 | AQ 112 | 806,400 | 233,000 | Ff | | | | | 7.8 | 8.2 | 69 | 69 | 0.04 |
| 9 | AQ 70 | 504,000 | 229,000 | Ff | 34 | 40 | 75 | 126 | 7.0 | 8.6 | 66 | 66 | 0.49 |
| 10 | H-T | 288,000 | 114,000 | Sp | 16 | 15 | 236 | 230 | 7.1 | 6.5 | 56 | 60 | 0.13 |
| 11 | AQ 40 | 288,000 | 84,300 | Im | 11 | 39 | 18 | 20 | 6.5 | 8.1 | 52 | 54 | 0.09 |
| 12 | AQ 70 | 504,000 | 80,000 | Sp | 86 | 82 | 98 | 94 | 7.4 | 7.4 | 50 | 52 | 0.20 |
| 13 | WB 133 | 144,000 | 70,000 | Im | 1 | 6 | 28 | 30 | 5.5 | 6.6 | 53 | 54 | 0.72 |
| 14 | AQ 40 | 288,000 | 70,000 | Sp | 0 | 7 | 10 | 30 | 4.7 | 7.9 | 57 | 60 | 0.02 |
| 15 | AQ 112 | 806,000 | 43,200 | Im | 6 | 16 | 8 | 22 | 6.9 | 7.5 | 59 | 59 | 0.01 |
| 16 | AQ 180 | 1,296,000 | 450,000 | Ff | 42 | 36 | 106 | 102 | 7.3 | 7.3 | 59 | 59 | 0.60 |

Water Sources:
- Gr - Ground water
- Sp - Spring
- Ff - Free-flowing surface water
- Im - Impounded surface water

Table A-1. MUNICIPAL PLANTS (Cont.)

| Plant No. | Fluoride, mg/ℓ Finished | Turbidity, NTU Raw | Turbidity, NTU Finished | Average Chemical Doses, mg/ℓ Alum | Polyelectrolyte | Soda Ash | Other | Coliforms/100 mℓ Raw | Coliforms/100 mℓ Finished | Free Chlorine residual, mg/ℓ | Trihalomethanes μg/ℓ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.10 | 6.4 | 0.9 | 31 | 0.02 | 37 | | TNTC | 0 | 2.5 | 355.0 |
| 2 | 0.18 | 20. | 0.7 | 13 | 0.1 | | | 38 | 23,7 | < 0.1 | < 1.0 |
| 3 | (0.17 raw) 1.15 | 7.0 | 0.5 | | 0.03 | | ferric sulfate 8 mg/ℓ<br>fluoride 0.5 mg/ℓ<br>lime 18 mg/ℓ | 780 | 0 | 1.0 | < 1.0 |
| 4 | 0.07 | 5.2 | 0.5 | 20 | 0.3 | | lime 18 mg/ℓ | TNTC | 0 | 1.5 | 35.1 |
| 5 | 0.13 | 1.8 | 1.6 | | | 13 | | TNTC | 0 | 1.5 | 57.5 |
| 6 | (0.05 raw) 0.80 | 0.6 | 0.8 | 9 | 0.04 | 17 | fluoride 0.6 mg/ℓ | TNTC | 0 | 1.0 | 68.0 |
| 7 | (0.14 raw) 1.66 | 0.04 | 0.03 | 22 | | | sodium hydroxide 13 mg/ℓ<br>fluoride 0.6 mg/ℓ<br>lime 339 mg/ℓ | 4 | 0 | 0.6 | < 1.0 |
| 8 | 0.12 | 7.0 | 0.2 | 43 | 0.5 | 66 | | TNTC | 0,3 | 2.5 | 24.0 |
| 9 | 0.20 | 520. | 1.4 | 52 | | | lime 23 mg/ℓ | | 0 | 1.7 | 112.0 |
| 10 | 0.12 | 5.0 | 0.7 | | | | $KMnO_4$ 0.2 mg/ℓ | TNTC | 0 | 3.0 | 5.1 |
| 11 | 0.02 | 6.6 | 0.7 | 57 | | 52 | | | | 0.6 | 46.3 |
| 12 | (0.05 raw) 1.11 | 1.1 | 0.4 | 11 | | 5 | fluoride 1.6 mg/ℓ | TNTC | 0,1 | 0.4 | 14.8 |
| 13 | 0.07 | 3.4 | 0.4 | 7 | | 9 | | | | 1.0 | 41.0 |
| 14 | 0.02 | 0.8 | 0.3 | 37 | | | lime 22 mg/ℓ | TNTC | 0 | 2.5 | 34.0 |
| 15 | 0.01 | 5.9 | 0.7 | 20 | 0.4 | 12 | lime 9 mg/ℓ | TNTC | 0 | 1.5 | 59.0 |
| 16 | 0.07 | 29. | 6.0 | 14 | | | lime 4 mg/ℓ | | 0 | 1.7 | 10.8 |

Table A-2. RECREATIONAL PLANTS

| Plant No. | Type of Plant | Capacity gpd | Plant Output gpd | Water Source | Alkalinity, mg/ℓ Raw | Alkalinity, mg/ℓ Finished | Hardness, mg/ℓ Raw | Hardness, mg/ℓ Finished | pH Raw | pH Finished | Temperature, °F Raw | Temperature, °F Finished | $NO_3$ (as N), mg/ℓ Finished |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | WB 27 | 28,800 | 1,000 | Im | 16 | 31 | 30 | 30 | 6.4 | 7.3 | 74 | 73 | 0.01 |
| 2 | ISI | 86,400 | 5,200 | Im | 19 | 25 | 30 | 32 | 7.0 | 7.4 | 72 | 72 | 0.06 |
| 3 | WB 27 | 28,800 | 2,700 | Im | 65 | 72 | 215 | 219 | 7.1 | 7.3 | 68 | 72 | 0.38 |
| 4 | WB 82 | 86,400 | 3,250 | Im | 98 | 102 | 114 | 106 | 7.9 | 7.7 | 75 | 81 | 0.07 |
| 5 | WB 82 | 86,400 | 4,700 | Im | 90 | 97 | 115 | 120 | 8.0 | 8.3 | 81 | 84 | < 0.01 |
| 6 | WB 27 | 28,800 | 1,150 | Im | 108 | 110 | 118 | 118 | 7.4 | 7.6 | 79 | 79 | 0.04 |
| 7 | Per. 48 | 69,120 | 6,000 | Im | 92 | 96 | 114 | 116 | 8.2 | 7.9 | 82 | 82 | |
| 8 | Per.200 | 288,000 | 50,000 | Ff | 12 | 88 | 24 | 26 | 6.2 | 8.4 | 48 | 52 | 0.03 |
| 9 | WB 82 | 86,400 | 1,250 | Im | 50 | 46 | 62 | 72 | 7.9 | 7.2 | 55 | 61 | 0.17 |
| 10 | WB 82 | 86,400 | 6,300 | Im | 40 | 52 | 63 | 65 | 7.3 | 7.4 | 64 | 64 | 0.31 |
| 11 | AQ 40 | 288,000 | 12,000 | Im | 80 | 75 | 110 | 112 | 7.2 | 7.0 | 58 | 58 | 0.21 |
| 12 | WB 27 | 28,800 | 13,000 | Ff | 73 | 80 | 100 | 94 | 6.9 | 7.5 | 59 | 59 | 0.26 |
| 13 | WB 27 | 28,800 | 3,000 | Im | 38 | 57 | 159 | 180 | 6.9 | 7.1 | 64 | 63 | 0.27 |
| 14 | WB 82 | 86,400 | 3,600 | Im | 56 | 58 | 98 | 115 | 7.6 | 7.6 | 59 | 61 | 0.20 |
| 15 | WB 133 | 144,000 | 33,400 | Im | 36 | 57 | 43 | 48 | 7.8 | 8.3 | 57 | 59 | < 0.01 |

Water sources: Im - impounded surface water
Ff - free-flowing surface water

Table A-2. RECREATIONAL PLANTS (Cont.)

| Plant No. | Fluoride, mg/ℓ Finished | Turbidity, NTU Raw | Finished | Average Chemical Doses, mg/ℓ Alum | Polyelectrolyte | Soda Ash | Other | Coliforms/100 mℓ Raw | Finished | Free Chlorine residual, mg/ℓ | Trihalomethanes μg/ℓ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.01 | 7.4 | 0.3 | 62 | 0.9 | 108 | | TNTC | 0 | 0.4 | 95.0 |
| 2 | 0.02 | 6.0 | 0.4 | 30 | 0.7 | 31 | | TNTC | 0 | 2.5 - 3.0 | 26.0 |
| 3 | 0.07 | 38. | 0.4 | 48 | | | | 166 | 0 | 1.0 | 4.7 |
| 4 | 0.12 | 2.6 | 2.1 | 10 | 1.2 | | | 4 | 0 | 1.0 | 98.0 |
| 5 | 0.11 | 28. | 2.0 | 2 | 0.3 | | | 0 | 0 | 0.7 | 55.0 |
| 6 | 0.12 | 4.8 | 2.7 | 3 | 0.5 | | | 1 | 0 | 0.1 - 0.4 | 45.0 |
| 7 | 0.13 | 22. | 2.5 | 2 | 0.5 | | | 0 | 0 | 2.0 | 70.3 |
| 8 | 0.01 | 2.8 | 0.5 | 83 | | 88 | | TNTC | 0 | 1.5 | 185.0 |
| 9 | 0.02 | 11. | 1.0 | 680 | 0.9 | | | 0 | 0 | 0.2 | 23.6 |
| 10 | 0.06 | 5.0 | 2.5 | 10 | 2.8 | 9 | | 25 | 0 | 1.8 | 45.0 |
| 11 | 0.03 | 2.5 | 0.5 | 33 | | | | TNTC | 0 | 1.5 | 42.8 |
| 12 | 0.12 | 1.4 | 0.7 | 15 | | | | TNTC | 0 | 2.0 | 64.0 |
| 13 | 0.20 | > 100. | 1.4 | 8 | 2.0 | | | 0 | 0 | > 3.0 | 376.0 |
| 14 | 0.14 | 31. | 12. | 19 | 0.4 | | | 0 | 0 | 6.1 | < 1.0 |
| 15 | 0.03 | 1.7 | 0.7 | 8 | | 16 | | 32 | 0 | 3.9 | 132.0 |

## APPENDIX B - INTERVIEW GUIDE FOR PACKAGE PLANTS

I. GENERAL

A. Date: Mo. _______ Day______ Year

B. City or Owner ________________________________________

C. Ownership Type: Municipal ( ) Investor ( )

D. Utility Name ________________________________________

E. Address ________________________________________

________________________________________

F. Contact: Name of Plant Manager, Operator, or Interviewee: ____________________

G. Population Served: Wholesaling ______________

Retailing ______________

H. Purchased Water

| | Percent | Amount |
|---|---|---|
| Raw | _____ | _____ |
| Treated | _____ | _____ |

I. Source of water:

| | Percent |
|---|---|
| Ground: | _____ |
| Surface impounded | _____ |
| freeflowing | _____ |

J. Number of Meters: _______

Number of Accounts _______

Number of Flat-rate Accounts _______

K. Total Treated Water _______

L. Total Billed Consumption _______

M. Average price charged per unit of water _______

| | |
|---|---|
| Year | |
| Number of Meters | |
| Number of Accounts | |
| Number of Flat-rate Accounts | |
| Total Treated Water | |
| Total Billed Consumption | |
| Average Price Charged | |

| II. WATER QUALITY | Raw | Finished |
|---|---|---|
| A. Bacterial count (total coliform, per 100 ml) | ______ | ______ |
| B. Chlorine residual | ______ | ______ |
| C. Alkalinity | ______ | ______ |
| D. Hardness | ______ | ______ |
| E. pH | ______ | ______ |
| F. Temperature | ______ | ______ |
| H. Total THM | ______ | ______ |
| 1. Chloroform | ______ | ______ |
| 2. Dibromochloromethane | ______ | ______ |
| 3. Bromoform | ______ | ______ |
| 4. Bromodichloromethane | ______ | ______ |

I. Drinking Water Regulation Constituents

| | | | |
|---|---|---|---|
| 1. | Arsenic | ______ | ______ |
| 2. | Barium | ______ | ______ |
| 3. | Cadmium | ______ | ______ |
| 4. | Chromium | ______ | ______ |
| 5. | Lead | ______ | ______ |
| 6. | Mercury | ______ | ______ |
| 7. | Nitrate | ______ | ______ |
| 8. | Selenium | ______ | ______ |
| 9. | Silver | ______ | ______ |
| 10. | Fluoride | ______ | ______ |
| 11. | Endrin | ______ | ______ |
| 12. | Lindane | ______ | ______ |
| 13. | Methoxychlor | ______ | ______ |
| 14. | Toxaphene | ______ | ______ |
| 15. | 2,4-D | ______ | ______ |
| 16. | 2,4,5-TP | ______ | ______ |
| 17. | Turbidity | ______ | ______ |

III. SUPPLEMENTAL QUALITY INFORMATION FROM STATE RECORDS, MANUFACTURERS' RECORDS, OR OTHER SOURCES:

IV. CHEMICALS USED*

| | | Point of Application | lbs/year | Concentration |
|---|---|---|---|---|
| A. | Chlorine | | | |
| B. | Fluoride | | | |
| C. | Carbon | | | |
| D. | Lime | | | |
| E. | Ammonia | | | |
| F. | Alum | | | |
| G. | Copper Sulfate | | | |
| H. | Soda Ash | | | |
| I. | Polymer | | | |
| J. | Iron Chloride | | | |
| K. | Iron Sulfate | | | |
| L. | Others | | | |

* If the only available data are for time periods shorter than one year, record the flow rate along with the lbs per time period.

# V. PLANT AND SYSTEM DESIGN

## A. Flow Diagram of Treatment Plant

## B. Flow Diagram of Major Pipe Network and Position of Pump Stations and Treatment Plant.

# VI. TREATMENT PLANT STRUCTURE

## A. Treatment Process (General)

| | Design Detention Time | Notes |
|---|---|---|
| 1. Activated | ________ | ____________________ |
| 2. Aeration | ________ | ____________________ |
| 3. Chlorination | ________ | ____________________ |
| 4. Coagulation | ________ | ____________________ |
| 5. Dechlorination | ________ | ____________________ |
| 6. Filtration | ________ | ____________________ |
| 7. Fluoridation | ________ | ____________________ |
| 8. Fluoride Removal | ________ | ____________________ |
| 9. Sedimentation | ________ | ____________________ |
| 10. Softening | ________ | ____________________ |
| 11. Stabilization | ________ | ____________________ |
| 12. Others | ________ | ____________________ |

B. Filter Media Yes ( ) No ( )

If yes, what type? ____________________

| 1. Layer | Material | Eff. size | Uniformity Coefficient | Thickness (inches) |
|---|---|---|---|---|
| Top | | | | |
| Intermediate (if used) | | | | |
| Intermediate (if used) | | | | |
| Bottom | | | | |

2. Support Medium:

   a. graded gravel ______________ d. Leopold block ________

   b. porous plate ______________ e. Other ______________

   c. wheeler bottom ______________

3. Chemical addition immediately prior or at filter? Yes ( ) No ( )

   If no, where? ______________________________

4. Brand names of chemicals:

   a. ______________________________, ________mg/1

   b. ______________________________, ________mg/1

   c. ______________________________, ________mg/1

5. How mixed? ______________________________

   ______________________________

6. Backwash practices:

| | Duration, minutes | Rate: gpm/ft$^2$ or inches rise/min | When used in backwash cycle |
|---|---|---|---|
| Backwash | | | |
| Surface Wash | | | |
| Air Assisted Wash | | | |

Air flow, standard cubin feet/minute______________

C. Treatment Manufacturer's name and Address:

______________________________

______________________________

D. Package Plant Model Number ______________

E. Expected Lifetime ______________

F. Date of Plant Installation______________

G. Flow Rate at Time of Sampling ______________

VII. Cost Information for Year

A. Plant capacity ______________

B. Total O&M cost (all cost components) ______________

C. Total depreciation expense (all cost components) ______________

D. Total interest expense (all cost components) ______________

E. Total overhead cost (includes billing, collecting, meter reading and administrative operations) ______________

F. Total payroll expense ______________

G. Total man-hours ______________

H. Total energy expense ______________

I. Total KWH ______________

J. Treatment

1. Total chemical cost ______________
2. Total labor cost ______________
3. Number of man-hours per year ______________
   a. percent of time spent on treatment maintenance. ______________
   b. percent of time spent on treatment operation. ______________
4. Total energy cost ______________
5. Total KWH ______________
6. Laboratory expense ______________
7. Treatment plant purchase cost ______________
8. Plant housing cost ______________
9. Plant installation cost ______________
10. Reservoir and/or storage cost ______________
11. Other O&M cost ______________
12. Other capital cost ______________

K. Acquisition

1. Plant investment ____________
2. Labor expense ____________
3. Man-hours ____________
4. Energy cost ____________
5. KWH ____________
6. Other O&M cost ____________
7. Other capital cost ____________

# APPENDIX C

## COST DATA FOR PACKAGE PLANTS

### Table C-1. MUNICIPAL PLANTS

| I.D. | Design | Treatment Operation Rate | Acquisition O&M | Treatment O&M | Chemical O&M | Distribution O&M | Support Services O&M | Total O&M | Power | Acquisition KI |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 288000 | 97400. | 456. | 6752. | 1970. | 4981. | 2069. | 14258. | 2113. | 173040. |
| 2 | | 98500. | 1250. | 4184. | 1200. | 4420. | 1053. | 10907. | 4282. | - 2. |
| 3 | | 75000. | 1063. | 4364. | 607. | 4076. | 1028. | 10531. | 5314. | 23359. |
| 4 | | 47350. | 1241. | 10905. | 1000. | 10278. | 5039. | 27463. | 6204. | 17124. |
| 5 | | | 2183. | 11614. | 505. | 12766. | 6301. | 32864. | 9406. | 112895. |
| 6 | | | 4447. | 33323. | 6076. | 31335. | 11550. | 80655. | 18474. | 93001. |
| | | | 2158. | 29947. | 8732. | 24173. | 33193. | 89471. | 7994. | 10500. |
| | | | 3750. | 23716. | 7940. | 19500. | 9202. | 56168. | 18228. | 15000. |
| | | | 2000. | 23795. | 3666. | 28829. | 14181. | 68805. | 8286. | 81865. |
| | | | 1133. | 9060. | 300. | 9100. | 3473. | 22766. | 5666. | 10000. |
| | | | 822. | 6877. | 2832. | 4292. | 9072. | 21063. | 4109. | 0. |
| | | | 411. | 6265. | 2174. | 3690. | 5024. | 15420. | 2639. | 57192. |
| | | | | 1015. | -2. | 1555. | 58. | 3406. | 3348. | 0. |
| | | | | 8068. | 1648. | 6601. | 11450. | 26723. | 3021. | 38410. |
| | | | | 6586. | 767. | 6100. | 7376. | 20998. | 4681. | 21221. |
| | | | | 22220. | 3636. | -2. | -2. | -2. | -2. | 12200. |
| | | | | -2. | -2. | -2. | -2. | -2. | -2. | 25332. |
| | | | | -2. | -2. | -2. | -2. | -2. | -2. | 50000. |
| | | | | -2. | -2. | -2. | -2. | -2. | -2. | 4209. |
| | | | | 3043.2 | 2870.2 | 11446.4 | 8004.6 | 33433.2 | 6917.7 | 41408.2 |

Table C-1. MUNICIPAL PLANTS (Cont.)

| I.D. | Total Treatment KI | Plant Equipment KI | Treatment Building KI | Treatment Installation KI | Distribution Storage KI | Overhead KI | Interest | Total KI | Payroll O&M | Treatment Labor $ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 272593. | 106593. | 93737. | 72264. | 295295. | 0. | 25994. | 740928. | 10175. | 4070. |
| 2 | 196645. | 122652. | 25384. | 48609. | 16520. | 0. | 5003. | 213165. | 5425. | 1920. |
| 3 | 165031. | 54180. | 69795. | 41056. | 12317. | 0. | 7502. | 200707. | 4610. | 1844. |
| 4 | 199347. | 88565. | 64263. | 46520. | 438589. | 11340. | 23379. | 666400. | 19180. | 7672. |
| 5 | 225785. | 58700. | 111391. | 55694. | 2264095. | 0. | 26106. | 2602775. | 21000. | 8400. |
| 6 | 923415. | 161203. | 479911. | 282301. | 1610674. | 123131. | 69697. | 2750222. | 56105. | 22442. |
| 7 | 244841. | 219533. | 9047. | 16261. | 1551985. | -2. | 11820. | 1807326. | 49640. | 19856. |
| 8 | 413850. | 135000. | 137250. | 141600. | 2110706. | -2. | 33936. | 2539556. | 30000. | 12000. |
| 9 | 571440. | 183201. | 257428. | 130811. | -2. | -2. | 87619. | 653304. | 43080. | 17709. |
| 10 | 322025. | 55000. | 168127. | 98898. | 950970. | 29670. | 28859. | 1312665. | 16800. | 6720. |
| 11 | 339325. | 60893. | 185622. | 92810. | 327816. | 0. | 3522. | 667141. | 6415. | 2566. |
| 12 | 342662. | 69440. | 182688. | 90131. | 549053. | 0. | 18967. | 948503. | 7020. | 2808. |
| 13 | 97710. | 43970. | 24428. | 29313. | 445292. | -2. | 10050. | 543002. | -2. | -2. |
| 14 | 133600. | 53440. | 53440. | 26720. | 542830. | -2. | 18075. | 714840. | 1664. | 5332. |
| 15 | 457995. | 124749. | 234219. | 99027. | 986653. | 0. | 27172. | 1265869. | 10335. | 4134. |
| 16 | 430996. | 93071. | 135830. | 202094. | 153560. | -2. | 23584. | 596756. | 18584. | 18584. |
| 17 | 363934. | 69663. | 196181. | 98090. | 710734. | 0. | 15700. | 404966. | -2. | -2. |
| 18 | 595965. | 85000. | 340643. | 170322. | 228712. | -2. | 36500. | 874677. | -2. | -2. |
| 19 | 318067. | 196881. | 87890. | 33196. | 45716. | 1564. | 18400. | 367992. | -2. | -2. |
| Ave. | 348169.8 | 104301.7 | 150382.8 | 93458.8 | 724528.7 | 13808.7 | 25888.7 | 1045831.4 | 20002.2 | 9070.5 |

Table C-1. MUNICIPAL PLANTS (Cont.)

| I.D. | Treatment Energy | Lab Expense | Total Depreciation | CPI O&M | CPI Deprec. & KI |
|---|---|---|---|---|---|
| 1 | 712.00 | -2.00 | 37046.40 | 1.00 | 1.36 |
| 2 | 1064.00 | 0.00 | 10658.00 | 1.00 | 1.00 |
| 3 | 1913.00 | -2.00 | 10034.91 | 1.00 | 1.29 |
| 4 | 2233.00 | -2.00 | 33320.00 | 1.00 | 1.36 |
| 5 | 2709.00 | 670.00 | 130138.99 | 1.00 | 1.81 |
| 6 | 4805.00 | -2.00 | 137511.23 | 1.00 | 1.11 |
| 7 | 1359.00 | -2.00 | 61379.85 | 1.00 | 1.05 |
| 8 | 3776.00 | -2.00 | 126978.00 | 1.00 | 1.50 |
| 9 | 2420.00 | 6215.00 | 32665.42 | 1.00 | 1.01 |
| 10 | 2040.00 | -2.00 | 65633.00 | 1.00 | 1.00 |
| 11 | 1479.00 | -2.00 | 33356.72 | 1.00 | 1.36 |
| 12 | 1283.00 | -2.00 | 47425.28 | 1.00 | 2.24 |
| 13 | 1015.00 | -2.00 | 27150.00 | 1.00 | 1.50 |
| 14 | 1088.00 | -2.00 | 17114.16 | 1.00 | 1.67 |
| 15 | 1685.00 | -2.00 | 63293.44 | 1.00 | 1.12 |
| 16 | -2.00 | -2.00 | 29837.54 | 1.01 | 1.22 |
| 17 | -2.00 | -2.00 | 20248.00 | 1.00 | 1.00 |
| 18 | -2.00 | -2.00 | 43734.00 | 1.00 | 1.00 |
| 19 | -2.00 | -2.00 | 18400.00 | 1.00 | 1.00 |
| Ave. | 1972.1 | 2295.0 | 49785.5 | | |

Table C-2. RECREATIONAL PLANTS

| I.D. | Design | Treatment Operation Rate | Acquisition O&M | Treatment O&M | Chemical O&M | Distribution O&M | Support Services O&M | Total O&M | Power | Acquisition KI |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 28800. | 1000. | 80. | 2025. | 143. | 1906. | 1127. | 5138. | 400. | 2040. |
| 2 | 86400. | 5200. | 147. | 3464. | 186. | 71. | 260. | 3942. | 352. | 2040. |
| 3 | 28800. | 2700. | 132. | 4569. | 321. | 52. | 200. | 4953. | 244. | 13362. |
| 4 | 86400. | 3250. | 182. | 2486. | 68. | 1617. | 833. | 5118. | 404. | 10500. |
| 5 | 86400. | 4700. | 182. | 2588. | 170. | 1617. | 833. | 5220. | 404. | 13100. |
| 6 | 28800. | 1150. | 182. | 2469. | 52. | 1617. | 833. | 5102. | 404. | 16700. |
| 7 | 69120. | 6000. | 182. | 2632. | 214. | 1617. | 732. | 5163. | 404. | 12200. |
| 8 | 288000. | 50000. | 1095. | 4317. | 1315. | 4754. | 4090. | 14256. | 3176. | -2. |
| 9 | 86400. | 1250. | 392. | 1443. | 350. | 187. | 220. | 2242. | 932. | 97071. |
| 10 | 86400. | 6300. | 1800. | 2389. | 379. | 300. | 100. | 4589. | 1800. | 59393. |
| 11 | 288000. | 12000. | 480. | 3722. | 170. | 3696. | 1392. | 9290. | 2400. | 10500. |
| 12 | 28800. | 13000. | 396. | 5603. | 1050. | 832. | 39. | 6870. | 1980. | 5240. |
| 13 | 28800. | 3000. | 146. | 924. | 122. | 307. | 255. | 1632. | 731. | 80199. |
| 14 | 86400. | 3600. | 353. | 1811. | 75. | 35. | 104. | 2303. | 882. | 14443. |
| 15 | 144000. | 144000. | 10. | 4539. | 890. | 880. | 485. | 5914. | 1795. | 6477. |
| 16 | 504000. | 302400. | -2. | -2. | -2. | -2. | -2. | -2. | -2. | 213754. |
| 17 | 86400. | -2. | -2. | -2. | -2. | -2. | -2. | -2. | -2. | 3750. |
| Ave. | 120112.9 | 34971.9 | 383.9 | 2998.8 | 366.9 | 1299.2 | 766.9 | 5448.7 | 1087.3 | 35048.1 |

Table C-2. RECREATIONAL PLANTS (Cont.)

| I.D. | Total Treatment KI | Plant Equipment KI | Treatment Building KI | Treatment Installation KI | Distribution Storage KI | Overhead KI | Interest | Total KI | Payroll O&M | Treatment Labor $ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 56100. | 17850. | 20400. | 17850. | 2040. | 0. | 2111. | 60180. | 4095. | 1738. |
| 2 | 74800. | 34000. | 6800. | 34000. | -2. | 0. | 2696. | 76840. | 3151. | 3151. |
| 3 | 47237. | 17063. | 12873. | 17301. | 40898. | 0. | 3697. | 101497. | 4136. | 4120. |
| 4 | 136500. | 20370. | 77420. | 38710. | 79800. | 0. | 10617. | 226800. | 4545. | 2273. |
| 5 | 72050. | 20174. | 34584. | 17292. | 55020. | 0. | 5105. | 140170. | 4545. | 2273. |
| 6 | 66800. | 25050. | 41750. | 0. | 58450. | 0. | 3963. | 141950. | 4444. | 2273. |
| 7 | 79300. | 19520. | 42700. | 17080. | 75640. | 0. | 6605. | 167140. | 3829. | 2273. |
| 8 | -2. | -2. | -2. | -2. | -2. | -2. | -2. | -2. | 6135. | 2454. |
| 9 | 106405 | 53992. | 38062. | 14351. | 236617. | 0. | 16029. | 440093. | 758. | 758. |
| 10 | 90525. | 38823. | 37581. | 14121. | 41111. | 0. | 8942. | 191029. | 2410. | 1410. |
| 11 | 454230. | 50820. | 268940. | 134470. | -2. | 0. | 21754. | 464730. | 6720. | 2688. |
| 12 | 22139. | 8450. | 5240. | 8450. | 29344. | 0. | 1940. | 56723. | 3840. | 3840. |
| 13 | 115289. | 59920. | 40249. | 15120. | 16100. | 0. | 9199. | 211588. | 539. | 539. |
| 14 | 161600. | 30805. | 87196. | 43599. | 27427. | 0. | 9990. | 203470. | 1260. | 1260. |
| 15 | 151225. | 58670. | 51467. | 41089. | 112885. | -2. | 12668. | 270617. | 2779. | 2779. |
| 16 | 99431. | -2. | -2. | -2. | 567035. | 1029. | 35423. | 880219. | -2. | -2. |
| 17 | 40866 | 21000. | 13244. | 6622. | 27892. | 0. | 3625. | 72508. | -2. | -2. |
| Ave. | 110906.1 | 31767. | 51900.4 | 28003.7 | 97875.7 | 68.6 | 9647.8 | 231597.1 | 3545.7 | 2255.1 |

Table C-2. RECREATIONAL PLANTS (Cont.)

| I.D. | Treatment Energy | Lab Expense | Total Depreciation | CPI O&M | CPI Deprec. & KI |
|---|---|---|---|---|---|
| 1 | 144.00 | 250.00 | 3008.32 | 1.00 | 1.36 |
| 2 | 127.26 | 252.50 | 3842.00 | 1.01 | 1.36 |
| 3 | 128.00 | 100.00 | 5074.94 | 1.00 | 1.31 |
| 4 | 145.44 | 101.00 | 11340.00 | 1.01 | 1.05 |
| 5 | 145.44 | 101.00 | 7008.50 | 1.01 | 1.31 |
| 6 | 145.44 | 101.00 | 7097.50 | 1.01 | 1.67 |
| 7 | 145.44 | 101.00 | 8357.00 | 1.01 | 1.22 |
| 8 | 548.00 | -2.00 | -2.00 | 1.00 | 1.00 |
| 9 | 335.32 | 202.00 | 22004.07 | 1.01 | 1.31 |
| 10 | 600.00 | 0.00 | 9551.85 | 1.00 | 1.05 |
| 11 | 864.00 | -2.00 | 23236.50 | 1.00 | 1.05 |
| 12 | 713.00 | 0.00 | 2836.15 | 1.00 | 1.31 |
| 13 | 263.00 | 0.00 | 10579.52 | 1.00 | 1.12 |
| 14 | 476.00 | 0.00 | 10173.73 | 1.00 | 1.01 |
| 15 | 870.00 | 0.00 | 13530.30 | 1.00 | 1.05 |
| 16 | -2.00 | -2.00 | 29911.20 | 1.00 | 1.21 |
| 17 | -2.00 | -2.00 | 3625.00 | 1.00 | 1.00 |
| Ave. | 376.7 | 92.9 | 10698.5 | | |

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

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Volume 2. A Cost Evaluation

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**16. ABSTRACT**

Many small and rural systems have both cost and quality problems. Their unit costs tend to be higher because of the small number of connections they service. As shown by the Community Water Supply Survey of 1969, many small systems have trouble meeting minimal drinking water standards. These problems are likely to be compounded in the future as drinking water standards are raised. The cost of building a conventional water treatment plant to provide higher quality water for a small community may be prohibitive. A possible alternative to a conventional water treatment plant is a package water treatment plant. These plants are self-contained units that can be installed for a minimum cost.

Results from a study of 36 package plants in Kentucky, West Virginia, and Tennessee show that treatment plants can provide water that meets the turbidity requirement of the National Interim Drinking Water Standards. However, as with all treatment plants, proper operation is required. These plants, contrary to some manufacturers' claims, are not totally automatic but require supervision. Nevertheless, when properly maintained and operated, they can provide water that meets the Safe Drinking Water Act's MCKs at a cost less than that associated with conventional treatment.

This report (Volume 2) presents the results of a cost evaluation study for package water treatment plants. Volume 1 discusses the performance of package plants with minimal cost evaluation.

**17. KEY WORDS AND DOCUMENT ANALYSIS**

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Construction Costs; Cost Analysis; Cost Centers; Cost Control; Cost Effectiveness; Distribution Costs; Distribution Systems; Economic Analysis; Operating Cost; Performance Evaluation; Quality; Statistical Analysis; Regression Analysis; Utility; Water Supply; Water Treatment | Capital Costs; Chemical Costs; Conventional Treatment; Field Evaluation; Maximum Contaminant Levels; Operating and Maintenance Cost; Package Plants; Predictive Relationships; Safe Drinking Water Act; Small Systems; Treatment Systems | 13B<br>14A |

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