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THE COST OF WATER SUPPLY AND WATER UTILITY MANAGEMENT

Volume I

by

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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 user community.

The Safe Drinking Water Act of 1974 establishes primary, health-related standards and secondary, aesthetic-related but nonenforceable guidelines for drinking water supplies. These standards will bring about fundamental changes in the way water is handled before it is delivered to the consumer. Many of these changes will have an economic impact on the affected water utilities. This report provides detailed information on the current costs of water supply for 12 selected water utilities. In addition to providing information on the individual supplies, data are aggregated to provide projections of the relative impact of various strategies that might be undertaken to satisfy the Act's requirements. These data and associated analyses are presented in two volumes. Volume I is a summary of selected data from the study together with its analysis. Volume II contains detailed, in-depth information for each utility studied.

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ABSTRACT

A study of 12 selected water utilities was undertaken to determine the economics of water delivery. Data were collected from at least one class A water utility (revenues greater than $500,000/year) in each of the U.S. Environmental Protection Agency's 10 regions. Volume I provides summary information and in-depth analyses of five of the 12 utilities studied. All the utilities are analyzed in aggregate, and factors affecting the cost of water supply are examined. Also provided is an evaluation of the hypothetical impact of the Safe Drinking Water Act in 1980.

Volume II contains the basic data from each of the 12 utilities studied. Services of each utility were divided into five functional areas common to all water supply delivery systems -- support services, acquisition, treatment or purification, distribution, and power and pumping. These areas provided a common basis for collecting and comparing data. Costs were categorized as operating or capital expenditures.

This report was submitted in fulfillment of Contract No. 68-03-2071 by ACT Systems, Inc., under the sponsorship of the U. S. Environmental Protection Agency. The report covers the period July 1974 to July 1976, and work was completed as of September 1977.

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FIGURES (continued)

FIGURES (continued)

FIGURES (continued)

TABLES

TABLES (continued)

METRIC CONVERSION TABLE

English Units	Metric Equivalents
1 foot	0.305 meters
1 mile	1.61 kilometers
1 square mile	2.59 square kilometers
1 million gallons	3.79 thousand cubic meters
1 $/million gallons	0.26 $/thousand cubic meters
1 ¢/1000 gallons	0.26 ¢/cubic meter

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SECTION 1

EXECUTIVE SUMMARY

A two-year study of 12 selected water utilities was undertaken to determine the economics of water delivery. Data were collected from at least one class A water utility (revenues greater than $500,000/year) in each of U. S. Environmental Protection Agency's (EPA) 10 regions. The finished water from all utilities selected meets the 1962 Public Health Service Drinking Water Standards. Volume I of this report provides in-depth analyses for five of the 12 utilities studied: Cincinnati, Ohio; Kansas City, Missouri; Fairfax County Water Authority in Fairfax, Virginia; Dallas, Texas; and the Elizabethtown Water Company in Elizabeth, New Jersey. Aggregate analysis of data from all the utilities is also provided in Volume I, along with an evaluation of factors affecting the cost of water supply and a consideration of the impact of technologies that might be used to satisfy requirements of the Safe Drinking Water Act.

Volume II contains the basic data from each of the 12 utilities studied. They represent many institutional arrangements, physically different water supply systems, and different conditions faced by water utilities across the United States. For example, Cincinnati and Kansas City are single-source utilities distributing water to far-flung distribution areas. Others, such as the Dallas Water Utility and the Fairfax County Water Authority, are in rapidly growing areas with capital costs distributed over a fast-growing, revenue-producing base that keeps water costs low. Two investor-owned utilities, Elizabethtown Water Company and New Haven Water Company, were included in the sample to demonstrate problems associated with investor-owned utilities. The San Diego and Phoenix utilities operate in water-short areas. Pueblo and Kenton County were the smallest utilities studied. Seattle has made extensive investments in controlled source protection, and Orlando uses groundwater from a deep aquifer.

Data were collected for 10 years in five operating cost categories and two capital cost categories. The operating cost categories are support services, acquisition, treatment, power and pumping, and transmission and distribution. Capital costs were divided into interest and depreciation. Each operating cost category was examined as to total expenditures, unit costs, and percent of total cost. Revenue-producing water was used for all cost calculations because it represents the basis on which utilities obtain their operating revenues, and provides the real basis for comparing productivity and costs between systems. Systems vary in the proportion of water sold, meaning that uncertainties are introduced in the comparison of unit cost and productivity over time for a single utility. To convert to a basis of water produced, a simple conversion based on the ratio of water sold to water produced can be used. The impact of operating expenditures, increasing labor costs, and increasing labor productivity on total water production costs were examined.

A systems evaluation was made for each utility in which the service area was divided into its components. Schematic diagrams of the system components have been developed for each of the utilities studied. For some utilities, these diagrams are very detailed, and for others, because of the complexity of the system, the diagram is somewhat superficial. By using the systems diagram and the previous cost categorizations, it was possible to evaluate the costs associated with delivering water to various subsections of the distribution system and to make some estimates as to how the costs of water vary throughout the distribution area.

Individual and comparative analyses reveal certain trends. Labor cost is a significant part of the annual operating costs for all utilities and has nearly doubled in some cases over the period of analysis. More and more dollars are being shifted into support service activities. Examination of water delivery costs shows that they increase with the distance from the treatment plant; thus there are definite limits to the efficient size of water utility service areas.

Mathematical models have been developed that relate labor cost ($/man-hour), productivity (man-hours/million gallons (MG), and production (revenue-producing water) to annual operating costs. Another model has been developed for annual capital costs incorporating revenue-producing water and depreciation.

Extrapolations have been made with historical data for future water costs. Estimates for meeting the Safe Drinking Water Act's organic standards have been superimposed on these costs. Between 1975 and 1980, and using data from this study, it is estimated that the price of water will have increased by 36% as a result of normal inflation and increased demands. For those few utilities required by the Safe Drinking Water Act to install the most expensive control technology (granular activated carbon), costs will increase an additional 24% above the expected 1980 levels.

Total costs for each of the 12 utilities during the latest year of data collection are shown in Table 1. Taxes for the investor-owned utilities are reported separately. Table 1 also contains the name and average distribution for the utilities studied so that in using this document one can examine the data for a specific utility as contained in Volume II.

We hope these data will provide useful information on water supply costs from various utility systems and an example of the means by which data can be collected from water supplies to provide comparative information. With the advent of the Safe Drinking Water Act, regulatory agencies, utility managers, and the public should be able to isolate and understand various cost impacts on utilities of inflation and expansion demand versus regulatory impacts.

TABLE 1. COST ANALYSIS SUMMARY FOR LATEST YEAR OF RECORD (1974)

Utility	Revenue-producing water (mil gal/day)	Cost categories ($/mil gal)					
		Support services	Acquisition	Treatment	Distribution	Interest	Total
Kansas City	26,855	$ 145	$ 15	$ 82	$ 138	$ 50	$ 430
Dallas	63,030	83	25	52	120	58	338
San Diego	47,192	96	277	28	106	7	514
New Haven	17,714	113	29	15	106	117	560*
Fairfax Co.	19,232	88	35	56	134	209	522
Phoenix	63,661	91	17	47	112	53	320
Kenton Co.	2,259	82	12	103	124	73	394
Orlando	12,522	110	42	22	135	85	394
Elizabeth	38,256	89	67	33	144	113	492+
Pueblo	6,793	99	38	84	232	164	617
Seattle	45,967	109	37	13	77	27	263
Cincinnati	38,104	85	17	36	139	18	295

* Includes $179 taxes.

\+ Includes $76 taxes.

The approach suggested here will allow the utility manager to pinpoint areas where costs are spiraling out of control and allow him to take corrective action. Table 2 summarizes some of the expected cost increases resulting from inflation and demand, as well as the effects of add-on technologies.

TABLE 2. EXPECTED INCREASE IN COSTS FOR 1980
Based on Data from Study

Item	Cost in 1975	Expected cost in 1980	1980 costs with add-on technologies: GAC - contactors	1980 costs with add-on technologies: GAC - media replacement	1980 costs with add-on technologies: Chlorine dioxide
Treatment operating cost ($/yr in millions)	1.10	1.50	2.97	4.17	2.17
Treatment capital cost ($/yr in millions)	0.48	0.60	3.34	1.33	0.73
Total operating cost ($/yr in millions)	8.85	12.40	13.87	15.07	13.07
Total capital cost ($/yr in millions)	3.80	4.95	7.69	5.68	5.08
Total production cost ($/yr in millions)	12.75	17.35	21.56	20.75	18.25
Total unit cost ($/mil gal)	412.00	480.00	596.47	574.06	504.90

SECTION 2

INTRODUCTION

The Safe Drinking Water Act of 1974 will bring about a fundamental examination of the way drinking water is handled before it is delivered to consumers. The Act establishes primary health-related standards and secondary or aesthetic-related, but nonenforceable, guidelines for drinking water supplies. Throughout the Act, emphasis is placed on the need to consider the economics of water delivery.

In response to this need, a two-year study of selected water utilities was undertaken in which data were collected from at least one class A water utility (revenues greater than $500,000/yr) in each of the U. S. Environmental Protection Agency's (EPA) 10 regions.[3] Figure 1 shows the locations of utilities studied. Twelve utilities were selected for investigation -- one in regions I, II, III, V, VI, VII, VIII, and X, and two in regions IV and IX. The study, which ran from 1974 through 1976, was conducted in two phases, with a special study in Cincinnati, Ohio. Data were collected so that costs could be easily compared among utilities.

Each utility's services were divided into the functional areas of acquisition, treatment or purification, and distribution. These functional areas or subsystems are common to all water supply delivery systems and can therefore provide a common basis for data collection. Another category common to all water utilities is the management or administrative function, which completes the framework of the institution for insuring an adequate supply of safe drinking water. This institution is most commonly called a water supply utility.

Costs were categorized as either operating or capital expenditures. Operating costs have been assigned to the following functional areas: acquisition, treatment, power and pumping, transmission and distribution (including storage), and support services. The first four functional areas are related to the physical delivery of water, and the fifth, support services, is related to the overall integrative responsibility of utility management. Operating costs include operating labor, maintenance, and materials. For example, if the utility has a treatment division, laboratory personnel costs are included in the treatment cost category, but management costs for the division are included in the support services category. Support services include, therefore, all of the administrative and customer services that are required to manage the water utility and collect revenues but that are not directly related to the physical process of delivering water.

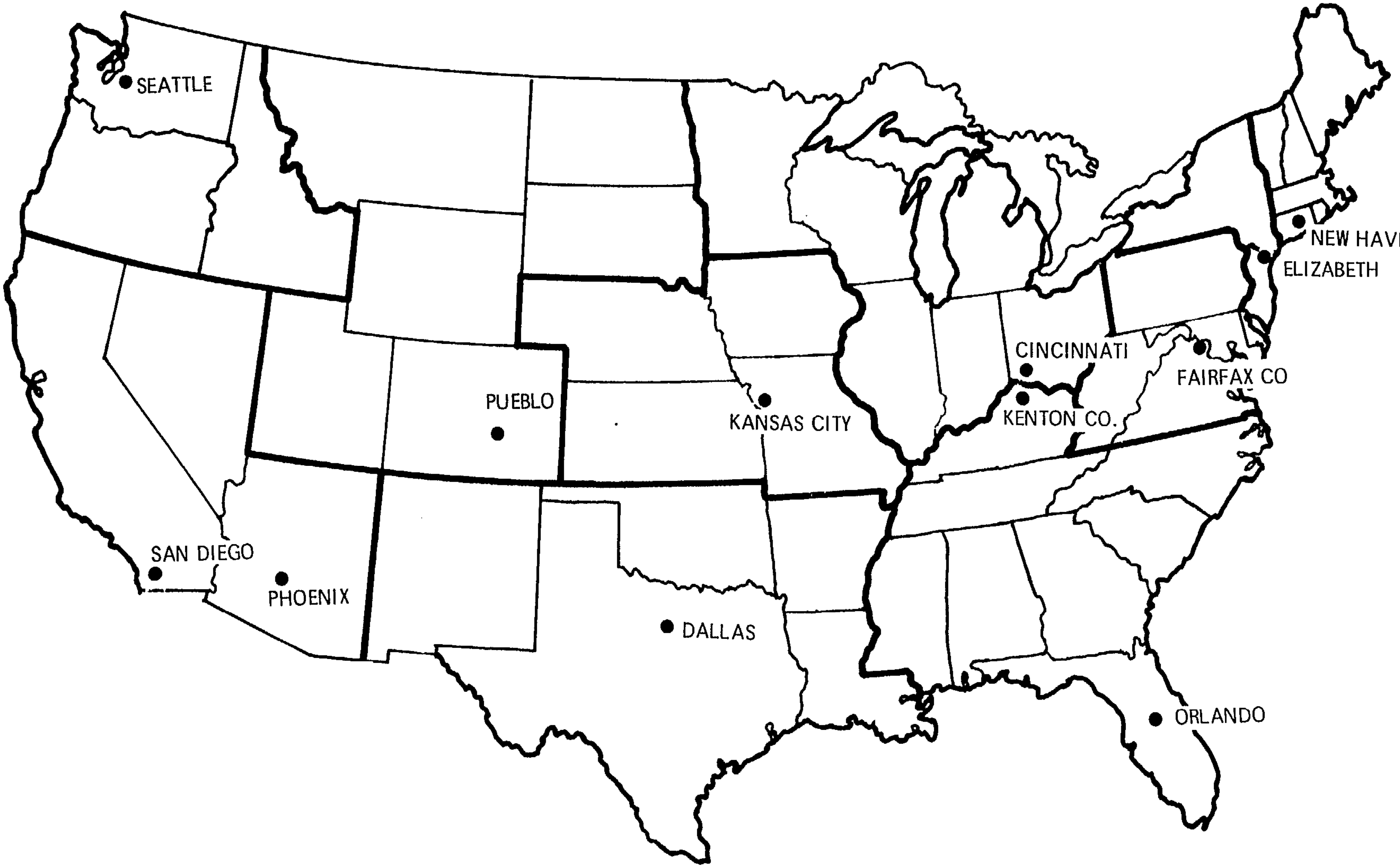

FIG. 1 LOCATION OF WATER UTILITIES STUDIED

Capital costs are assumed as depreciation and interest for the plant-in-service. Depreciation is based on the historic cost of the facility divided by its useful life, and not on the costs required to reproduce the facility. Lower costs will therefore be associated with older utilities. Most of the utilities analyzed constructed the major portion of their facilities in the 1930s and 40s. Interest costs are the dollars the utilities must pay for their bonds or other money-raising mechanisms.

Revenues were not considered in this report. All of the data reported are strictly related to the cost of water supply and do not include some of the broader aspects of elasticity of demand and optimal pricing policies of water supply.[4] All costs reported are based on revenue-producing water pumped by the utilities for a 10-year period from 1965 through 1974. Revenue-producing water was used for all cost calculations because it represents the basis on which utilities obtain their operating revenues and provides the real basis for comparing productivity and costs between systems. Systems vary in the proportion of water sold, meaning that uncertainties are introduced in the comparison of unit cost and productivity over time for a single utility. To convert to a basis of water produced, a simple conversion based on the ratio of water sold to water produced can be used.

The finished water from all of the utilities selected for the study meets the 1962 Public Health Service Drinking Water Standards. Although efficiency of removal and the raw water source quality influence the cost of treatment, these factors were not explicitly considered as part of the data collection effort. An equation has been developed, however, that relates chemical costs to the quality of source water. Because all of the utilities meet with 1962 standards it can be assumed that any changes required to meet SDWA standards will be incremental and will not involve construction of an entirely new treatment complex.

The report has been prepared in two volumes. Volume I contains summary information and an analysis of the factors that affect the cost of water supply, and Volume II contains the basic data from each of the selected utilities.

SECTION 3

CONCLUSIONS

In Volume I of this report, five of 12 utilities have been selected for in-depth analysis. System and cost data have been summarized for each utility individually, and some individual comparisons have been made. These data indicate a general increasing trend in demand for revenue-producing water, increasing labor wage rates, and the other operating and capital expenses associated with water supply. The systems evaluations for Kansas City and Cincinnati indicate increasing unit costs with increasing distance from the treatment plant. This analysis implies that there are definite limitations to the efficient size of a water supply system. Using a ratio of unit costs to the Consumer Price Index, however, it is shown that if not for inflation unit costs would have risen less rapidly or perhaps declined over time.

A mathematical model has been developed that relates operating cost to labor *wage* rate, labor productivity, and revenue-producing water. Other models have been developed to relate capital cost to unit depreciation and revenue-producing water and to demonstrate decreasing returns to distance of transmission. A relationship between interest and depreciation has also been developed.

Finally, the data and associated analyses presented here are used to evaluate the hypothetical impact of the safe Drinking Water Act in 1980. These data show the cost of water will increase by 36% between 1975 and 1980 as a result of normal demand and inflationary pressures. If expensive add-on technology, such as granular activated carbon, is required by the Safe Drinking Water Act, water costs will increase by another 24%.

These data will be useful for planners, designers, and decision makers in planning for the implementation of the Safe Drinking Water Act. Appendix A summarizes the slopes of the various cost curves for each utility and for the average of all utilities, and will provide useful information on the variations in *costs* associated with each utility.

SECTION 4

DATA ANALYSIS FROM SELECTED WATER UTILITIES

Data from five selected utilities will be analyzed in detail in this section. Each featured utility has some aspect that makes it representative of many other utilities across the country. The Kansas City water system, which will be examined first, is relatively simple and provides some useful insights into the cost of distributing water; it represents a no-growth situation.[5] The Cincinnati water supply system is similar to that of Kansas City, but somewhat more complex. A depreciation analysis has been made of Cincinnati's total system.[6] The Dallas, Texas, water utility is supplying water to a rapidly growing area. Its distribution system is complex, including reservoirs and three treatment plants.[7] Fairfax County Water Authority is a regional water utility of recent origin that illustrates the economies of scale that might result from a group of utilities banding together. The Elizabethtown Water Company is a private utility that demonstrates some of the problems associated with private sector water supplies.

KANSAS CITY, MISSOURI

The Kansas City Water Utility serves its metropolitan area with a population of nearly 500,000 and a land area of 400 square miles. The utility's total service population is approximately 600,000, which includes several smaller surrounding cities. The total population of the metropolitan area is greater than 1 million.

Figure 2 shows the total revenue-producing water pumped by the utility during the 10 years of analysis. Note that the abscissa is in integer number of years. This was done to facilitate later comparisons Year 1 is 1965 and year 10 is 1974. Table 3 contains the cost data collected during the 10-year period. The analysis for unit costs has been based on revenue-producing water rather than on total water pumped. Because the utility draws its water from a free-flowing river and little pumping is required, acquisition costs are small. It can be seen that the total operating cost of water supply has increased during the period of analysis from $6.7 million to $11.6 million. Support services has increased from $1.8 million to $3.8 million (Figure 3). The unit operating cost of water supply increased from $176.56/million gallons (mil gal) to $331.45/mil gal, with the greatest increase occurring under support services -- from $70.11/mil gal to $140.99/mil gal (Figure 4). Figure 5 shows that as a percent of total cost, support services increased from 39.71% to 42.54%.

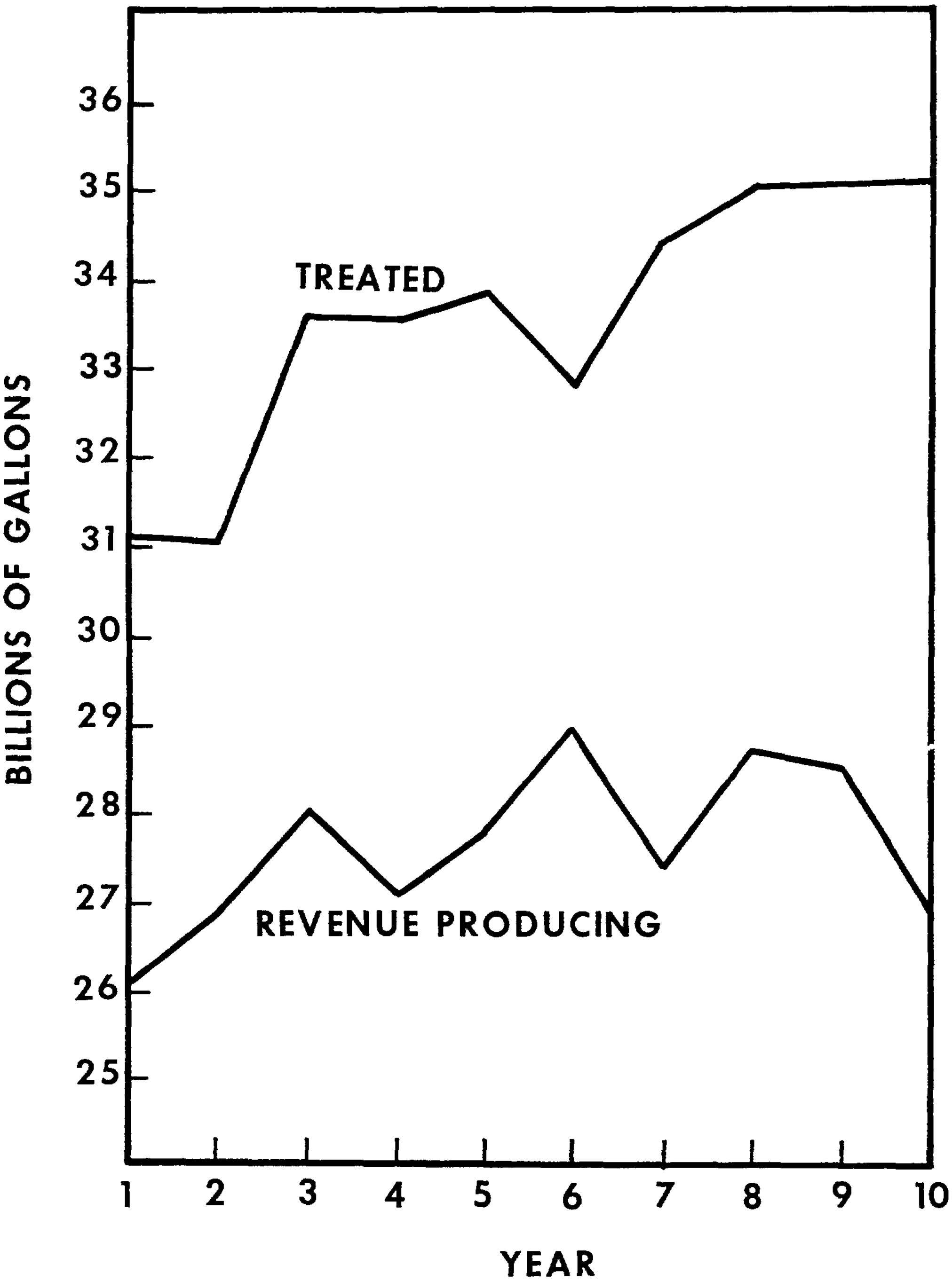

FIG. 2 TREATED AND REVENUE PRODUCING WATER FOR KANSAS CITY WATER UTILITY

TABLE 3. OPERATING AND CAPITAL COSTS FOR KANSAS CITY, MISSOURI

Item	Year									
	1	2	3	4	5	6	7	8	9	10
OPERATING COSTS:										
Support services:										
$, in millions	1.837	2.062	2.145	2.651	3.148	3.417	3.566	3.580	3.815	3.786
% of total	39.71	41.63	40.10	43.96	45.74	44.92	44.78	43.24	43.78	42.54
$/mil gal	70.11	76.43	76.43	97.68	113.09	118.29	129.99	124.61	135.43	140.99
Acquisition:										
$, in millions	0.233	0.230	0.251	0.277	0.307	0.318	0.337	0.350	0.365	0.374
% of total	5.04	4.64	4.69	4.59	4.46	4.16	4.23	4.23	4.19	4.20
$/mil gal	8.90	8.52	8.94	10.20	11.03	10.97	12.28	12.19	12.96	13.92
Treatment:										
$, in millions	1.018	1.086	1.195	1.196	1.291	1.535	1.562	1.716	1.883	1.999
% of total	22.00	21.92	22.33	19.84	18.74	19.70	19.62	20.73	21.61	22.45
$/mil gal	36.84	40.25	42.57	44.08	46.33	51.87	56.96	59.73	66.84	74.42
Power and pumping:										
$, in millions	0.955	0.946	1.030	1.138	1.260	1.306	1.384	1.438	1.500	1.537
% of total	20.64	19.10	19.26	18.87	18.31	17.09	17.38	17.38	17.21	17.27
$/mil gal	36.44	35.07	36.71	41.93	45.27	45.05	50.45	50.09	53.24	57.24
Transmission and distribution:										
$, in millions	0.584	0.629	0.729	0.769	0.878	1.068	1.113	1.196	1.152	1.205
% of total	12.61	12.71	13.63	12.75	12.76	14.03	13.98	14.44	13.21	13.54
$/mil gal	22.27	23.33	25.98	28.32	31.55	36.95	40.58	41.62	40.88	44.87
Total operating costs:										
$, in millions	4.627	4.954	5.349	6.031	6.883	7.644	7.962	8.280	8.716	8.902
$/mil gal	176.56	183.60	190.61	222.20	247.23	263.61	290.27	288.18	309.37	331.45

TABLE 3 (Continued). OPERATING AND CAPITAL COSTS FOR KANSAS CITY, MISSOURI

Item	Year									
	1	2	3	4	5	6	7	8	9	10
CAPITAL COSTS:										
Depreciation ($, in millions)	1.009	1.043	1.056	1.065	1.098	1.118	1.157	1.202	1.264	1.315
Interest ($, in millions)	1.064	1.067	0.981	0.940	1.061	1.207	1.519	1.456	1.407	1.351
Total capital costs ($, in millions)	2.073	2.110	2.037	2.006	2.159	2.325	2.676	2.658	2.671	2.666
TOTAL OPERATING AND CAPITAL COSTS:										
$, in millions	6.700	7.064	7.386	8.037	9.042	9.968	10.639	10.938	11.387	11.567
$/mil gal	255.65	241.15	263.21	296.10	324.84	345.03	387.82	380.71	404.18	430.74

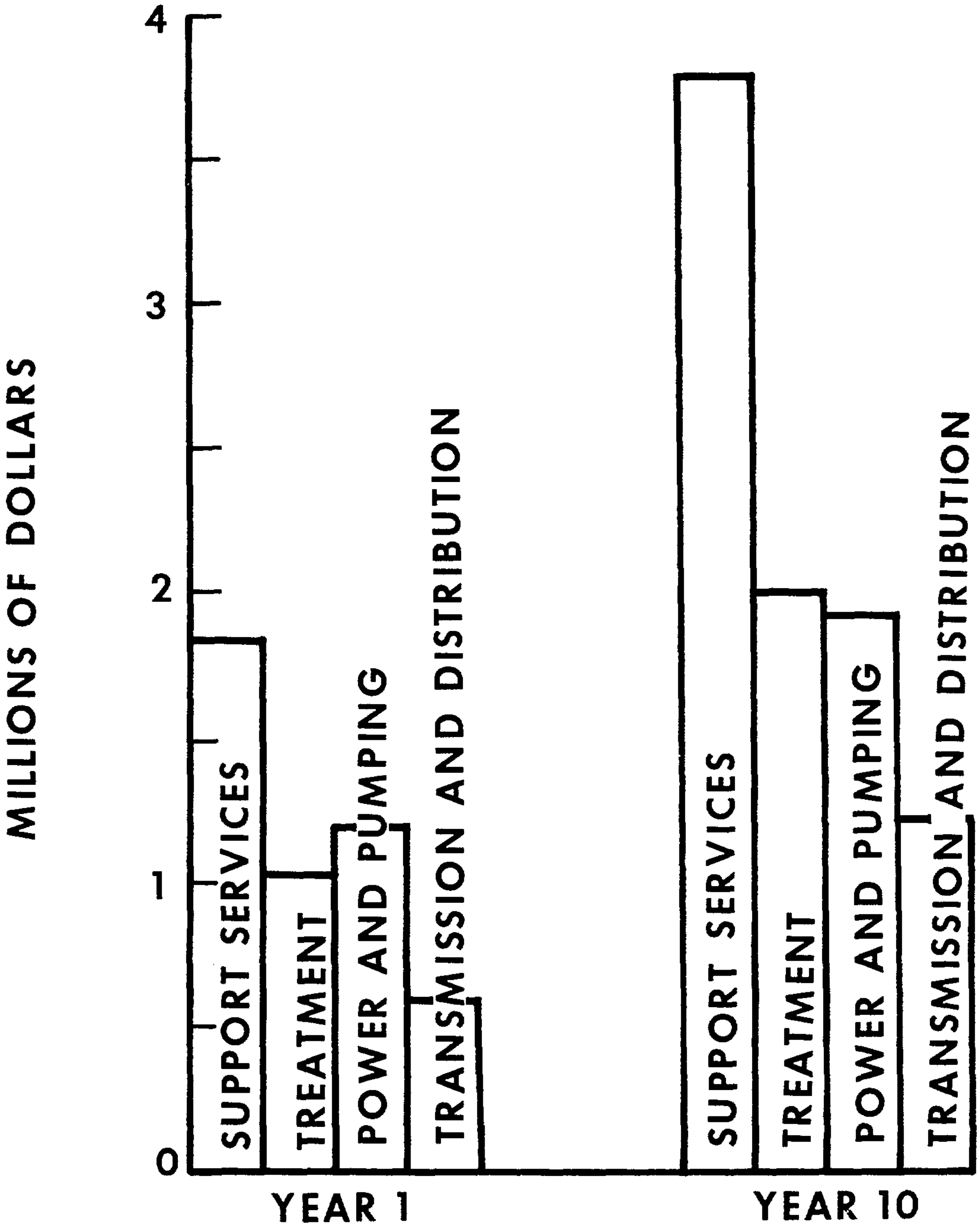

FIG. 3 OPERATING COSTS FOR KANSAS CITY WATER UTILITY

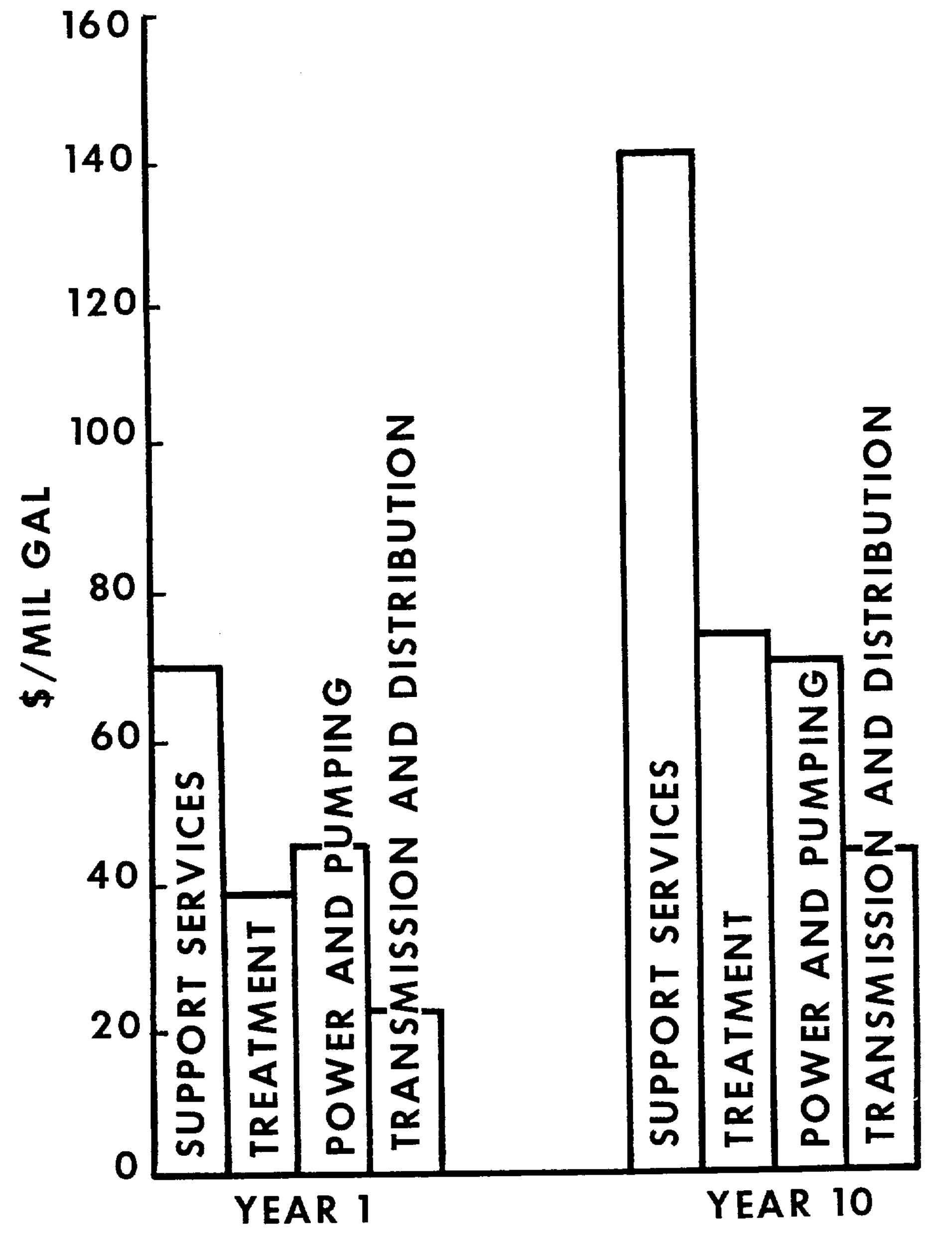

FIG. 4 OPERATING COSTS IN $/MIL GAL FOR KANSAS CITY WATER UTILITY

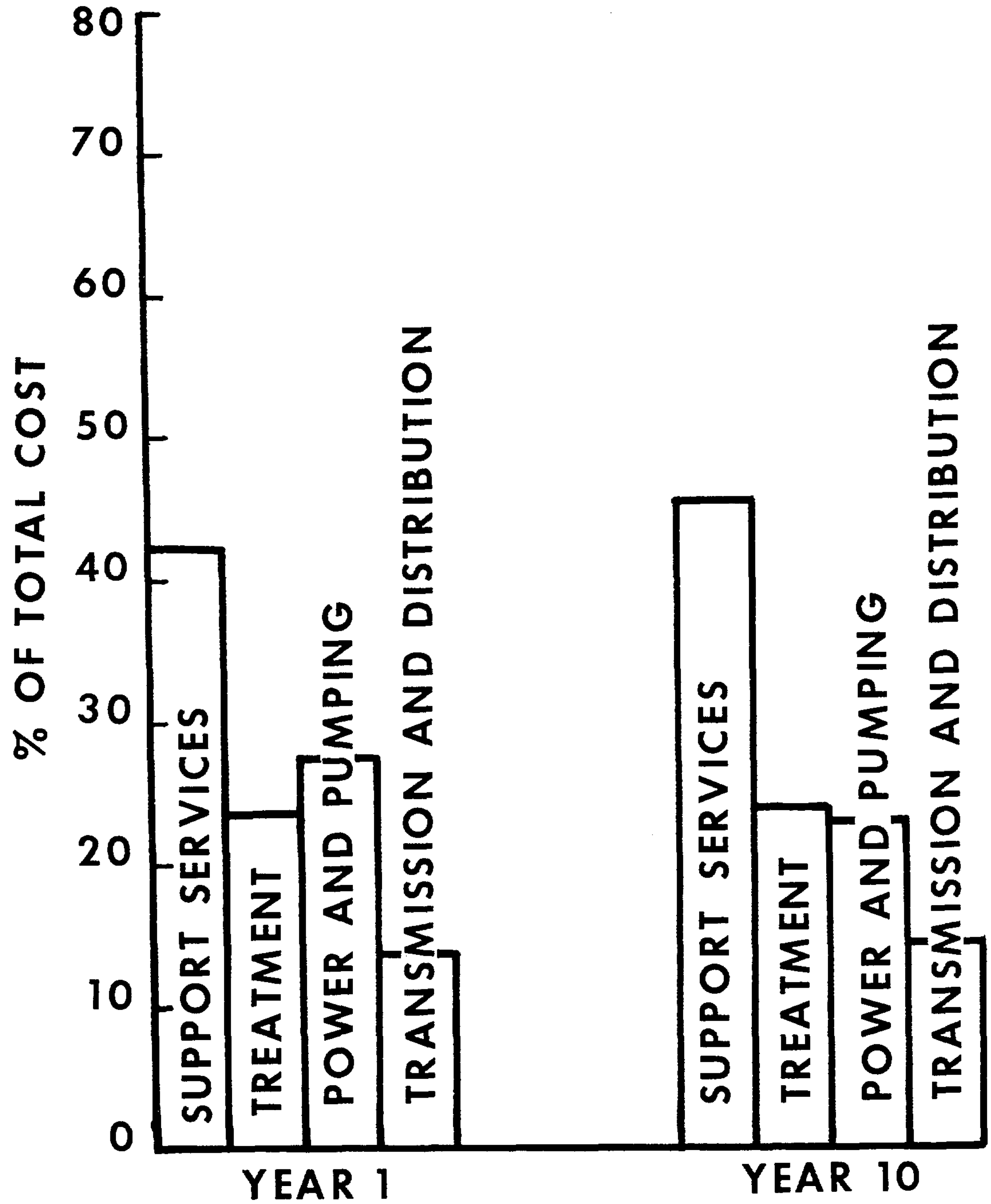

FIG. 5 OPERATING COSTS AS PERCENT OF TOTAL COST FOR KANSAS CITY WATER UTILITY

Figure 6 shows the shift in operating expenditures relative to capital expenditures. The utility is becoming less capital intensive on a historical cost basis over the 10-year period.

Figure 7 shows the total operating and capital expenditures over time. The slope of the operating cost curve is much steeper than capital cost.

Figures 8 and 9 show total and unit costs, respectively. Each expenditure category has been corrected by the CPI assuming 1965 as the base year. The slopes of the total and unit costs are much flatter than for the historical costs. Corrected unit costs have increased slightly over time.

The data presented in the previous section can be used to develop insights into the ways that the cost of water varies throughout the distribution system.[5,8] Figure 10 is a schematic diagram of the utility service area. Water is taken into the system at the intake (denoted by I in the diagram), passed through the Treatment plant (T), and pumped north through a high head system (P_N) and south by a low head system (P_S). To the south, the water passed through a tunnel/flow line to a set of reservoirs and repumping stations (RPS_1 and RPS_2) and then to another set of reservoirs and repumping stations (RPS_3 and RPS_4). Stations RPS_1 and RPS_2 serve the distribution area denoted as zone 3 on the schematic diagram, and stations RPS_3 and RPS_4 serve zone 4. The high head pumping station PN is designed so that it can serve zone 2 directly as well as pump water to the reservoir and pumping station denoted by RPN.

The costs shown in Figure 10 were derived from the current depreciation and operating cost for each component. Once derived, the costs can be divided by the amount of revenue-producing water passing through the facility or transmission line, yielding a cost for that given component in dollars per million gallons ($/mil gal). Transmission costs shown in Table 4 are derived this way. As water moves from one facility to another, the unit costs are added. Table 4 shows the cost per million gallons for water transmitted from T to RSP_1 and RSP_2 is $9.12/mil gal.

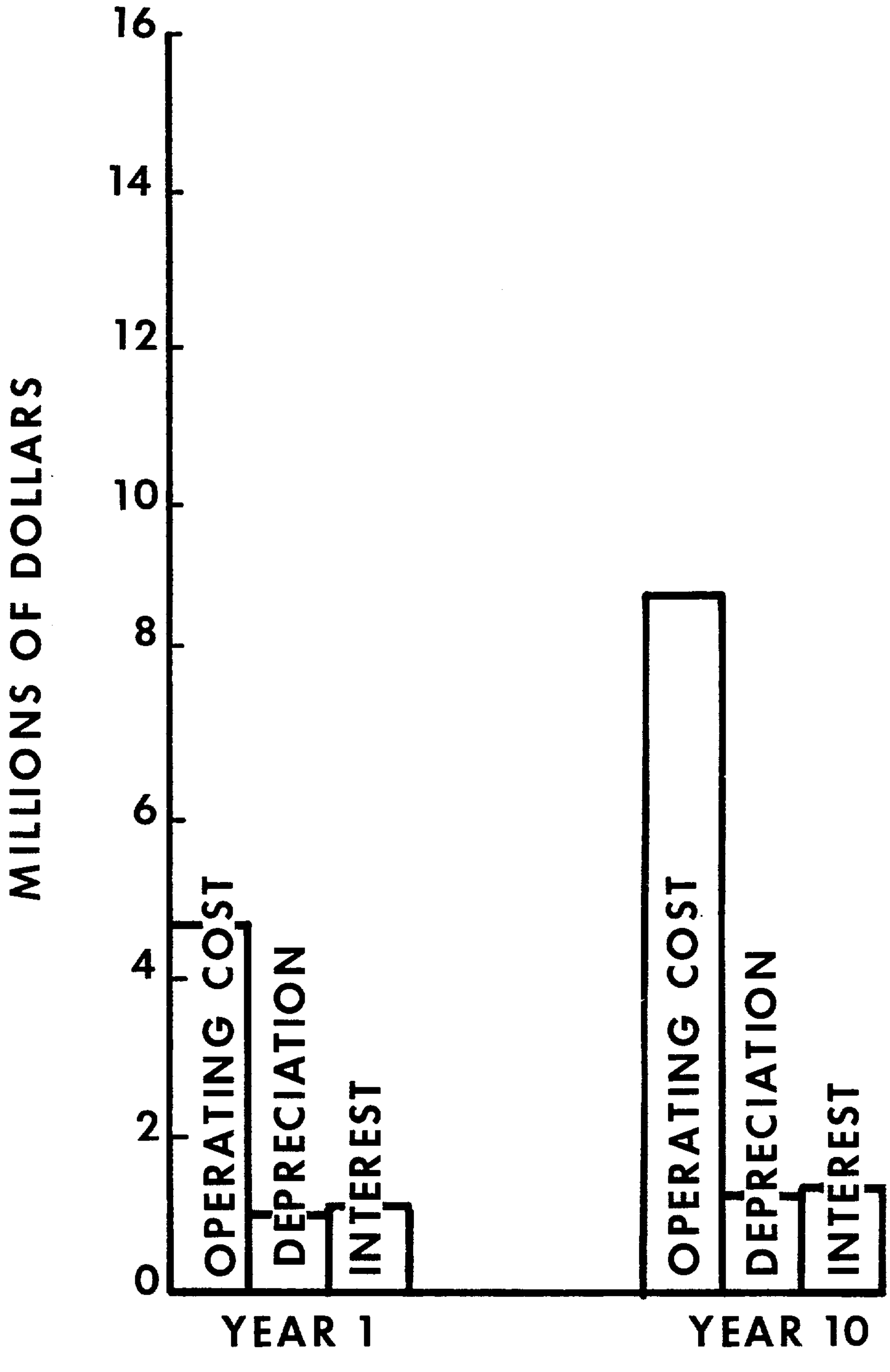

FIG. 6 CAPITAL AND OPERATING COSTS FOR KANSAS CITY WATER UTILITY

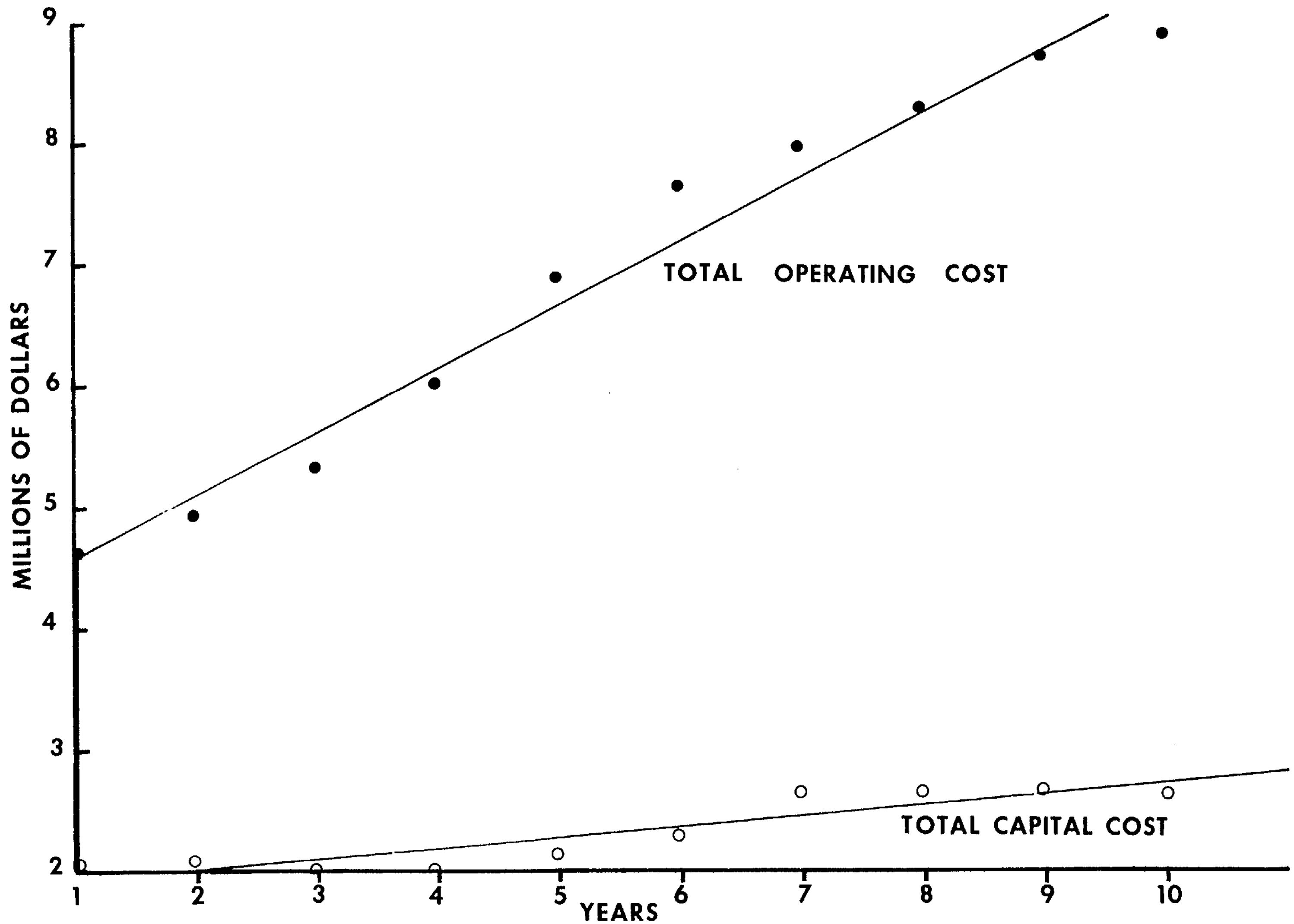

FIG 7 OPERATING AND CAPITAL EXPENDITURES FOR KANSAS CITY WATER UTILITY

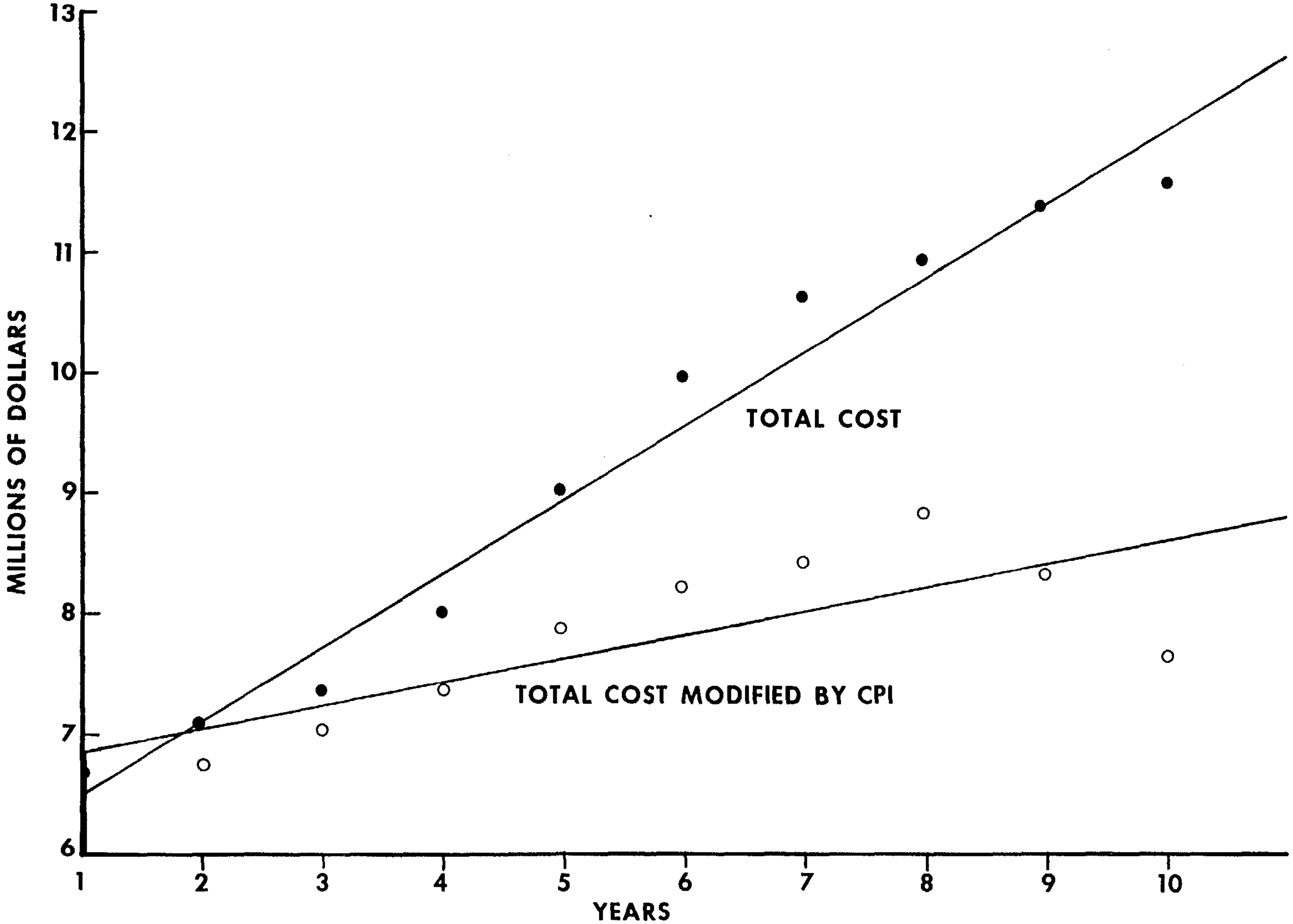

FIG. 8 TOTAL EXPENDITURES VERSUS TIME FOR KANSAS CITY WATER UTILITY: HISTORICAL AND MODIFIED COSTS

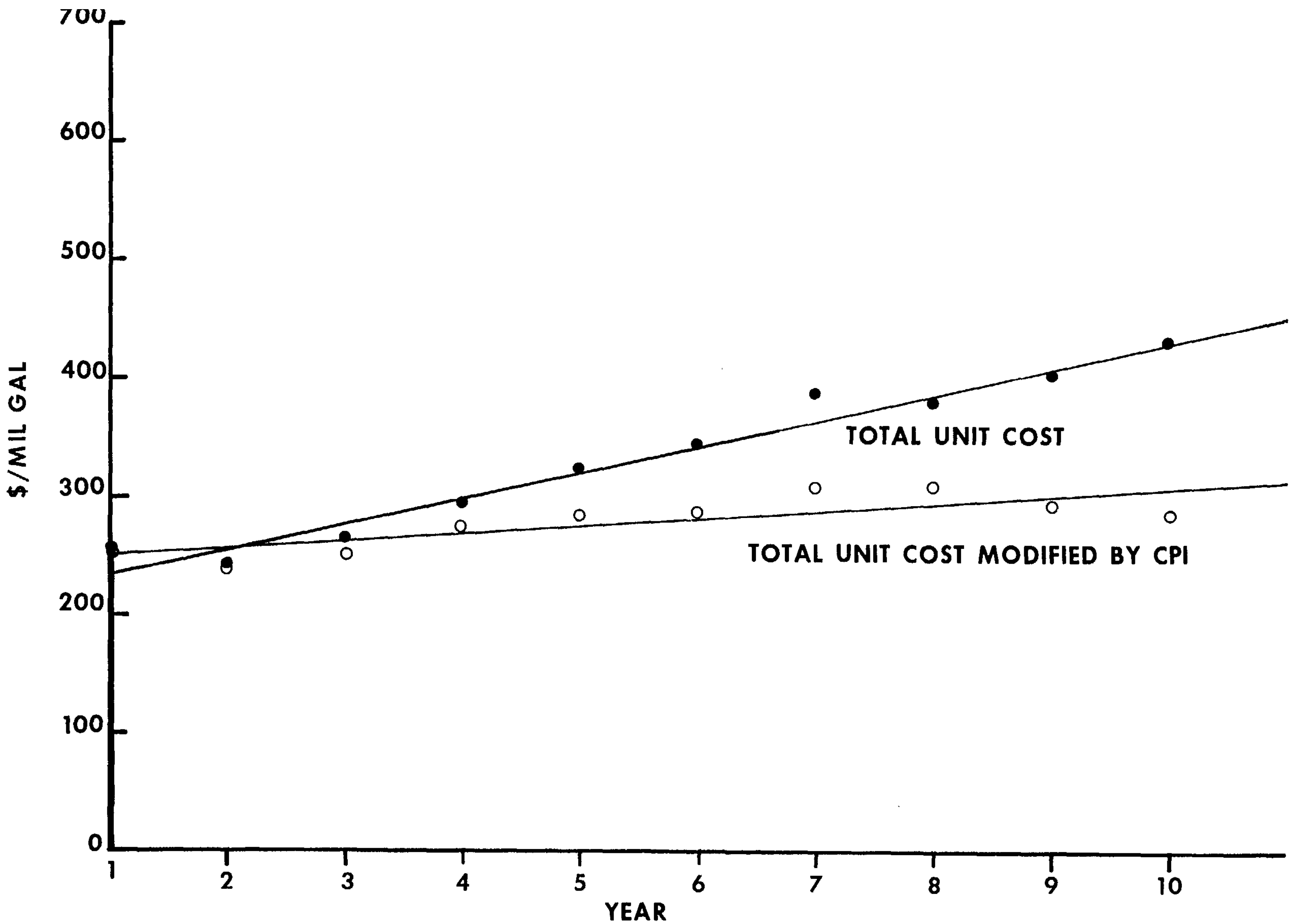

FIGURE 9 UNIT COSTS FOR KANSAS CITY WATER UTILITY: HISTORICAL AND MODIFIED

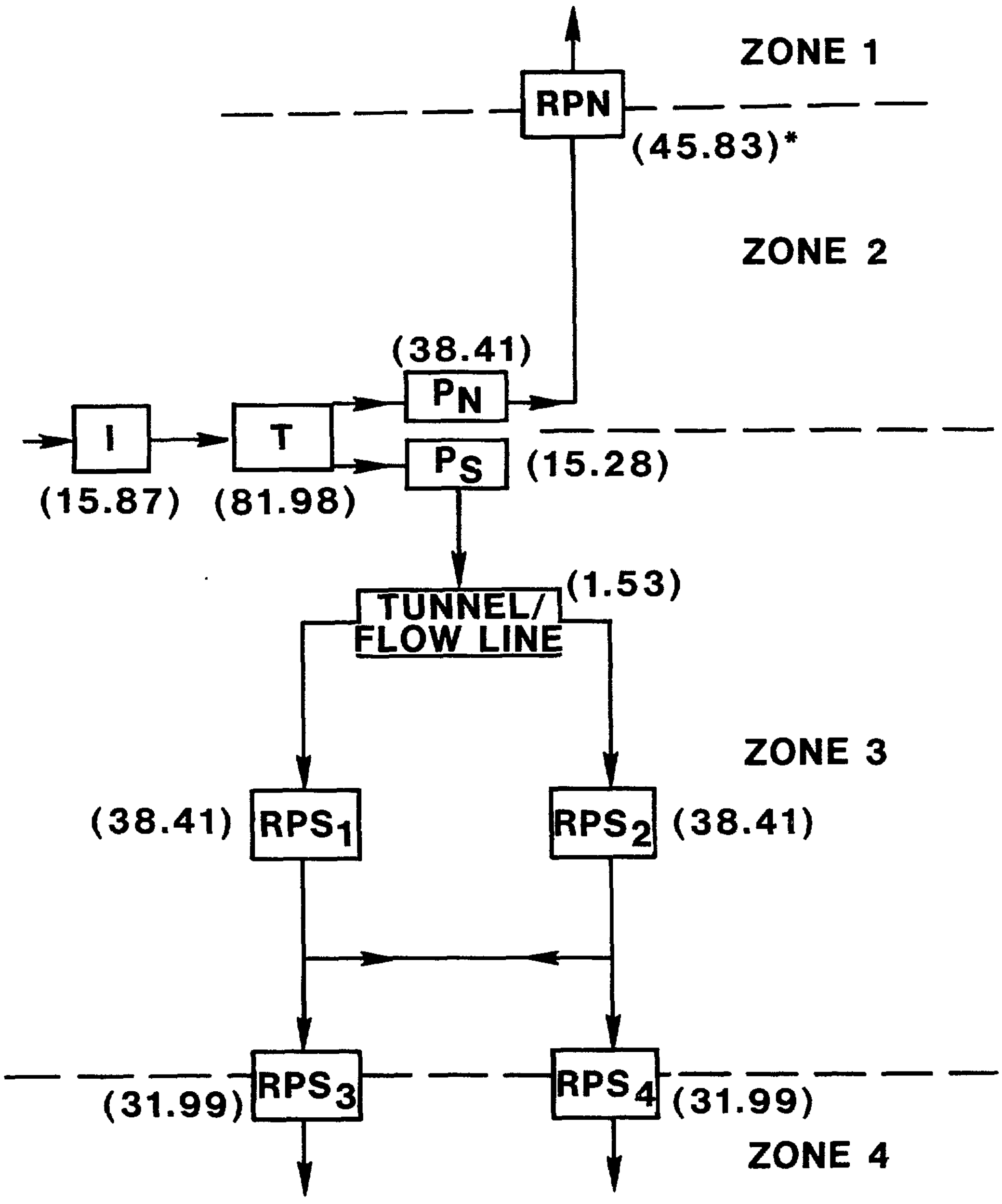

FIG. 10 SCHEMATIC DIAGRAM OF KANSAS CITY SERVICE AREA

***(COSTS IN $/MIL GAL OF REVENUE PRODUCING WATER)**

TABLE 4. TRANSMISSION COSTS BETWEEN FACILITIES IN SERVICE AREA ($/mil gal)

From	To			
	P_N	RPN	RPS_1 and RPS_2	RPS_3 and RPS_4
T	10.69	---	9.12	---
P_N	---	13.21	---	---
RPS_1 and RPS_2	---	---	---	13.27

Each zone represents a consumer service area and a demand point for delivered water. For purposes of this analysis, an attempt was made to discriminate between the water transmitted from one distribution area to another.

Using data for the most recent year, the capital and operating costs for each facility were computed as shown in Figure 10. When a unit of water moves through one facility to another distribution zone, the unit costs of moving the water from one facility to another are added, thereby creating the unit costs for distribution interest, and overhead to yield a total average unit cost to serve each zone.

Distribution costs are obtained by dividing the total operating and capital (depreciation) costs associated with the distribution system by the total revenue-producing water, and the assumption is made that the cost of a distribution system is essentially constant throughout the system.

Costs for interest and support services are calculated in this same manner. Some argument could be made that the interest cost should be proportional to the capital cost for a facility and that support services costs will vary, depending on consumption. However, the burden and difficulty of making these allocations proved to beyond the scope of the study.

To illustrate how the costs in Table 5 are obtained, we can work through the following example. Incremental costs for zone 3 are obtained by adding the costs in $/mil gal for the intake facility, the treatment plant, the facility costs for the pumping station (P_S). the facility costs for the

TABLE 5. INCREMENTAL COST FOR SERVICE ZONES
($/mil gal)

Zone number	Incremental cost	Distribution costs	Interest costs	Support services costs	Total costs	Metered consumption (mil gal/yr)	Revenue recovered
1	205.40	61.05	50.32	144.52	461.33	458	211,289
2	146.36	61.05	50.32	144.52	402.25	2,072	833,462
3	163.19	61.05	50.32	144.52	419.43	17,383	7,290,952
4	208.45	61.05	50.32	144.52	464.34	6,942	3,223,448

tunnel/flow line, the facility costs for RPS_1 and RPS_2, and the transmission costs from T to RPS_1 and RPS_2. To this incremental cost we add the constant distribution cost, interest cost, and support services cost, yielding a total of $419.43/mil gal. Table 5 gives the cost for each zone in $/mil gal and the metered consumption in each zone (mil gal/year). The last column in Table 5 is revenue generated from each zone. The total revenue calculated in this manner is close to the revenue required to cover costs for the latest water year (Table 3).

The costs for each zone, plotted in Figure 11, are described by a step function. As water is pumped and moved to a new zone, the costs take a definable jump. This step function suggests that diseconomies of scale may result as the network for delivering water increases in size. Dajani and Gemmell confirm this observation in their study of the cost of treatment and transportation systems for wastewater.[9] They believe that a number of smaller and simpler networks may be more economical than a large enveloping system, and that a multiple plant treatment system may be called for. Following this logic, we might hypothesize a situation in which an extension of the service area beyond zone 1 (to the north) is contemplated, thereby creating a new zone, la. Figure 12 shows the costs for zones 1 and 2 north of the treatment plant and the assumed cost for the new zone la, given that additional pumping and storage facilities and possibly expanded plant capacity are required to service the area. This cost curve is represented by a dotted line and assumes that the additional cost to serve zone la is approximately $32/mil gal.

If the option of building another plant were available (and in this study area it is), and if the plant could be operated in such a way as to achieve reasonable economies of scale, then the cost curve for zone la might look like the solid line in Figure 12. In this case, the cost savings resulting from the new plant's construction would be represented by the area formed by the dotted and solid lines in zone la, as shown in Figure 12.

The step functions that represent the cost curves are only approximations to the actual costs. However, the curves serve a useful purpose for approximating the costs to a given service zone, and they illustrate the difference in costs as a function of distance for transporting water to the consumer's tap.

Because of the simplicity of the Kansas City distribution system (one treatment plant), it represents an ideal case study area for relating the cost of water supply to distance transported.

CINCINNATI WATER WORKS

The Cincinnati Water Works' service area lies almost entirely within Hamilton County, Ohio, with fringe extensions into three adjoining counties. Although for the most part they are surrounded by the Cincinnati Water Works service area, a number of communities maintain their own systems. Emergency service is provided to most of them, but as long as their source of supply can be maintained, most of the communities will not change their present status.

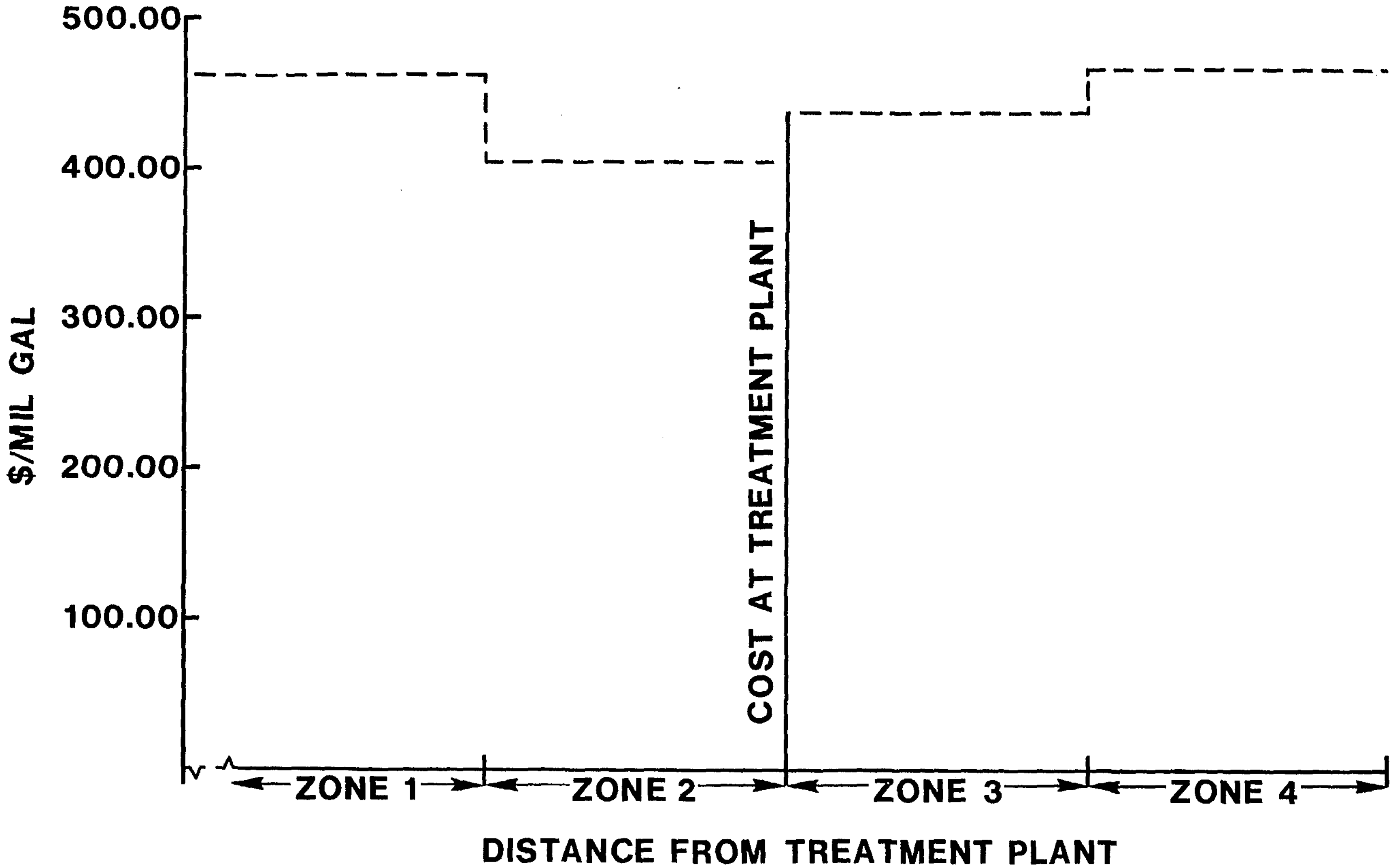

FIG. 11 COSTS BY SERVICE ZONES

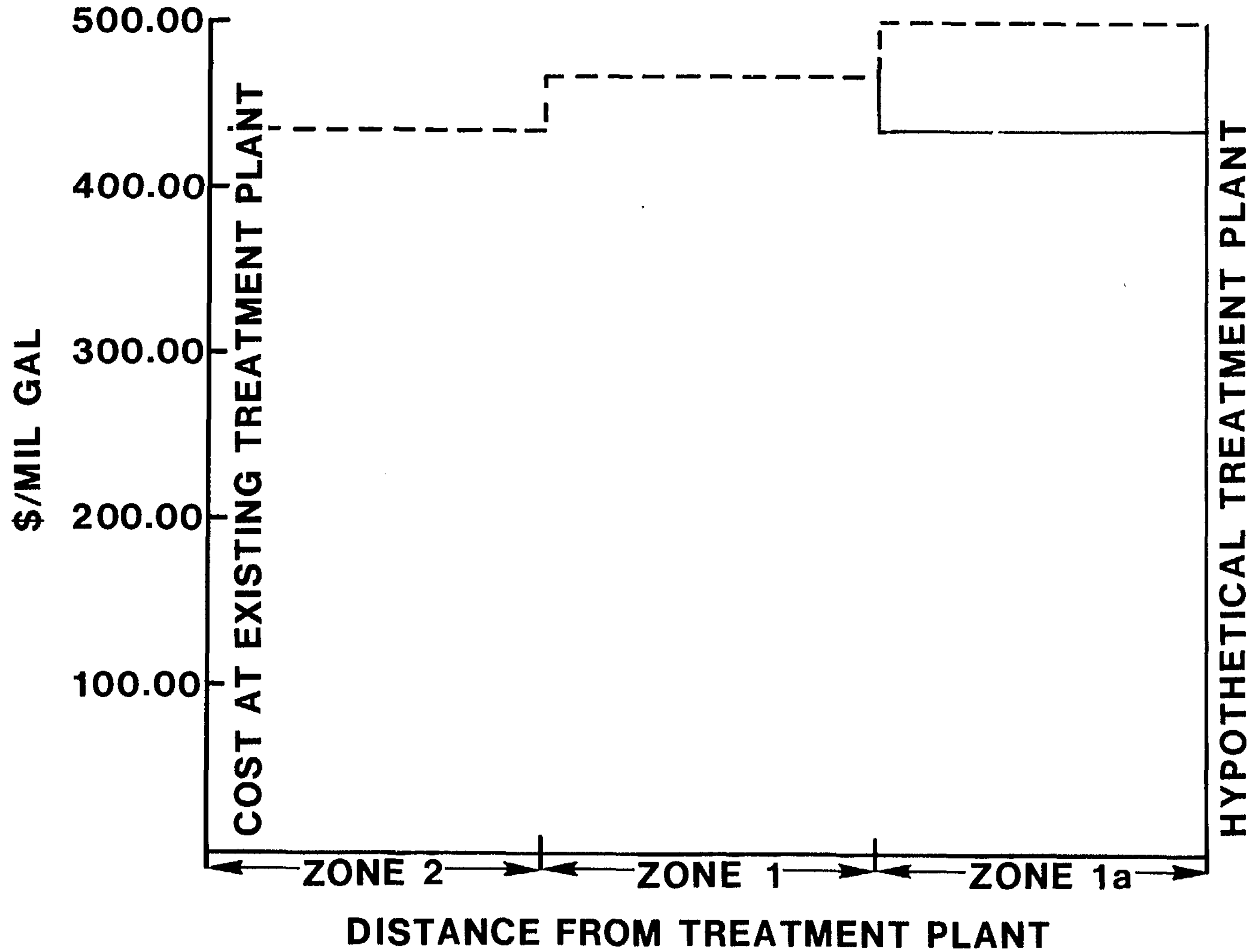

FIG. 12 COST IN EXISTING NORTHERN SERVICE ZONES PLUS HYPOTHETICAL ZONE

The current source of supply is the Ohio River. Water is pumped from the river to two presettling reservoirs on a municipal golf course near the river, and is then pumped to a single treatment plant with a capacity of 235 million gallons per day (MGD). In 1974 the plant treated an average of 136 MGD. To the north and west, water passes through two gravity tunnels and two pump stations into a large reservoir; it is then repumped into outlying service areas.

Cost Analysis

Figure 13 shows the treated water and metered (revenue-producing) water pumped by the utility during the period of analysis. All cost data are based on revenue-producing water. Figure 13 shows the total water pumped exceeded revenue-producing water by nearly 13 billion gallons during the final year of analysis.

Table 6 contains the total operating cost for each of the previously mentioned categories. Support services includes all operating costs that support but are not directly chargeable to the production of water -- general administration, accounting and collection, and meter reading, for example. Treatment includes costs related to operating the laboratory, labor involved in the treatment function, chemicals for purifying the water, and maintenance of the treatment plant. Power and pumping includes costs related to operating labor, maintenance, and power and pumping water throughout the service area. The transmission and distribution category includes the operating labor and maintenance costs associated with supplying water to the consumer.

Costs for support services have more than doubled in the 10-year period (see Table 6 and Figure 14). Although all of the other cost categories increased during this period, their rate of increase was less than that of support services. Total operating costs increased by about 65%.

Table 6 also contains the average unit operating costs for each major category based on the number of revenue-producing gallons pumped in a given year. As shown, all cost categories ($/mil gal) increased by a factor of less than two. Unit operating costs increased by about 40% (Figure 15).

Each cost category is presented as a percent of total operating cost. Support services accounted for a significant portion of the utility's budget, increasing from approximately 26% to 31.5%. The other cost categories either decreased or remained constant (Figure 16).

Depreciation and interest are defined as the capital expenses for the water works system. These capital expenses remained essentially constant, but operating expenses increased by approximately 65% (Figure 17). Table 6 shows the percent of expenditures allocated to capital decreased from approximately 27% to 22% during the period of analysis.

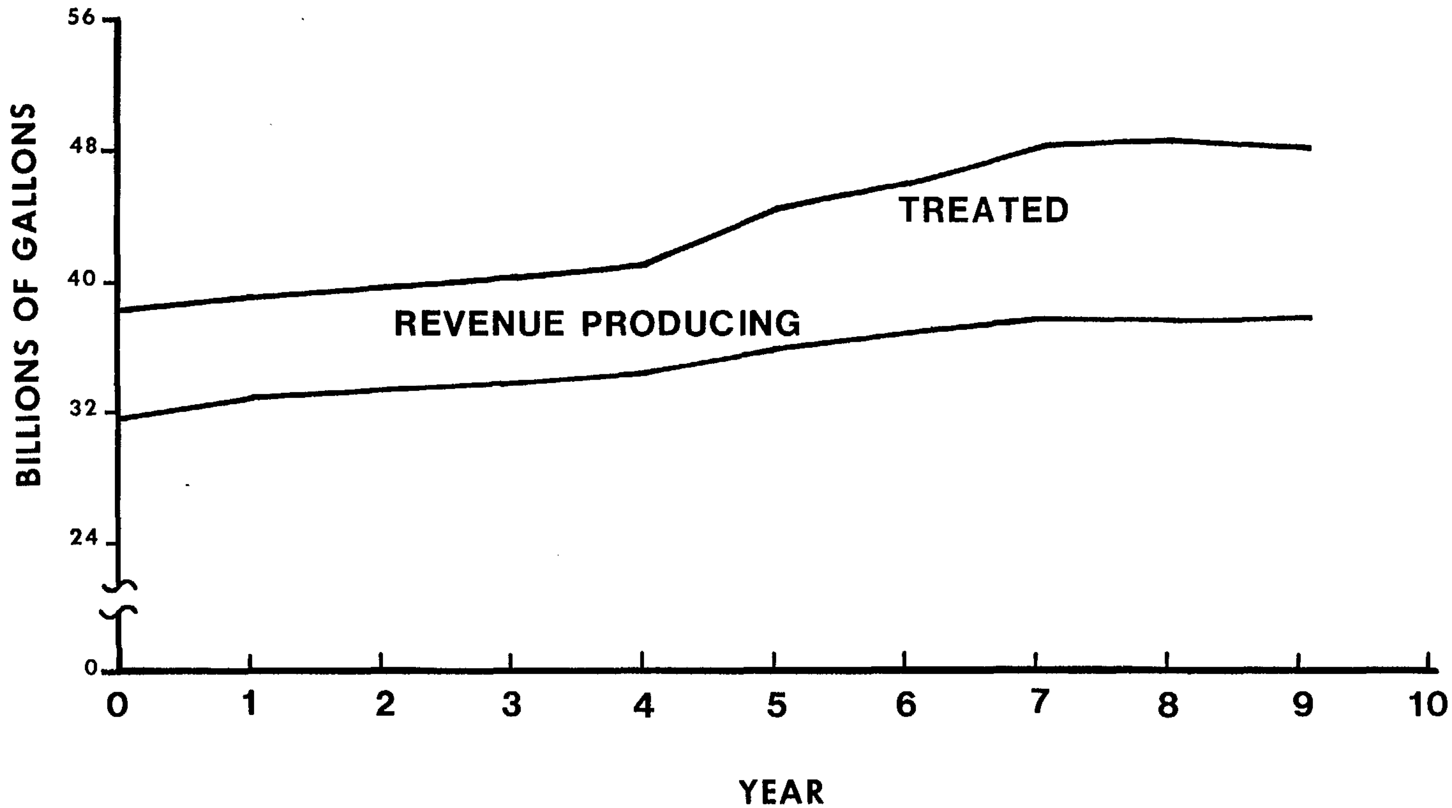

FIG. 13 TREATED AND REVENUE PRODUCING WATER FOR CINCINNATI WATER UTILITY.

TABLE 6. OPERATING AND CAPITAL COSTS FOR CINCINNATI WATER WORKS

Item	Year 1	2	3	4	5	6	7	8	9	10
OPERATING COSTS:										
Support services:										
$, in millions	1.360	1.331	1.413	1.499	1.616	2.109	2.081	2.371	2.633	2.766
% of total	25.6	25.2	25.2	24.9	26.1	29.9	28.6	29.1	30.7	31.5
$/mil gal	42.41	40.24	41.90	43.87	46.55	58.25	56.06	62.20	69.43	72.60
Acquisition:										
$, in millions	0.395	0.369	0.3724	0.372	0.380	0.405	0.427	0.496	0.480	0.485
% of total	7.4	7.0	6.7	6.2	6.1	5.8	5.9	6.1	5.6	5.5
$/mil gal	12.25	11.15	11.10	10.90	10.94	11.19	11.50	13.02	12.66	12.73
Treatment:										
$, in millions	0.913	0.906	0.934	1.005	1.012	1.041	1.065	1.165	1.240	1.210
% of total	17.2	17.2	16.6	16.7	16.4	14.8	14.6	14.3	14.4	13.8
$/mil gal	28.48	27.42	27.69	29.41	29.14	28.76	28.69	30.54	32.70	31.75
Power and pumping:										
$, in millions	1.086	1.115	1.182	1.256	1.247	1.412	1.382	1.638	1.635	1.667
% of total	20.5	21.1	21.0	20.9	20.2	20.0	19.0	20.0	19.0	19.0
$/mil gal	33.88	33.74	35.07	36.77	35.92	39.01	37.23	42.97	43.10	43.75
Transmission and distribution:										
$, in millions	1.558	1.554	1.711	1.885	1.928	2.084	2.323	2.487	2.606	2.654
% of total	29.3	29.5	30.5	31.3	31.2	29.5	31.9	30.5	30.3	30.2
$/mil gal	48.60	47.00	50.74	55.19	55.52	57.57	62.58	65.23	68.72	69.65
Total operaing costs:										
$, in millions	5.310	5.275	5.615	6.017	6.183	7.051	7.277	8.158	8.595	8.782
$/mil gal	165.62	159.55	166.50	176.14	178.07	194.78	196.06	213.96	226.61	230.48

TABLE 6 (Continued). OPERATING AND CAPITAL COSTS FOR CINCINNATI WATER WORKS

	Year									
	1	2	3	4	5	6	7	8	9	10
CAPITAL COSTS:										
Depreciation ($, in millions)	1.177	1.230	1.422	1.550	1.605	1.634	1.632	1.657	1.699	1.771
Interest ($, in millions)	0.826	0.947	0.927	0.877	0.887	0.887	0.793	0.802	0.711	0.669
Total capital costs ($, in millions)	2.003	2.177	2.349	2.427	2.492	2.521	2.425	2.459	2.410	2.440
TOTAL OPERATING AND CAPITAL COSTS:										
$, in millions	7.314	7.452	7.964	8.444	8.665	9.571	9.702	10.617	11.005	11.223
$/mil gal	228.10	225.41	236.14	247.19	249.56	264.41	261.39	278.45	290.14	294.54