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Research and Development

Managing Small Water Systems: A Cost Study

Volume I

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MANAGING SMALL WATER SYSTEMS: A COST STUDY

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 the 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.

The Safe Drinking Water Act of 1974 establishes primary health-related standards and secondary aesthethic-related but nonenforceable guidelines for drinking water supplies. These standards will bring about a fundamental examination of 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 23 selected small 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. The data and associated analyses presented in two volumes. Volume I is a summary of selected data from the study along with analyses of the data. Volume II contains detailed in-depth information for each utility studied.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

EXECUTIVE SUMMARY

This two-volume report is the culmination of a study of 30 selected small water utilities located in EPA regions III, V, and VI, conducted to examine the cost of water supply.[1] Volume I of this report contains a summary of the small utilities data, presents a statistical evaluation of the factors affecting the cost of water supply, and contains an evaluation of the cost impact of add-on technologies to satisfy the requirements of the Safe Drinking Water Act. It represents an in-house analysis of the data collected under Contract 68-03-2071. After careful consideration, only data from 23 of 30 utilities visited were considered complete enough for inclusion in this report. These data represent a variety of water utilities. Some are private, others public; there are surface and ground sources; and, while most may be considered small, a few are significantly greater than the others in size. Volume II contains the basic data for each of the 23 selected utilities as well as summary system descriptions.

Data were collected for a 10-year period on four major operating-maintenance (O&M) components, three significant O&M subelements, and the capital costs associated with depreciation and interest. The O&M cost components are support services, acquisition, treatment, and distribution.[2] Chemical, payroll, and power are three elements contained in each of the other four components, but are considered separately because of their individual impacts on operating expenditures. Depreciation expense for each major cost component was also obtained in order to examine the relative capital intensiveness of the components.

Revenue-producing water (RPW) is used as the basis for all calculations since it represents the means by which utilities obtain their revenue. RPW also aids in comparison between utilities, but may be easily converted to total treated water.

Total costs not including taxes during the most recent year of the study for each of the 23 utilities are provided in Table 1. The name of the utility and the average revenue-producing water produced per day are also presented.

Individual and comparative analyses of the cost variables have revealed certain trends. The distribution category remains the most significant cost component, though other components have increased more rapidly in cost. Labor

Table 1. SUMMARY OF RESULTS FROM UTILITIES STUDIED

Utility	Revenue-producing water (MGD)	Cost Categories ($/MG)					
		Support Services	Acquisition	Treatment	Distribution	Interest	Total
Killeen	4.39	62	181	1	230	94	568
Manassas Park	0.28	303	106	0	72	135	616
Algonquon	0.27	2	20	2	56	35	114
Colony MUD #1	0.19	489	241	40	1997	248	3015
Cockrell Hill	0.28	166	394	0	204	26	791
Belton	0.98	91	317	1	335	33	778
Bell Co. WCID #1	15.28	12	28	27	50	22	139
Batavia	0.13	133	78	128	729	298	1366
Culpepper	0.71	96	0	351	368	133	948
Dallas Co. WCID #6	0.92	199	274	0	272	203	948
Honeybrook Borough	0.11	34	116	38	94	119	401
Great Valley Water Co.	1.05	223	223	112	201	81	840*

* Taxes = $26/MG

(Continued)

Table 1. (Continued)

Utility	Revenue-producing water (MGD)	Cost Categories ($/MG)					
		Support Services	Acquisition	Treatment	Distribution	Interest	Total
Audubon Water Co.	0.39	373	218	16	124	227	957*
Taylor	0.78	157	97	31	428	95	809
Lebanon	0.67	173	141	117	671	116	1218
Burlington	0.06	131	124	110	273	0	638
Downingtown	0.86	174	49	172	243	15	653
West Dundee	0.34	42	159	12	160	0	373
Manassas	1.25	103	135	477	268	439	1423
Lowell	0.42	285	152	119	536	139	1231
Lake Zurich	0.68	71	118	21	307	264	781
Georgetown	0.86	122	16	13	290	58	500
Denton	6.35	35	46	138	167	88	475

* Taxes = $2/MG

costs represent a significant part of total O&M cost and, in many cases, have more than doubled over the 10-year study period. A mathematical relationship has been developed which relates labor cost and productivity to a measure of capital cost and productivity. In this manner, cost impacts of increased output can be examined in relation to payroll and capital expenditures. The effect of inflation on the utility budget has also been analyzed.

Six of the 23 utilities studied were identified as having problems with meeting finished water requirements. Using historical cost trends and costs of new treatment technologies the costs for meeting requirements of the Safe Drinking Water Act were examined. Figure 1 shows the historical and projected costs for meeting the drinking water act requirements. On the average, the costs for 23 utilities increase by less than 5%, but extreme increases of more than 100% can occur, as discussed in the text.

It is hoped that the basic data in conjunction with the analyses presented in this report will aid utility managers in understanding the effects of inflation and control over the cost of water supply.

This report covers a period from 1967 to 1976 and work was completed as of 1977.

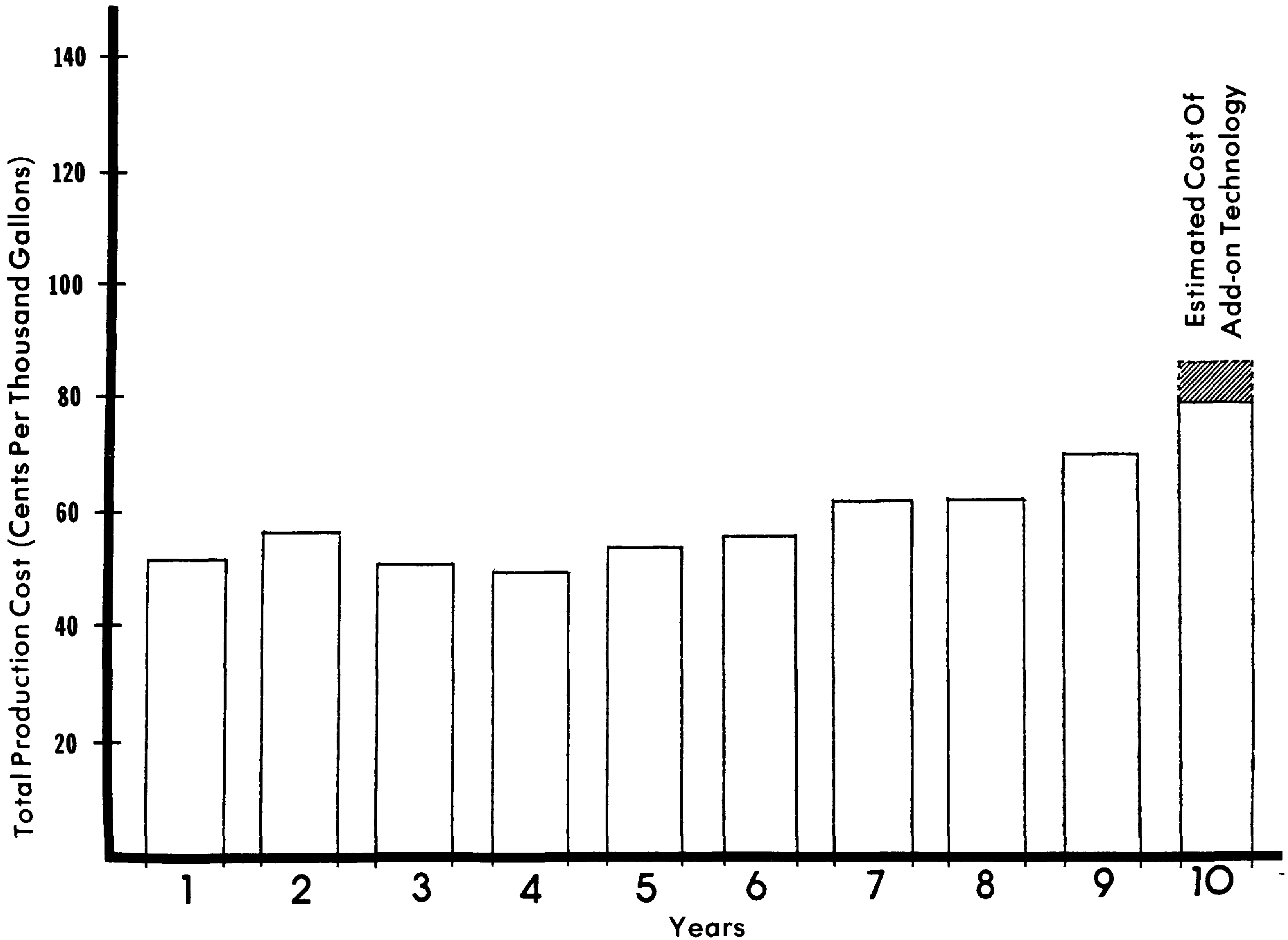

Figure 1. Average production cost for all utilities with estimated cost of add-on technology.

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FIGURES

FIGURES (Continued)

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ABBREVIATIONS AND DEFINITIONS

Cost	--	expense of water production
kwh	--	kilowatt hours
Maximum/day maximum hour	--	maximum day flow for the year in MGD/maximum hour flow for the year in MGD
MGD	--	million gallons per day
mil gal	--	million gallons
Price	--	amount charged user
Retail service area	--	area in which water is retailed by the utility
Revenue-producing water (RPW)	--	the water measured as metered consumption and paid for by wholesale and retail customers in the service area
SMSA	--	standard metropolitan statistical area
Source water	--	raw water from ground or surface supply
Treated water	--	the amount of water treated through the water utility's treatment plant

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

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SECTION 1

INTRODUCTION

Passage of the Safe Drinking Water Act of 1974 will bring about an extensive reexamination of current water treatment methods.[3] The Act establishes primary health-related and secondary or aesthetic-related, but nonenforceable, guidelines for drinking water supplies. Throughout the Act, emphasis is placed on the need to consider the economies of water treatment and delivery.

In an attempt to examine some of these economic issues, an earlier study of 12 relatively large (revenues greater than $500,000/year) water utilities was completed.[1] This report presents results from a complementary study of 23 smaller utilities conducted in EPA regions III, V, and VI. Figure 2 identifies the location of the utilities that provide data for this study.

Data were collected in a form which permitted ease of comparison. Each utility's functions were divided into four components: support services, acquisition, treatment, and distribution. Support services includes the billing, collecting, meter reading, management, and administrative functions of a water utility.[4]

Costs were categorized as either operating or capital expenditures. Operating costs have been assigned to the four functional areas mentioned earlier: support services, acquisition, treatment, and distribution (including storage). The last three functional areas are related to the physical supply of water, and the first, support services, is related to the overall integrative responsibility of utility management. Each operating cost category includes some operating labor, maintenance, and materials costs. 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. Chemical, payroll, and power O&M are three elements contained in portions of these four O&M components, but for which separate analysis can be performed.

Capital costs include 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

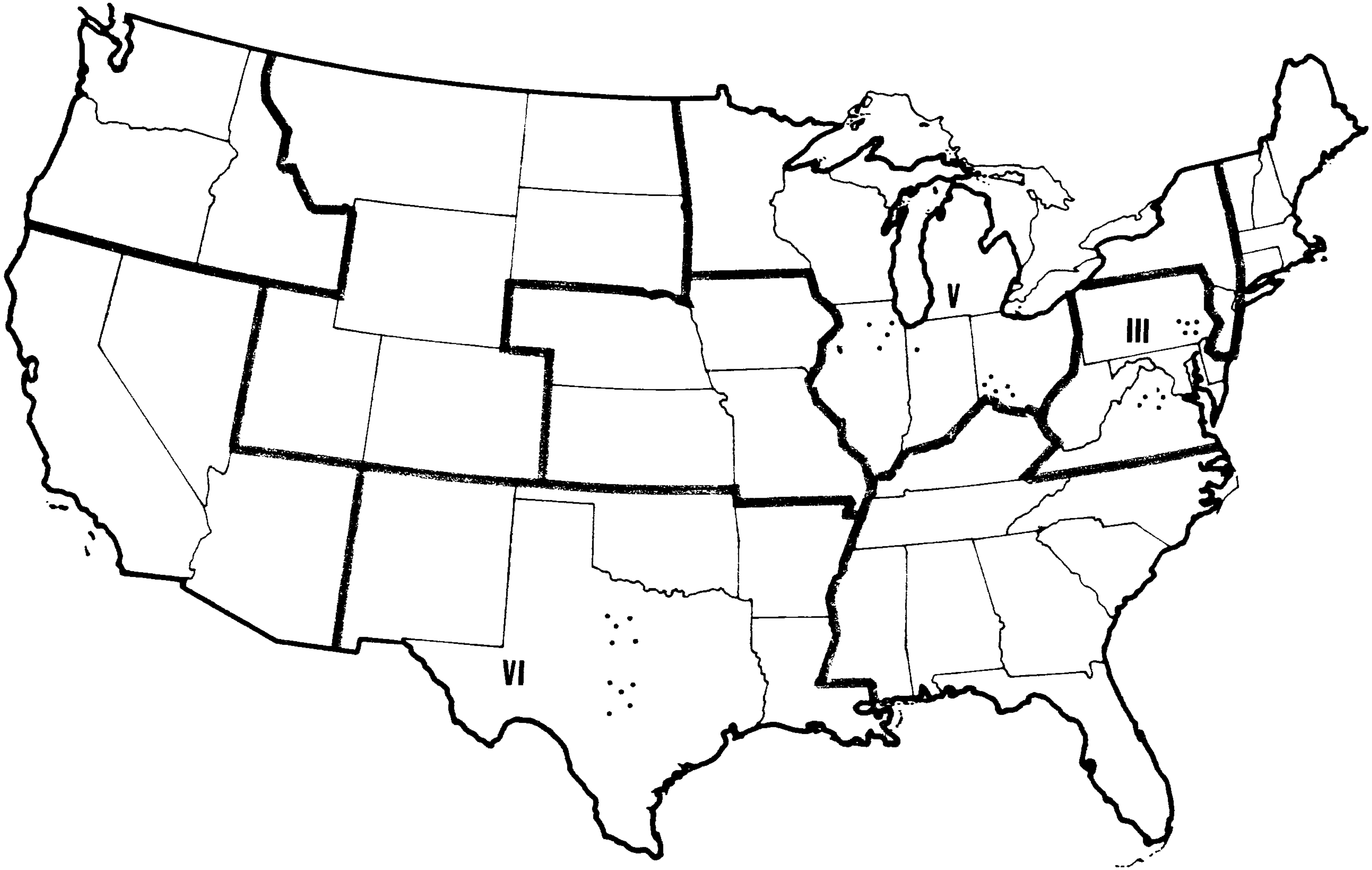

Figure 2. Water utilities under study.

facility.[5] 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 costs reported are based on revenue-producing water pumped by the utilities for a 10-year period from 1966 through 1975. Revenue-producing water was used for all cost calculations because it represents the basis on which utilities obtain their operating revenues and provides a basis for comparing productivity and costs between systems. To convert to a cost based on water produced, a simple conversion of the ratio of water sold to water produced can be used.

Raw and finished water samples were taken for each of the utilities studied. Almost all of the finished water samples were well below the maximum contaminant levels (MCLs) established by the National Interim Primary Drinking Water Standards.[6] For six utilities (at least one in each Region) in which one or more samples were either near or over the MCL, a quality problem was assumed and appropriate technology was hypothesized to solve the problem. These examples provided some indication of what a small utility in noncompliance may have to pay to meet the standards. It should be emphasized, however, that these are only examples. Actual noncompliance should be determined through more intensive monitoring than was conducted in this study.

Relationships between source quality and cost, and between pumping head and cost, have also been developed. These relationships may provide useful planning information.[7]

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

SECTION 2

CONCLUSIONS

This report provides an analysis of the underlying trends in cost and output for small water utilities as well as an estimate of the possible cost impact of the Safe Drinking Water Act. Many useful trends were developed.

These data demonstrate that costs have increased due to inflation as well as from growth in production. In general, operating costs have risen at a much faster rate than have capital costs. This differential is explained by the fact that current capital expenses are due to depreciation and interest from an investment in a prior year. If capital could be revalued at current prices, presumably both operating and capital costs would rise at similar rates. In any event, of the major operating expense factors -- payroll, power, and chemical costs -- payroll is the major expenditure having the maximum rate of increase. Therefore, increases in the payroll element alone can contribute a significant portion of the general increase in water supply costs.

A mathematical and statistical set of relationships were developed to examine the trade-offs among capital cost, operating cost, wage rates, man-hours, and output. Knowledge of these trade-offs can be useful for planning future plant expansion or adjustments in the production process.

Based on a hypothetical analysis of add-on treatment requirements, compliance with the Safe Drinking Water Act will increase unit costs on the average by less than 5%. However, cost to individual utilities may increase substantially. In one example unit costs increased by 195%.

On the other hand, only six out of the 23 utilities studied had problems that needed technological solution. Of these six, the unit cost increases associated with five of the utilities were less than 5%.

Above all, EPA must understand the diversity of problems that affect the ability of small systems to comply with standards promulgated under the Safe Drinking Water Act. Only with proper understanding can EPA develop a flexible and realistic policy concerning small systems and their problems. Achieving compliance will be a difficult and demanding, but not insurmountable, task.

SECTION 3

DATA ANALYSIS FROM SELECTED SMALL WATER UTILITIES

Of the 23 utilities for which data were collected, data from six utilities are analyzed here in detail. As mentioned before, this study covered six states within three EPA regions. For the analysis in this section, two utilities from each region were chosen: Downingtown, Pennsylvania, and Manassas Park, Virginia, from Region III; Burlington, Illinois, and Lebanon, Ohio, from Region V, and Taylor and Dallas Co. WCID #6, Texas, from Region VI. Manassas Park, Burlington, Lebanon, and Taylor all use ground water with varying degrees of treatment. Downingtown obtains its water from a surface source while the Dallas Co. WCID #6 purchases treated water from the Dallas Water Utility. These six utilities provide a wide spectrum from which to examine costs of supply for small water utilities.

DOWNINGTOWN, PENNSYLVANIA

The Downingtown Municipal Water Works is owned and operated by the Borough of Downingtown, located just west of Philadelphia. The utility serves a population of approximately 8,300 in a retail service area of about three square miles. Figure 3 shows the change in total treated and revenue-producing water over a 10-year period.

In Figure 3 the time axis is labeled 1 through 10 to facilitate analyses, but the span of this covered was from 1966 to 1975. Tables 2 and 3 contain the O&M and capital cost information collected on each cost category (support services, acquisition, treatment, and distribution) for the period of analysis. The costs per million gallons are based on revenue-producing water rather than total treated water. Total operating costs increased from $51,351 to $171,560, a 234% increase, while total revenue-producing water declined by 21.4%. Treatment costs represent a significant portion of total O&M costs for Downingtown. The utility utilizes surface water as a source and provides conventional treatment processes for the raw water. Support services cost increased 461% from $9252 to $51,876 (Figure 4). Unit O&M cost increased from $128/MG to $544/MG (325%) with the largest increase coming in support services, from $23/MG to $164/MG or 613% (Figure 5). Also, in Figure 6, support services as a percent of total O&M cost increased from 18.02% to 30.24% during the study period.

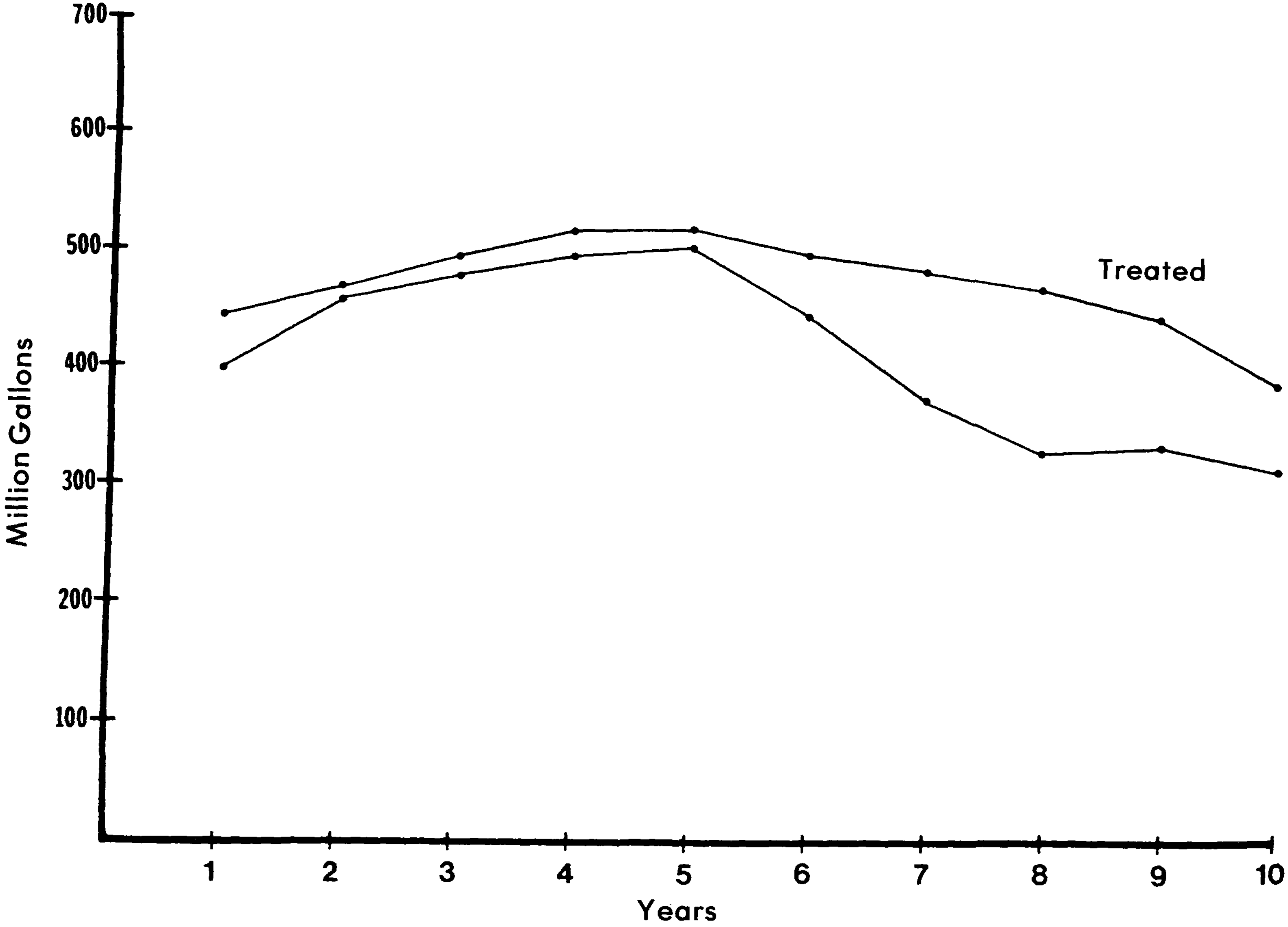

Figure 3. Treated and revenue producing water for Downingtcwn Water Utility.

Table 2. OPERATING AND MAINTENANCE COST

Downingtown, Pa.

	1	2	3	4	5	6	7	8	9	10
					Cost/Year					
Support Services	9252.	17220.	19824.	21791.	27914.	39557.	47254.	58876.	85024.	51876.
Acquisition	8359.	7729.	9020.	8865.	8964.	10177.	12677.	16805.	19375.	13989.
Treatment	16031.	19735.	23299.	29155.	34137.	38146.	48256.	49909.	54447.	52854.
Distribution	17710.	20836.	17181.	21303.	26048.	29142.	24395.	31154.	43299.	52841.
Total	51351.	65520.	69324.	81113.	97062.	117021.	132581.	156745.	202145.	171560.
					Cost/MG					
Support Services	23.	37.	41.	44.	55.	88.	126.	177.	254.	164.
Acquisition	21.	17.	19.	18.	18.	23.	34.	51.	58.	44.
Treatment	40.	43.	49.	58.	67.	85.	129.	150.	163.	167.
Distribution	44.	45.	36.	43.	51.	65.	65.	94.	129.	167.
Total	128.	142.	145.	163.	191.	262.	355.	472.	604.	544.
					% of Total					
Support Services	18.02	26.28	28.60	26.86	28.76	33.80	35.64	37.56	42.06	30.24
Acquisition	16.28	11.80	13.01	10.93	9.24	8.70	9.56	10.72	9.58	8.15
Treatment	31.22	30.12	33.61	35.94	35.17	32.60	36.40	31.84	26.93	30.81
Distribution	34.49	31.80	24.78	26.26	26.84	24.90	18.40	19.88	21.42	30.80
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 3. DEPRECIATION AND INTEREST COST

Downingtown, Pa.

	1	2	3	4	5	6	7	8	9	10
					Depreciation Cost $/Yr					
Support Services	1941.	2057.	2173.	2288.	2404.	2519.	2635.	2751.	2866.	2982.
Acquisition	971.	1028.	1086.	1144.	1202.	1260.	1317.	1375.	1433.	1491.
Treatment	971.	1028.	1086.	1144.	1202.	1260.	1317.	1375.	1433.	1491.
Distribution	15531.	16456.	17381.	18306.	19230.	20155.	21080.	22005.	22930.	23854.
Total	19414.	20570.	21726.	22882.	24038.	25194.	26350.	27506.	28662.	29818.
					Depreciation Cost $/MG					
Support Services	5.	4.	5.	5.	5.	6.	7.	8.	9.	9.
Acquisition	2.	2.	2.	2.	2.	3.	4.	4.	4.	5.
Treatment	2.	2.	2.	2.	2.	3.	4.	4.	4.	5.
Distribution	39.	36.	36.	37.	38.	45.	56.	66.	69.	76.
Total	48.	45.	45.	46.	47.	56.	71.	83.	86.	94.
					Depreciation Cost % of Total					
Support Services	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Acquisition	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Treatment	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Distribution	80.00	80.00	80.00	80.00	80.00	80.00	80 00	80.00	80.00	80.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
					Interest Cost $					
Interest $	13955.	10445.	9628.	9128.	8447.	7743.	7018.	6318.	5499.	4704.
Interest $/MG	35.	23.	20.	18.	17.	17.	19.	19.	16.	15.

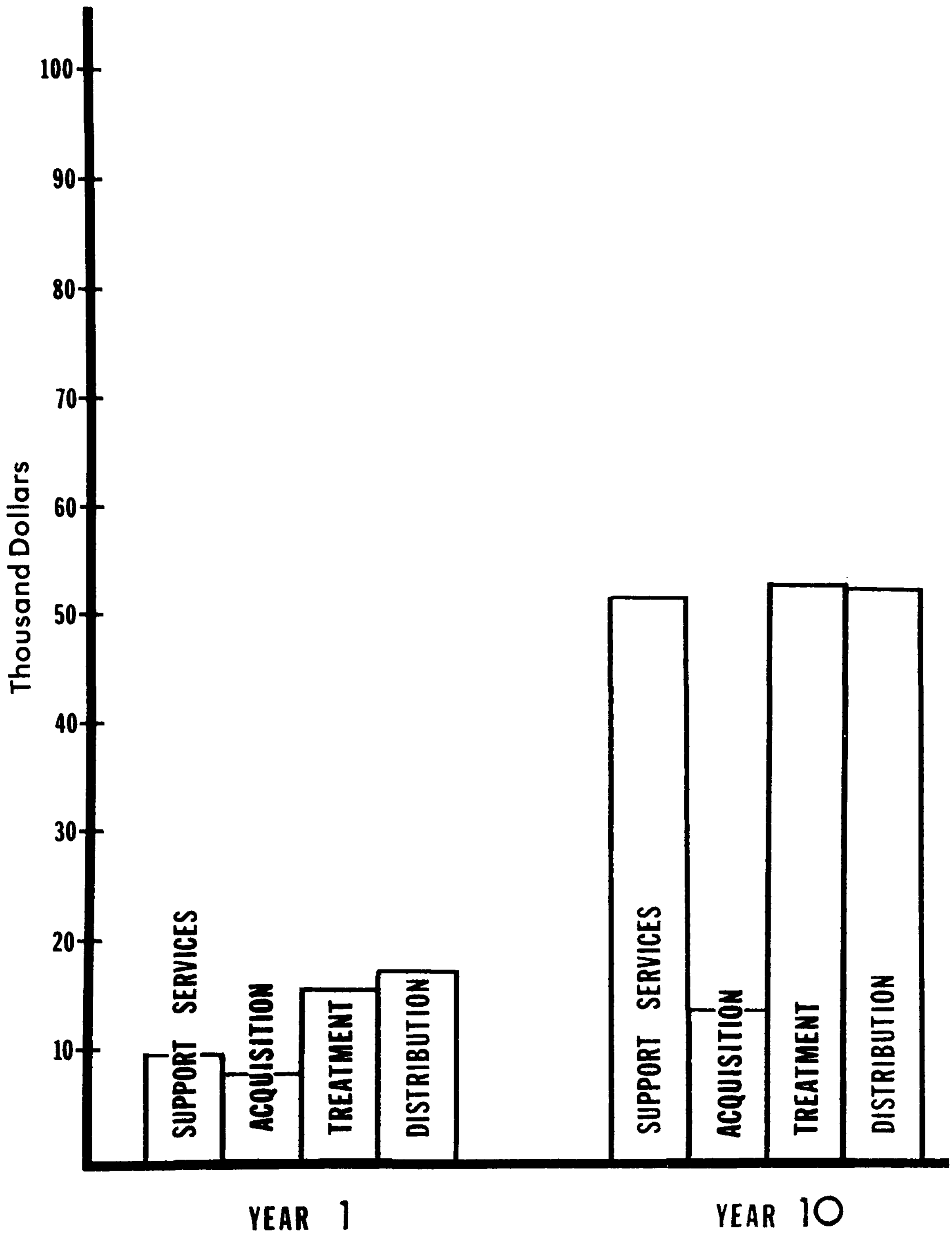

Figure 4. Operating costs for Downingtown Water Utility.

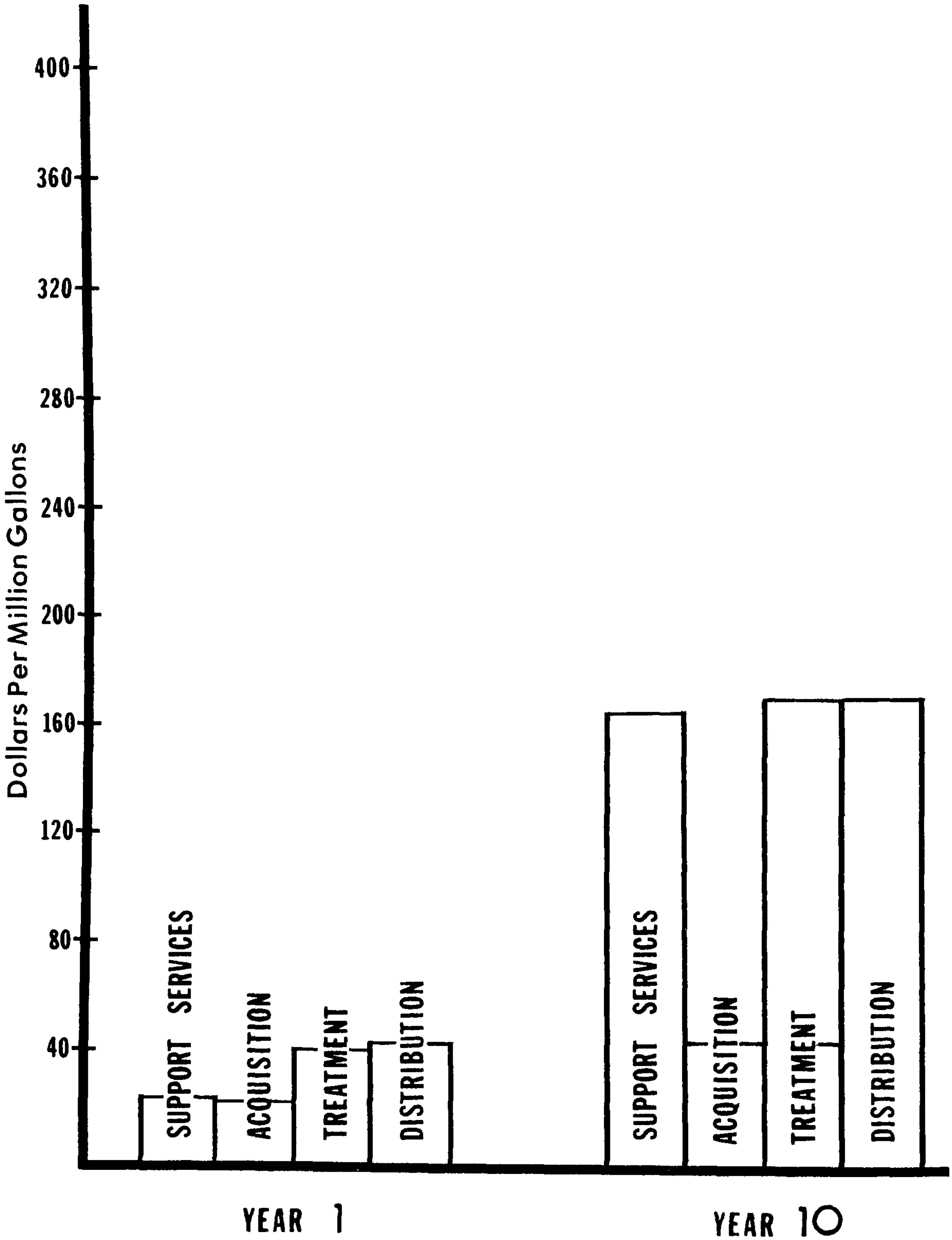

Figure 5. Operating costs in dollars per million gallons for Downingtown Water Utility.

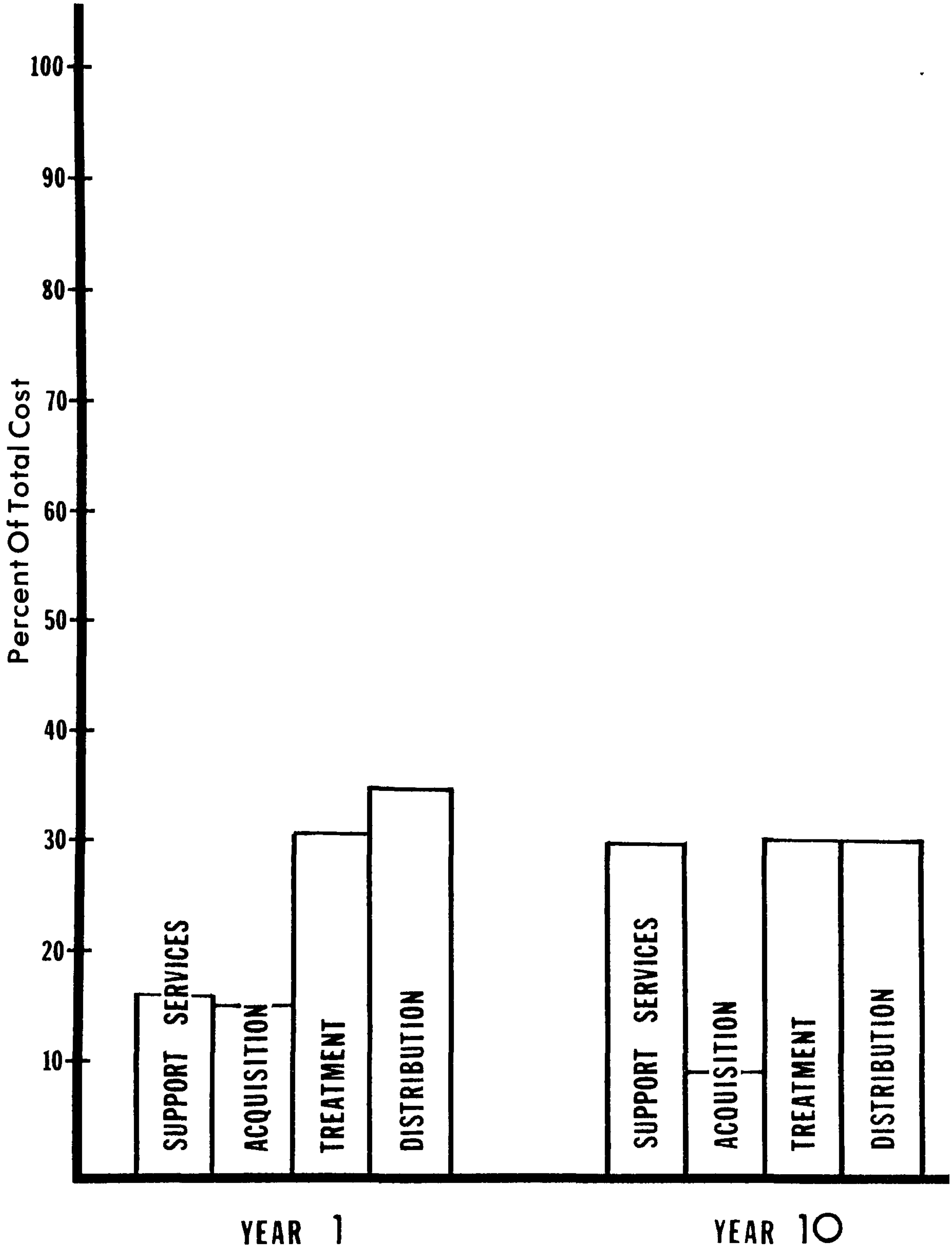

Figure 6. Operating costs as percent of total O & M cost for Downingtown Water Utility.

Figures 7 and 8 indicate the shift in operating expenditures to capital expenditures on a historical cost basis. O&M, as a percent of total costs, increased from 61% to 84% over the 10-year period which suggests a movement away from capital intensiveness. However, to evaluate this shift properly, current value of capital and depreciation would have to be compared to operating cost.

Figure 9 presents total O&M and total capital cost over time. Operating and maintenance cost has a steeper slope while capital cost remains relatively flat.

Figures 10 and 11 show total production and unit costs. Both total production and unit costs have been deflated to 1966. The deflated lines (real costs) are much flatter than the historical cost functions which indicate that inflation has a significant impact on total cost and the water utility budget. Figure 12 demonstrates the pattern of selected variable costs over time. As indicated by the graph, unit payroll costs have increased at an accelerated rate in comparison to unit power and chemical costs. Thus, labor costs at Downingtown are more significantly affected by inflation than other operating costs which suggests that substitution for labor inputs might reduce total cost. This is also evident in Figure 13 which shows MH/MG increasing with respect to time. Information of this type is useful for planning capital investment.

MANASSAS PARK, VIRGINIA

The Manassas Park Water Works is municipally owned and operated, serving a population of approximately 6844 people in an area of two square miles. Figure 14 shows the change in total treated and revenue-producing water over a 10-year period from 1965 to 1974. Tables 4 and 5 contain O&M and capital cost data for each cost component for the period of analysis. Total operating costs have increased from $20,256 to $32,412 or 60%, while, at the same time, total revenue-producing water increased only 37.3%. No water treatment costs are incurred (operating or capital) because all water is acquired from a ground source which is not treated.

Support services costs increased 60% from $12,761 to $20,419, as shown in Figure 15. Acquisition and distribution costs also increased 60%, but the absolute increase is not as pronounced as for support services.

Unit O&M cost of water supply rose 17% from $268/MG to $314/MG as did each component, except for treatment cost (Fig. 16). Support services obviously comprise the major portion of O&M costs.

Figure 17 shows operating costs as a percent of total O&M cost. As suggested above, no component increased in percentage importance over the period.

The shift from capital to operating expenditures is indicated in figures 18 and 19. The interesting item apparent here is that interest expense exceeds operating costs in year 1 both in total and percent. It

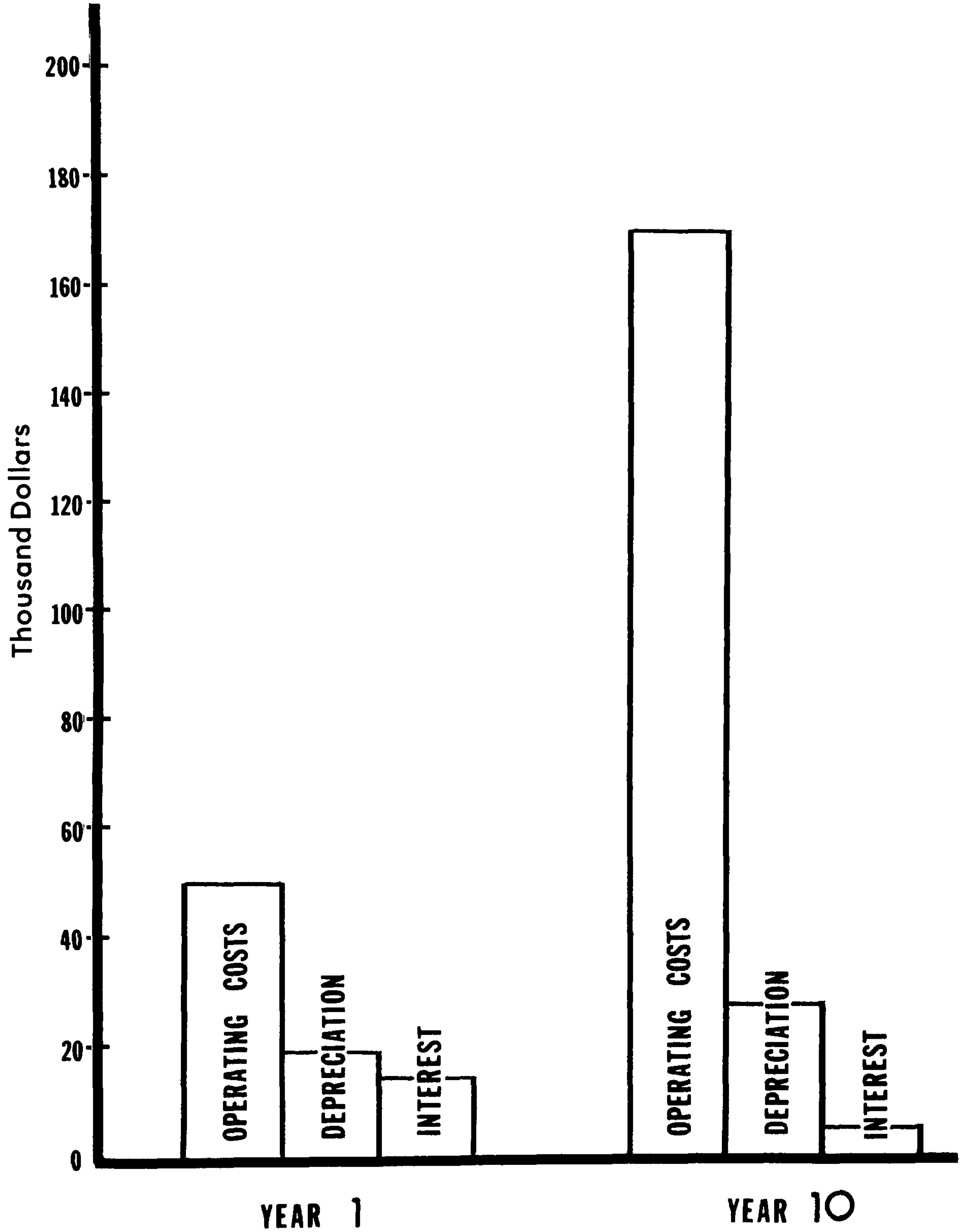

Figure 7. Capital and operating costs for Downingtown Water Utility.

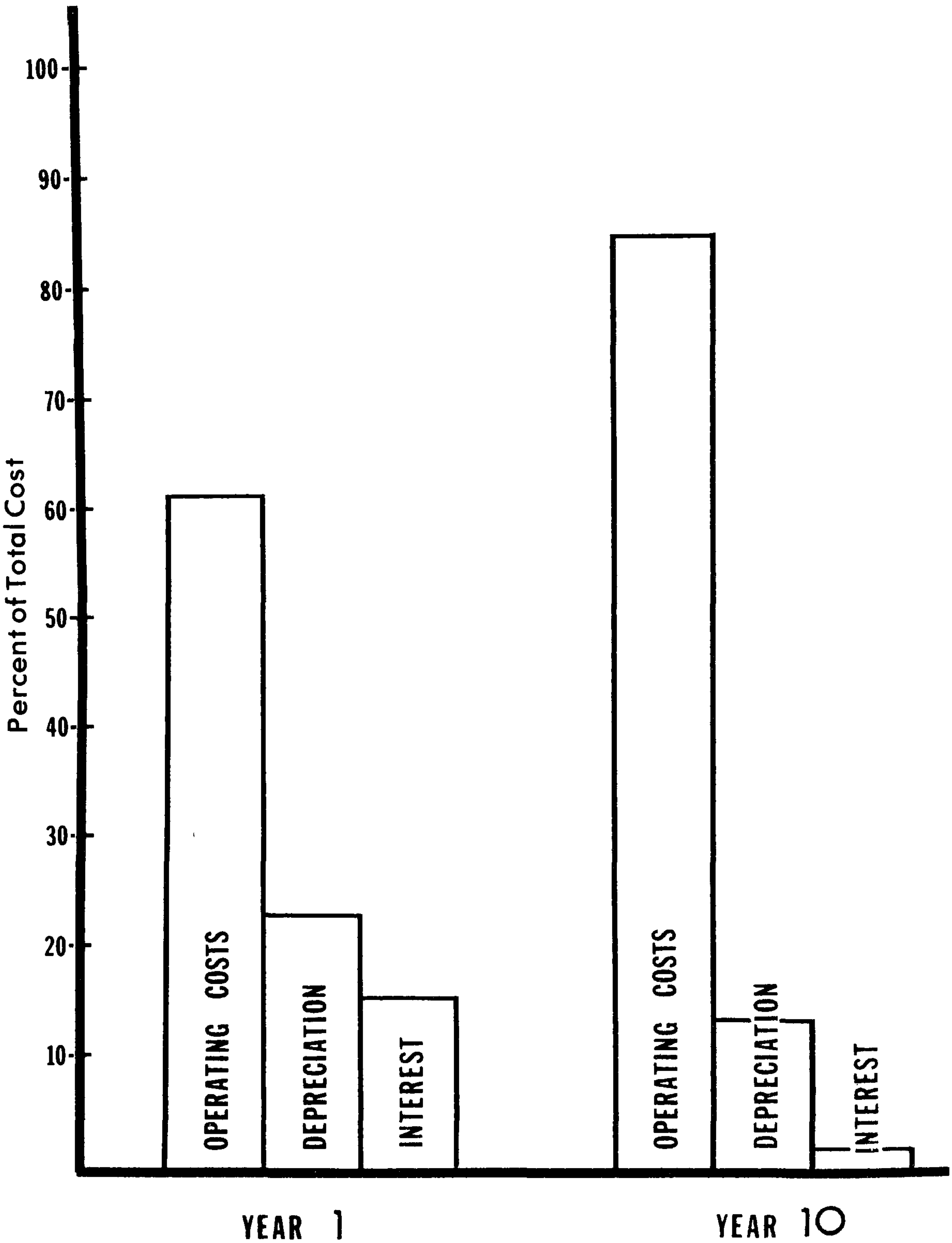

Figure 8. Capital and operating costs as a percent of total cost for Downingtown Water Utility.

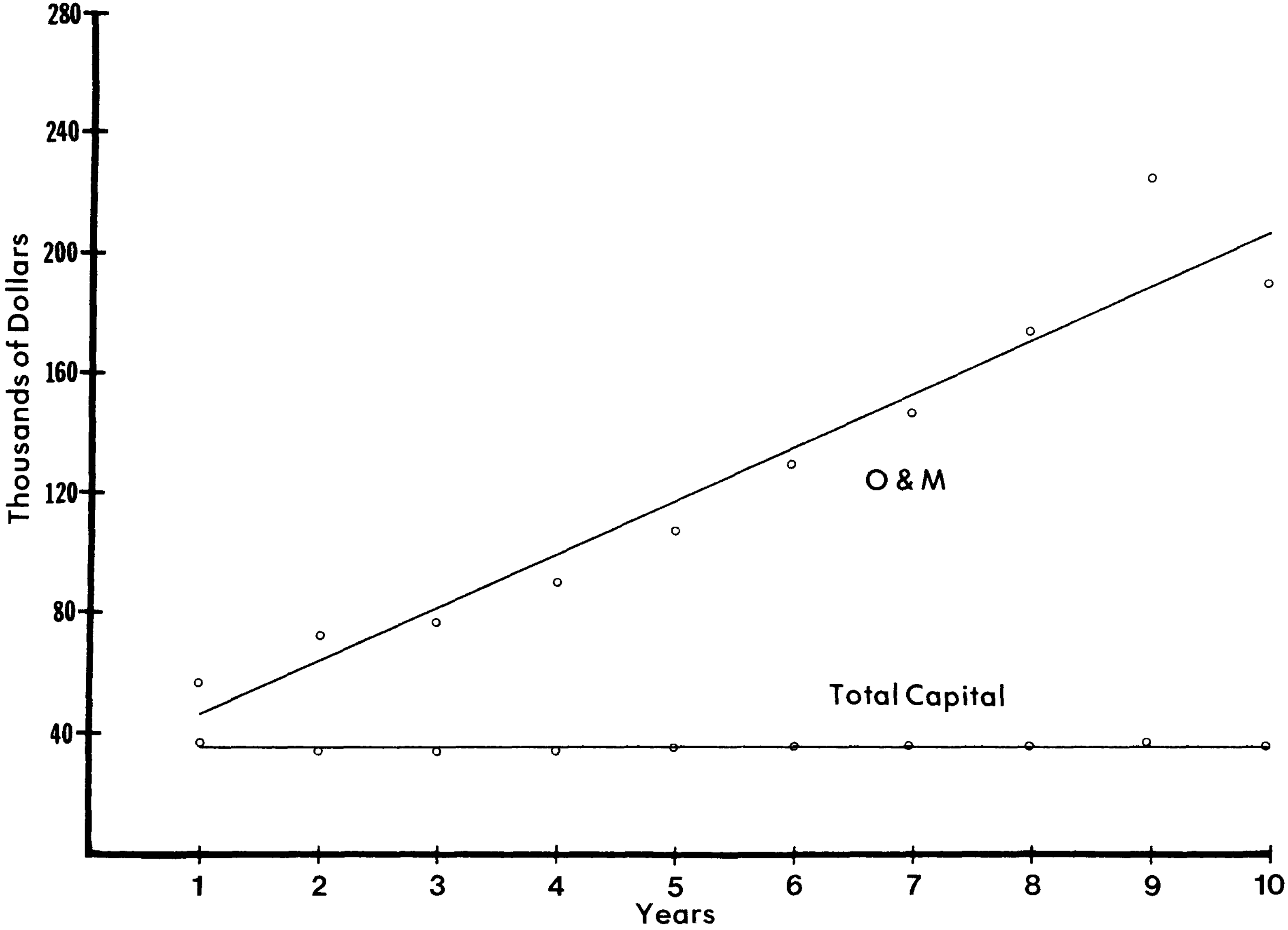

Figure 9. Operating and capital expenditures for Downingtown Water Utility.

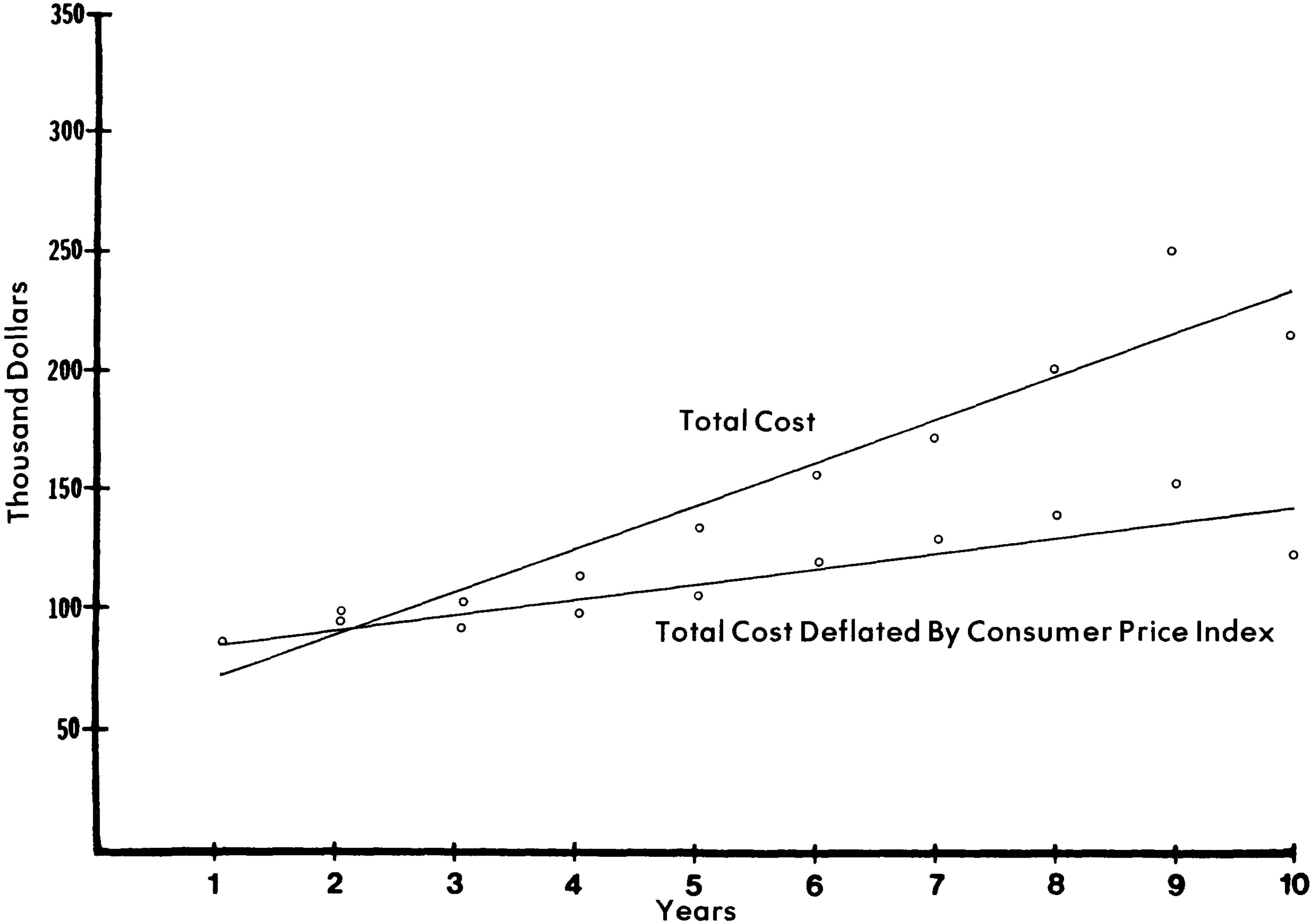

Figure 10. Total costs versus time for Downingtown Water Utility: historical and deflated.

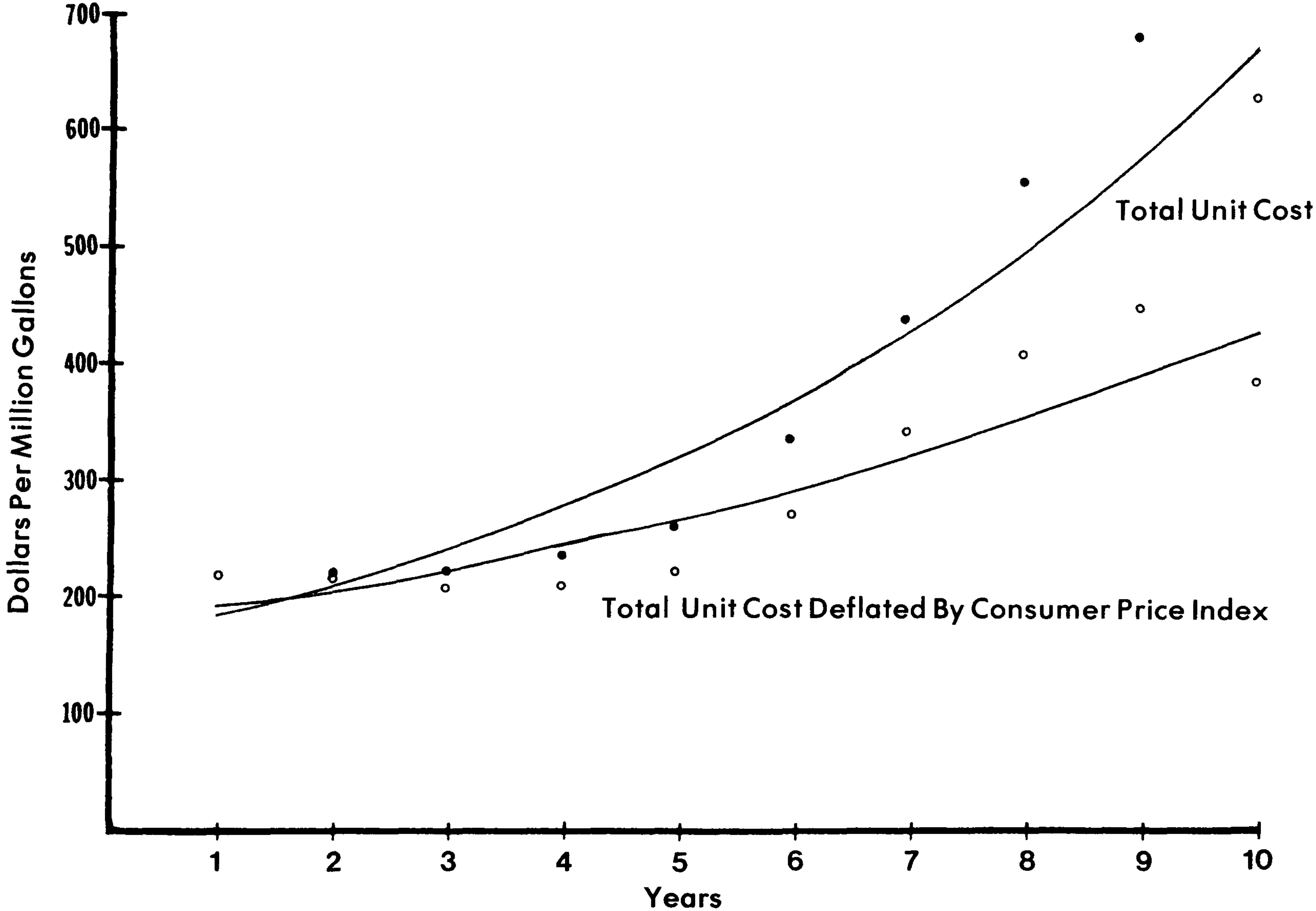

Figure 11. Total unit costs versus time for Downingtown Water Utility: historical and deflated.

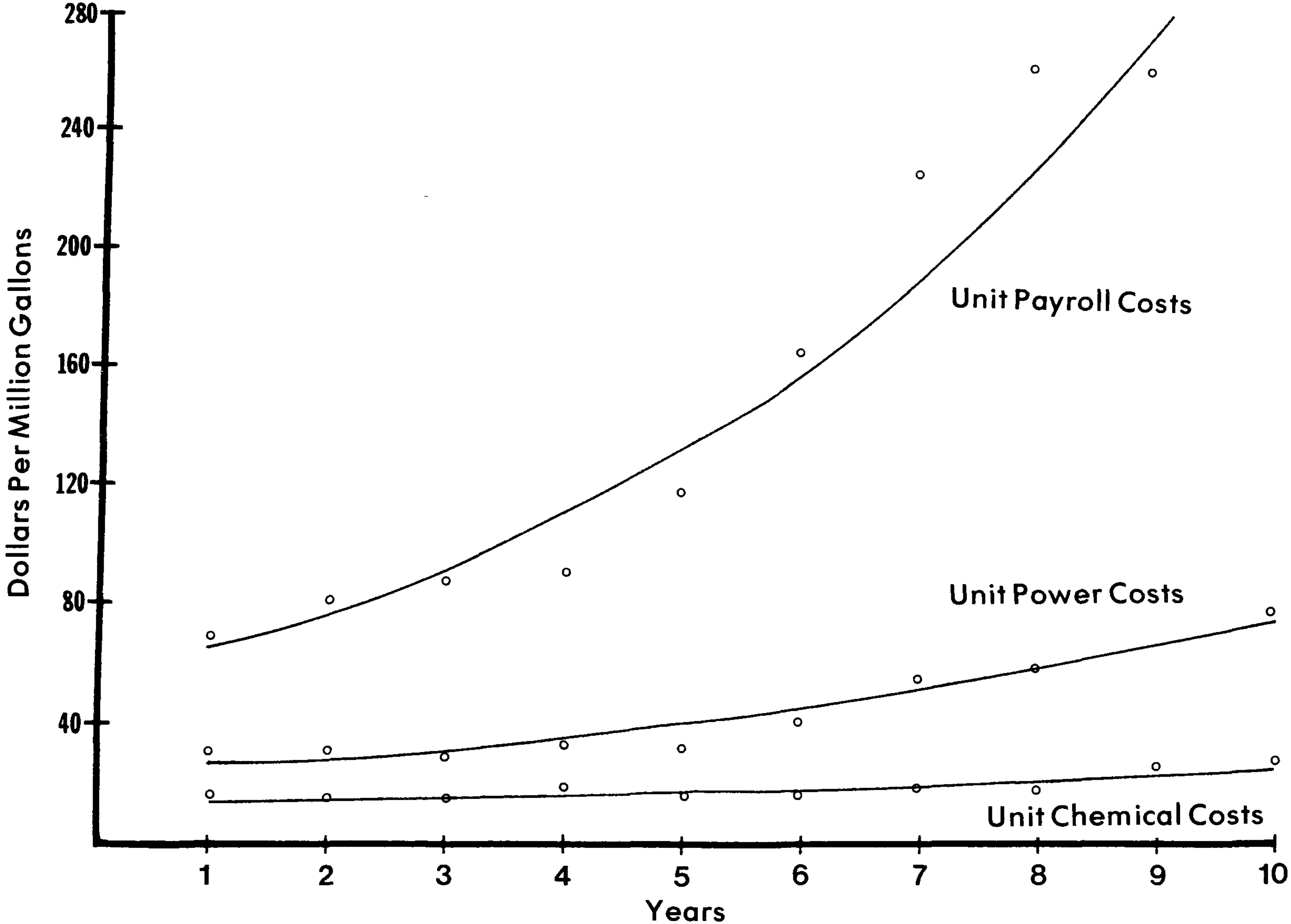

Figure 12. Unit payroll, power, and chemical costs versus time for Downingtown Water Utility.

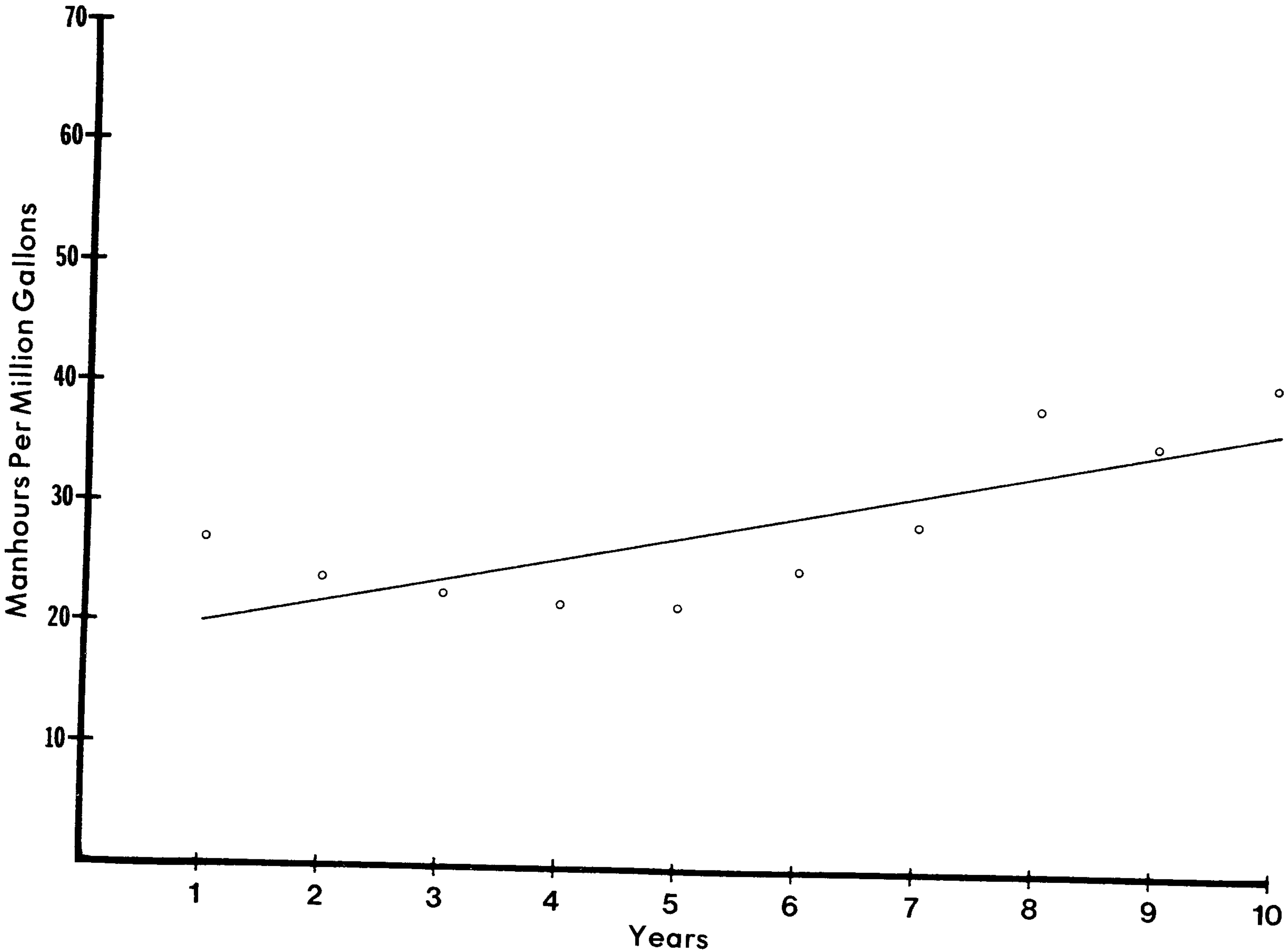

Figure 13. Manhours per million gallons versus time for Downingtown Water Utility.

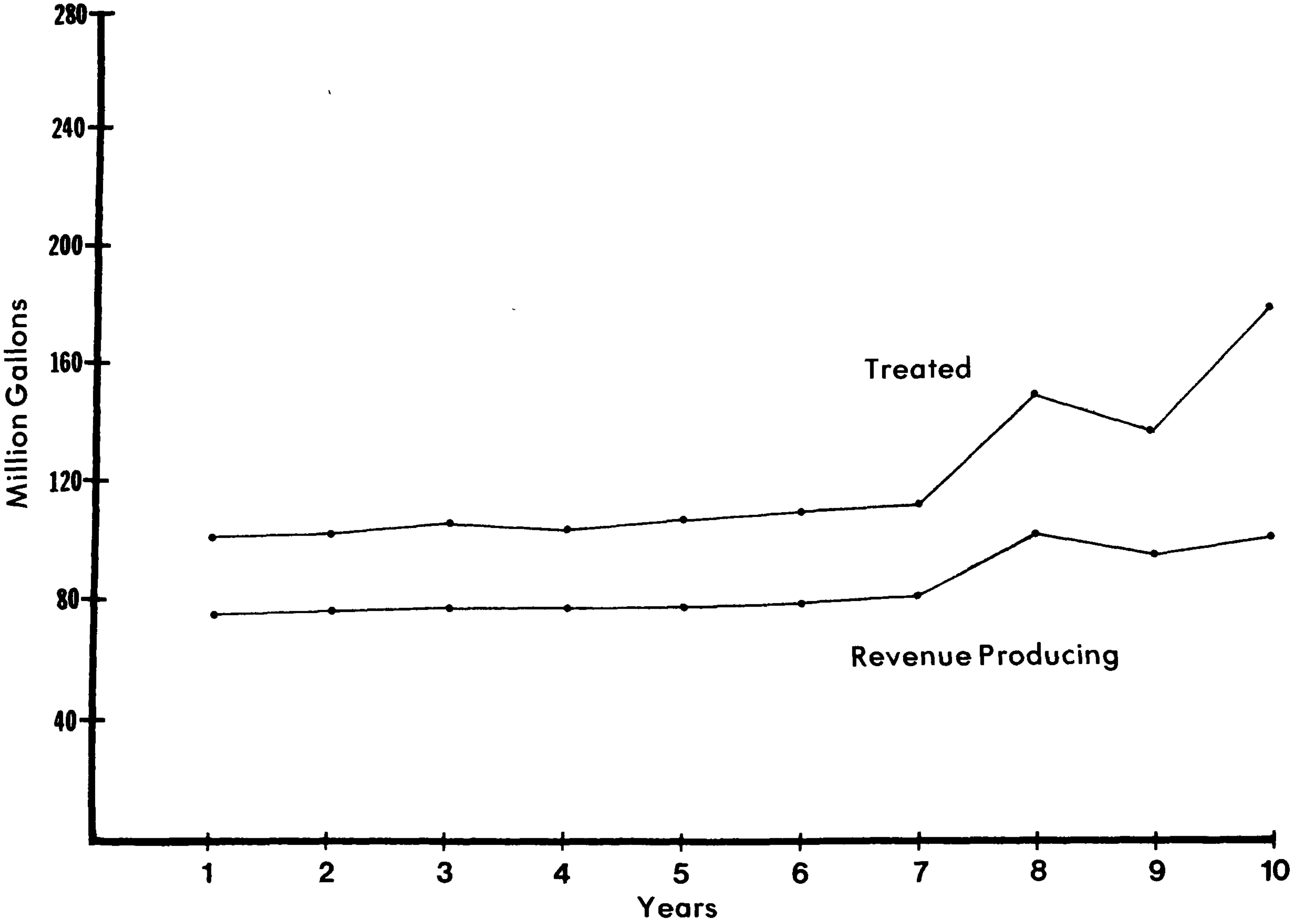

Figure 14. Treated and revenue producing water for Manassas Park Water Utility.

Table 4. OPERATING AND MAINTENANCE COST

Manassas Park, Va.

	1	2	3	4	5	6	7	8	9	10
					Cost/Year					
Support Services	12761.	11941.	13661.	14070.	15819.	17903.	19735.	17452.	16380.	20419.
Acquisition	4456.	4170.	4770.	4913.	5524.	6252.	6892.	6094.	5720.	7131.
Treatment	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Distribution	3038.	2843.	3253.	3350.	3766.	4263.	4699.	4156.	3900.	4862.
Total	20256.	18953.	21683.	22334.	25109.	28418.	31325.	27702.	26000.	32412.
					Cost/MG					
Support Services	169.	156.	174.	180.	201.	223.	243.	167.	169.	198.
Acquisition	59.	55.	61.	63.	70.	78.	85.	58.	59.	69.
Treatment	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Distribution	40.	37.	41.	43.	48.	53.	58.	40.	40.	47.
Total	268.	248.	277.	286.	320.	354.	386.	266.	268.	314.
					% of Total					
Support Services	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00
Acquisition	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
Treatment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Distribution	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 5. DEPRECIATION AND INTEREST COST

Manassas Park, Va.

	1	2	3	4	5	6	7	8	9	10
					Depreciation Cost $/Yr					
Support Services	8669.	8669.	8729.	8795.	8814.	8829.	8832.	8883.	8933.	10804.
Acquisition	3027.	3027.	3048.	3071.	3078.	3083.	3084.	3102.	3120.	3773.
Treatment	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Distribution	2064.	2064.	2078.	2094.	2099.	2102.	2103.	2115.	2127.	2572.
Total	13760.	13760.	13855.	13961.	13991.	14014.	14020.	14100.	14180.	17149.
					Depreciation Cost $/MG					
Support Services	115.	114.	111.	113.	112.	110.	109.	85.	92.	105.
Acquisition	40.	40.	39.	39.	39.	38.	38.	30.	32.	37.
Treatment	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Distribution	27.	27.	27.	27.	27.	26.	26.	20.	22.	25.
Total	182.	180.	177.	179.	178.	174.	173.	135.	146.	166.
					Depreciation Cost % of Total					
Support Services	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00
Acquisition	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
Treatment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Distribution	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
					Interest Cost $					
Interest $	22577.	21703.	20853.	19918.	18983.	18048.	17028.	16008.	14996.	13960.
Interest $/MG	299.	284.	266.	255.	242.	225.	210.	153.	154.	135.

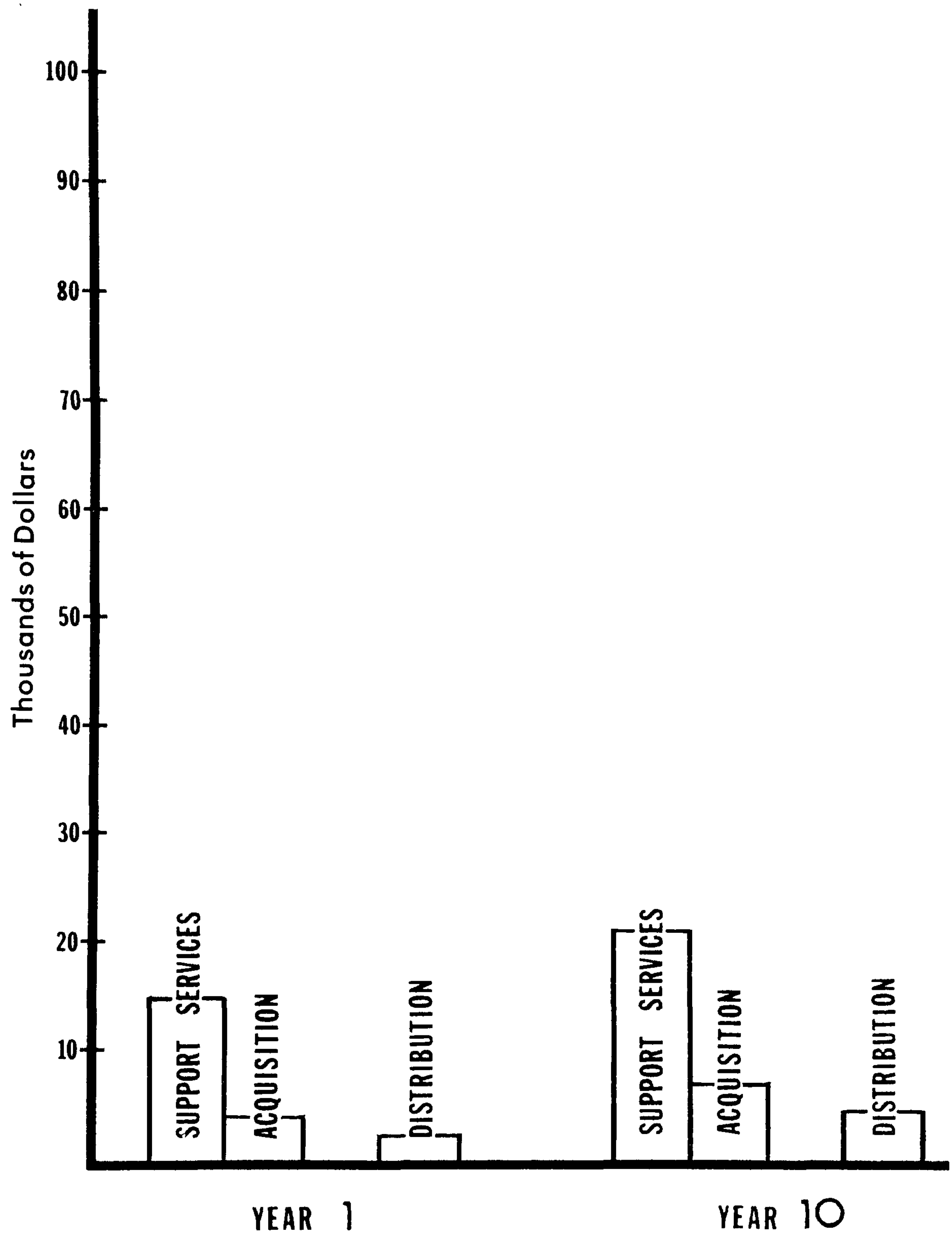

Figure 15. Operating costs for Manassas Park Water Utility.

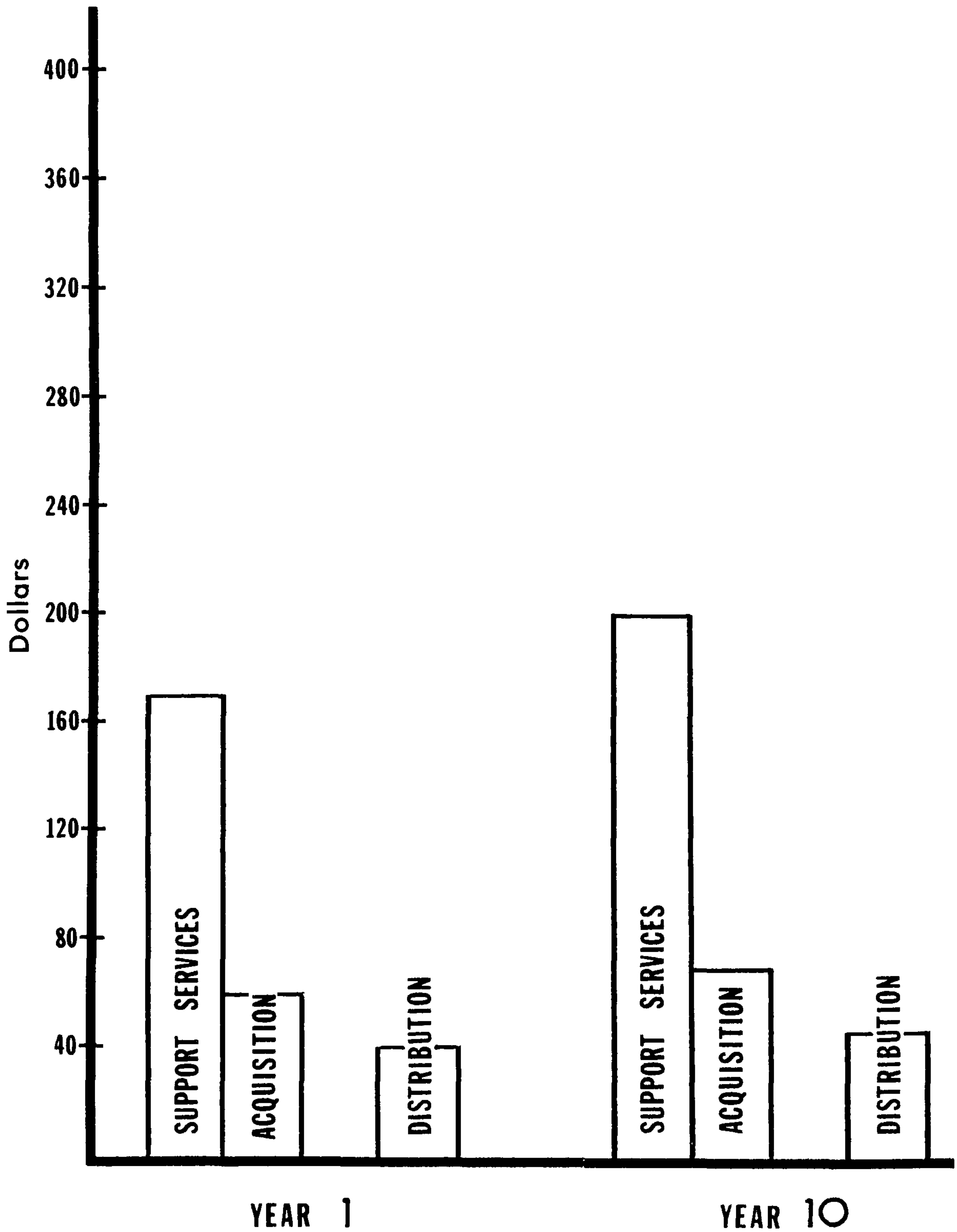

Figure 16. Operating costs in dollars per million gallons for Manassas Park Water Utility.

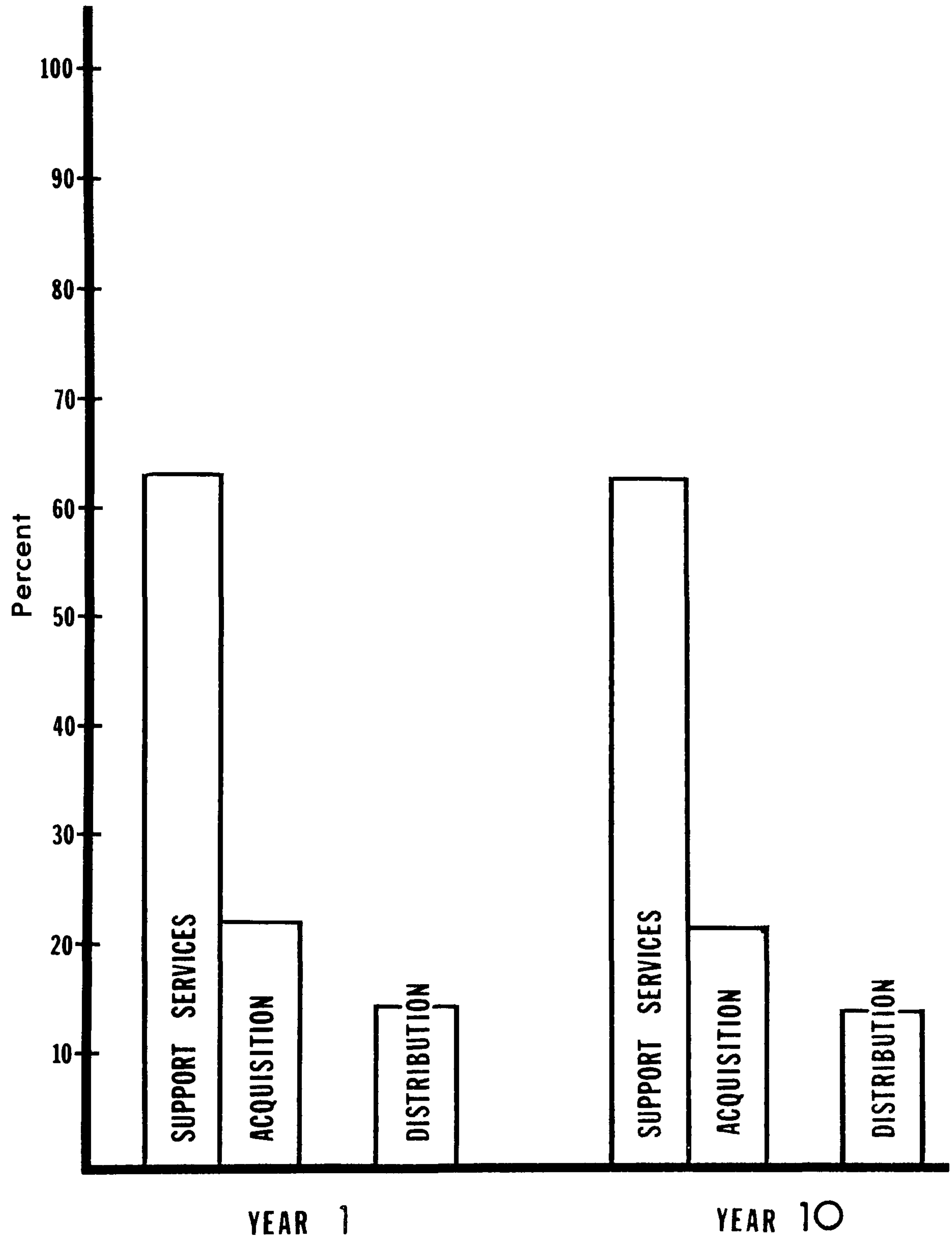

Figure 17. Operating costs as a percent of total O & M cost for Manassas Park Utility.

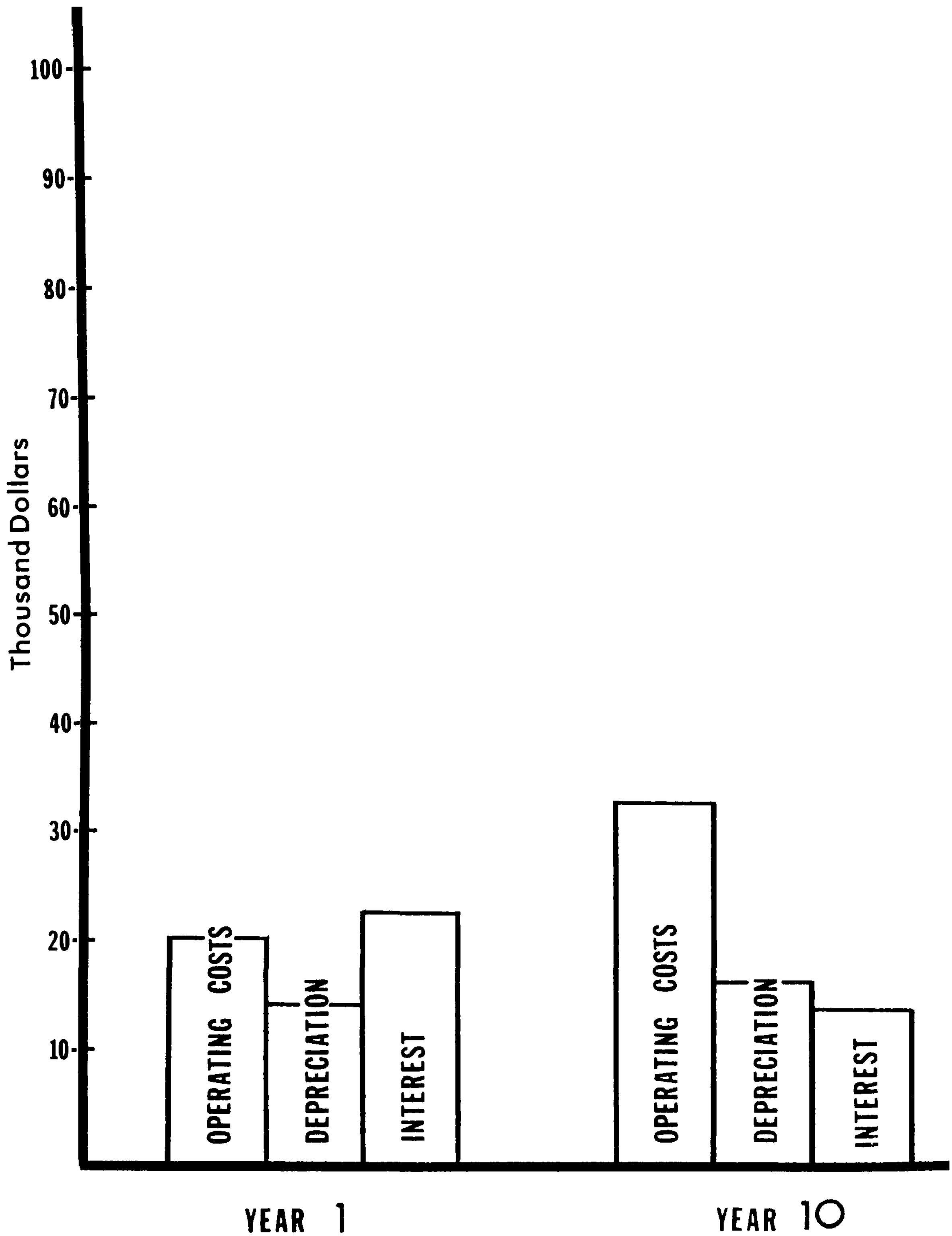

Figure 18. Operating and capital costs for Manassas Park Water Utility.

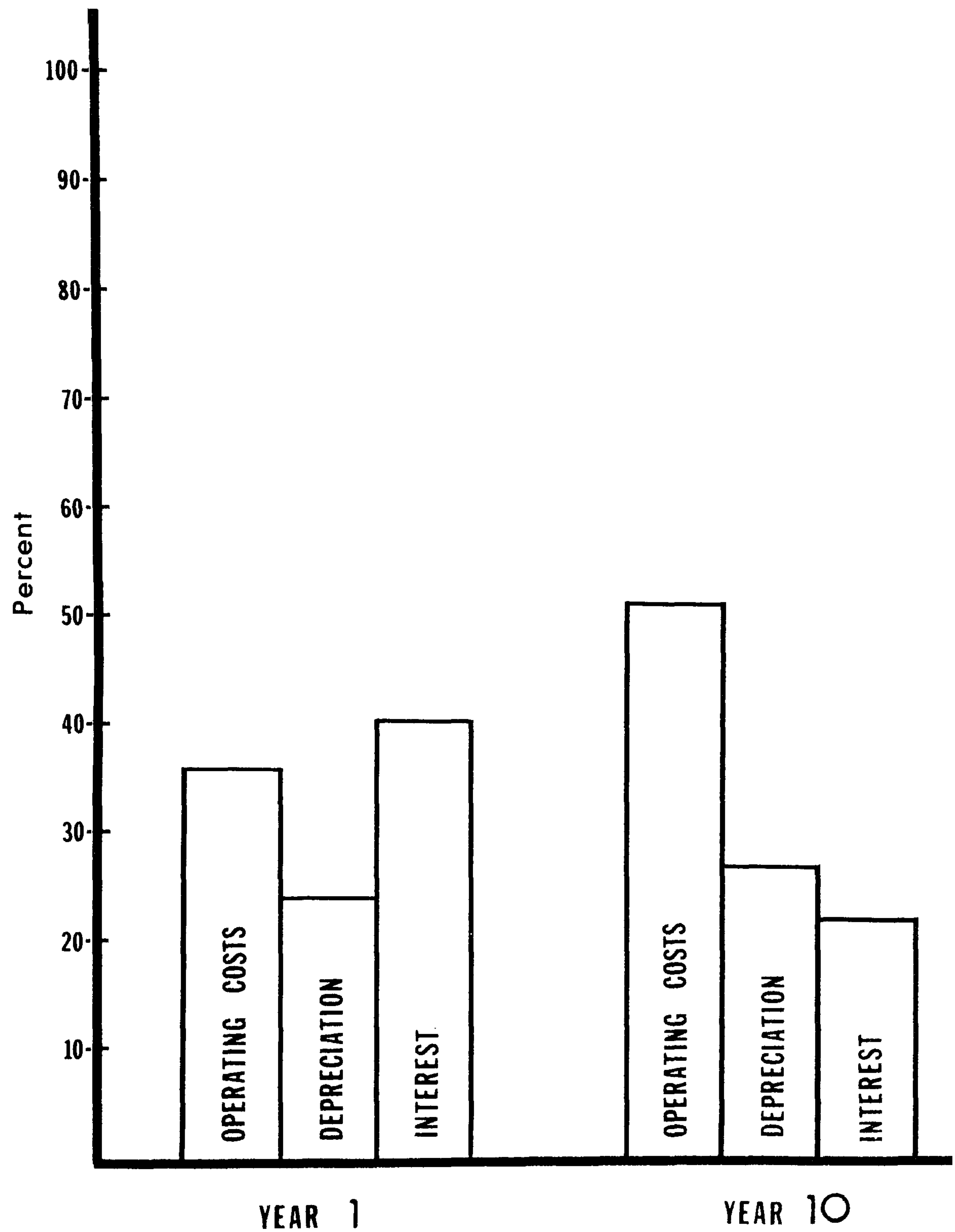

Figure 19. Capital and operating costs as a percent of total cost for Manassas Park Water Utility.

declines, however, to a lesser factor by year 10. The trend over the study period is toward increased operating costs over increased historical capital costs.

Figure 20 shows total O&M and capital costs versus time. Operating and maintenance cost has a greater slope than capital cost, but it lies almost completely below capital cost. In addition, the capital cost curve is downward sloping which suggests that the role of capital for Manassas Park is declining in relation to O&M.

In figures 21 and 22, total and unit costs (historical and deflated by the CPI) are plotted versus time. The lines representing (real) deflated costs lie below nominal expenditures for both total and unit costs. The interesting factor is that both deflated curves decrease over time, indicating that the real cost of water supply declined while total output increased. This possibily is explained by the realization that capital costs (depreciation + interest) for Manassas Park comprise the major portion of total cost. Since capital cost usually reflects historical cost for plant and equipment purchased in a previous time period, it is not subject to inflation as are current valued O&M costs. Therefore, for Manassas Park, though inflation had a significant impact on nominal costs, the effect has not been as pronounced as it could have been with a smaller ratio of capital cost to O&M.

Unit payroll and power costs versus time are presented in Figure 23. Unit payroll costs have increased 89%, while unit power costs declined about 35%. Thus, again, labor costs represent a factor that is more subject to inflation than power. However, as Figure 24 indicates, man-hours per MG have declined about 28%. Labor has become more productive, which offsets its inflationary impact. If productivity ceased to rise, then a substitution of capital for labor might be warranted, depending upon their relative costs.

BURLINGTON, ILLINOIS

The Village of Burlington, Illinois, owns and operates the Burlington Water Utility located west of Chicago. The utility serves a small population of approximately 384 over a 1/4 square mile area. Figure 25 presents the change in total treated and revenue-producing water over a 10-year period from 1966 to 1975. Tables 6 and 7 contain O&M and capital cost information for each component for the study period. Total operating costs have increased 116% from $4971 to $10,728 while revenue-producing water declined 9%. Unit O&M costs ($/MG) rose 134% from $223/MG to $523/MG. However, some of this increase is a result of the decline in output. Treatment O&M costs represent a small proportion of total cost. This occurs because the source of supply is ground water which only requires disinfection and fluoridation.

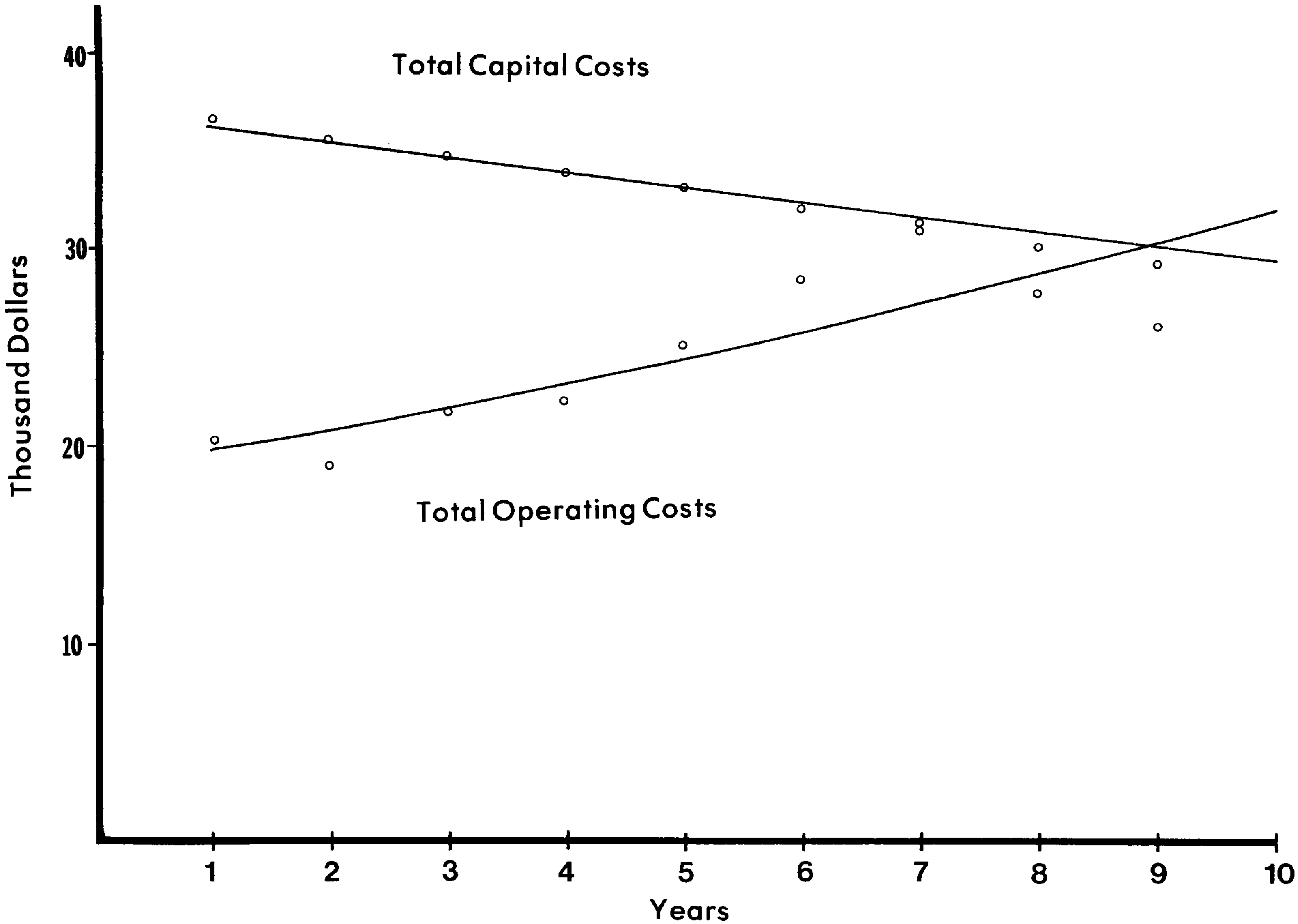

Figure 20. Total capital and operating costs versus time for Manassas Park Water Utility.

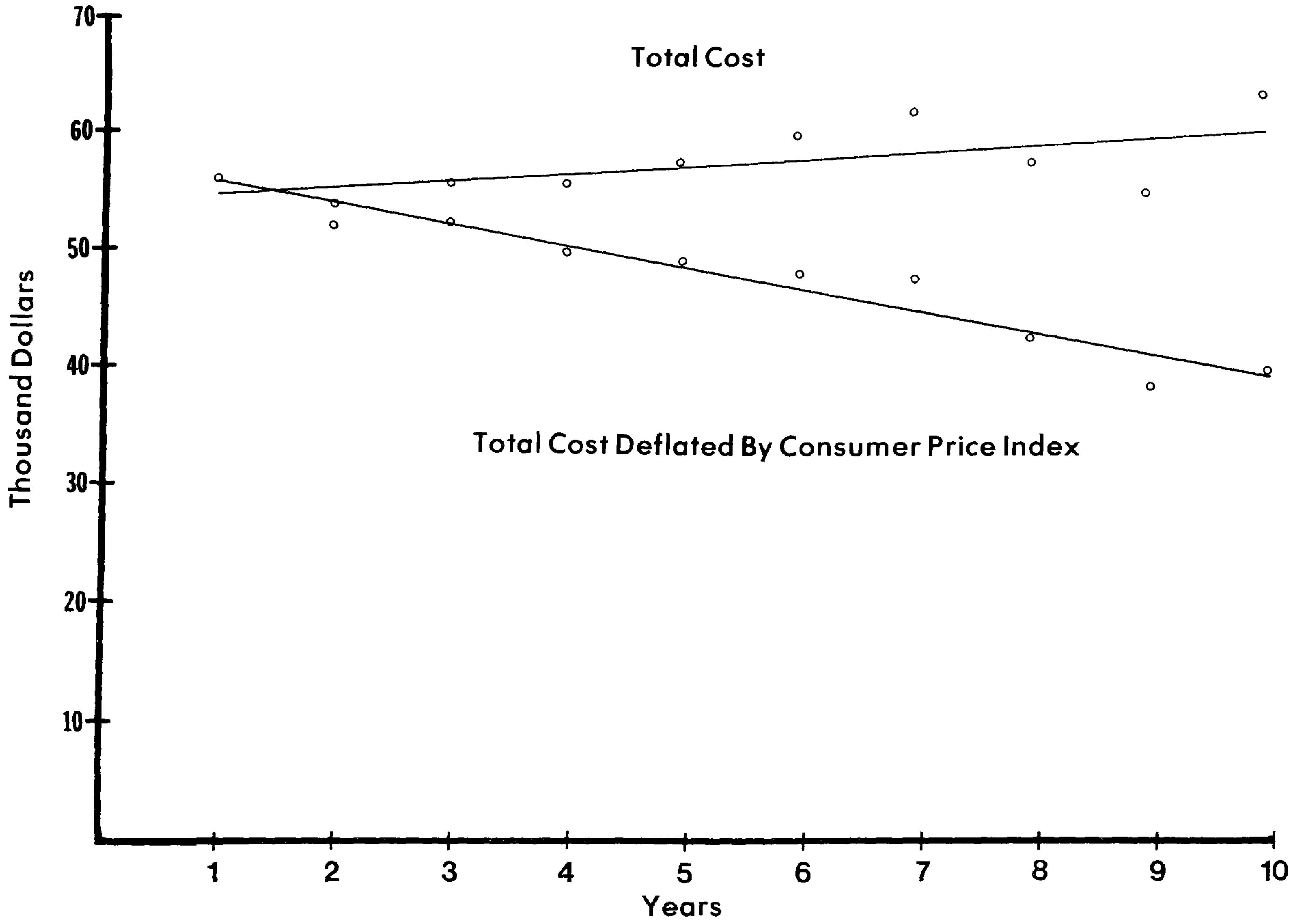

Figure 21. Total costs versus time for Manassas Park Water Utility: historical and deflated.

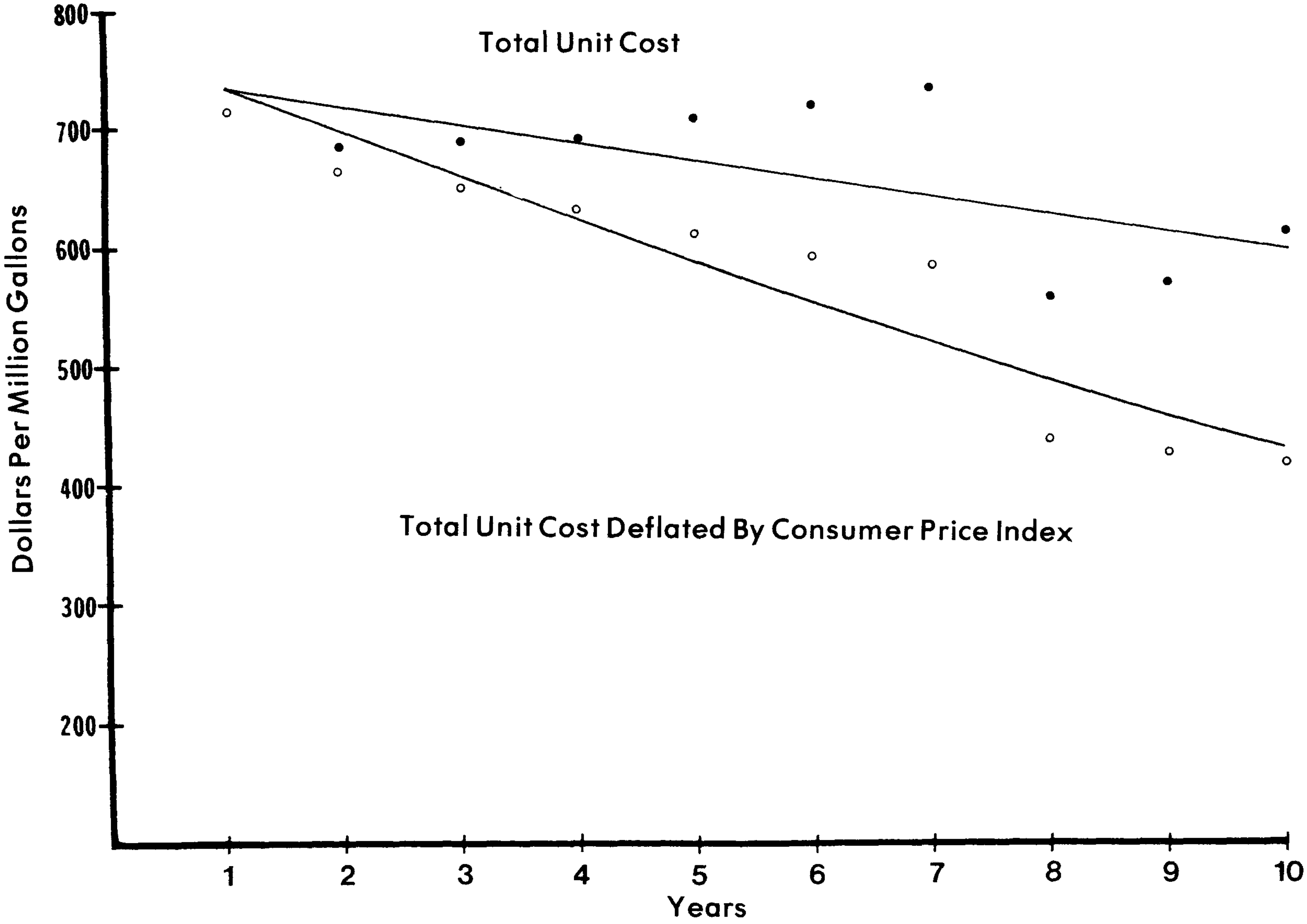

Figure 22. Total unit costs versus time for Manassas Park Water Utility: historical and deflated.

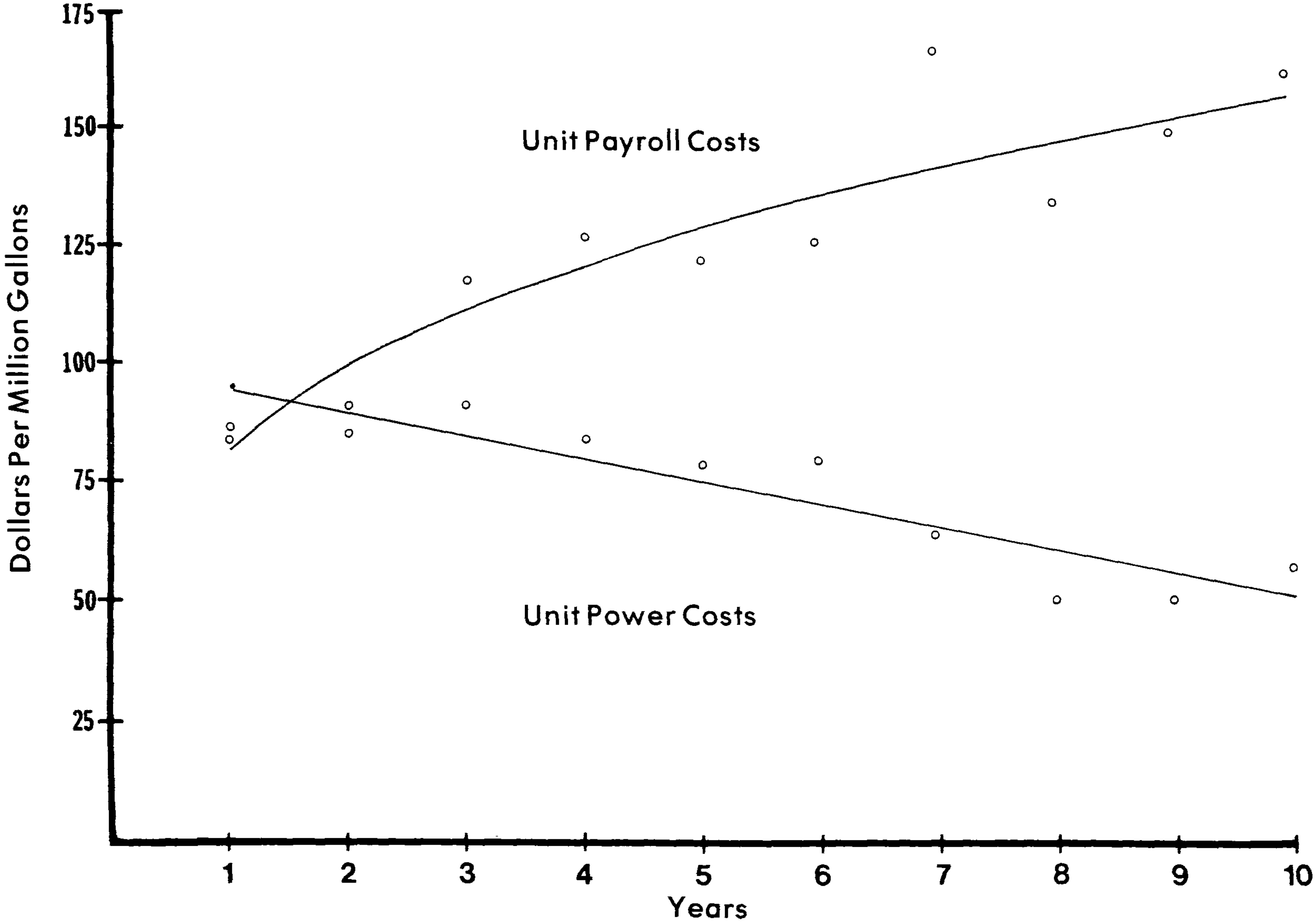

Figure 23. Unit payroll and power costs versus time for Manassas Park Water Utility.

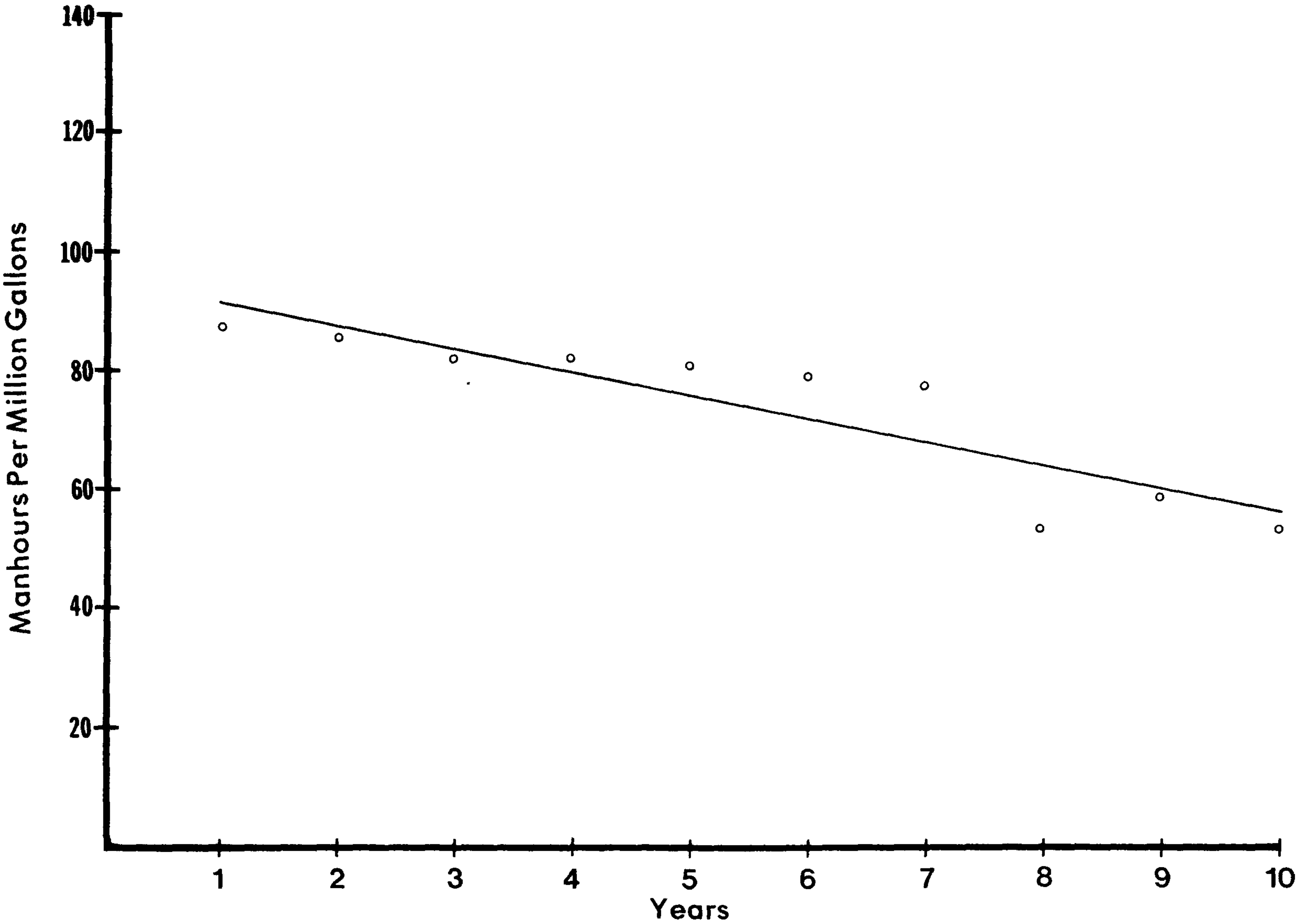

Figure 24. Manhours per million gallons versus time for Manassas Park Water Utility.

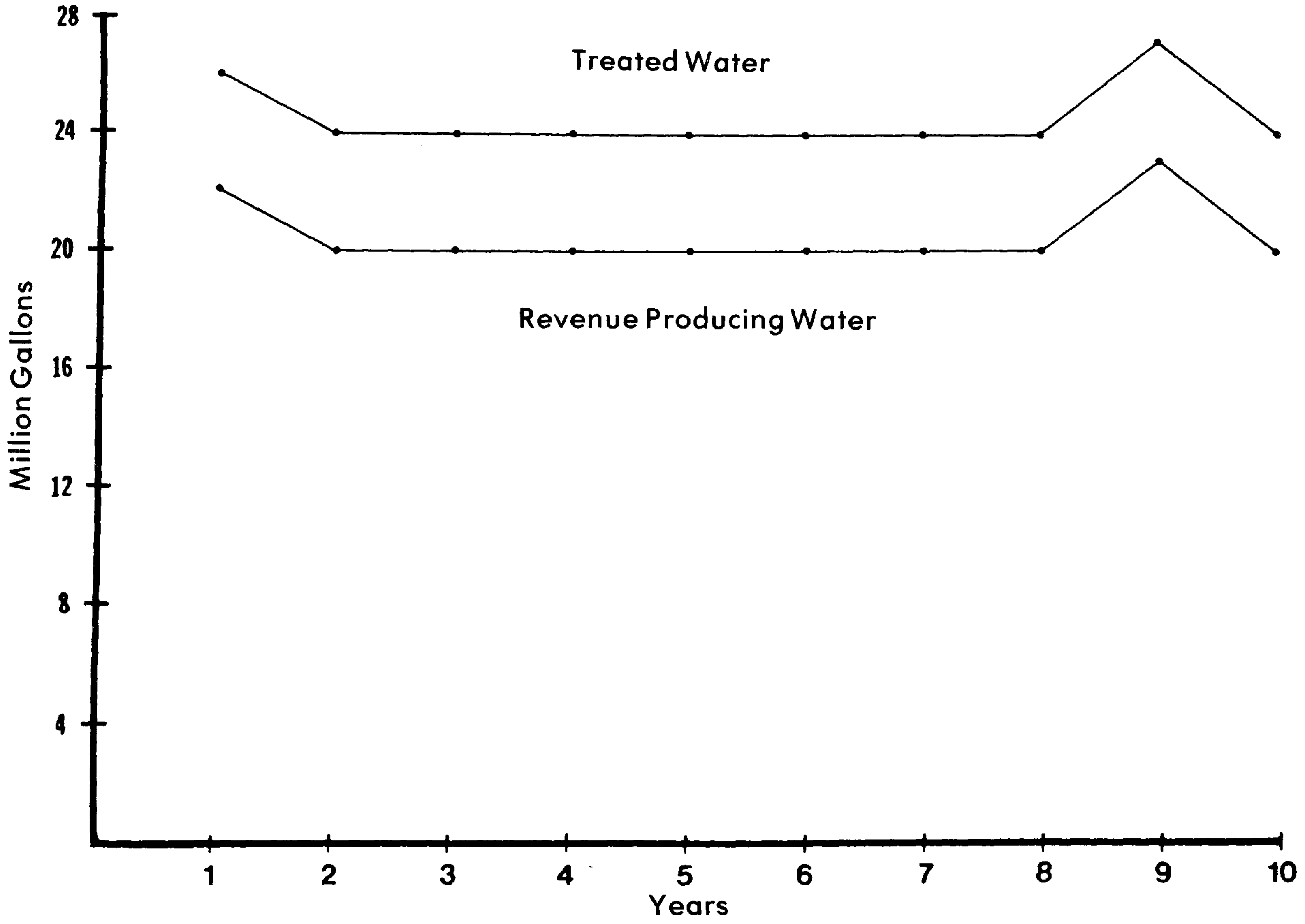

Figure 25. Treated and revenue producing water for Burlington Water Utility.

Table 6. OPERATING AND MAINTENANCE COST

Burlington, Ill.

	1	2	3	4	5	6	7	8	9	10
					Cost/Year					
Support Services	746.	667.	675.	851.	571.	681.	957.	1050.	1722.	2682.
Acquisition	1238.	1523.	915.	1082.	1246.	1414.	1549.	1420.	1696.	2195.
Treatment	0.	0.	0.	50.	55.	72.	50.	100.	990.	2145.
Distribution	2987.	2256.	2910.	3691.	1933.	2374.	3825.	4430.	4204.	3706.
Total	4971.	4446.	4500.	5673.	3804.	4542.	6381.	7000.	8612.	10728.
					Cost/MG					
Support Services	34.	33.	33.	42.	28.	33.	47.	51.	76.	131.
Acquisition	56.	75.	45.	53.	61.	69.	76.	70.	75.	107.
Treatment	0.	0.	0.	2.	3.	4.	2.	5.	44.	105.
Distribution	134.	111.	143.	181.	95.	116.	188.	217.	185.	181.
Total	223.	218.	221.	278.	186.	223.	313.	343.	379.	523.
					% of Total					
Support Services	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	20.00	25.00
Acquisition	24.90	34.26	20.33	19.06	32.75	31.14	24.27	20.29	19.69	20.46
Treatment	0.00	0.00	0.00	0.88	1.45	1.60	0.78	1.43	11.50	19.99
Distribution	60.10	50.74	64.67	65.06	50.80	52.27	59.95	63.29	48.81	34.55
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100 00	100.00	100.00

Table 7. DEPRECIATION AND INTEREST COST

Burlington, Ill.

	1	2	3	4	5	6	7	8	9	10
					Depreciation Cost $/Yr					
Support Services	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Acquisition	265.	287.	303.	303.	303.	303.	303.	303.	332.	353.
Treatment	88.	96.	101.	101.	101.	101.	101.	101.	111.	118.
Distribution	1415.	1532.	1617.	1617.	1617.	1617.	1617.	1617.	1769.	1880.
Total	1769.	1915.	2021.	2021.	2021.	2021.	2021.	2021.	2211.	2350.
					Depreciation Cost $/MG					
Support Services	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Acquisition	12.	14.	15.	15.	15.	15.	15.	15.	15.	17.
Treatment	4.	5.	5.	5.	5.	5.	5.	5.	5.	6.
Distribution	64.	75.	79.	79.	79.	79.	79.	79.	78.	92.
Total	80.	94.	99.	99.	99.	99.	99.	99.	97.	115.
					Depreciation Cost % of Total					
Support Services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acquisition	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Treatment	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Distribution	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
					Interest Cost $					
Interest $	605.	495.	385.	275.	110.	110.	0.	0.	0.	0.
Interest $/MG	27.	24.	19.	13.	5.	5.	0.	0.	0.	0.

Support services O&M costs rose 260% from $746 to $2682. While distribution costs still represent the major O&M cost factor, it only increased 24% or $719. This pattern is reflected in figures 26, 27 and 28. All three figures indicate the relative importance of each O&M cost component measured in total cost, $/MG, and percent of total O&M cost, respectively. In each one, support services has grown in importance, but distribution costs still remain the highest cost component. This may occur because the utility is very small, which limits its ability to obtain economies of scale.

Figures 29 and 30 reflect the importance of O&M in relation to capital costs. In both years presented, O&M costs dramatically outweigh capital costs. In fact, as a percent of total cost, O&M costs have increased from 68% to 82% which suggests a movement away from capital intensity. To completely evaluate the importance of this shift, further information on the current capital value of the plant is required.

Figure 31 plots total O&M and capital cost over the study period. Operating cost has a much steeper slope while capital cost remains relatively flat. This is a result of inflation and the fact that O&M costs are in current value.

In figures 32 and 33, total cost and total unit cost (historical and deflated) are presented. Both are rising at about the same rate and both deflated cost curves lie entirely below the historical curves. This suggests that the impact of inflation on utility expenditures has not changed over the study period.

Unit payroll, power, and chemical costs ($/MG) are depicted in Figure 34. Payroll costs represent the largest portion of unit costs, but unit chemical costs have risen most rapidly in the later years. The rapid increase in chemical cost may result more from the fact that chemical costs for the early part of the study period were not obtainable rather than from an absolute increase in chemical costs.

Figure 35 plots MH/MG as a measure of labor productivity for the Burlington Water Utility. It remains relatively flat, but output was decreasing. If output had remained constant, MH/MG probably would have decreased indicating economies of operation. The relative importance of this depends on the tradeoff between payroll costs and productivity.

LEBANON, OHIO

The Lebanon water utility is owned and operated by the City of Lebanon, Ohio, located about 15 miles northeast of Cincinnati. The utility serves approximately 10,050 people in a service area of 6.7 square miles. Change in treated and revenue-producing water over a 10-year period from 1966 to 1975 is presented in Figure 36. Also tables 8 and 9 contain O&M and capital cost data for each cost component for this period.

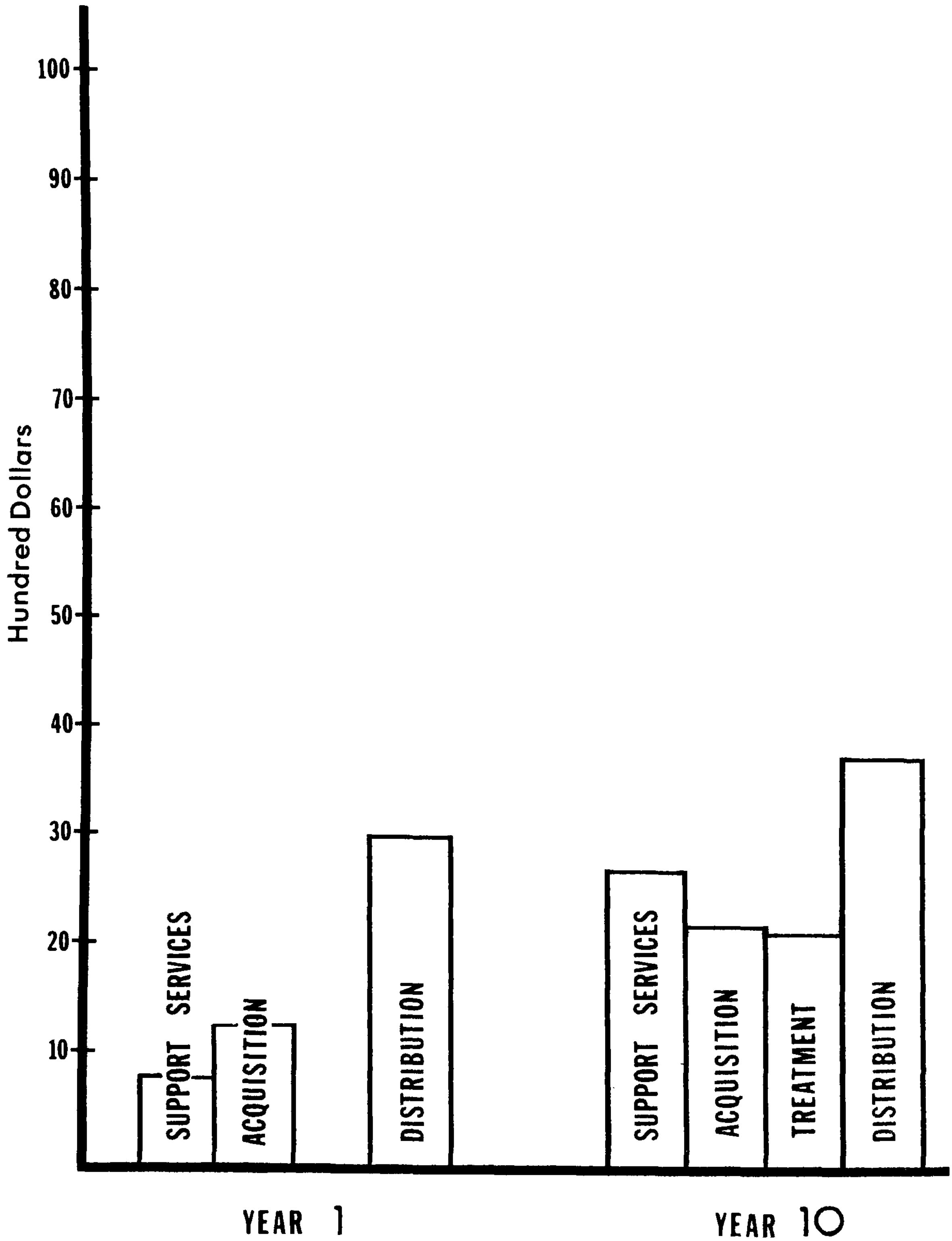

Figure 26. Operating costs for Burlington Water Utility.

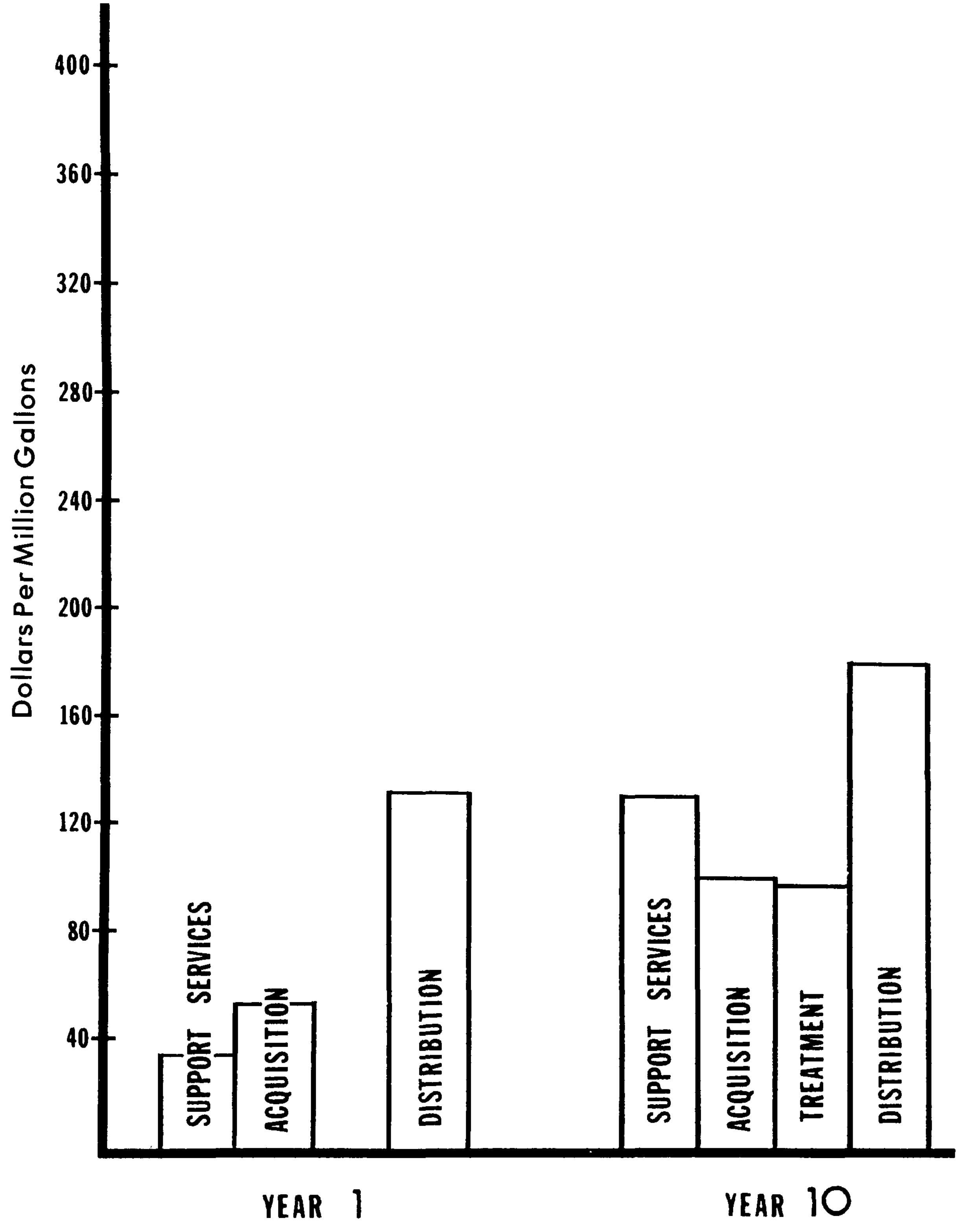

Figure 27. Operating costs in dollars per million gallons for Burlington Water Utility.

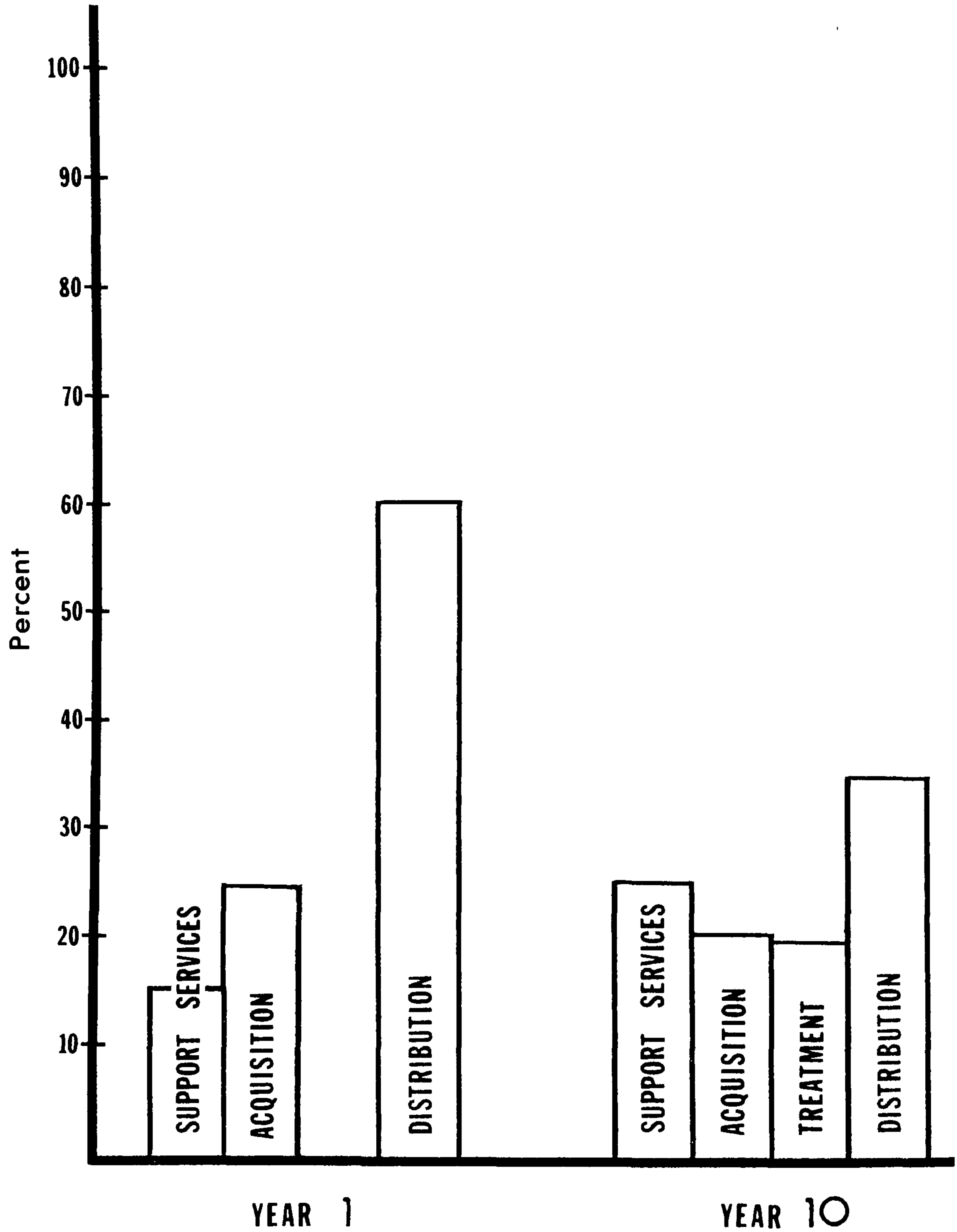

Figure 28. Operating costs as a percent of total O & M cost for Burlington Water Utility.

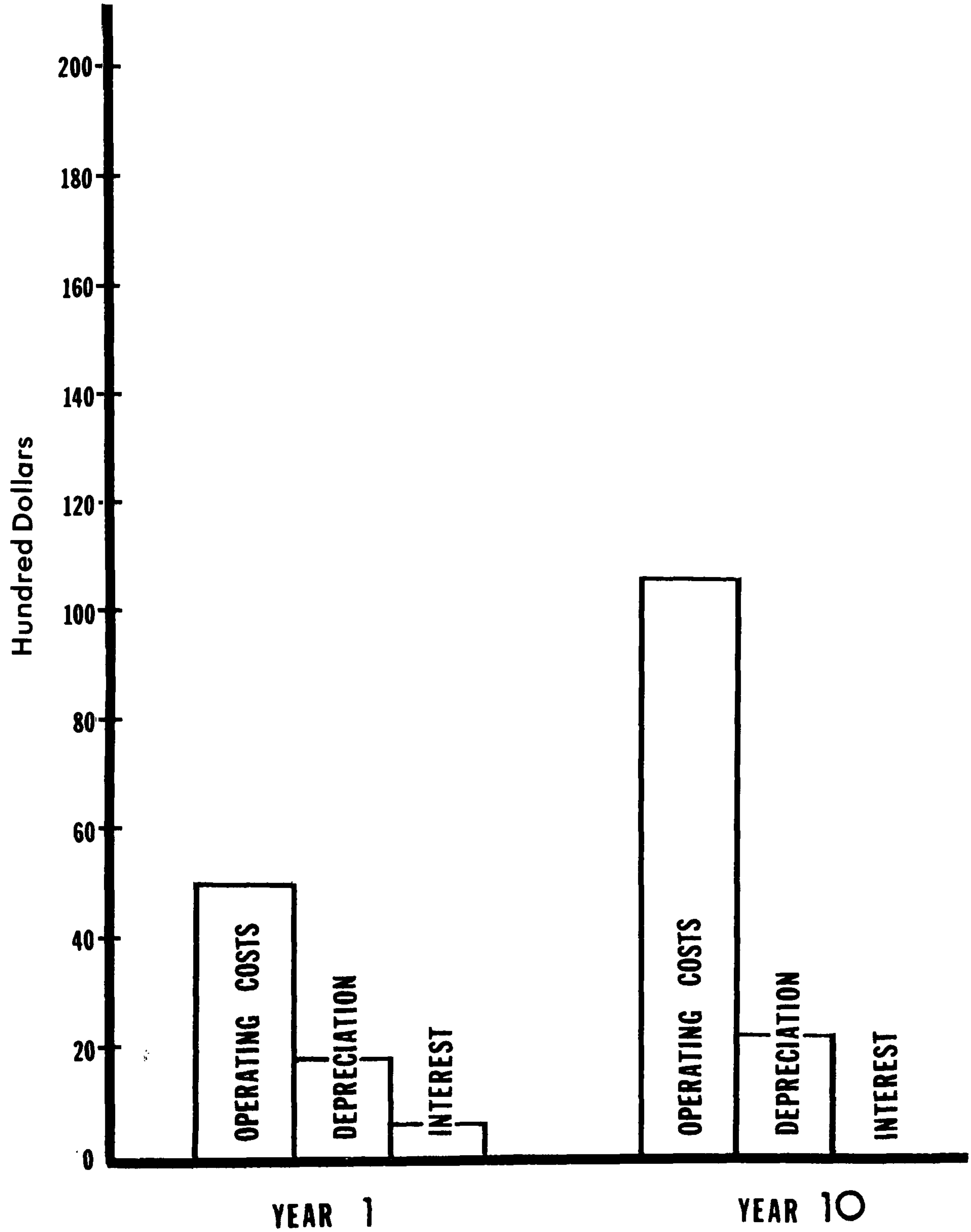

Figure 29. Operating and capital costs for Burlington Water Utility.

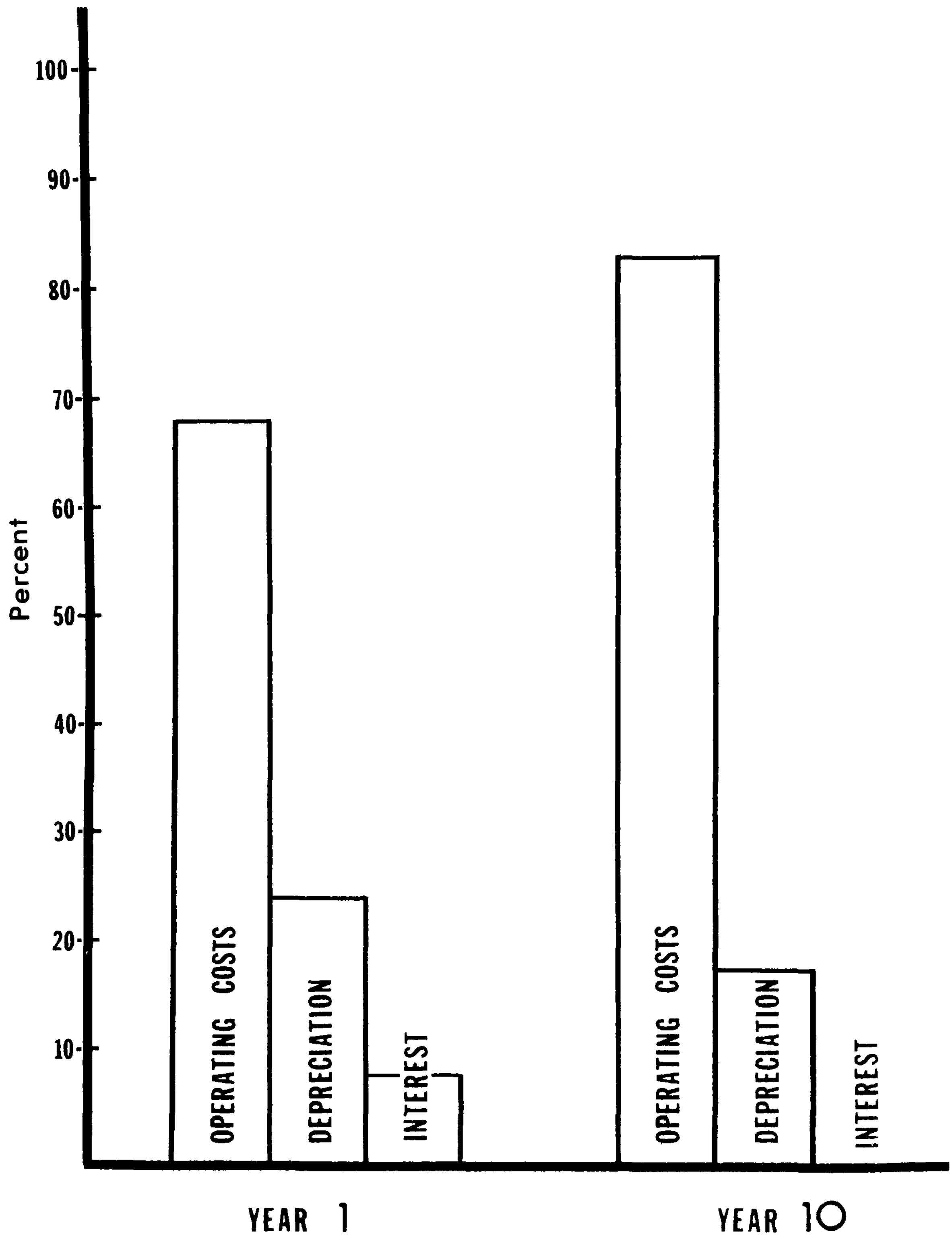

Figure 30. Capital and operating costs as a percent of total cost for Burlington Water Utility.

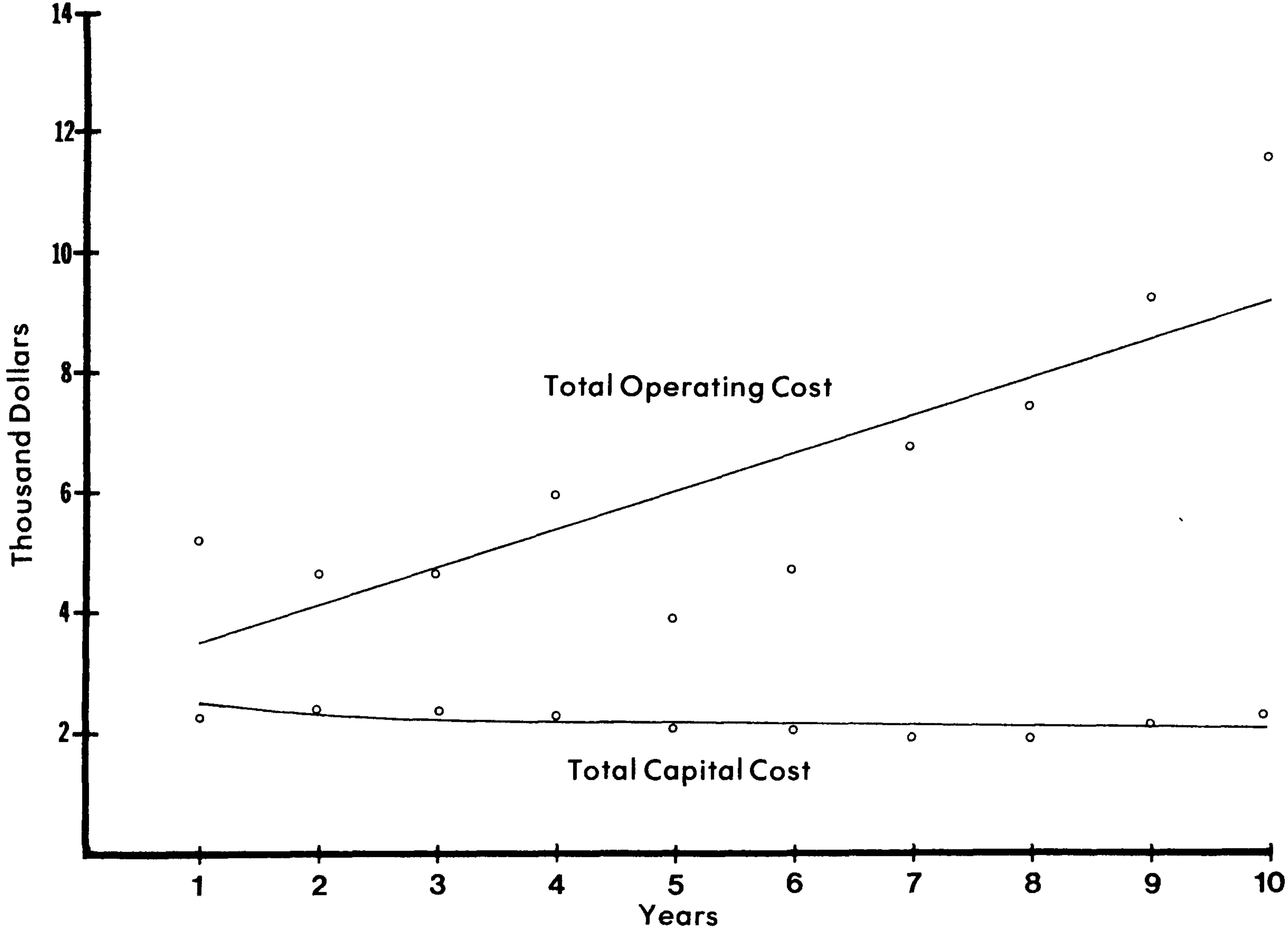

Figure 31. Total capital and operating costs versus time for Burlington Water Utility.

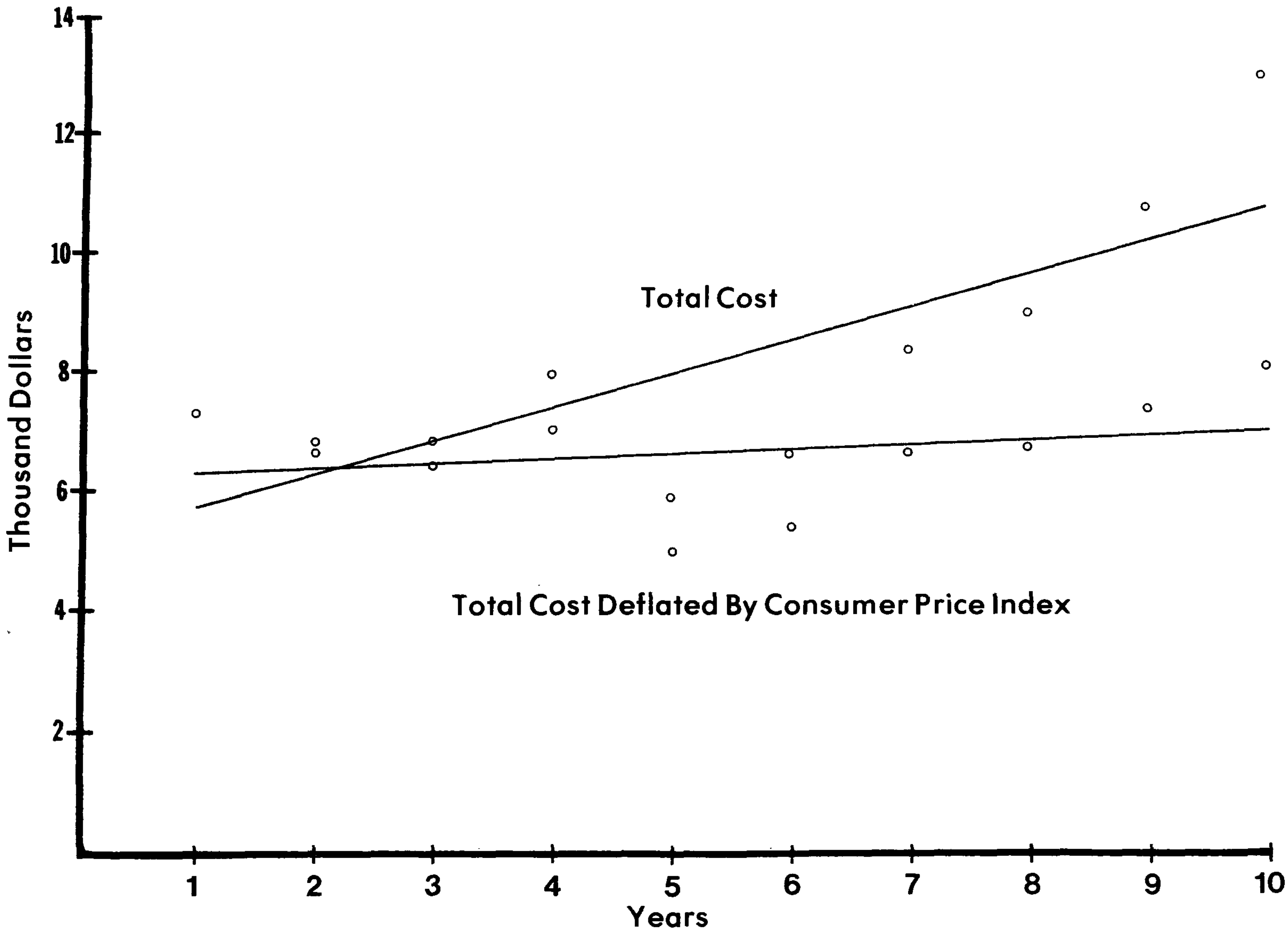

Figure 32. Total costs versus time for Burlington Water Utility: historical and deflated.

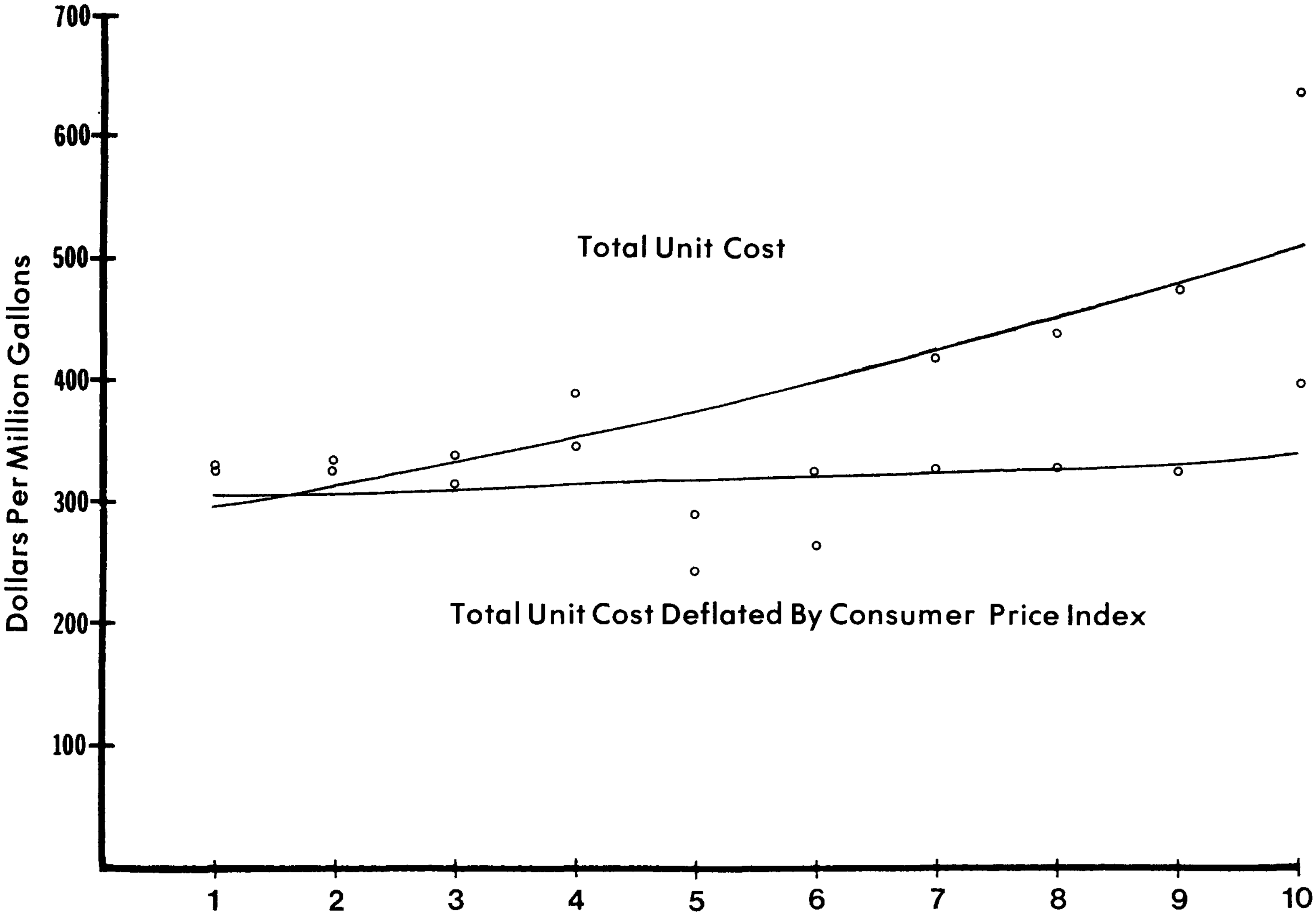

Figure 33. Total unit cost versus time for Burlington Water Utility: historical and deflated.

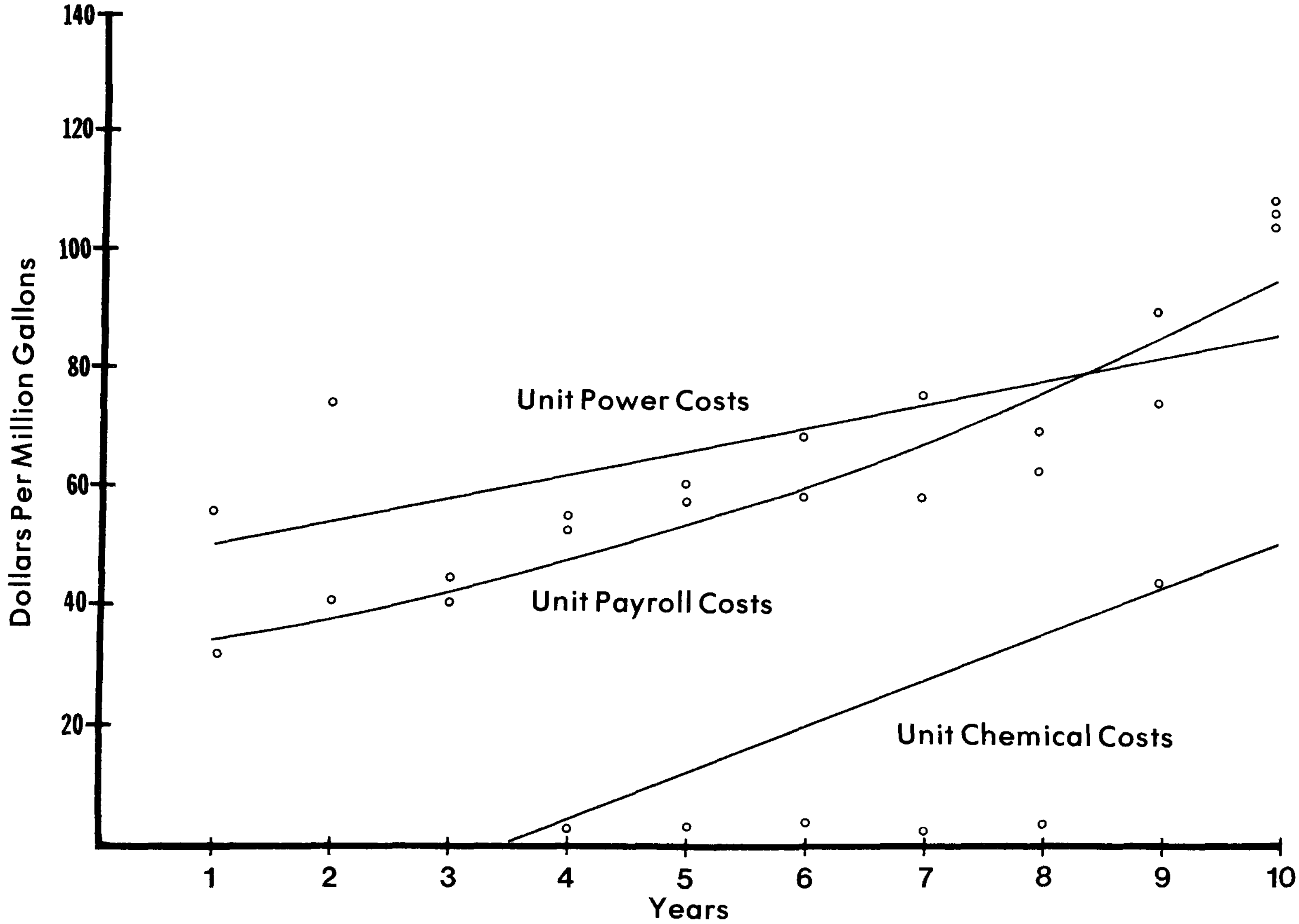

Figure 34. Unit payroll, power, and chemical costs versus time for Burlington Water Utility.

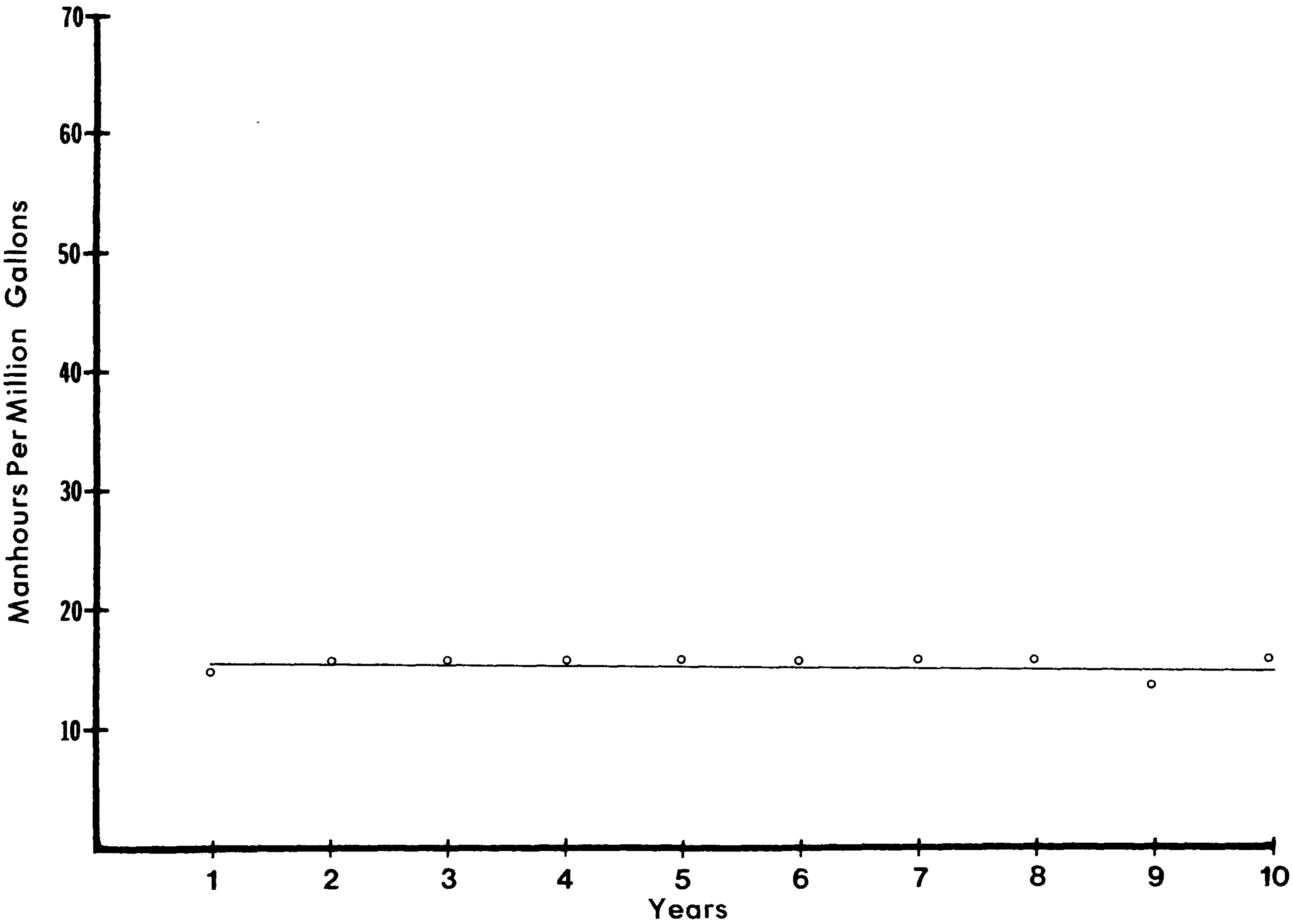

Figure 35. Manhours per million gallons versus time for Burlington Water Utility.

Table 8. OPERATING AND MAINTENANCE COST

Lebanon, Ohio

	1	2	3	4	5	6	7	8	9	10
					Cost/Year					
Support Services	14318.	14304.	23736.	20732.	28666.	28594.	28518.	31348.	32315.	37077.
Acquisition	4937.	8052.	8562.	10083.	11974.	11638.	12199.	19591.	19344.	25770.
Treatment	5578.	8753.	9217.	10879.	13311.	12542.	13014.	20463.	20152.	26581.
Distribution	26656.	25683.	25475.	30208.	45870.	43867.	51231.	61490.	67387.	71460.
Total	51490.	56792.	66990.	71902.	99821.	96640.	104962.	132891.	139198.	160887.
					Cost/MG					
Support Services	48.	43.	65.	49.	82.	66.	83.	94.	117.	151.
Acquisition	16.	24.	24.	24.	34.	27.	35.	59.	70.	105.
Treatment	19.	26.	25.	25.	38.	29.	38.	61.	73.	108.
Distribution	89.	77.	70.	71.	130.	101.	149.	184.	244.	291.
Total	172.	171.	185.	168.	284.	222.	305.	398.	503.	655.
					% of Total					
Support Services	27.81	25.19	35.43	28.83	28.72	29.59	27.17	23.59	23.22	23.05
Acquisition	9.59	14.18	12.78	14.02	12.00	12.04	11.62	14.74	13.90	16.02
Treatment	10.83	15.41	13.76	15.13	13.34	12.98	12.40	15.40	14.48	16.52
Distribution	51.77	45.22	38.03	42.01	45.95	45.39	48.81	46.27	48.41	44.42
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 9. DEPRECIATION AND INTEREST COST

Lebanon, Ohio

	1	2	3	4	5	6	7	8	9	10
					Cost/Year					
Support Services	5190.	5235.	5282.	5319.	5354.	5380.	5407.	5436.	5456.	5500.
Acquisition	8304.	8376.	8451.	8510.	8566.	8608.	8651.	8697.	8730.	8800.
Treatment	2076.	2094.	2113.	2127.	2141.	2152.	2163.	2174.	2183.	2200.
Distribution	88230.	88995.	89790.	90417.	91011.	91460.	91921.	92406.	92757.	93500.
Total	103800.	104700.	105635.	106373.	107072.	107600.	108142.	108713.	109126.	110000.
				Depreciation Cost $/MG						
Support Services	17.	16.	15.	12.	15.	12.	16.	16.	20.	22.
Acquisition	28.	25.	23.	20.	24.	20.	25.	26.	32.	36.
Treatment	7.	6.	6.	5.	6.	5.	6.	7.	8.	9.
Distribution	295.	268.	248.	212.	259.	210.	267.	276.	335.	380.
Total	347.	316.	291.	249.	304.	247.	314.	325.	395.	448.
				Depreciation Cost % of Total						
Support Services	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Acquisition	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Treatment	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Distribution	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
				Interest Cost $						
Interest $	7812.	6674.	6237.	5800.	11350.	28725.	22126.	43712.	30312.	28500.
Interest $/MG	26.	20.	17.	14.	32.	66.	64.	131.	110.	116.

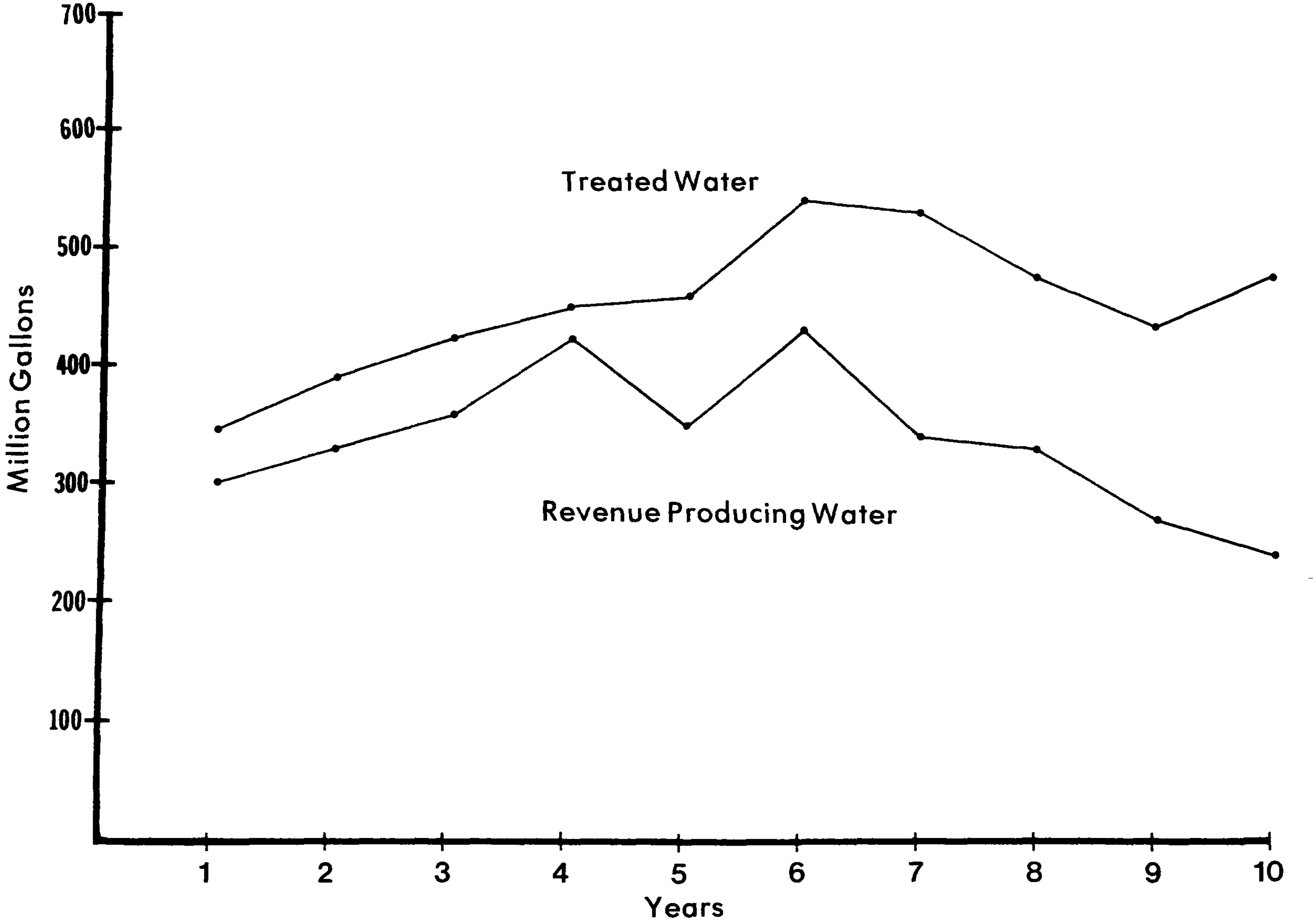

Figure 36. Treated and revenue producing water for Lebanon Water Utility.

Total O&M costs increased from $51,490 to $160,887, or 212%, while unit O&M costs ($/MG) rose 281%. However, some of this unit cost increase resulted from the 18% decline in revenue-producing water, from 299 MG to 246 MG.

In figures 37 and 38, each component has increased significantly. Acquisition increased 422% and treatment 376%. Treatment and acquisition costs represent a small but increasing portion of the budget since ground water is easily obtained and passed through a basic treatment process. Support services O&M cost has increased 159% and distribution O&M cost rose 168%. Even though distribution costs increased less proportionately than acquisition or treatment, it remains the major O&M cost component because the distribution system is rather extensive (see Figure 39).

Figures 40 and 41 indicate the relative importance of operating and capital in total as well as percent of total cost. Over the study period, operating costs have increased from 31% to 54% of total cost such that now it is the major component of total cost.

Total O&M and total capital cost is plotted in Figure 42. The operating cost curve rises more rapidly than does capital cost, which suggests that inflation has a greater impact on O&M than capital. Figures 43 and 44 present total and unit costs (historical and deflated), which indicate the impact of inflation. This effect appears more pronounced in the later years which coincides with the rapid increase in operating costs.

Unit payroll and power costs are presented in Figure 45. Chemical cost data were not available except for the last two years. Unit payroll costs represent a significant portion of operating costs heavily affected by inflation. Figure 46 shows that MH/MG as a measure of labor productivity increased over the study period. This is a result more of the decline in output than a loss of productivity. This information aids utility managers in identification of those elements which greatly impact cost.

TAYLOR, TEXAS

The City of Taylor, Texas, owns and operates the Taylor water utility. It is located 20 miles south of Temple, and supplies approximately 9,616 people in a 10.24 square mile service area. As presented in Figure 47, revenue-producing water increased from 186 million gallons to 286 million gallons over a 10-year period from 1966 to 1975. Also, in tables 10 and 11, O&M and capital cost data for each component is provided.

Total O&M costs increased 47%, from $94,208 to $138,814, but unit O&M costs declined 4% while revenue-producing water rose 54%. This could account for the decline in unit O&M costs. Figures 48 and 49 present total and unit O&M costs for each cost component. Figure 50 shows each component's relative position in terms of percent of total cost. In each figure, treatment costs represent a small portion of total O&M cost. This occurs because the ground water source utilized by the Taylor water utility is only treated with chlorine. No further treatment processes

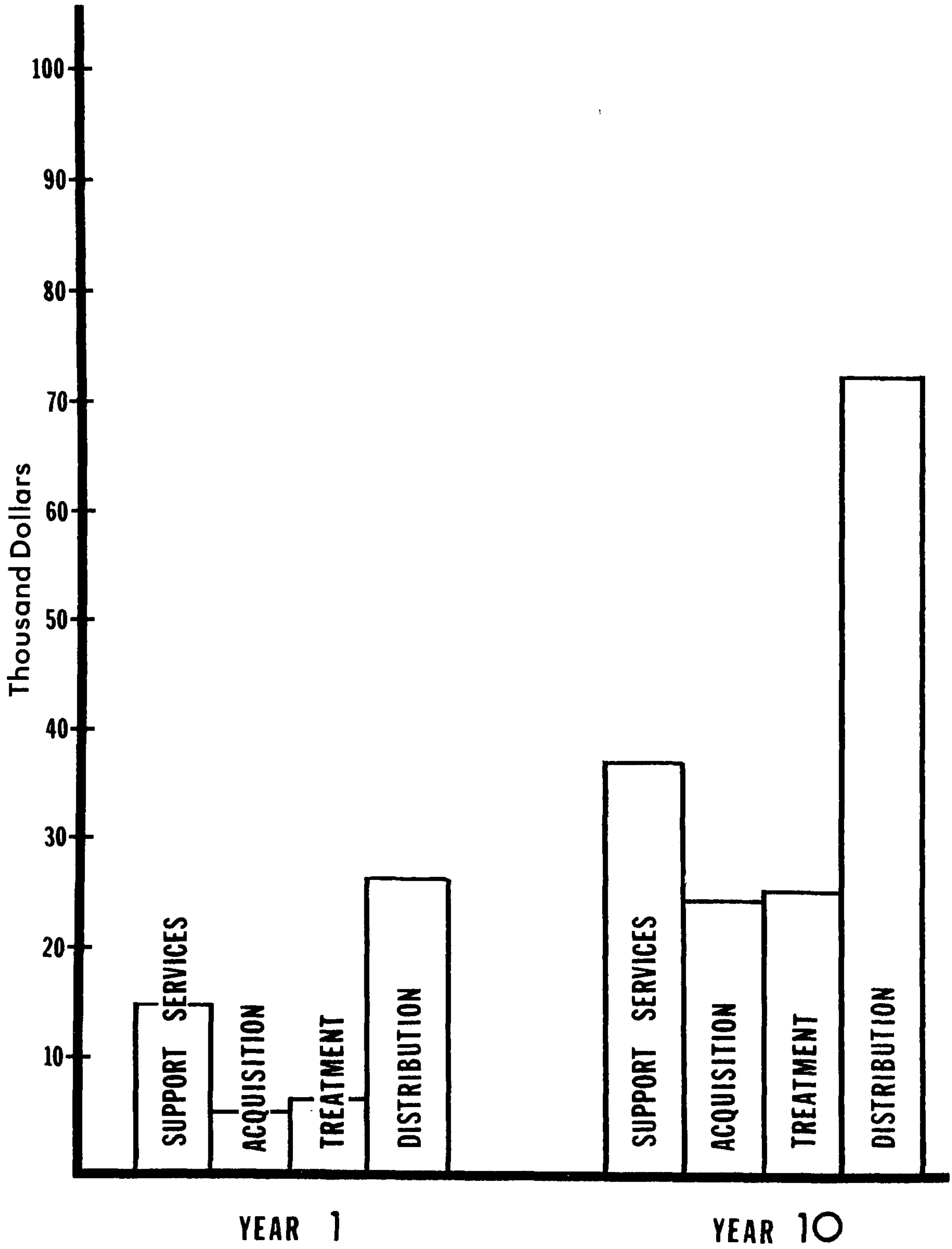

Figure 37. Operating costs for Lebanon Water Utility.

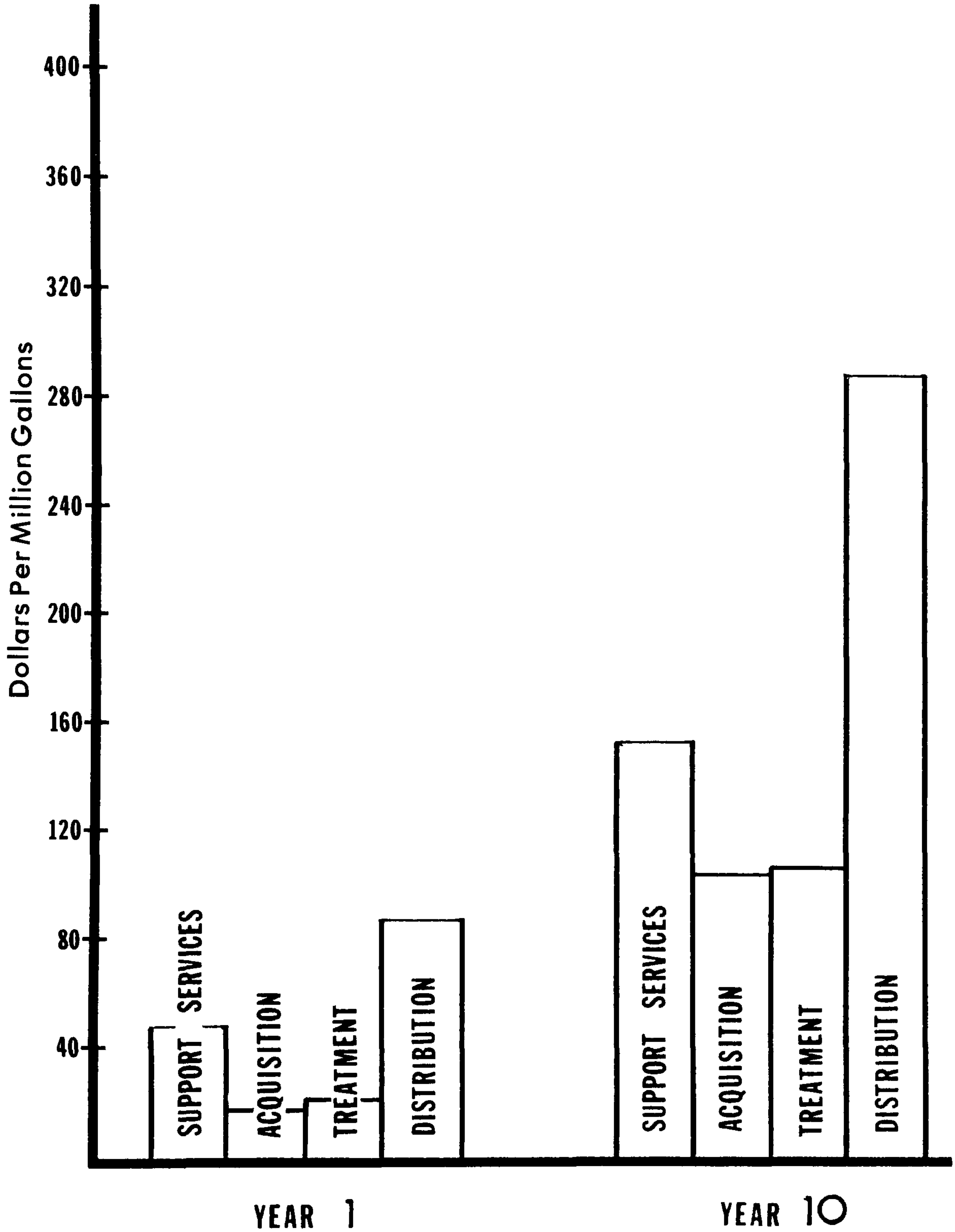

Figure 38. Operating costs in dollars per million gallons for Lebanon Water Utility.

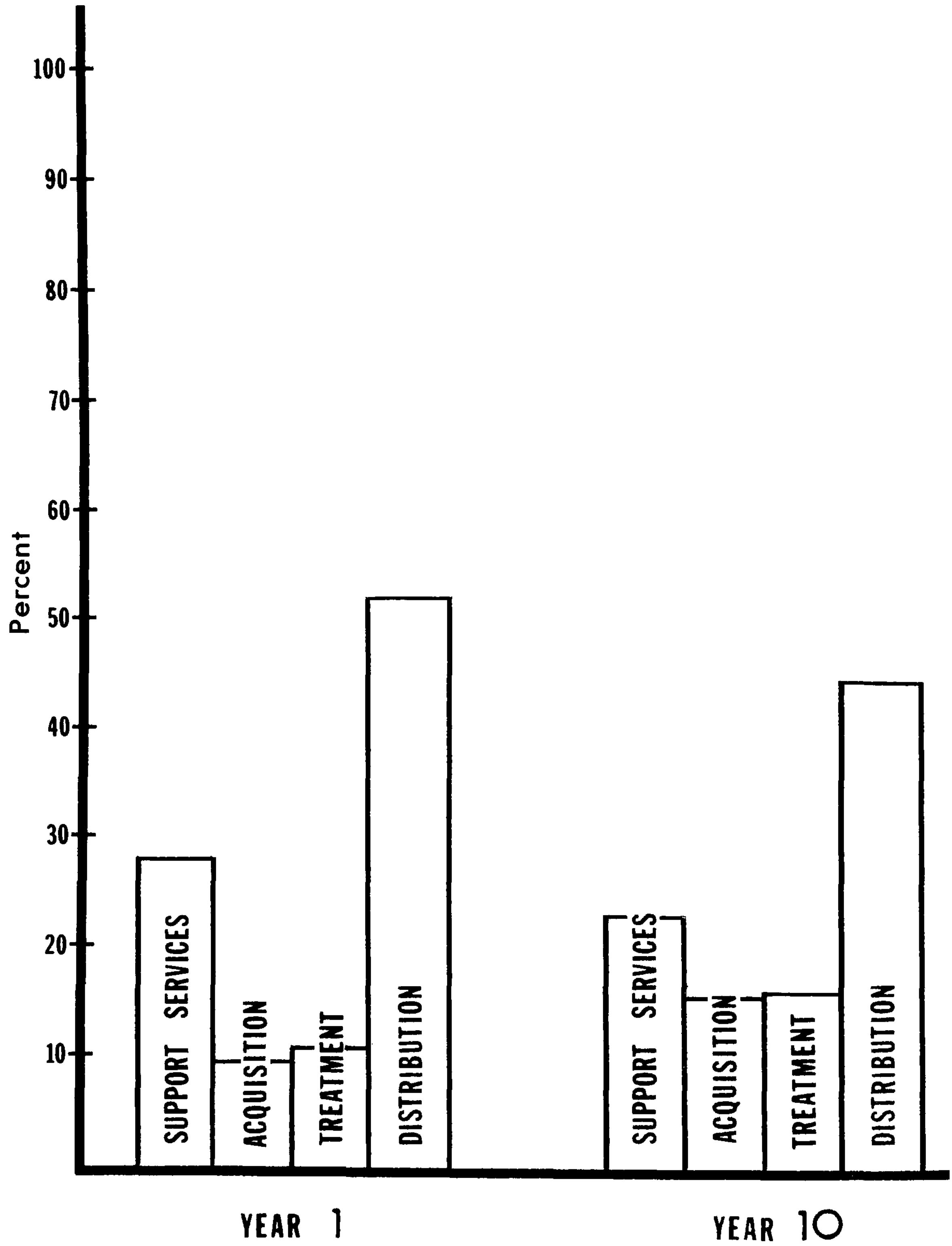

Figure 39. Operating costs as a percent of total O & M cost for Lebanon Water Utility.

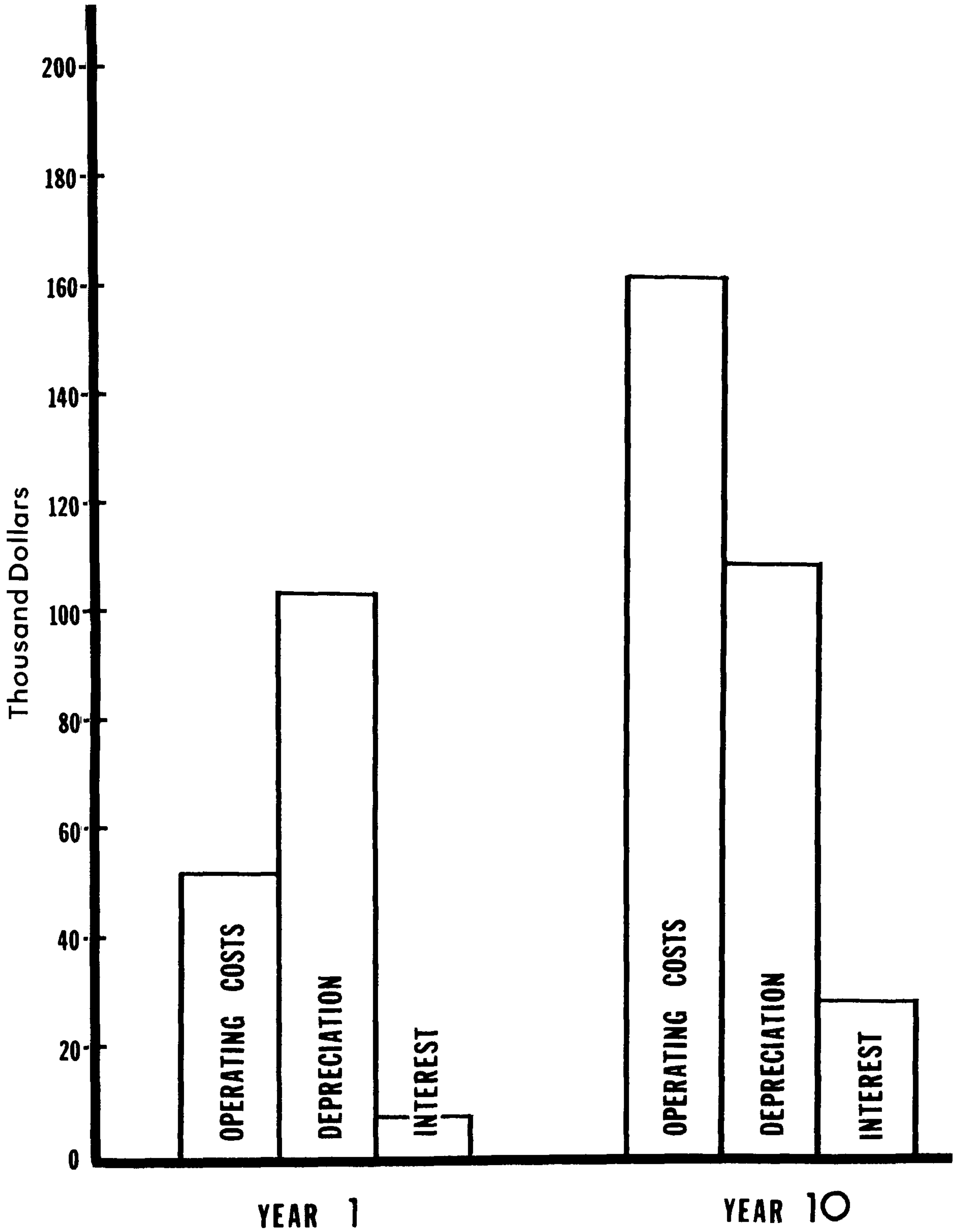

Figure 40. Capital and operating costs for Lebanon Water Utility.

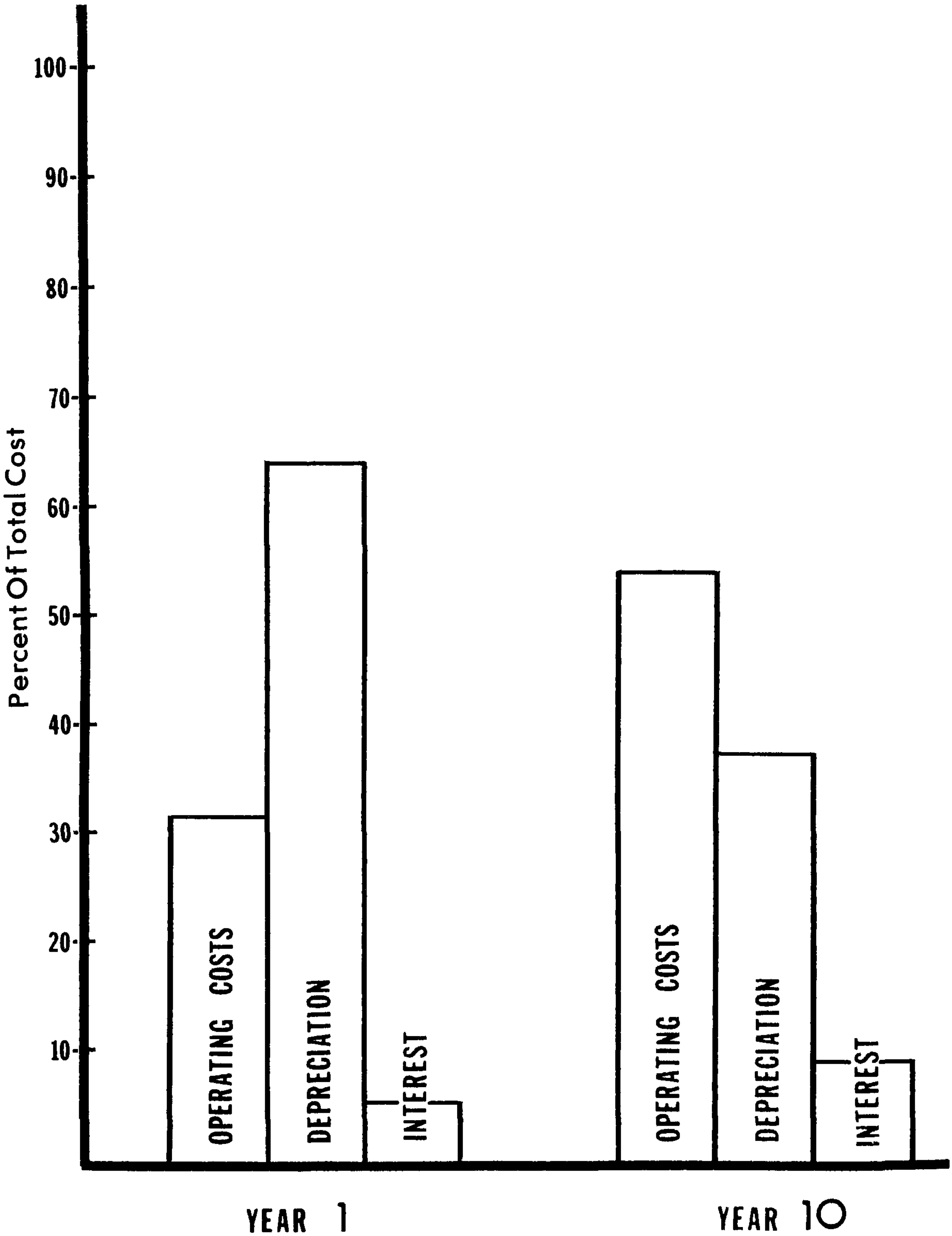

Figure 41. Capital and operating costs as a percent of total cost for Lebanon Water Utility.

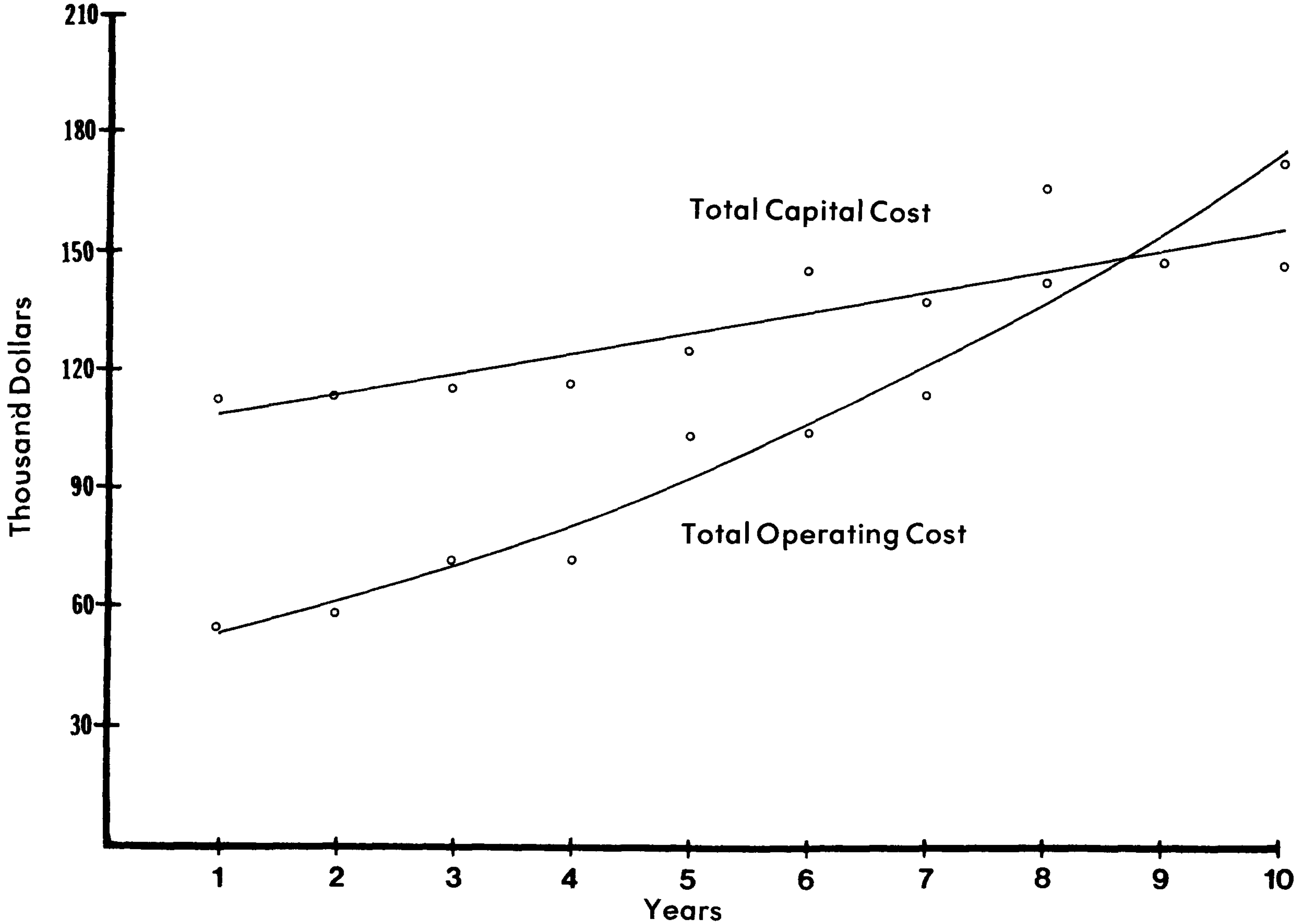

Figure 42. Total operating and capital expenditures for Lebanon Water Utility.

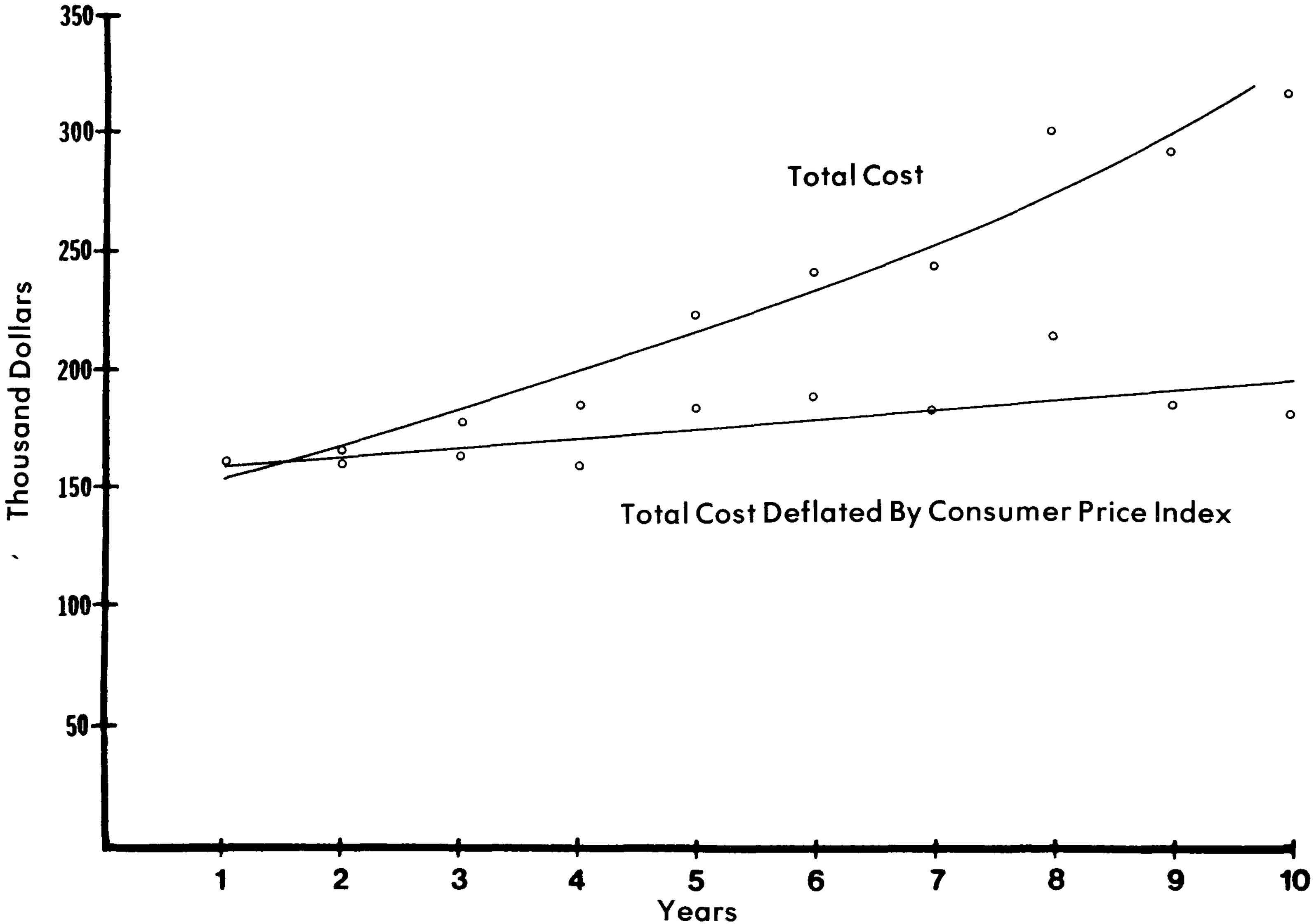

Figure 43. Total costs versus time for Lebanon Water Utility: historical and deflated.

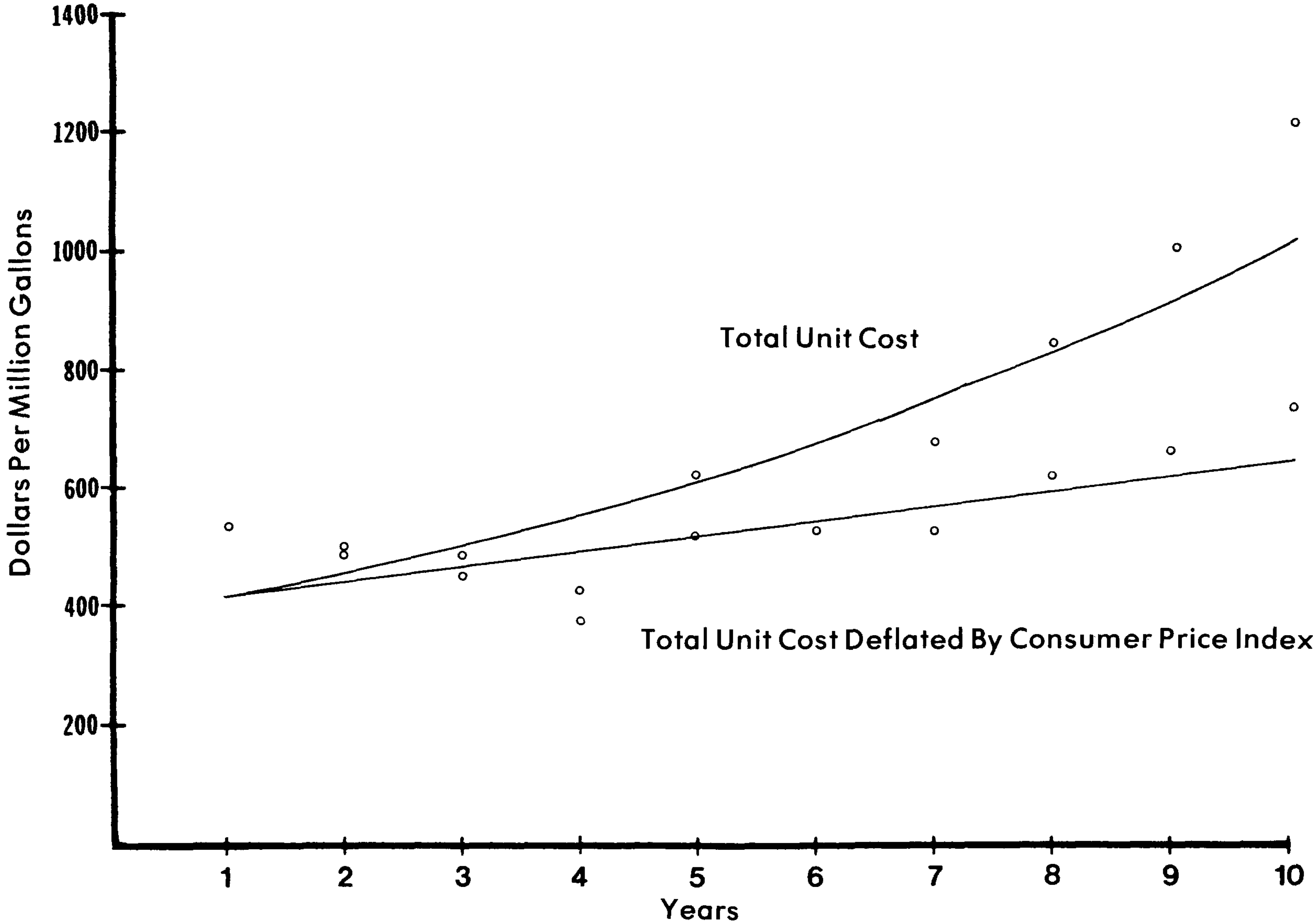

Figure 44. Total unit costs versus time for Lebanon Water Utility: historical and deflated.

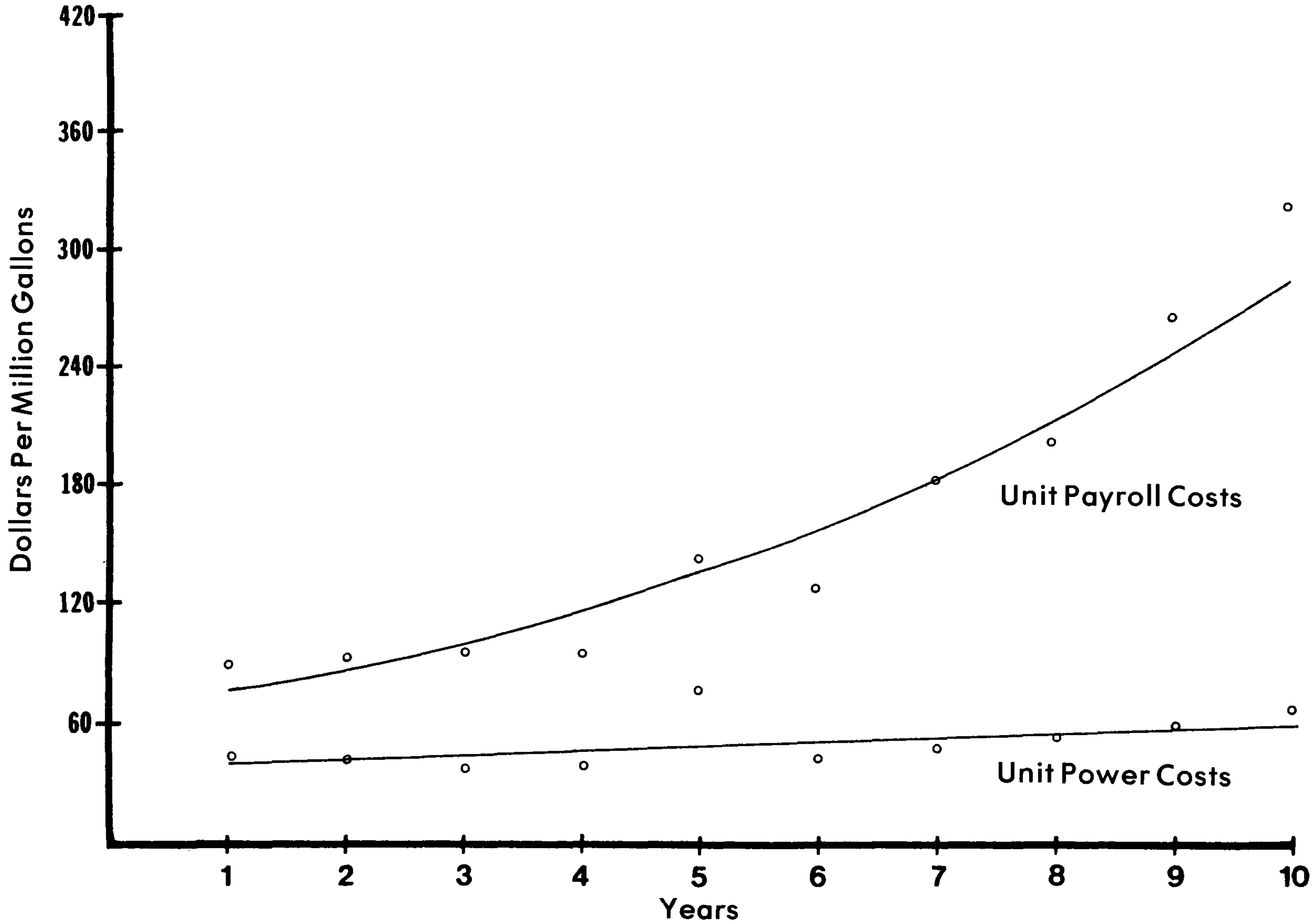

Figure 45. Unit payroll and power costs versus time for Lebanon Water Utility.

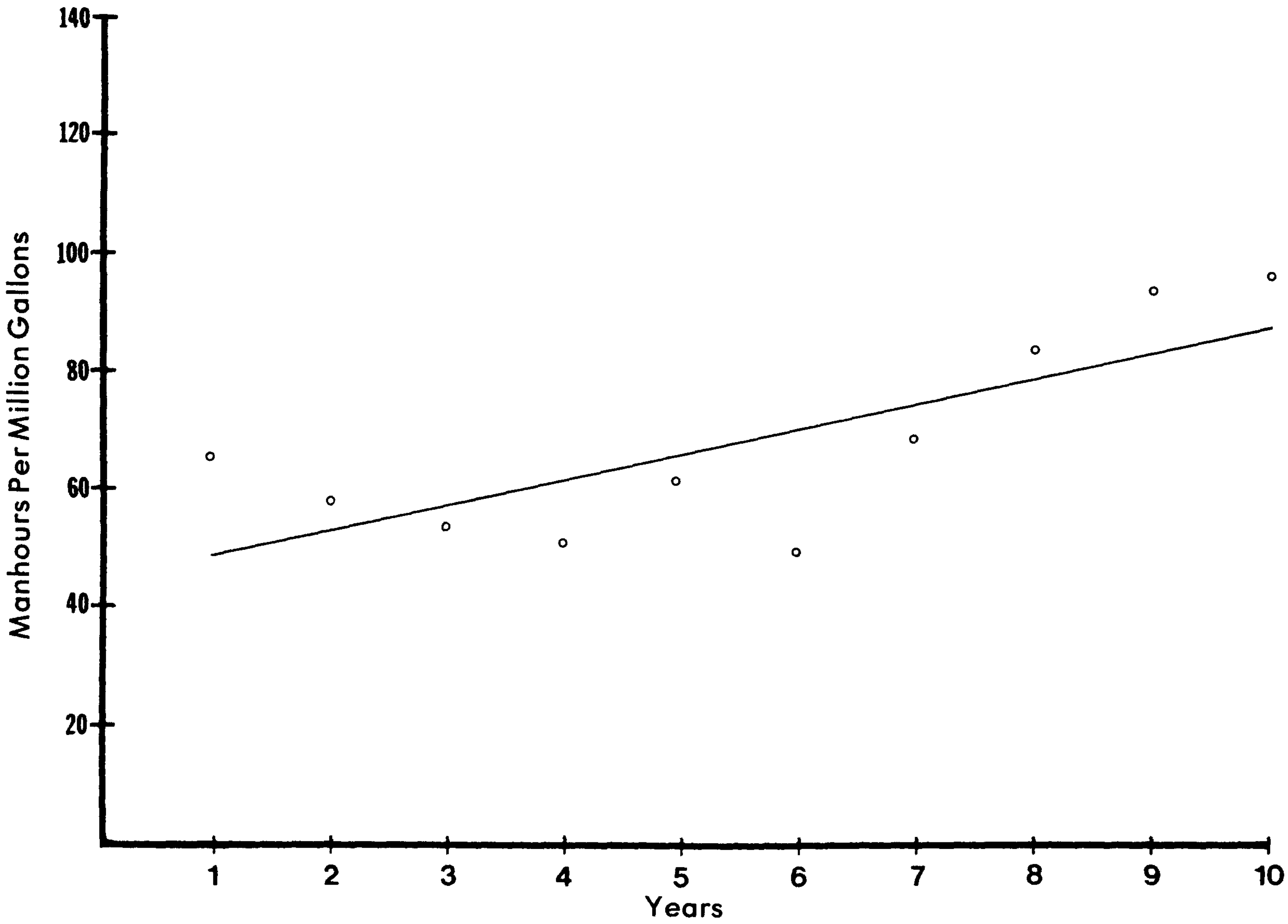

Figure 46. Manhours per million gallons versus time for Lebanon Water Utility.

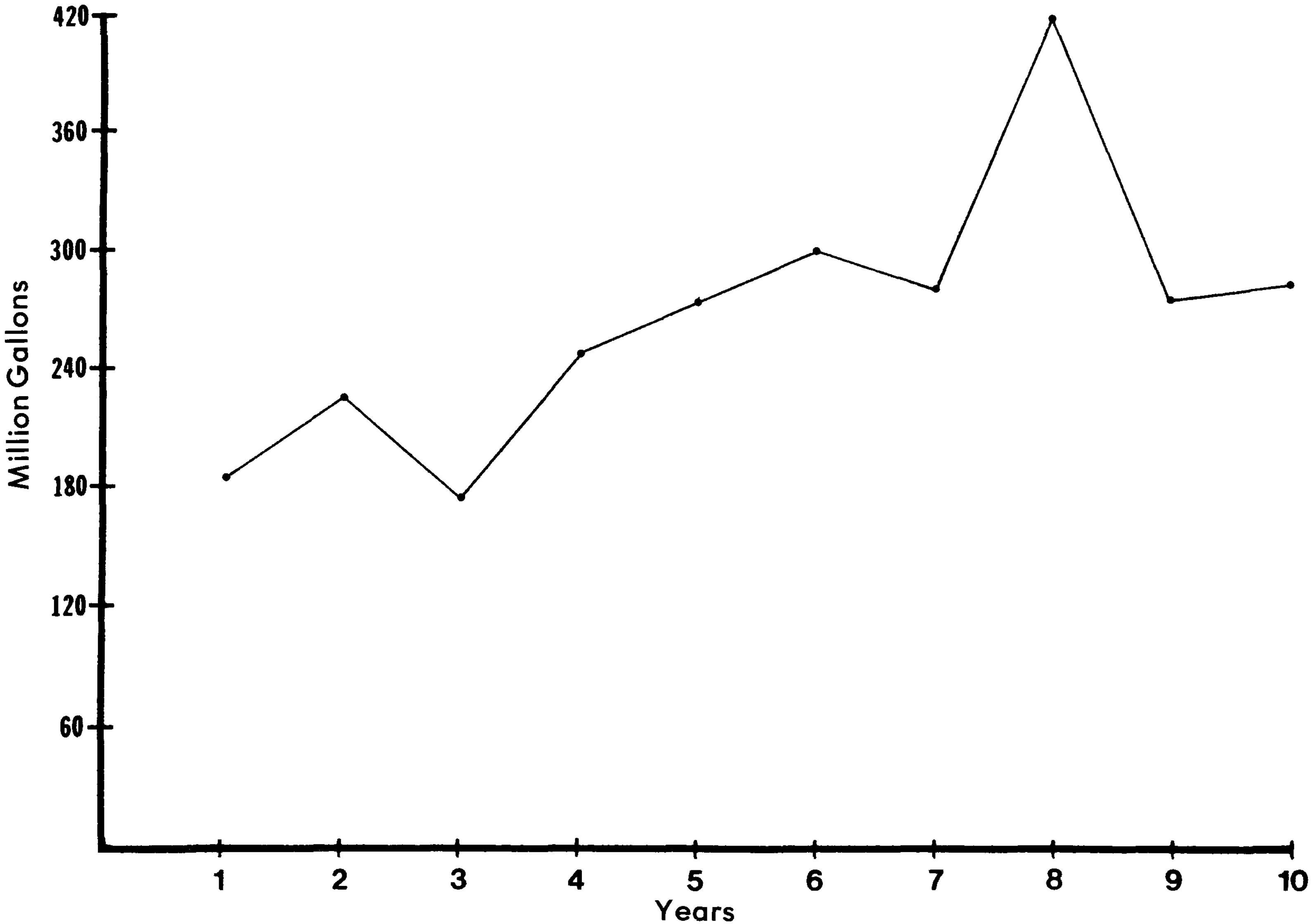

Figure 47. Revenue producing water for Taylor Water Utility.

Table 10. OPERATING AND MAINTENANCE COST

Taylor, Texas

	1	2	3	4	5	6	7	8	9	10
					Cost/Year					
Support Services	28262.	27082.	31156.	30754.	42800.	42476.	34205.	40299.	35401.	41644.
Acquisition	12247.	11736.	13501.	13327.	18547.	18406.	14822.	17463.	15340.	18046.
Treatment	3768.	3611.	4154.	4101.	5707.	5664.	4561.	5373.	4720.	5553.
Distribution	49930.	47845.	55043.	54332.	75614.	75041.	60428.	71194.	62542.	73571.
Total	94208.	90274.	103854.	102513.	142668.	141588.	114015.	134329.	118003.	138814.
					Cost/MG					
Support Services	152.	122.	176.	123.	154.	142.	120.	95.	128.	146.
Acquisition	66.	53.	76.	53.	67.	62.	52.	41.	55.	63.
Treatment	20.	16.	23.	16.	21.	19.	16.	13.	17.	19.
Distribution	268.	215.	311.	217.	272.	251.	212.	168.	226.	258.
Total	506.	406.	586.	409.	513.	474.	400.	317.	427.	486.
					% of Total					
Support Services	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Acquisition	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00
Treatment	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Distribution	53.00	53.00	53.00	53.00	53.00	53.00	53.00	53.00	53.00	53.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 11. DEPRECIATION AND INTEREST COST

Taylor, Texas

	1	2	3	4	5	6	7	8	9	10
					Depreciation Cost $/Yr					
Support Services	1850.	1950.	2050	2150.	2250.	2350.	2950.	3050.	3150.	3250.
Acquisition	5550.	5850.	6150.	6450.	6750.	7050.	8850.	9150.	9450.	9750.
Treatment	1850.	1950.	2050.	2150.	2250.	2350.	2950.	3050.	3150.	3250.
Distribution	27750.	29250.	30750.	32250.	33750.	35250.	44250.	45750.	47250.	48750.
Total	37000.	39000.	41000.	43000.	45000.	47000.	59000.	61000.	63000.	65000.
					Depreciation Cost $/MG					
Support Services	10.	9.	12.	9.	8.	8.	10.	7.	11.	11.
Acquisition	30.	26.	35.	26.	24.	24.	31.	22.	34.	34.
Treatment	10.	9.	12.	9.	8.	8.	10.	7.	11.	11.
Distribution	149.	132.	174.	129.	121.	118.	155.	108.	171.	171.
Total	199.	175.	231.	171.	162.	157.	207.	144.	228.	228.
					Depreciation Cost % of Total					
Support Services	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Acquisition	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Treatment	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Distribution	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
					Interest Cost $					
Interest $	8632.	7915.	7250.	6719.	5632.	3377.	30450.	27211.	27544.	27192.
Interest $/MG	46.	36.	41.	27.	20.	11.	107.	64.	100.	95.

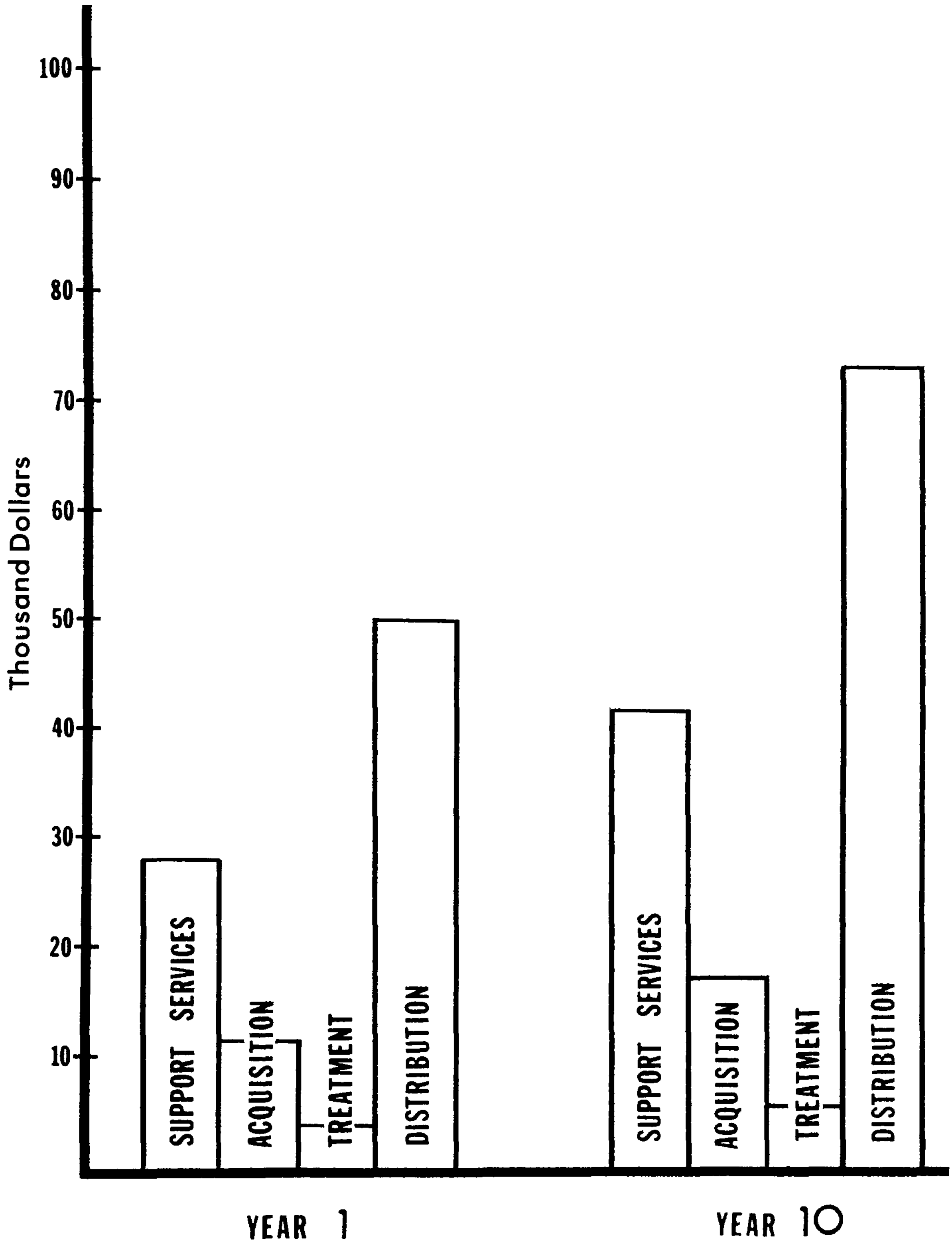

Figure 48. Operating costs for Taylor Water Utility.

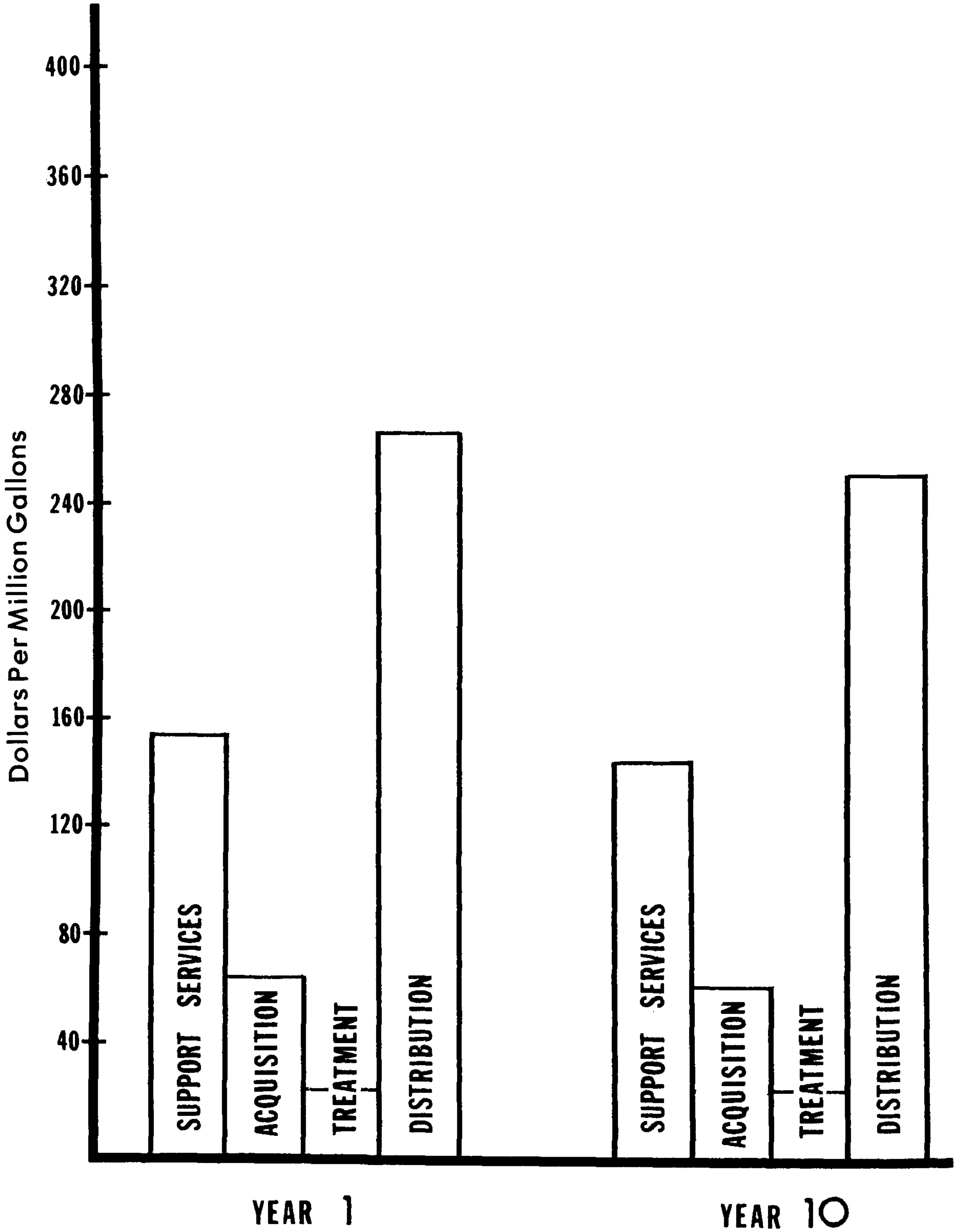

Figure 49. Operating costs in dollars per million gallons for Taylor Water Utility.

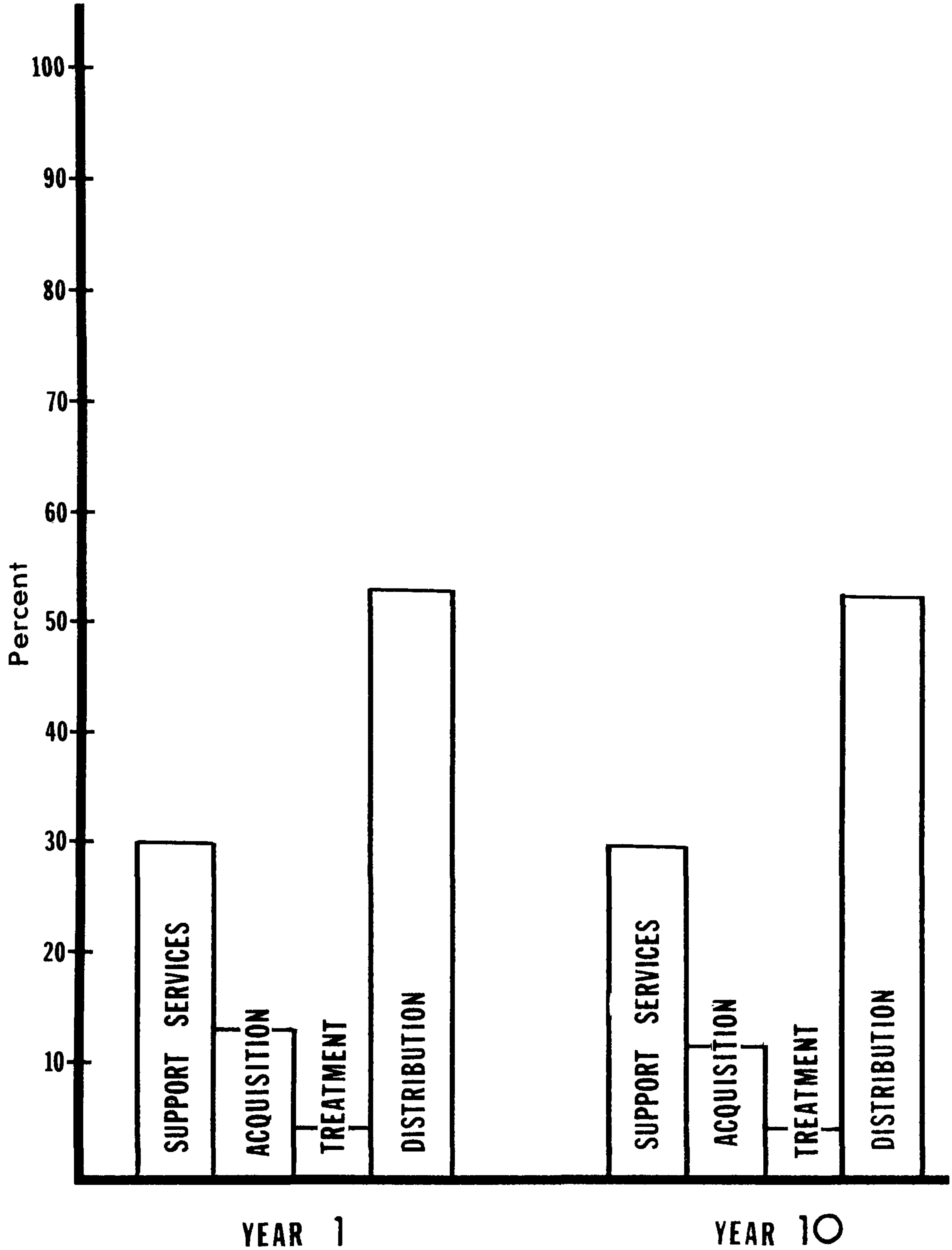

Figure 50. Operating costs as a percent of total O & M for Taylor Water Utility.

are performed on the raw water. Support services and distribution costs comprise the major elements of total O&M cost. Distribution O&M cost is the largest portion because of the decentralized supply network.

The relative importance of operating and capital costs (in total and as a percent of total cost) is demonstrated in figures 51 and 52. Operating cost has risen over the study period, but, as a percent of total cost, it has declined. This suggests that the Taylor water utility has substituted capital for operational inputs. Since capital investment is recent, it reflects the situation where the capital expense and O&M expenses and O&M expenses were made with dollars of close to the same value. An accurate estimate of the tradeoff requires complete information on the current value of capital as well as the productivity associated with O&M and capital costs. In 1972, at the time of greatest system expansion, operating cost/MG was $400.05, while capital cost/MG was $313.86. However, only 20% of the capital was in current value. Proper evaluation of the tradeoff requires further knowledge of the current value of all capital. Figure 53 plots total O&M and total capital cost over the study period. Both have similar slopes, indicating that the absolute impact of inflation over time is approximately the same for both costs. This is because major expenditures in capital occurred during the analysis period.

Figures 54 and 55 show the total and unit costs (historical and deflated by the CPI) over the 10-year period. There is quite a divergence between the lines which indicates that inflation has had a significant impact on costs.

In Figure 56, unit payroll, power, and chemical costs are plotted. Each remains relatively flat over the period. This is probably more a result of the increase in output than a lack of increase in O&M costs. Payroll costs obviously comprise the major cost factor here, but, as shown in Figure 57, labor productivity has increased. The increase in output and the rise in capital investment both contributed to the fall in MH/MG.

DALLAS COUNTY WATER COLLECTION AND IMPROVEMENT DISTRICT (WCID) #6

The Dallas County WCID #6 is owned by the citizens of the district. It is located in an unincorporated political subdivision outside the City of Dallas. Currently, all water is purchased as treated water from the Dallas Water Utility though a few years ago it acquired its source water from wells. The WCID #6 serves approximately 13,800 people in a 7.0 square mile area.

Figure 58 shows that revenue-producing water rose from 159 to 337 million gallons per year over the study period. Tables 12 and 13 contain O&M and capital cost data for each cost component. Total O&M costs increased 290% from $53,325 to $208,024. This explains how unit O&M costs increased 8.4% while revenue-producing water rose 112%. O&M costs were going up faster than output.

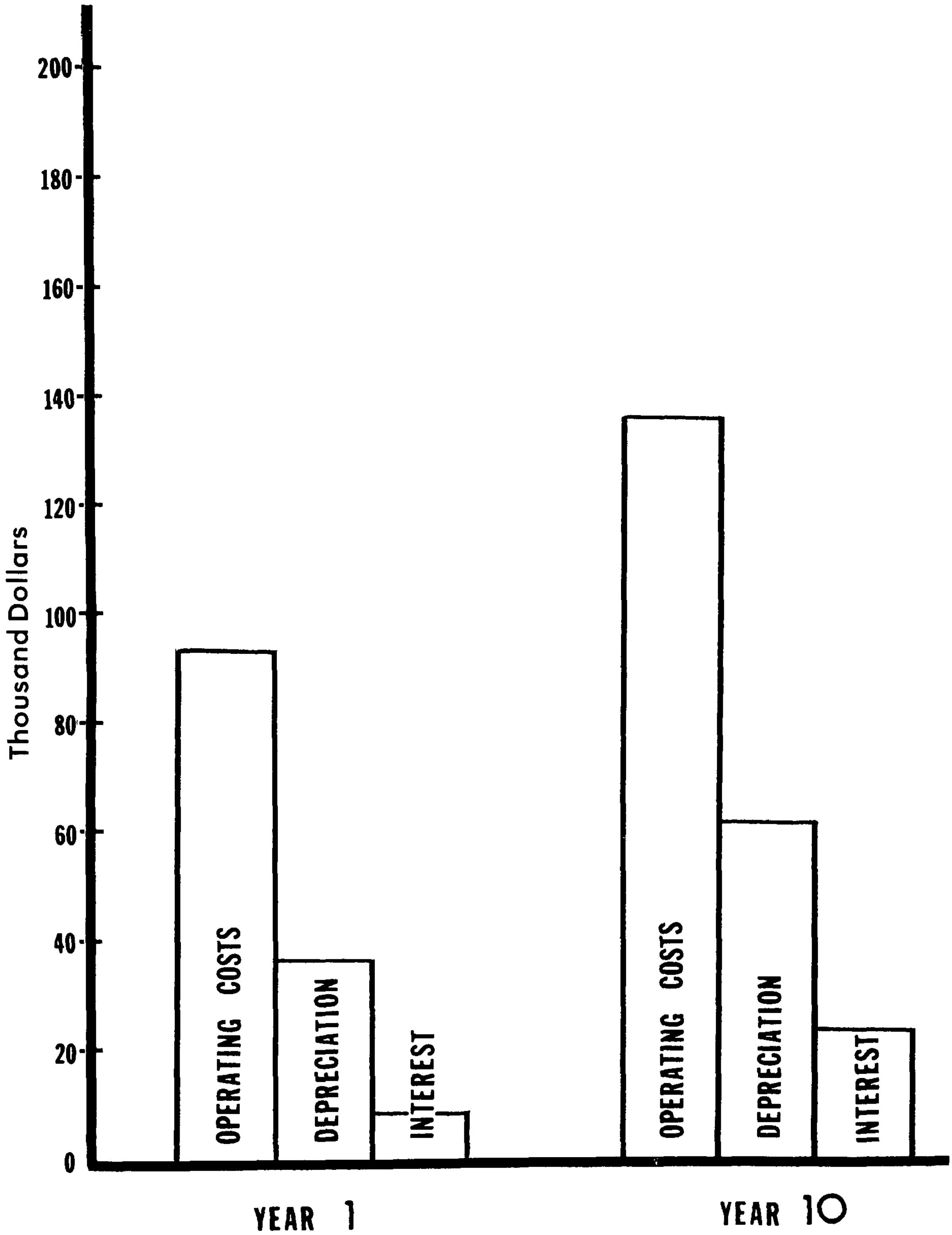

Figure 51. Capital and operating costs for Taylor Water Utility.

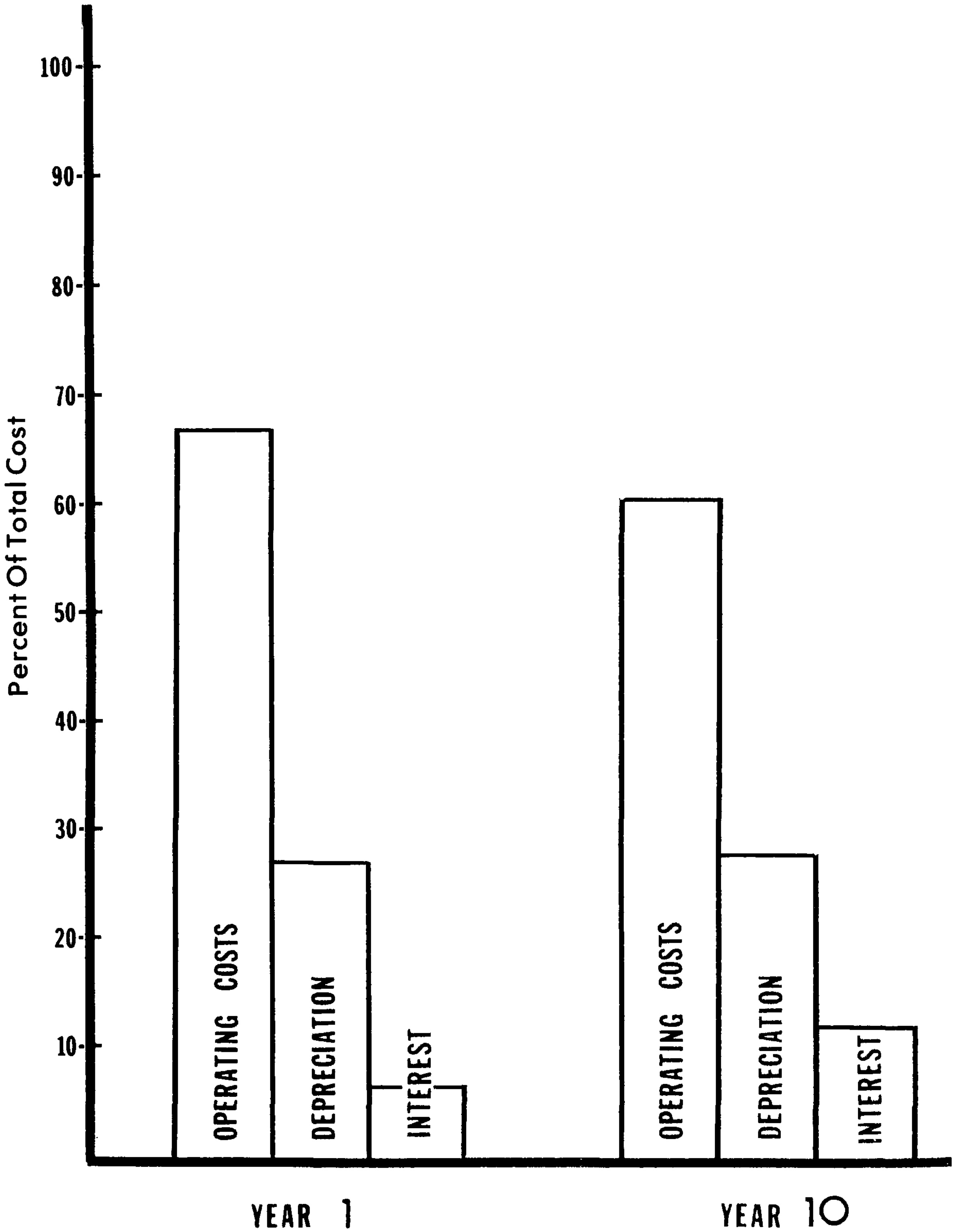

Figure 52. Capital and operating costs as a percent of total cost for Taylor Water Utility.

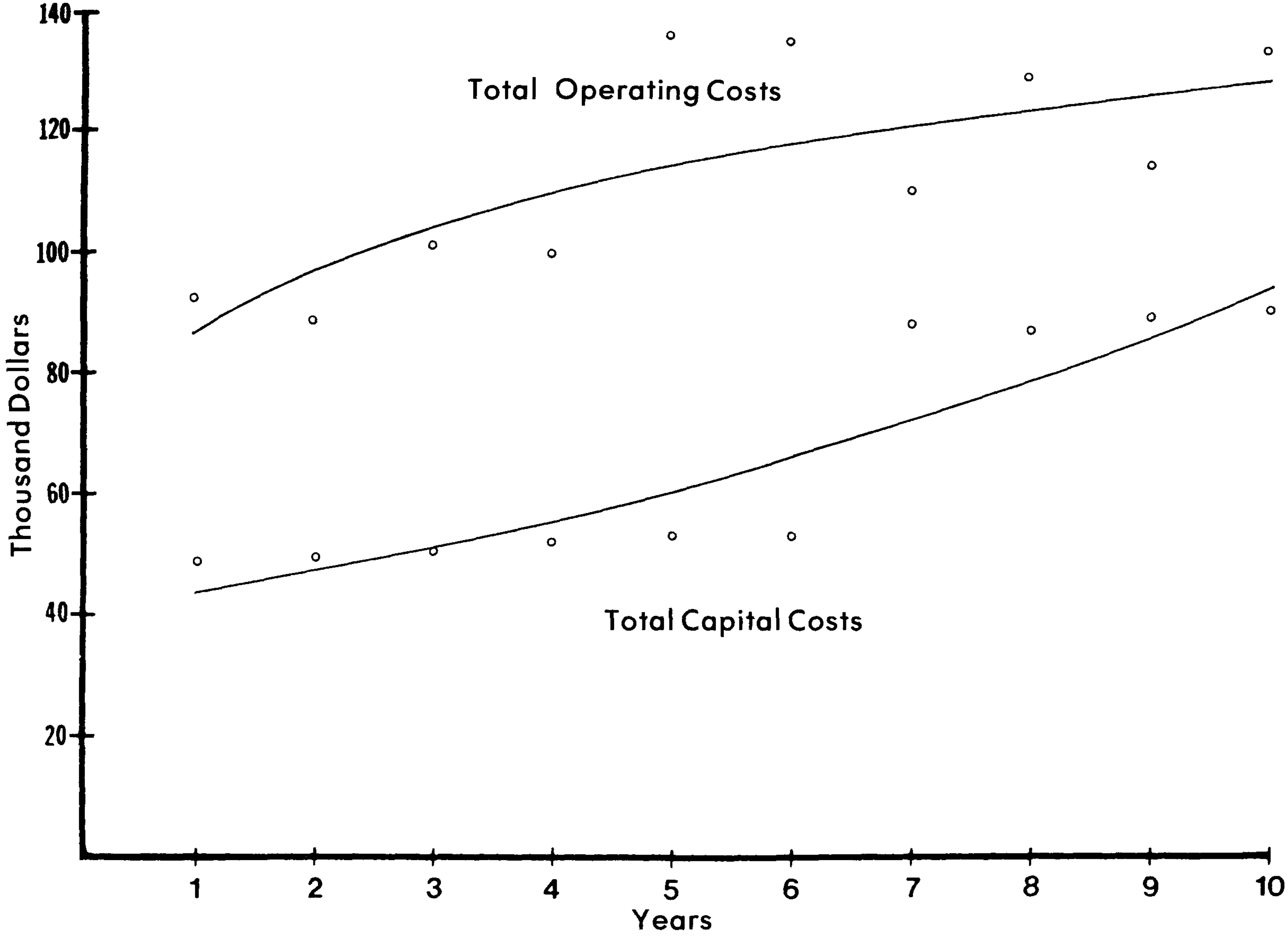

Figure 53. Total operating and capital expenditures versus time for Taylor Water Utility.

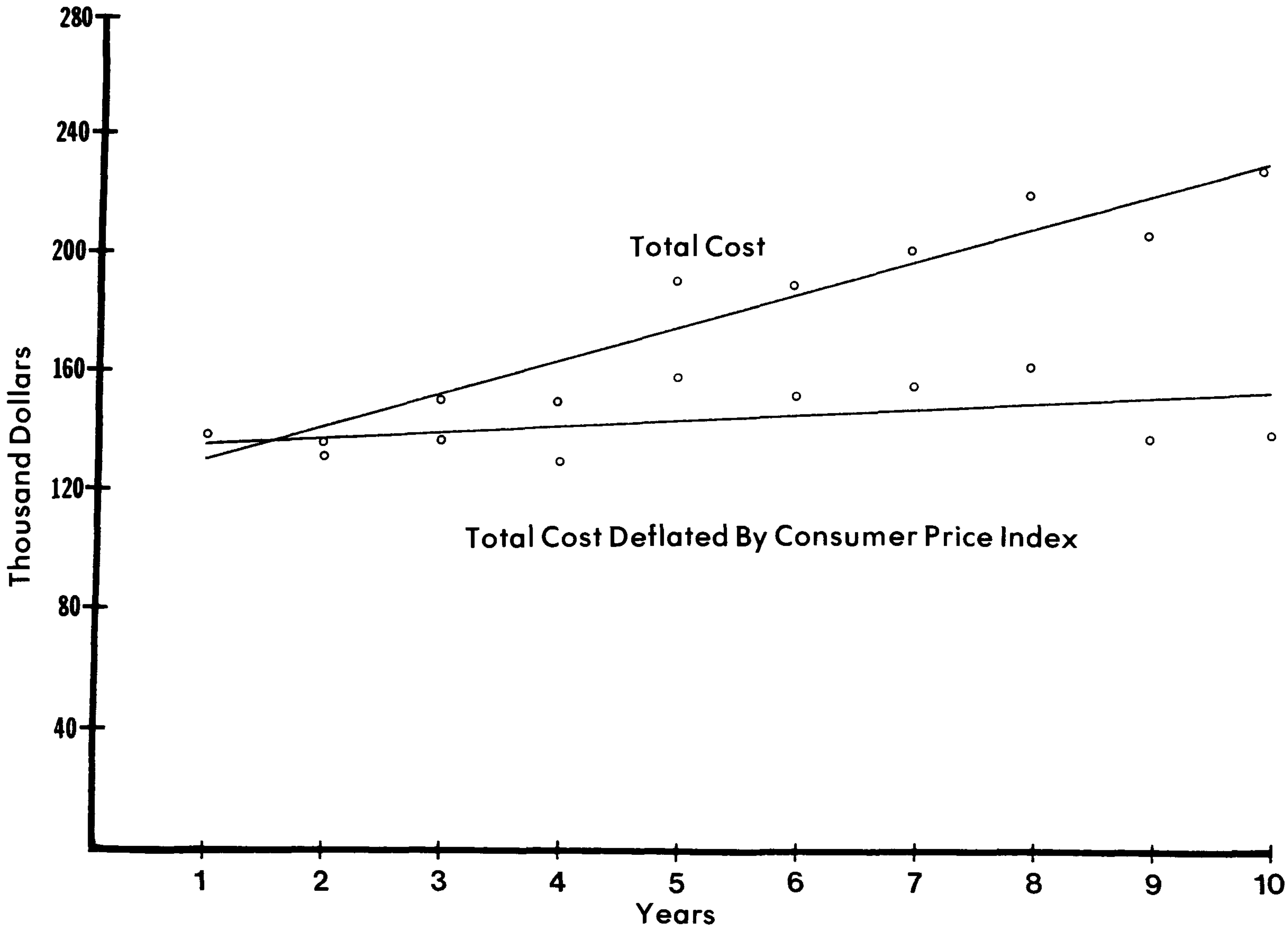

Figure 54. Total costs versus time for Taylor Water Utility: historical and deflated.

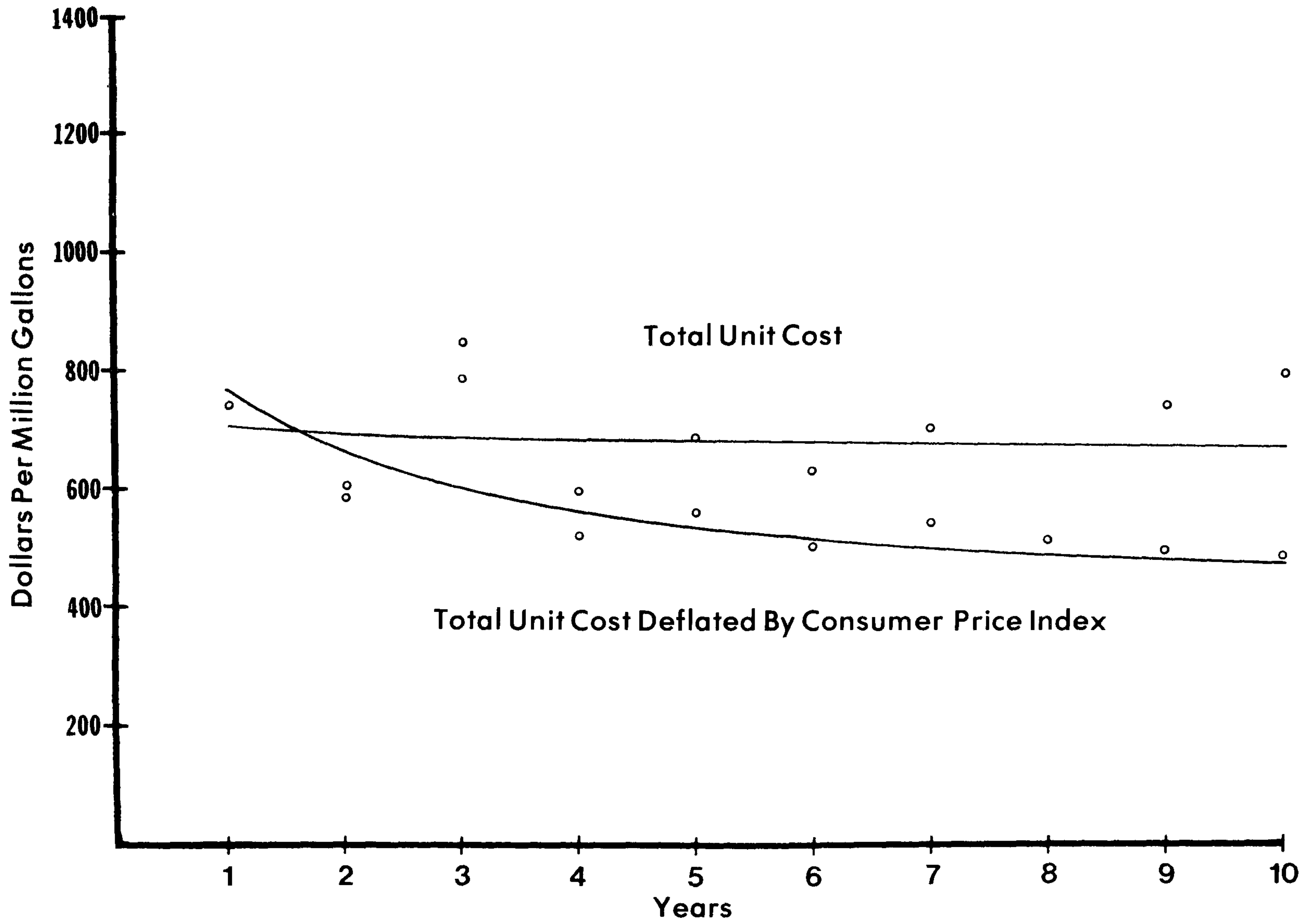

Figure 55. Total unit cost versus time for Taylor Water Utility: historical and deflated.

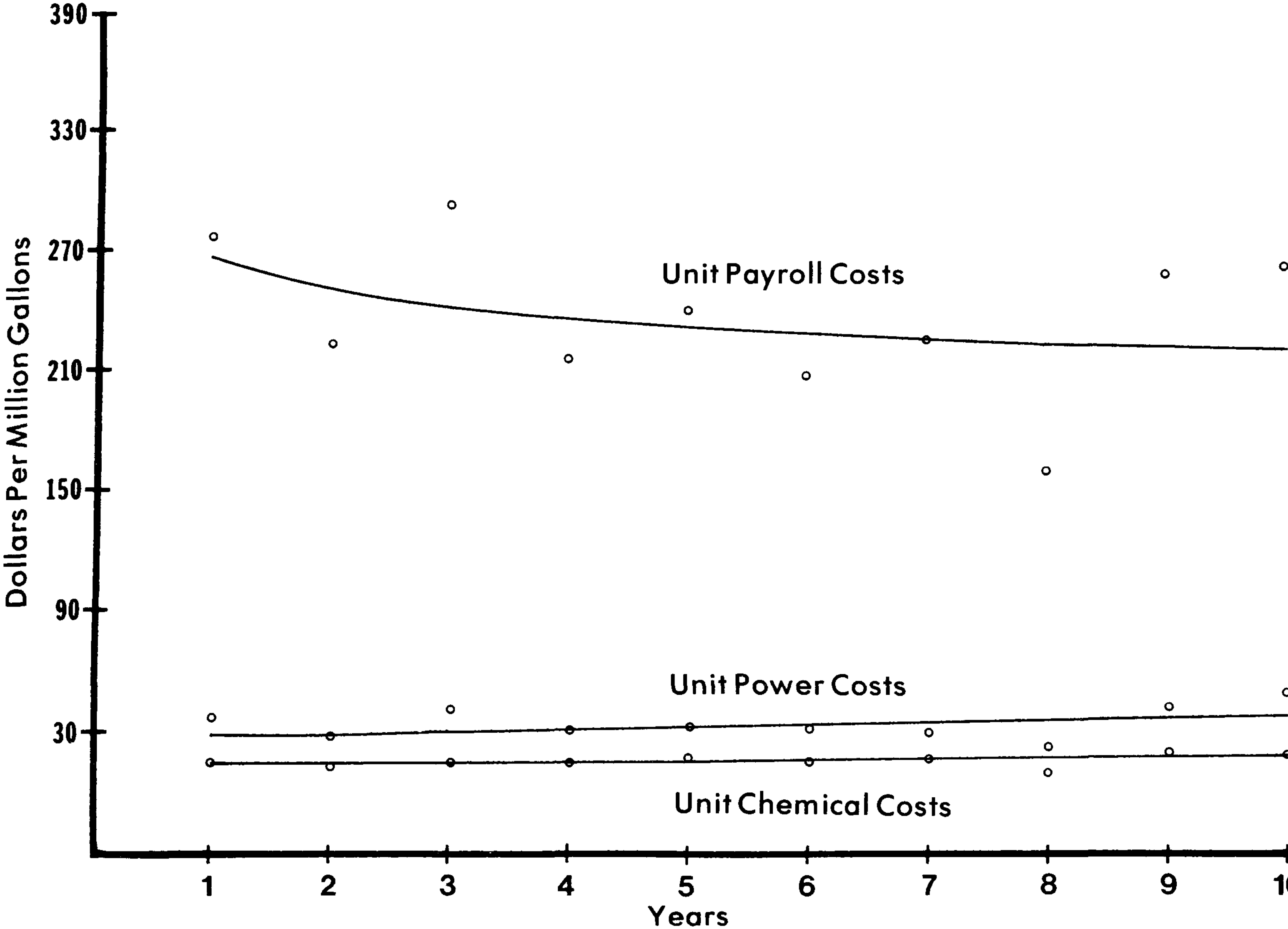

Figure 56. Unit payroll, power, and chemical costs versus time for Taylor Water Utility.

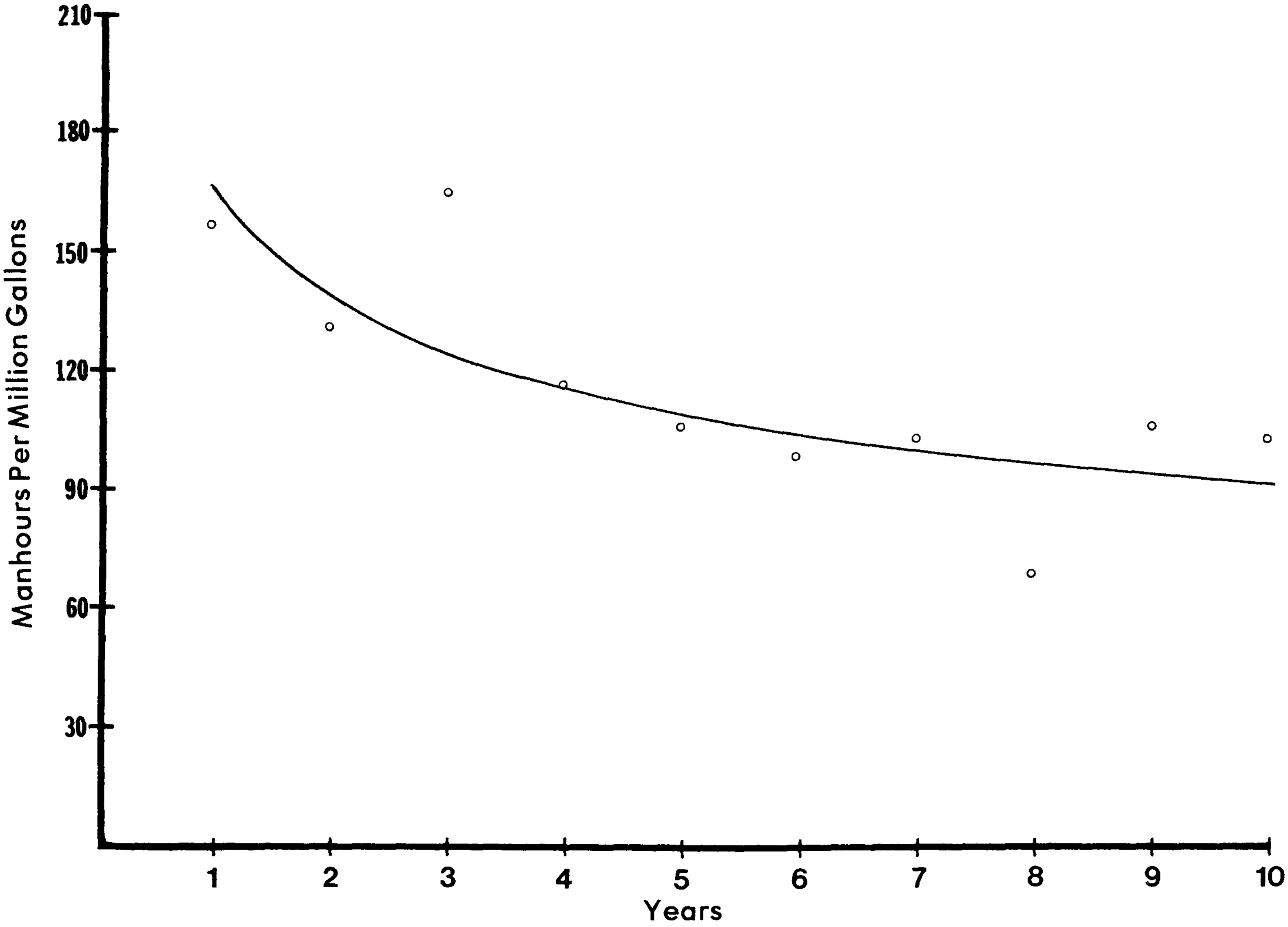

Figure 57. Manhours per million gallons versus time for Taylor Water Utility.

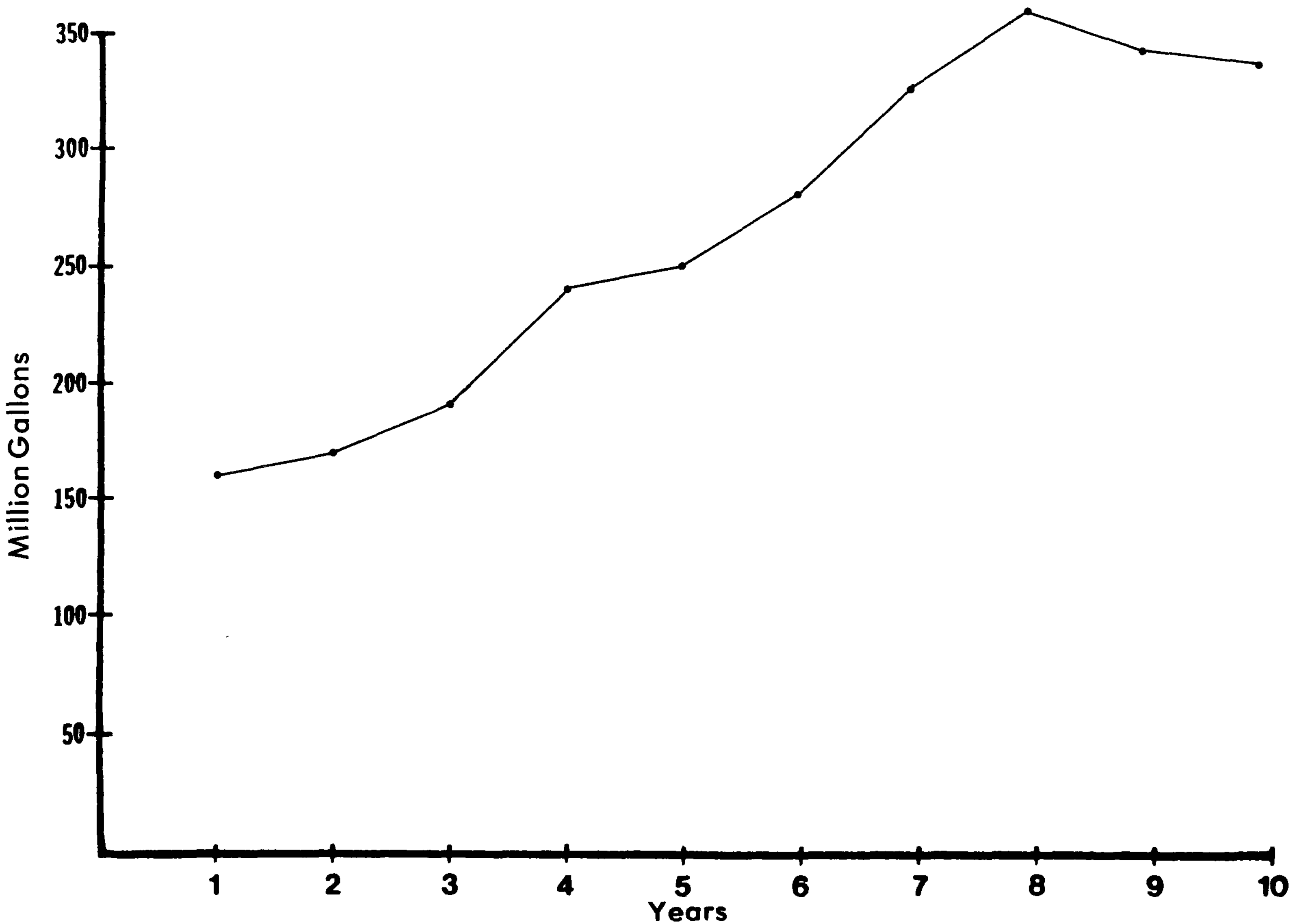

Figure 58. Revenue producing water for Dallas County WCID 6.

Table 12. OPERATING AND MAINTENANCE COST

Dallas County WCID #6

	1	2	3	4	5	6	7	8	9	10
					Cost/Year					
Support Services	27732.	29610.	28498.	35701.	35505.	42731.	54999.	68648.	76806.	61372.
Acquisition	8979.	9099.	25176.	32665.	47806.	47557.	68491.	79200.	84301.	89970.
Treatment	393.	252.	157.	146.	150.	228.	39.	39.	0.	0.
Distribution	16220.	22322.	15810.	19128.	18983.	23808.	33207.	34158.	38424.	56681.
Total	53325	61282.	69641.	87640.	102444.	114324.	156736.	182044.	199532.	208024.
					Cost/MG					
Support Services	175.	174.	149.	148.	141.	151.	167.	192.	225.	182.
Acquisition	57.	53.	132.	135.	190.	169.	209.	221.	247.	267.
Treatment	2.	1.	1.	1.	1.	1.	0.	0.	0.	0.
Distribution	102.	131.	83.	79.	75.	84.	101.	95.	113.	168.
Total	336.	360.	365.	363.	407.	405.	477.	509.	586.	618.
					% of Total					
Support Services	52.01	48.32	40.92	40.74	34.66	37.38	35.09	37.71	38.49	29.50
Acquisition	16.84	14.85	36.15	37.27	46.67	41.60	43.70	43.51	42.25	43.25
Treatment	0.74	0.41	0.23	0.17	0.15	0.20	0.02	0.02	0.00	0.00
Distribution	30.42	36.42	22.70	21.83	18.53	20.82	21.19	18.76	19.26	27.25
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 13. DEPRECIATION AND INTEREST COST

Dallas County WCID #6

	1	2	3	4	5	6	7	8	9	10
					Depreciation Cost $/Yr					
Support Services	2145.	2275.	2437.	2567.	2600.	2981.	3647.	543.	5586.	5531.
Acquisition	825.	875.	937.	987.	1000.	1147.	1403.	209.	2149.	2127.
Treatment	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Distribution	13530.	14350.	15375.	16195.	16400.	18805.	23005.	3426.	35236.	34885.
Total	16500.	17500.	18750.	19750.	20000.	22934.	28055.	4178.	42970.	42542.
					Depreciation Cost $/MG					
Support Services	14.	13.	13.	11.	10.	11.	11.	2.	16.	16.
Acquisition	5.	5.	5.	4.	4.	4.	4.	1.	6.	6.
Treatment	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Distribution	85.	84.	81.	67.	65.	67.	70.	10.	103.	104.
Total	104.	103.	98.	82.	79.	81.	85.	12.	126.	126.
					Depreciation Cost % of Total					
Support Services	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00
Acquisition	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Treatment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Distribution	82.00	82.00	82.00	82.00	82.00	82.00	82.00	82.00	82.00	82.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
					Interest Cost $					
Interest $	24115.	23740.	23320.	22900.	22400.	61326.	72444.	71094.	69744.	68394
Interest $/MG	152.	139.	122.	95.	89.	217.	221.	199.	205.	203.

Figures 59, 60, and 61 present each operating cost component as a total cost in $/MG, and as a percent of total O&M costs, respectively. One pattern is obvious here. In each figure, acquisition cost jumps from a minor role to becoming the most expensive O&M factor. Acquisition O&M cost rose 902%. This occurred because the Dallas County WCID #6 converted from a well source to purchased treated water over the 10-year period. As a result, treatment costs dropped to zero. All treatment costs were incorporated in the acquisition component because the purchased water is already treated. Support services cost increased during the period, however, its importance dropped relative to acquisition.

Capital and operating costs in total and as a percent are presented in figures 62 and 63. Operating costs increased relative to capital and interest. However, the impact of increased acquisition costs as well as inflation have most likely combined to drive up O&M cost more rapidly. Figure 64 plots the trend of total O&M and total capital cost over the study period.

Total production and unit costs (historical and deflated) are presented in figures 65 and 66. In both graphs, the deflated costs generally lie below the historical costs. There remains a significant divergence between the lines, which indicates that inflation has impacted total and unit costs.

Figure 67 shows unit payroll, power, and chemical costs, the major O&M cost inputs. Chemical costs have dropped out because all purchased water is treated. Unit payroll costs represent the major cost element. Even though unit payroll costs are increasing while unit power costs are declining, labor productivity (MH/MG) is falling (Figure 68). Proper decision-making on input substitution requires further information on the relative productivity, prices, and current value of capital.

SUMMARY

These six utilities represent a cross-section of small water utilities. Some use a ground source, others a surface source or purchased water. Different cost factors are evident in each. For Downingtown, acquisition costs are low, but treatment costs are high. This coincides with the fact that the raw water is obtained from a surface source. Manassas Park does not treat, but uses ground water. Burlington, Lebanon, and Taylor water utilities all have high distribution expenses, but low treatment costs. All three obtain water from a ground source. Dallas County WCID #6 purchases treated water from the Dallas Water Utility. Therefore, acquisition costs represent the major cost factor. In spite of the rather divergent situations facing each utility, there are some common patterns which are worth examining. The next chapter will present these in greater detail.

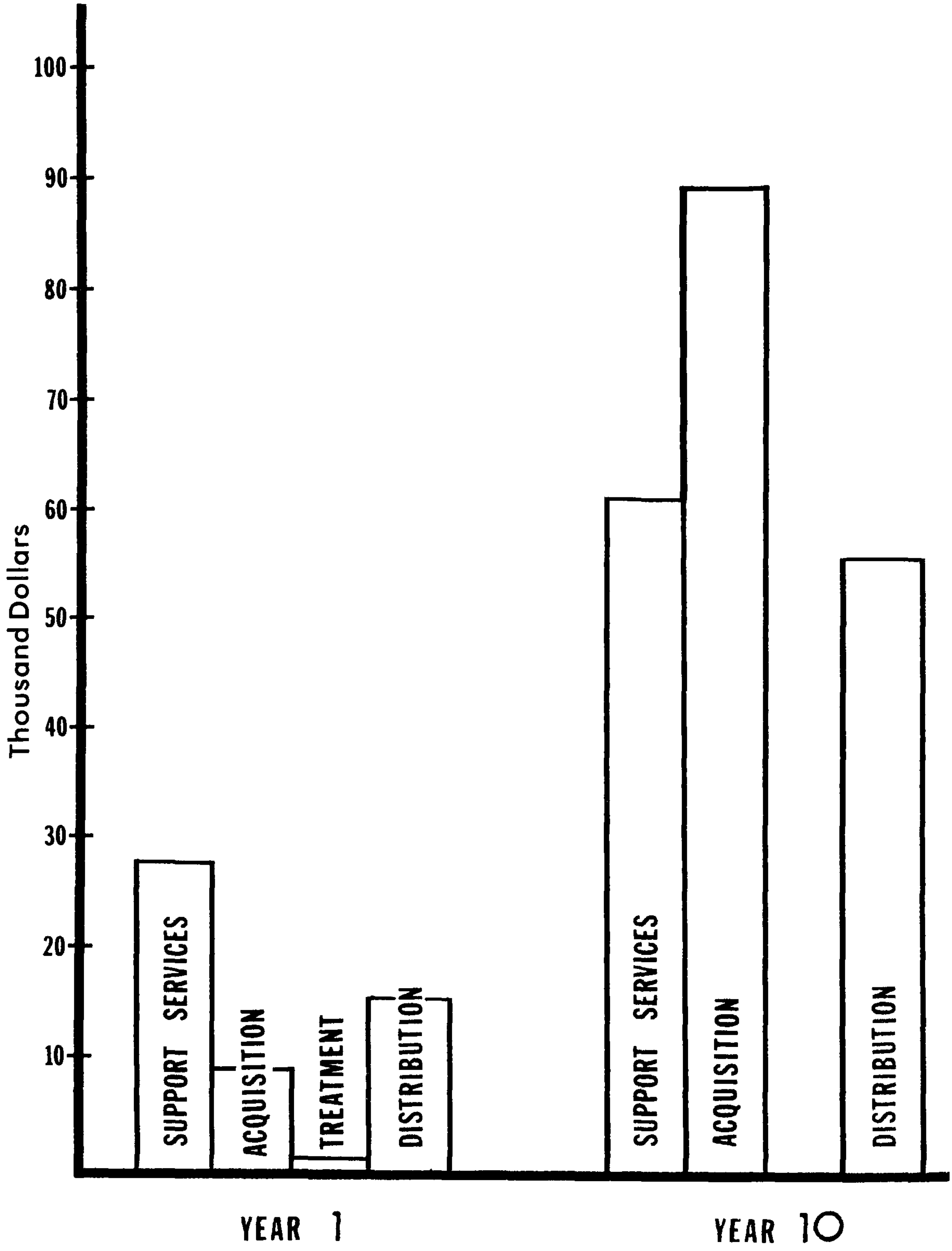

Figure 59. Operating costs for Dallas County WCID 6.

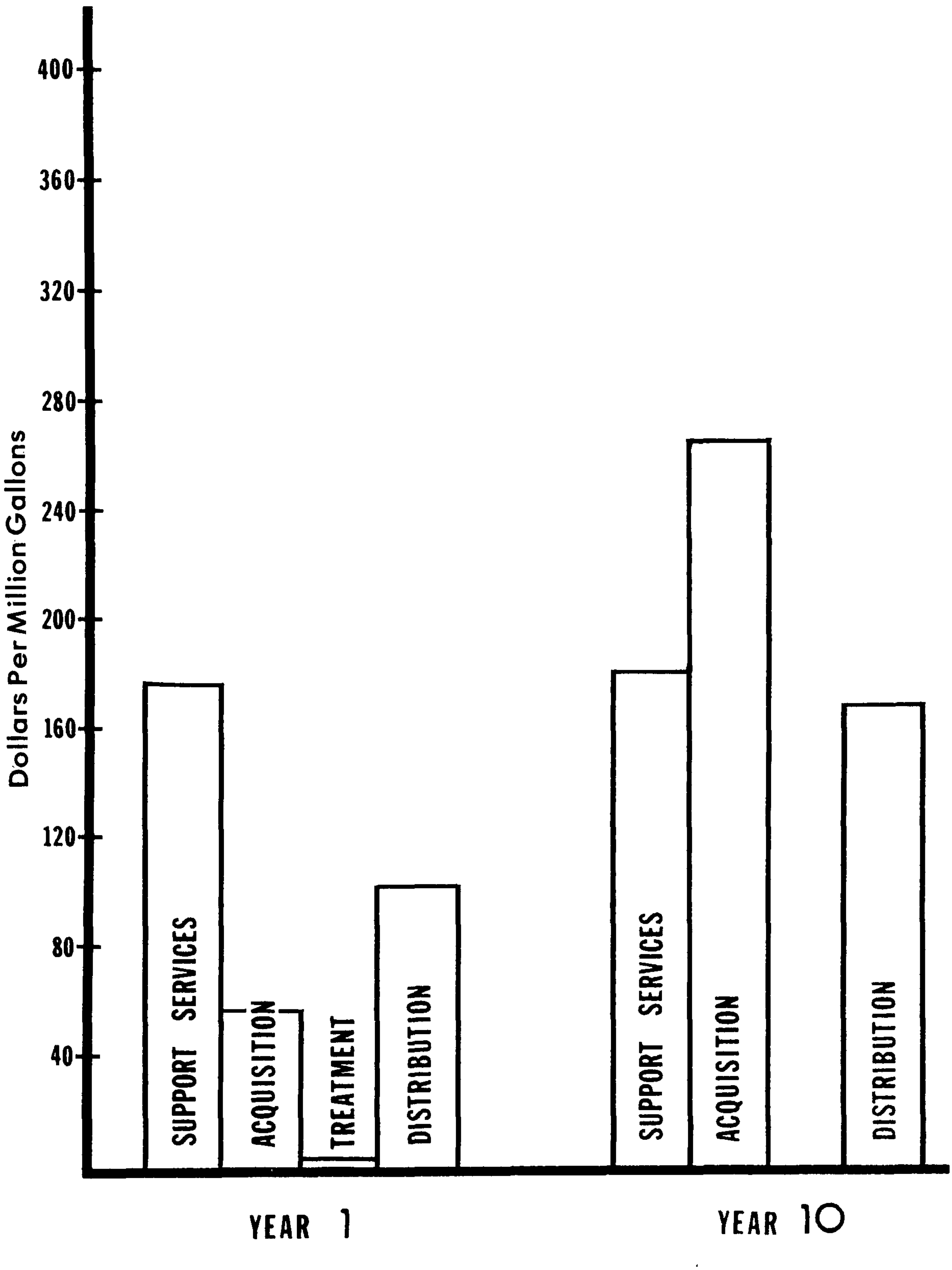

Figure 60. Operating costs in dollars per million gallons for Dallas County WCID 6.

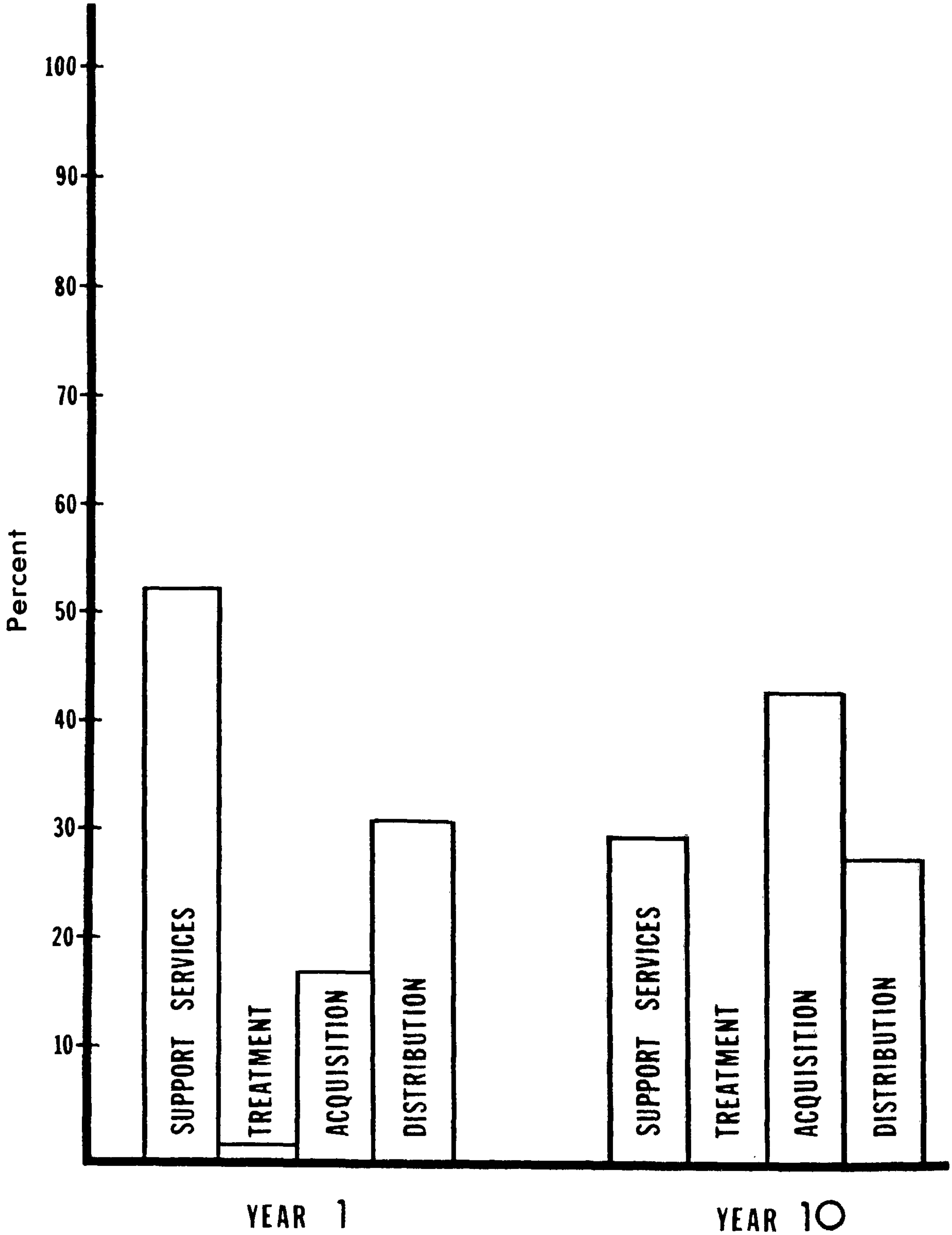

Figure 61. Operating costs as a percent of total O & M for Dallas County WCID 6

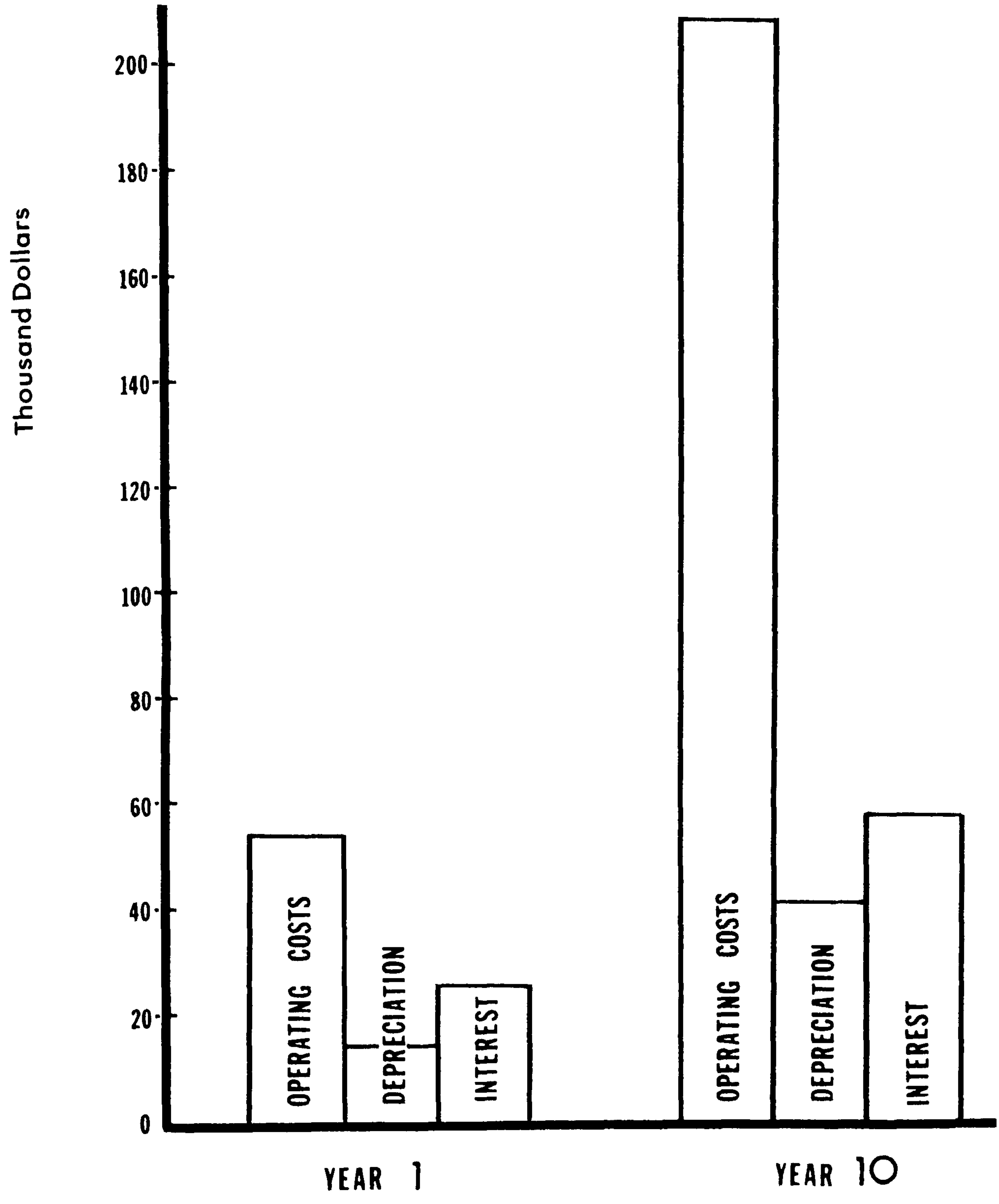

Figure 62. Capital and operating costs for Dallas County WCID 6

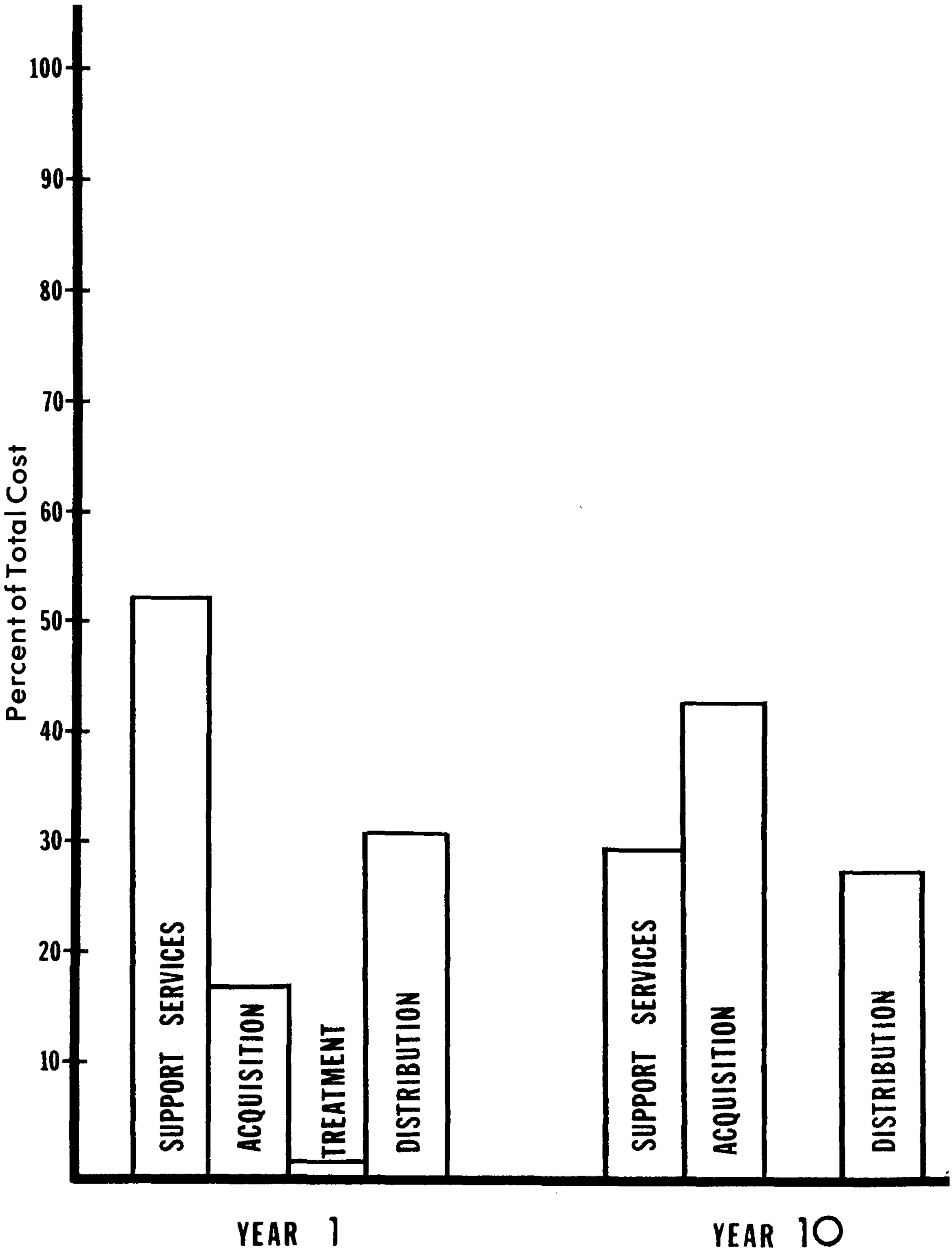

Figure 63. Capital and operating costs as a percent of total cost for Dallas County WCID 6.

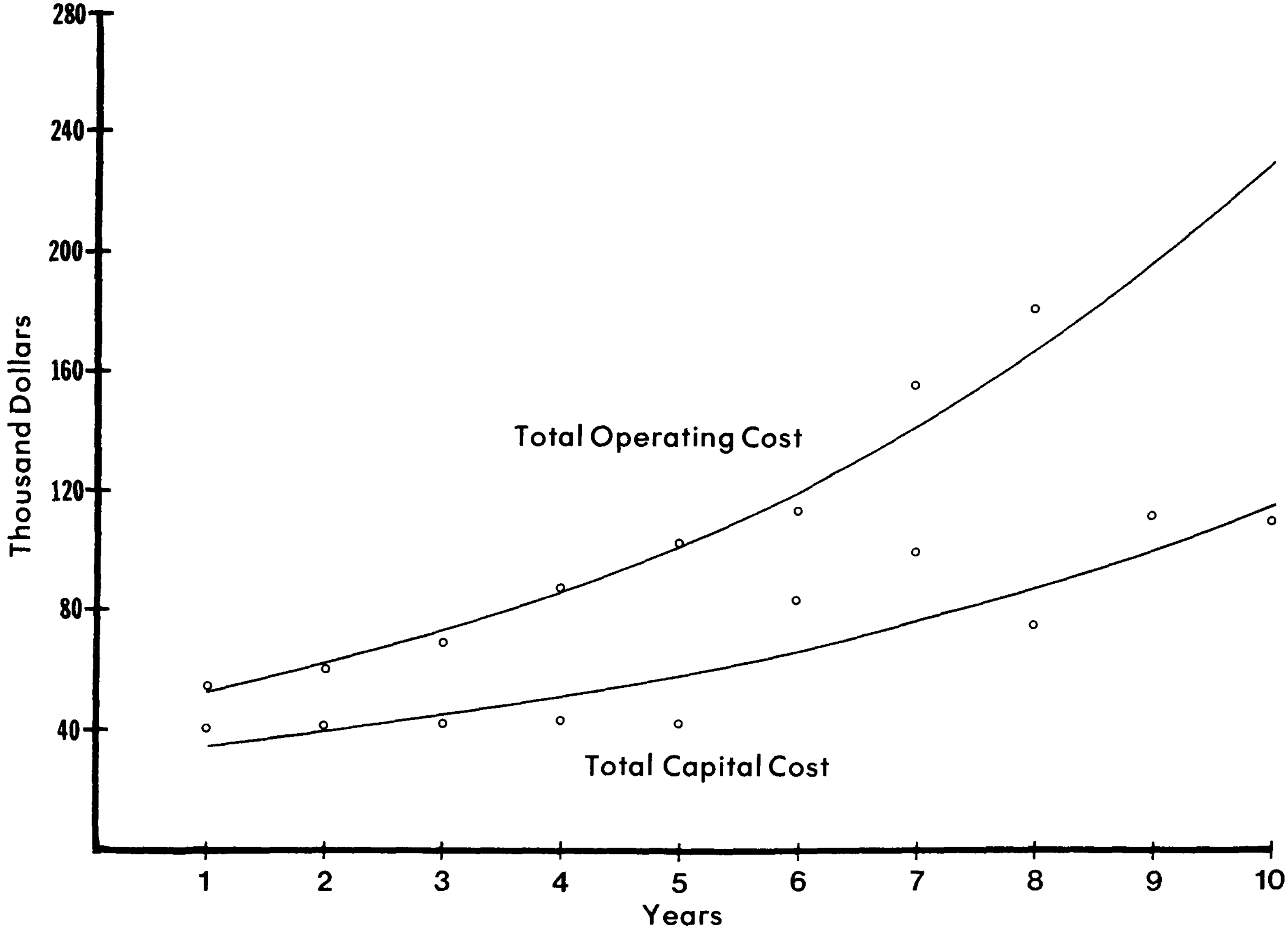

Figure 64. Total operating and capital expenditures versus time for Dallas County WCID 6.

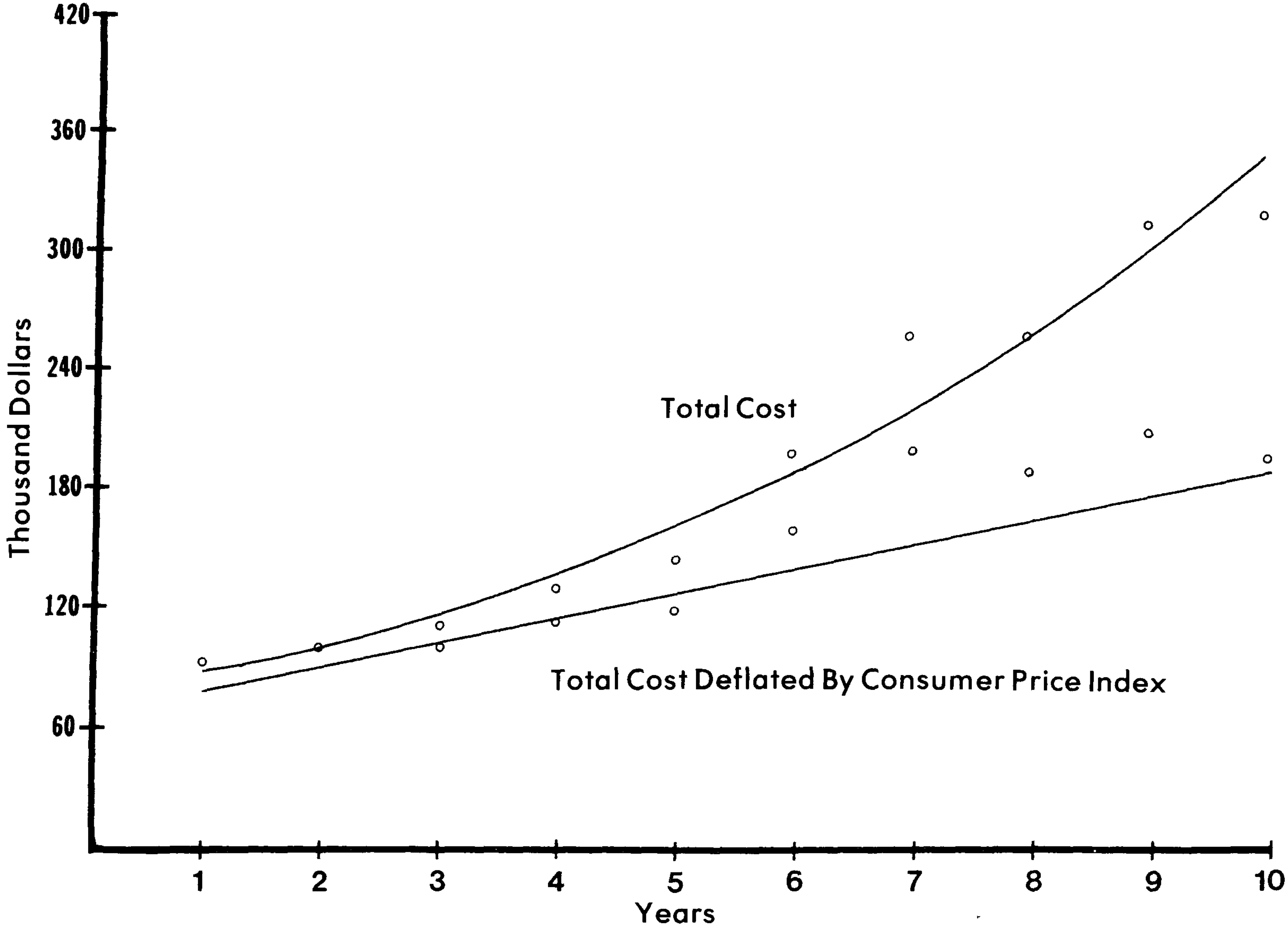

Figure 65. Total cost versus time for Dallas County WCID 6 : historical and deflated.

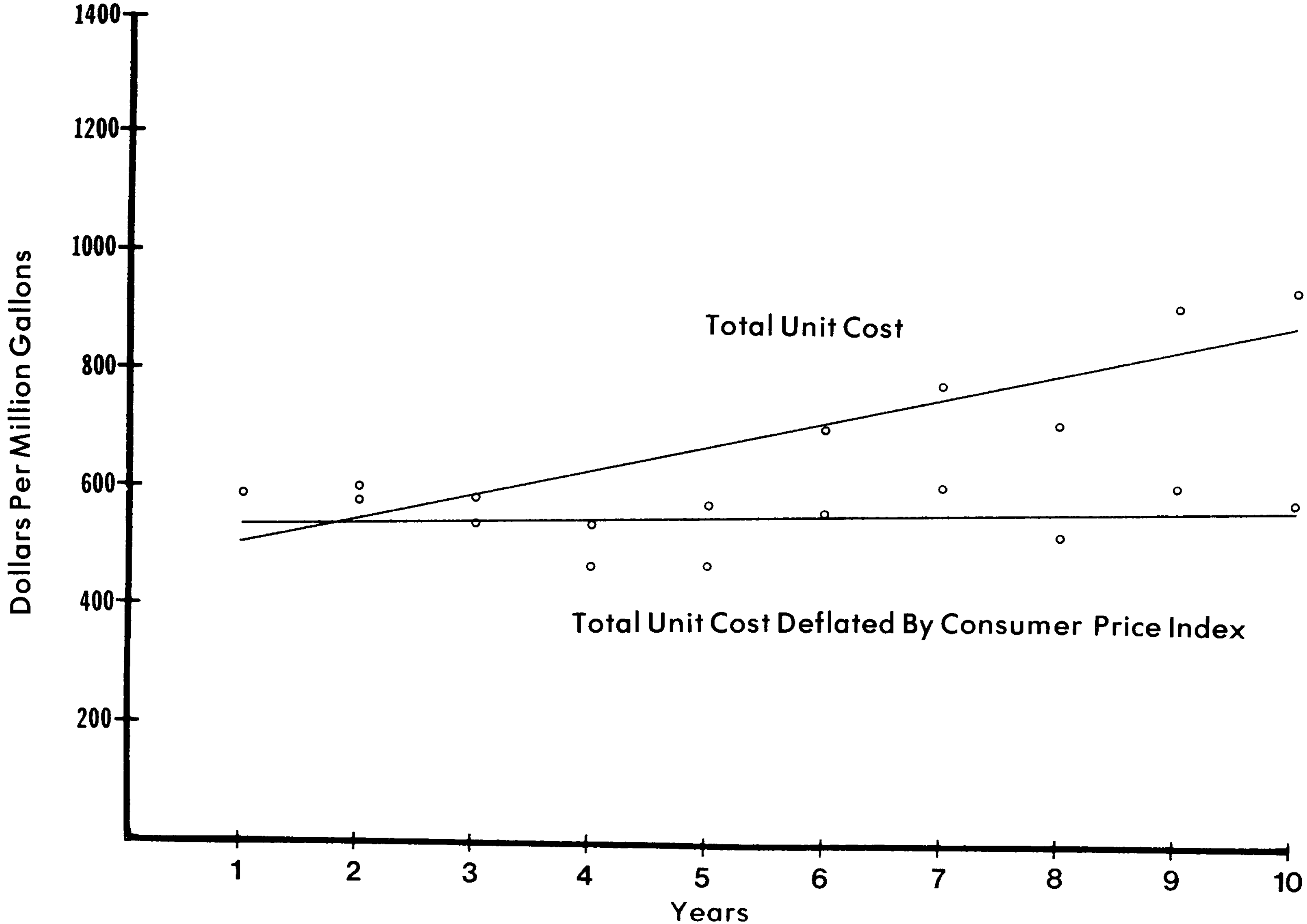

Figure 66. Total unit costs versus time for Dallas County WCID 6. : historical and deflated.

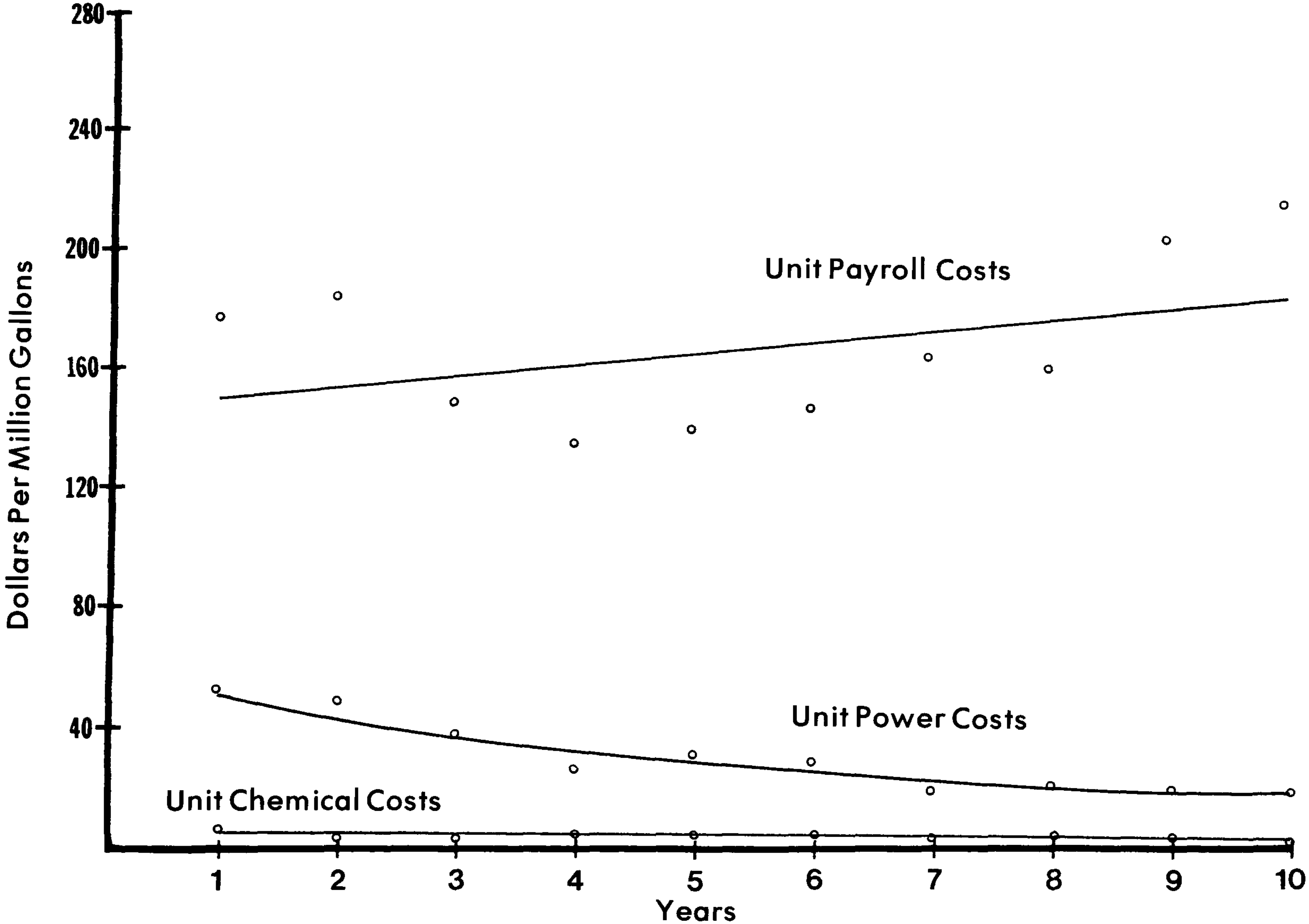

Figure 67. Unit payroll, power, and chemical costs versus time for Dallas County WCID 6.

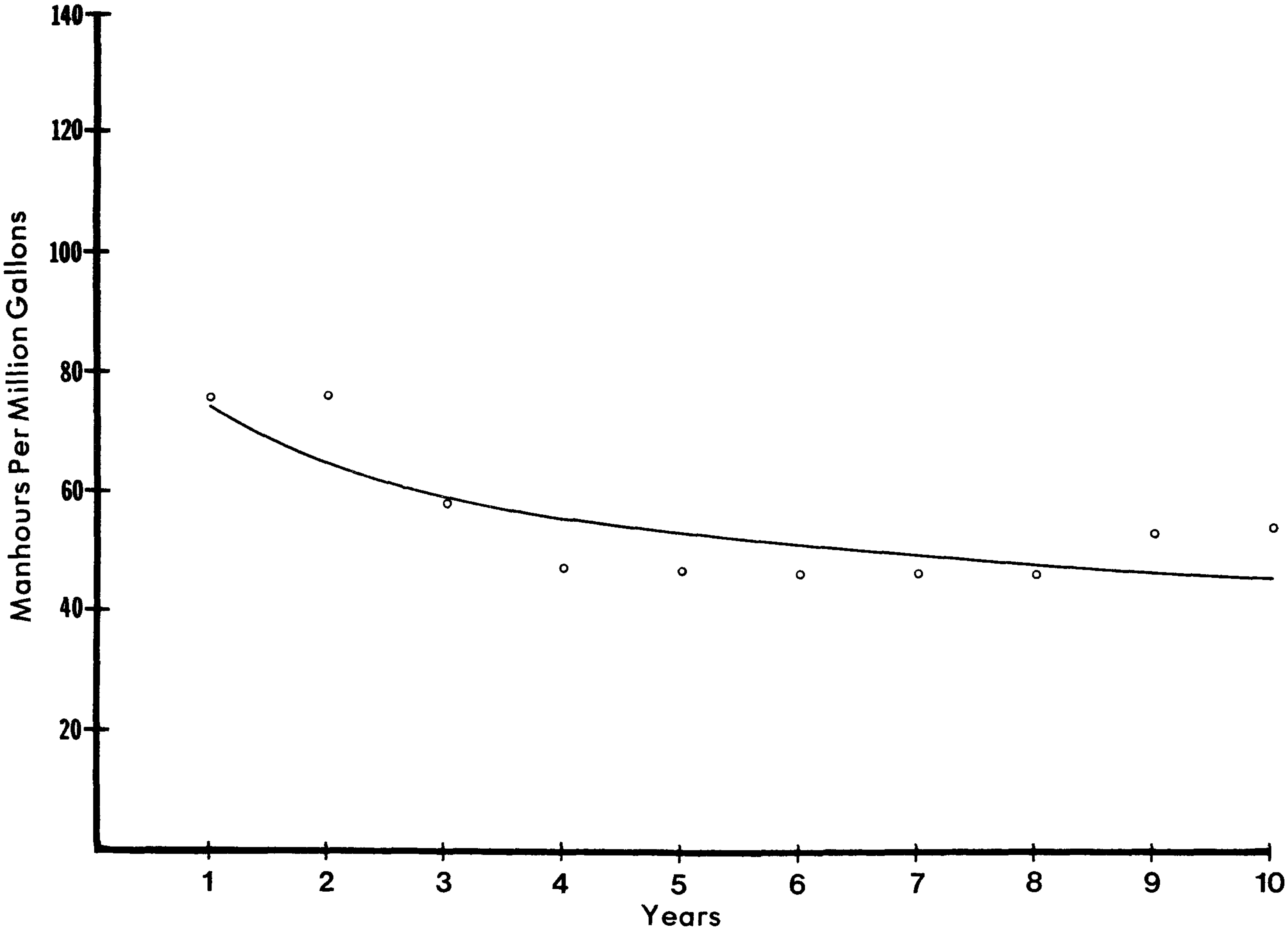

Figure 68. Manhours per million gallons versus time for Dallas County WCID 6.

SECTION 4

UTILITY COST COMPARISONS

It is difficult to distinguish any significant universal trends from the previous discussion. This chapter attempts to identify and present the important patterns existing among small water utilities. Appendix A summarizes the slopes of various cost curves for each utility, which should provide useful information on the variations in costs associated with each utility.

Figure 69 demonstrates the trend of revenue-producing water over the 10-year period for the six utilities. While average revenue-producing water increased about 14% for all six utilities, three utilities -- Downingtown, Burlington, and Lebanon -- declined in usage. Dallas County WCID #6 experienced the greatest increase, 112%, reflecting rapid growth in the Dallas area.

TRENDS IN COST OF WATER SUPPLY

Unit costs for the six utilities are plotted in Figure 70. Average unit costs rose 54% while unit costs for only one utility, Manassas Park, declined. Downingtown's unit costs increased the most, 209%. In general, these small water utilities experienced a significant increase in unit costs.

Figure 71 illustrates the relative change in O&M cost as a percent of total cost for the entire study period. O&M cost ranged from 30 to 85% of total cost, while the six-utility average rose from 53 to 66%. Only Taylor Park experienced a decline. Downingtown and Burlington increased to over 80%. These increases indicate that inflation is causing a shift in total cost from capital intensiveness to O&M intensiveness. To completely evaluate the shift toward O&M costs, information on the current value of capital would also have to be collected. One interesting factor is evident from examination of the graphs. Each drop in the percentage generally reflects an increase in capital expenditures.

Figures 72 and 73 show unit O&M costs for treatment and distribution, respectively. Average unit treatment costs increased 393%. Downingtown's and Lebanon's treatment costs rose dramatically while Taylor's remained fairly constant. Manassas Park incurred no treatment costs because it obtains high quality ground water. Only Dallas County WCID #6 experienced

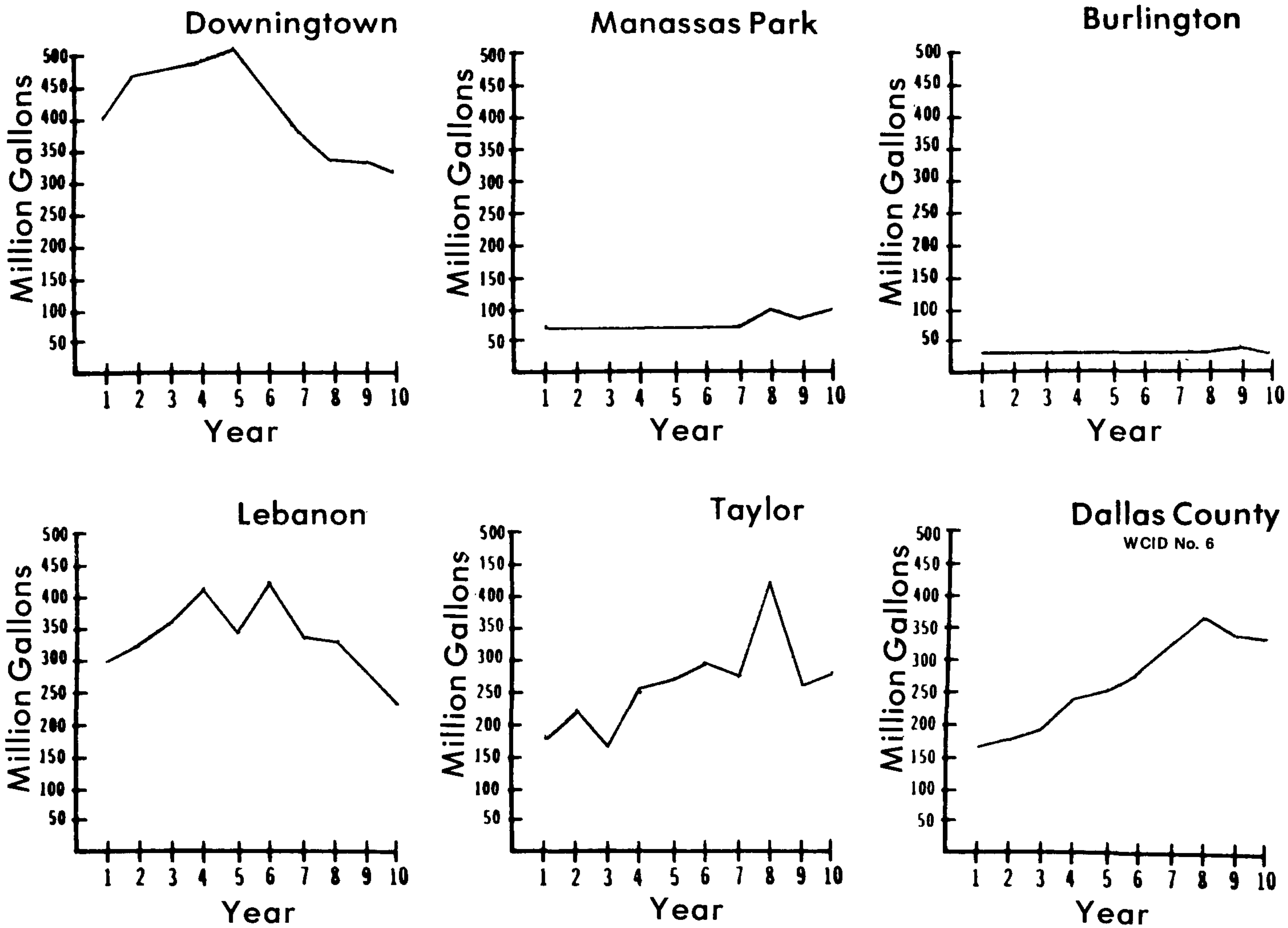

Figure 69. Revenue producing water for six utilities.

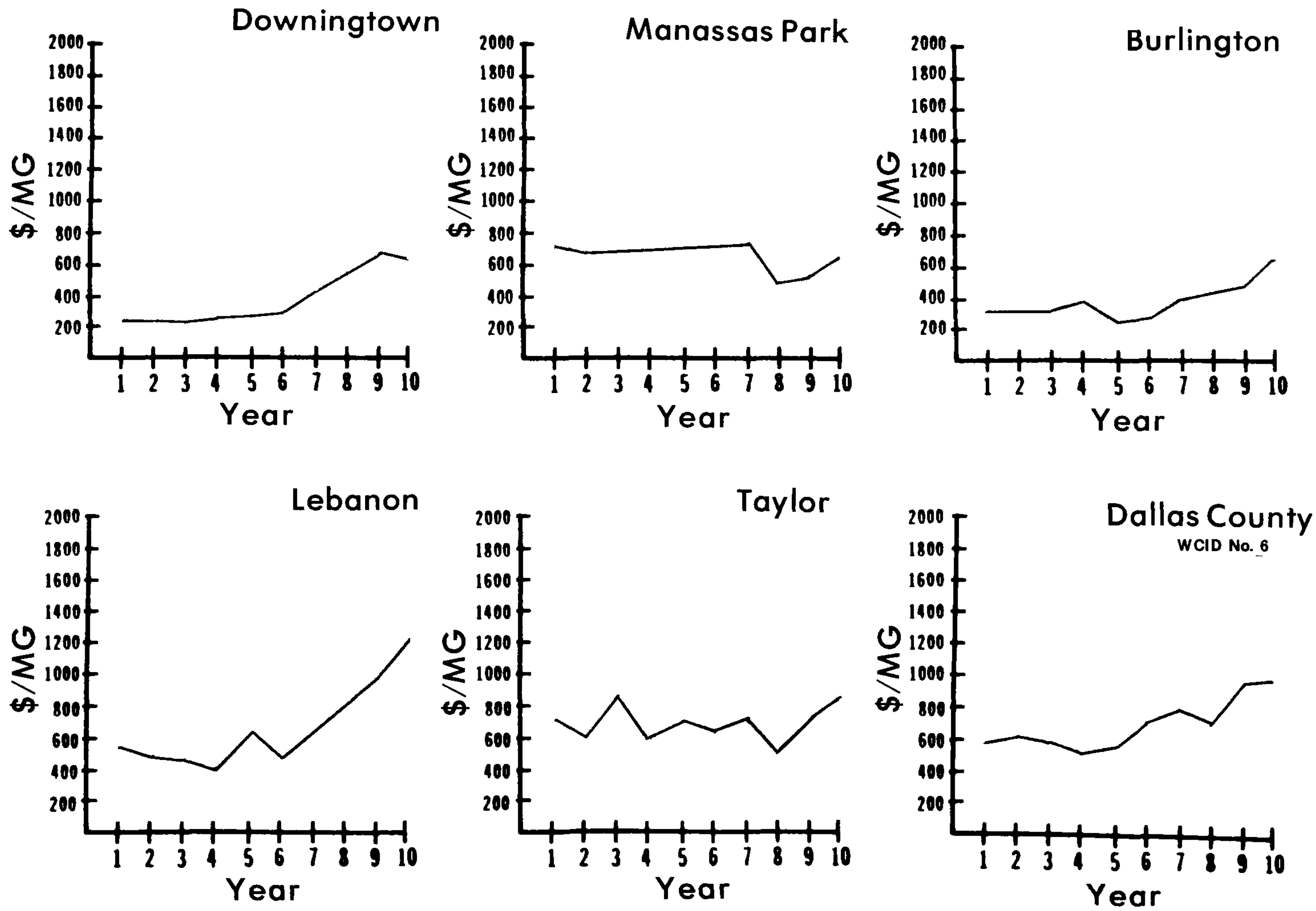

Figure 70. Total unit cost for six utilities.

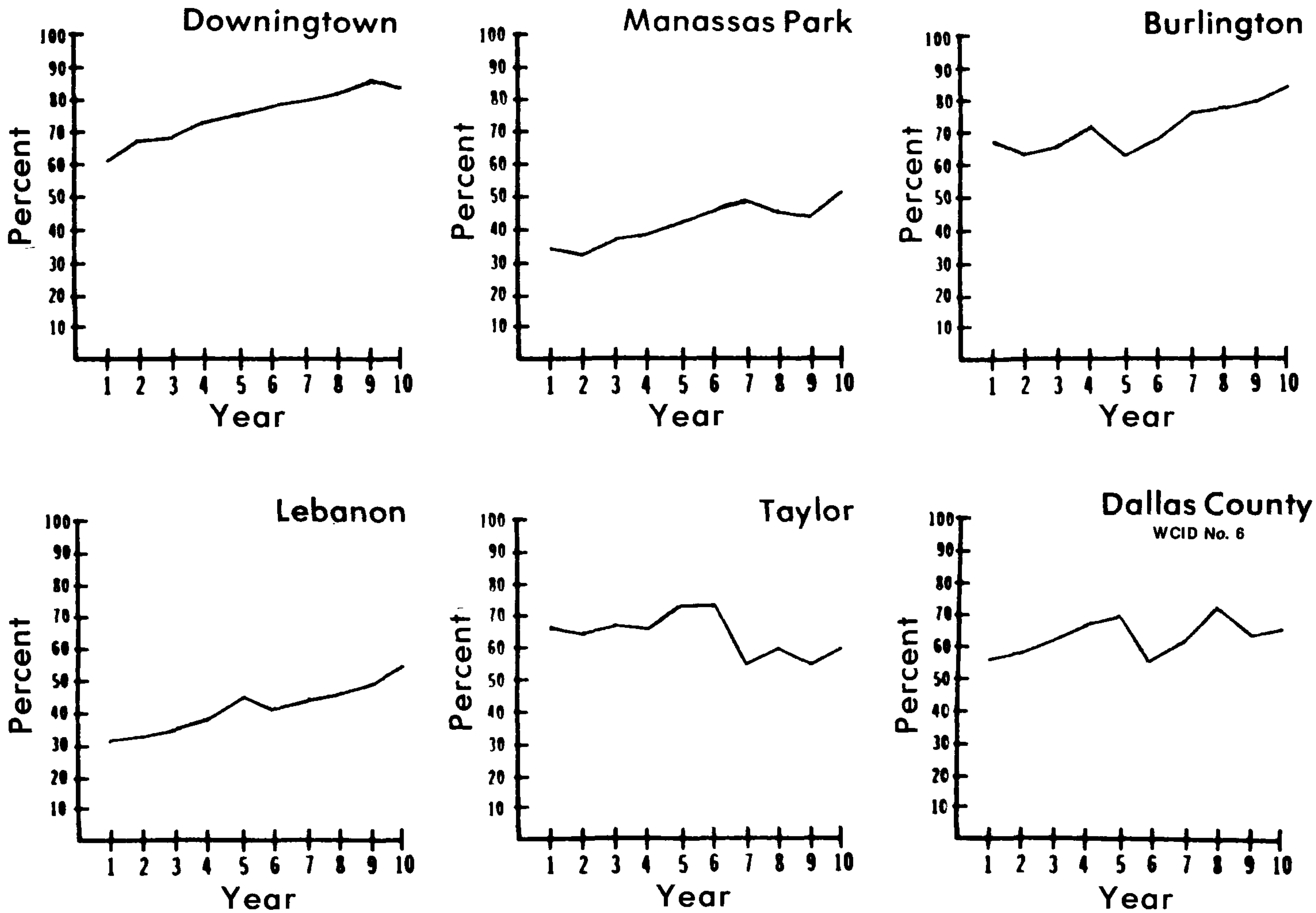

Figure 71. Operating and maintenance cost as a percent of total cost for six utilities.

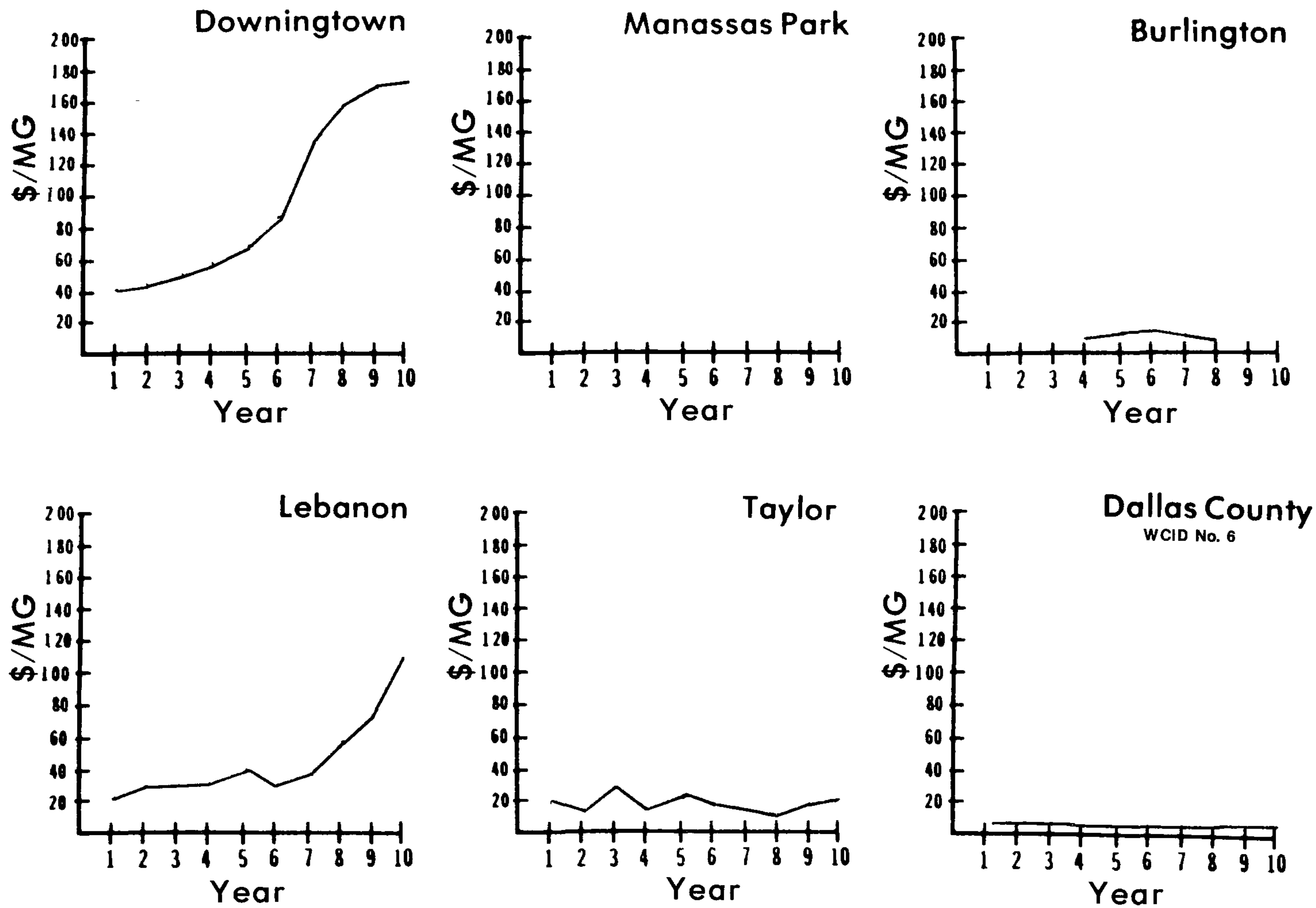

Figure 72. Treatment operation and maintenance unit costs for six utilities.

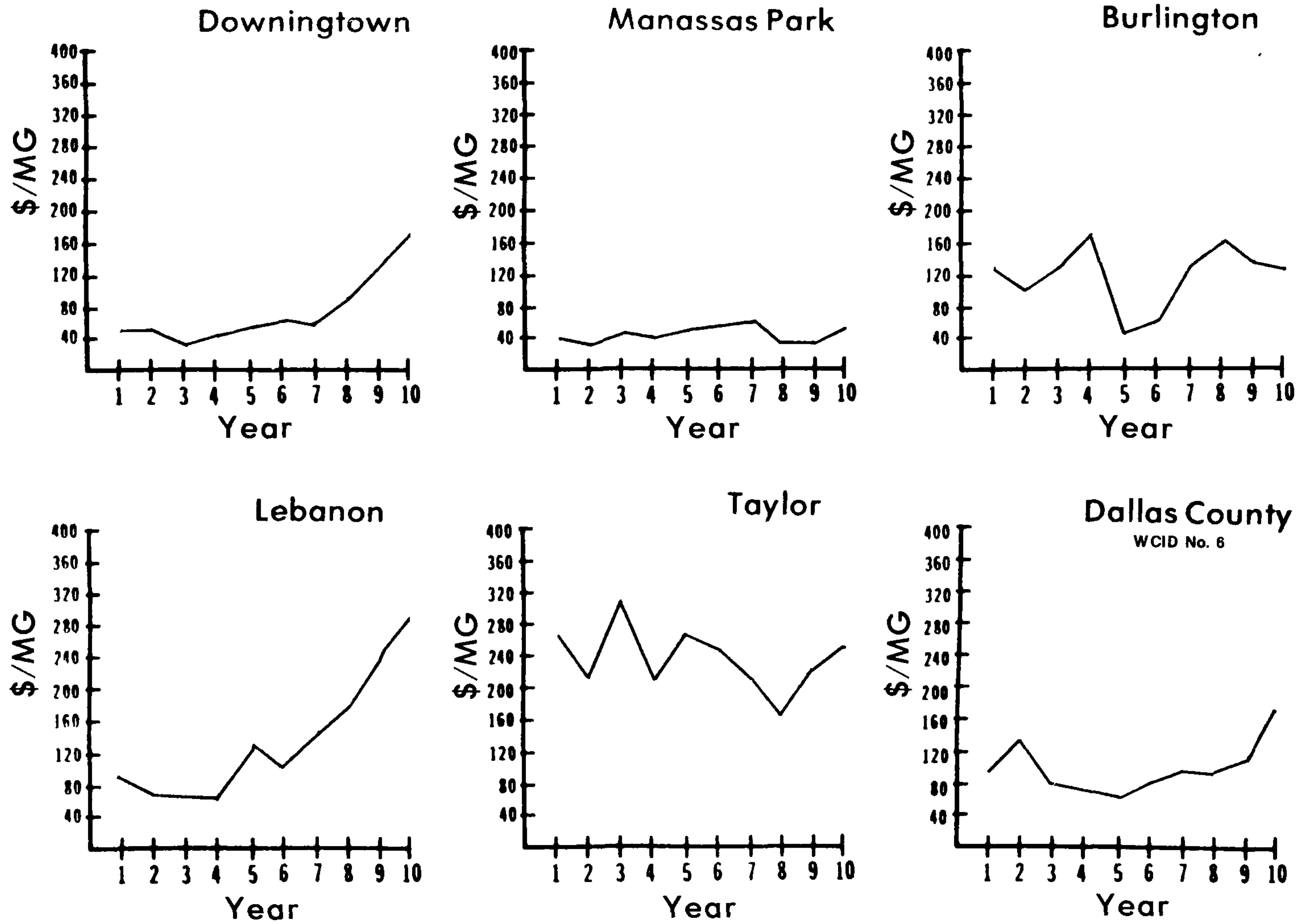

Figure 73. Distribution operation and maintenance unit costs for six utilities.

a decline in treatment costs because it stopped treating. The utility now purchases finished water from the Dallas Water Utility.

Average unit distribution costs increased 64% over the study period. Unit costs for Downingtown and Lebanon rose significantly, which is partly explained by the relatively larger size of their service areas and decreasing output. Taylor's unit distribution costs declined slightly even though their service area is larger than and has a comparable number of customers to Downingtown and Lebanon. However, Taylor's output rose 54% during the period. In general, distribution costs can be expected to rise rapidly as energy costs increase.

Unit O&M acquisition costs are depicted in Figure 74. Each utility falls within a common cost range except for the Dallas County WCID #6 which purchases treated water. Average unit costs rose 138%, but if Dallas County WCID #6 is eliminated, rose only 78%.

LABOR, POWER, AND SUPPORT SERVICE COSTS

Wage rates (dollars per man-hour) for the six utilities are illustrated in Figure 75. Downingtown pays the greatest hourly rate. Average wage rates increased 136% over the period, and none declined. Figure 76 indicates the change in labor productivity (man-hours per million gallons) over the period. For the average utility, productivity increased or man-hours per million gallons decreased 12%. Taylor and Dallas County WCID #6 both experienced a significant decrease in man-hours per million gallons since revenue-producing water increased the most for these two utilities. The three that faced an increase in man-hours per million gallons had a decline in output. Figure 77 illustrates payroll expenses per million gallons for each utility. Downingtown, Burlington, and Lebanon all increased over 200%, while the average payroll expense per million gallons rose 87%. The cost declined in Taylor.

Figure 78 presents support service cost as a percent of total O&M cost which includes administrative, accounting, billing, and design functions. Support services are a labor-intensive operation within the utility. These costs range from 15% to 63% of total O&M cost.

Power (KWH) is another significant element of O&M cost. Figure 79 shows KWH per million gallons. Data were not available on Manassas Park, Burlington, and the first five years of Taylor. As evident from the graphs, there is a wide degree of variability in power usage. A further indication of this is provided in Figure 80 which plots power cost per million gallons. Average power cost rose 26% which is significantly lower than that for labor. In fact, power cost per million gallons is lower than labor cost for each utility. However, fewer man-hours per million gallons than KWH are necessary for production. Considerations such as these become important when examining investment in labor-saving versus energy-saving equipment.

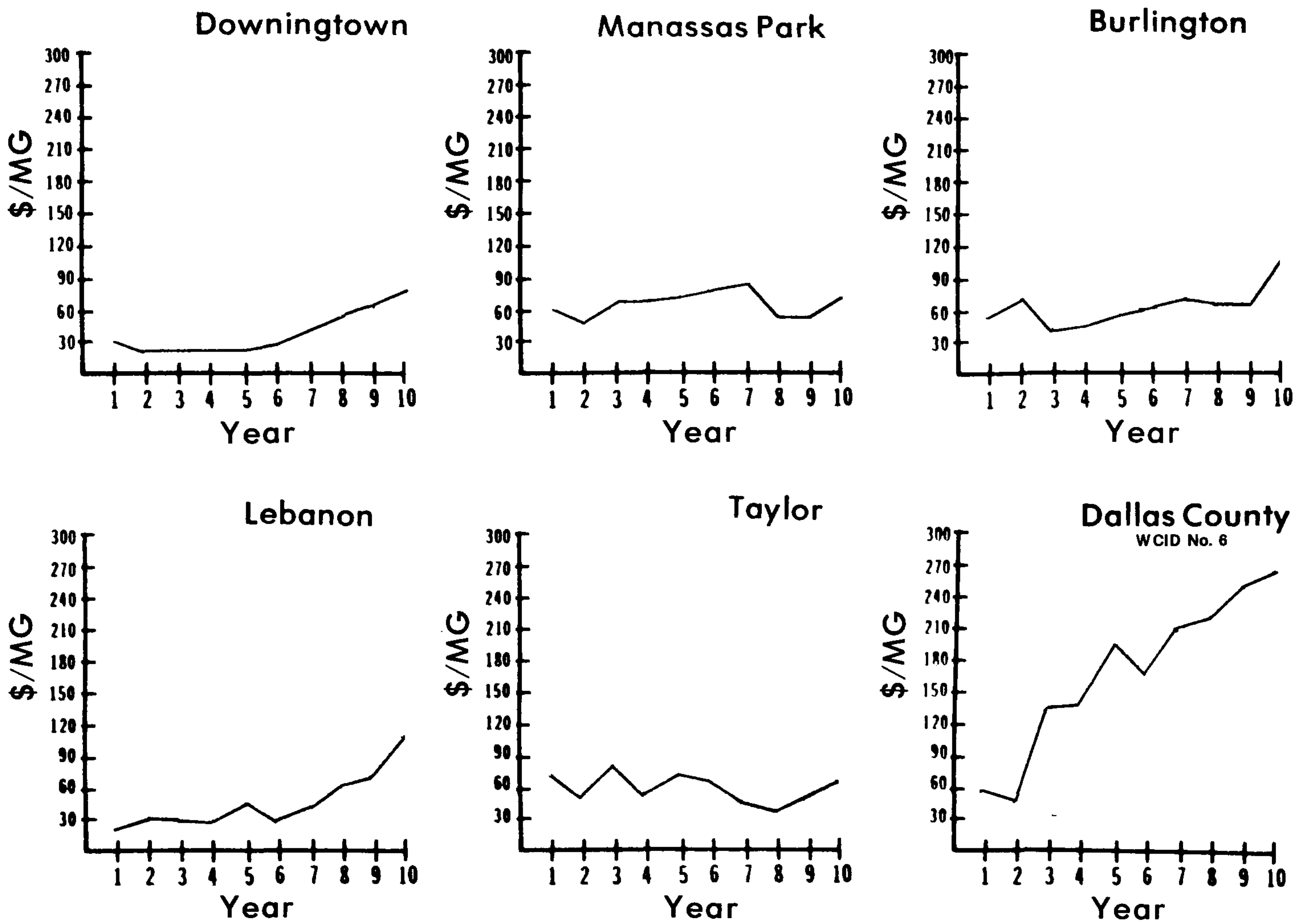

Figure 74. Acquisition O & M cost per million gallons for six utilities.

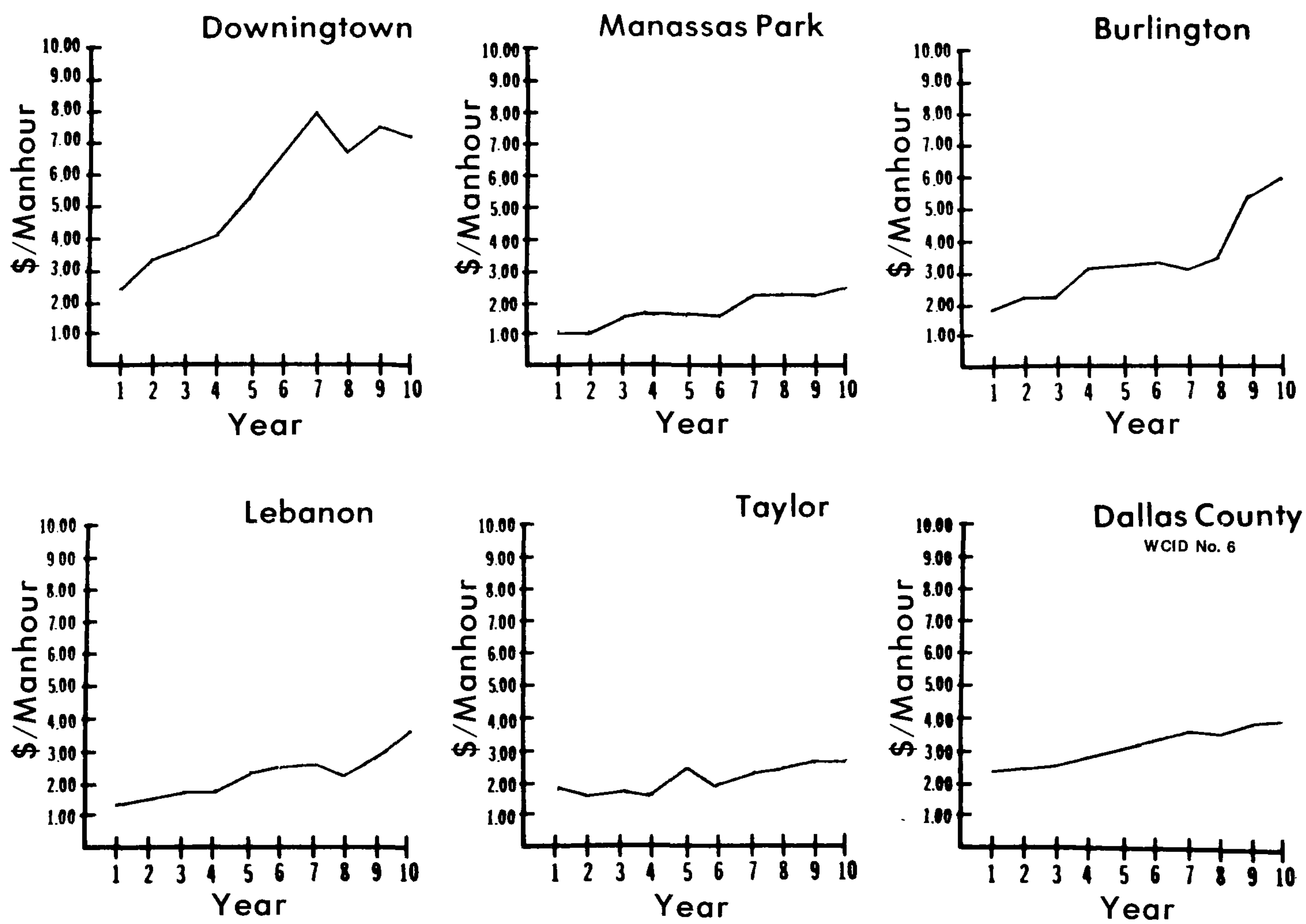

Figure 75. Dollars per manhour for six utilities.

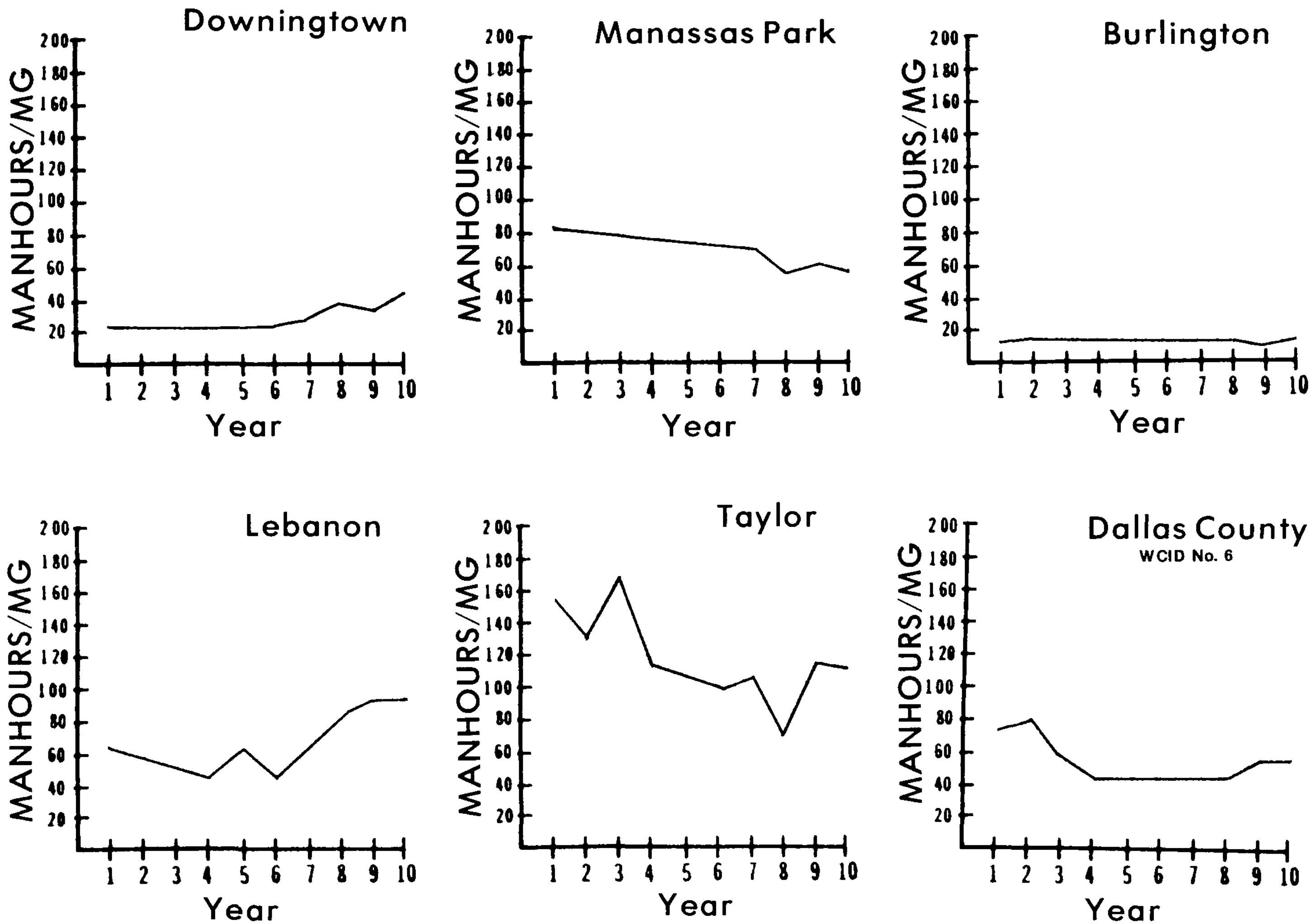

Figure 76. Manhours per million gallons for six utilities.

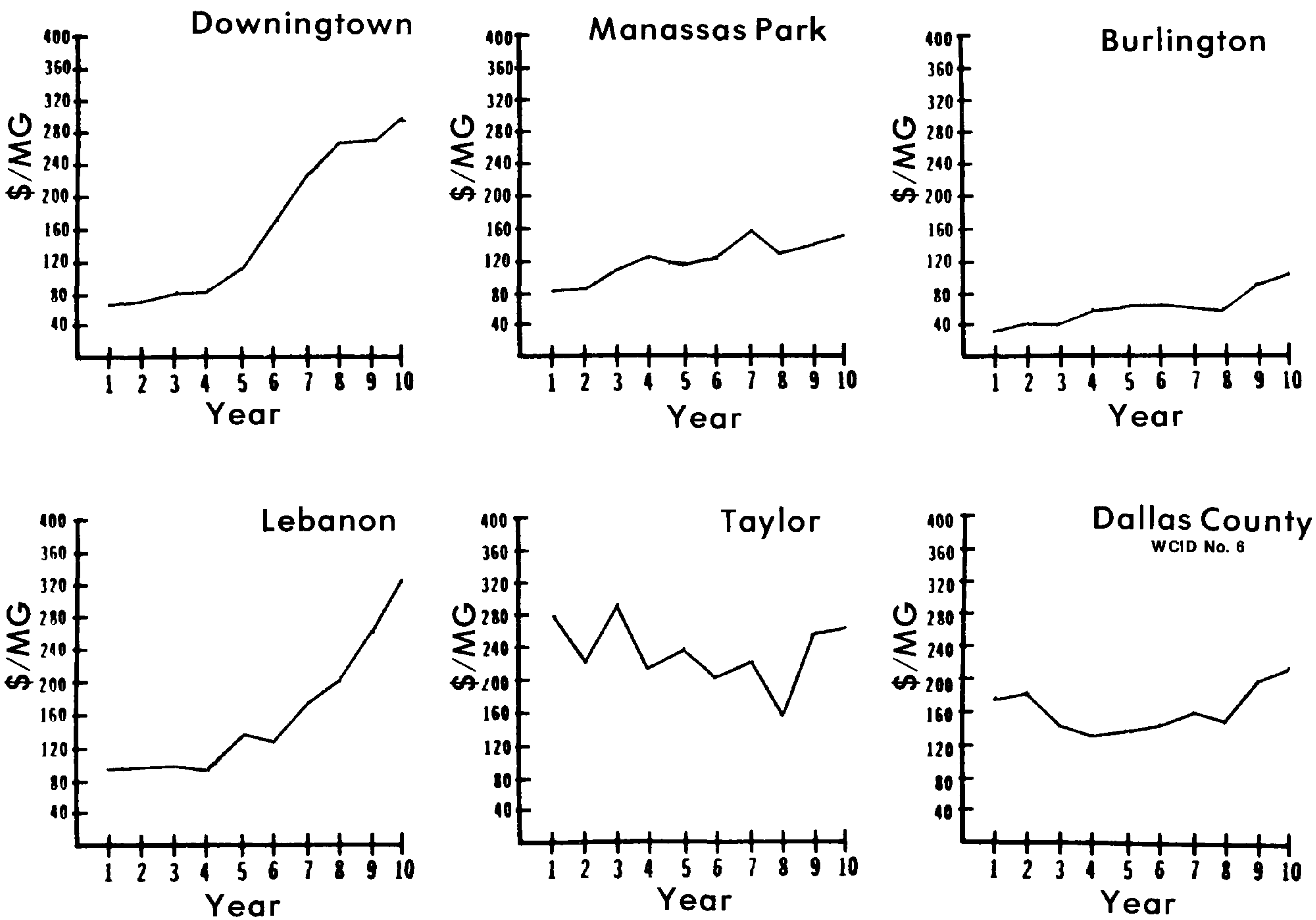

Figure 77. Payroll expense per million gallons for six utilities.

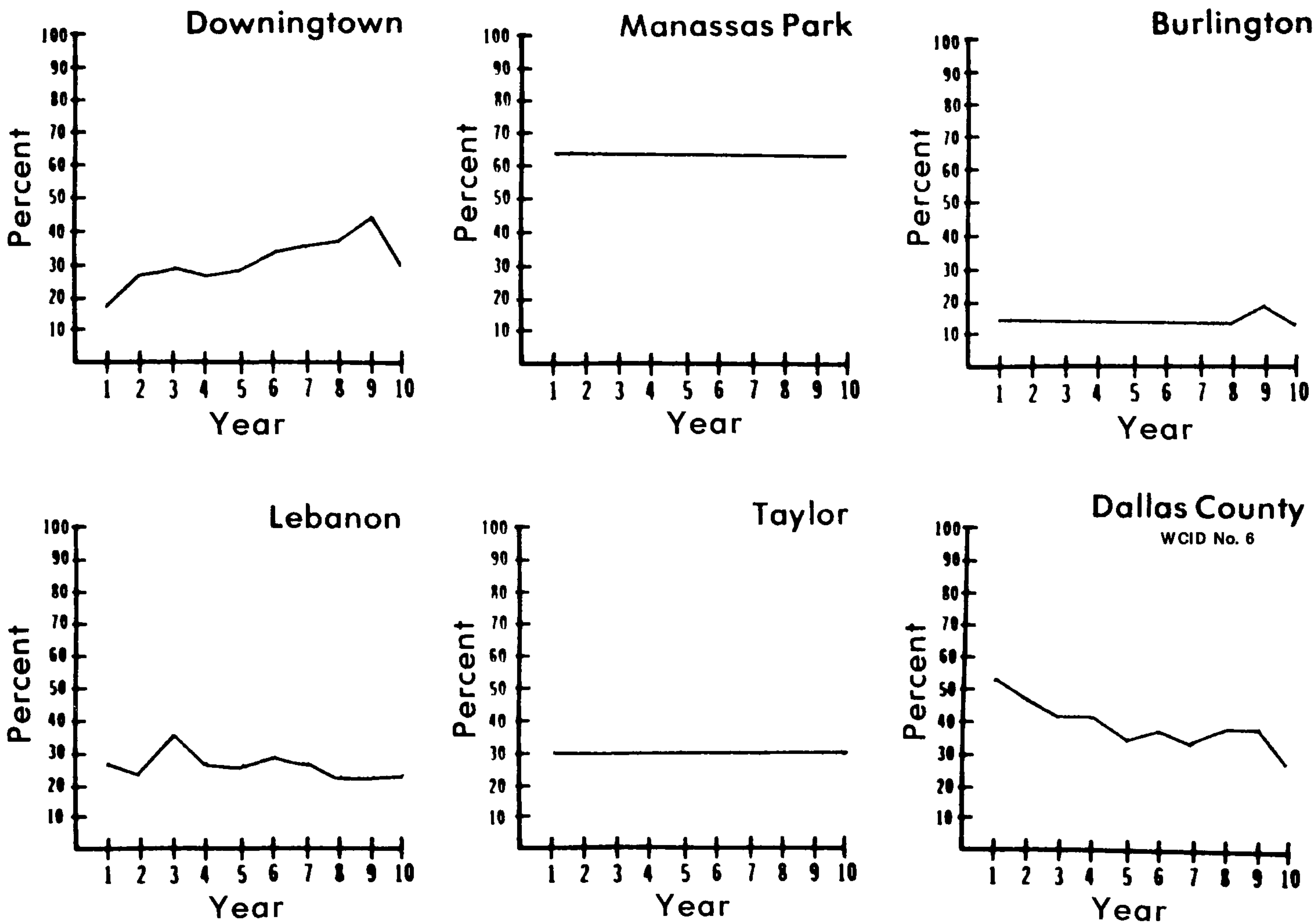

Figure 78. Support services as a percent of total O & M for six utilities.

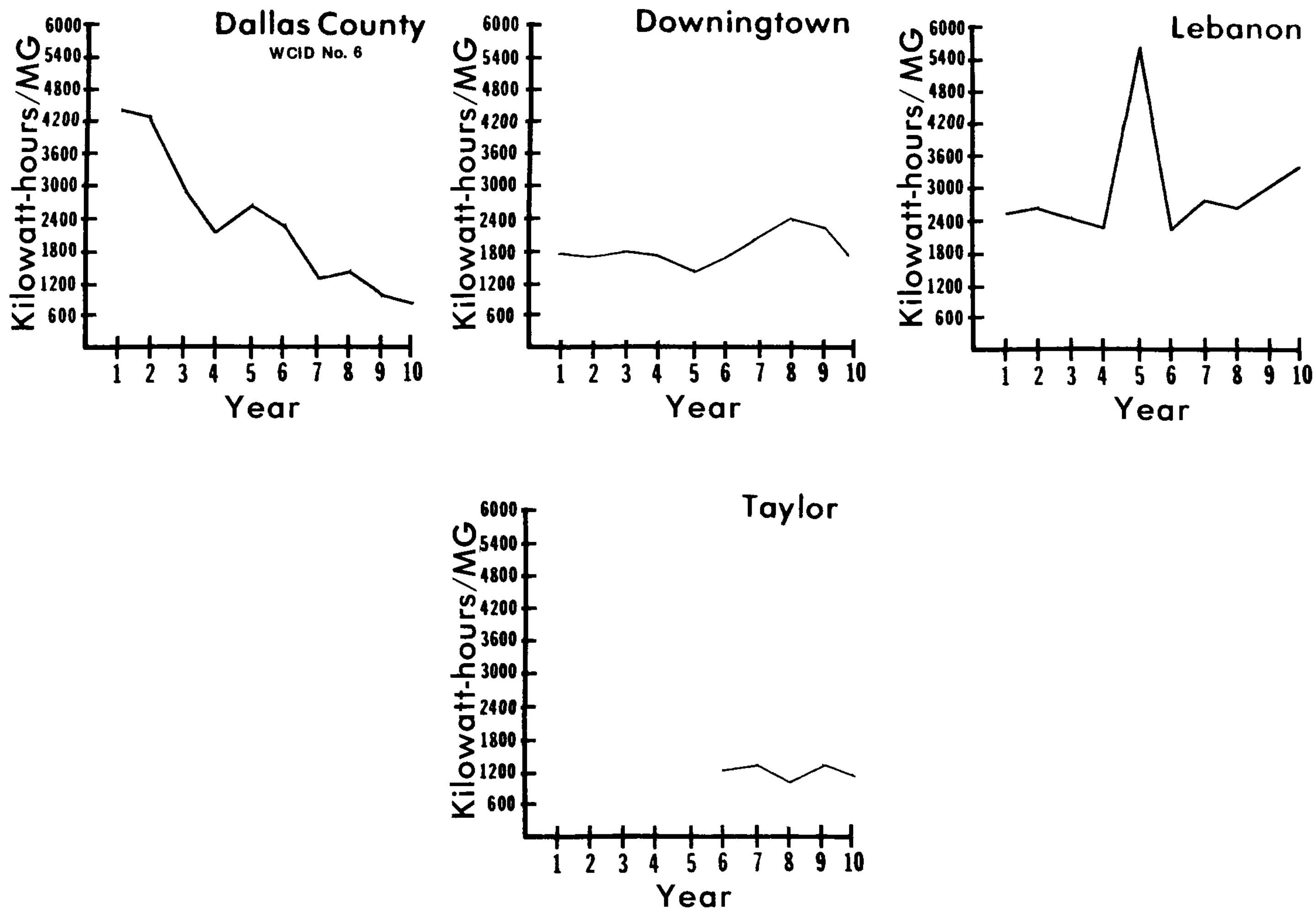

Figure 79. Kilowatt-hours per million gallons for six utilities.

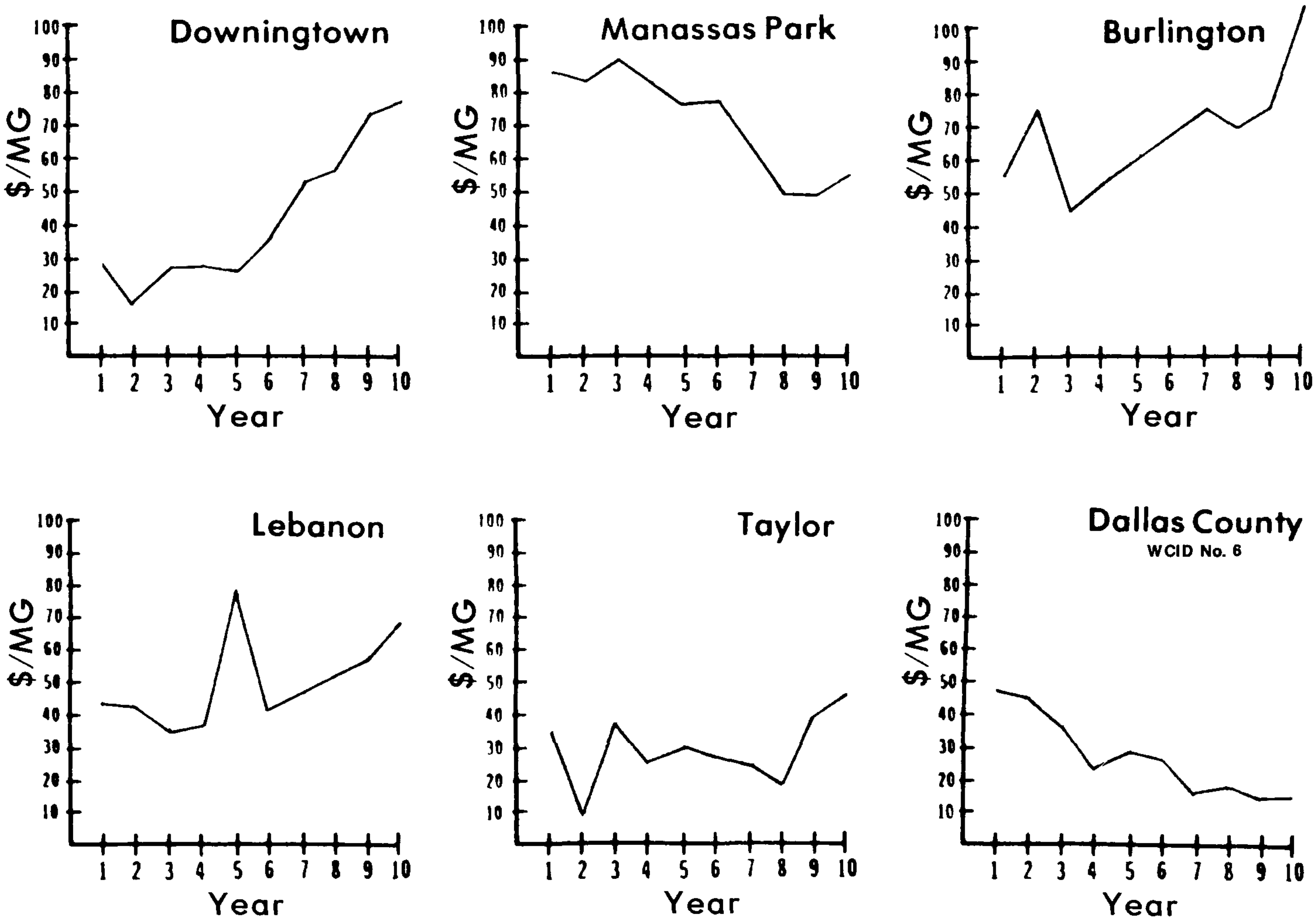

Figure 80. Power cost per million gallons for six utilities.

CAPITAL COST TRENDS

Figure 81 presents capital cost per million gallons during the study period. Average unit capital cost increased 12% while only Manassas Park experienced a decline. Other interesting information may be obtained upon examination of Figures 82 and 83. Figure 82 plots the ratio of capital to O&M cost while Figure 83 shows the ratio of capital to O&M cost deflated to year 1 of the study period. In general, the ratio is declining, through not as rapidly for deflated O&M costs. However, this indicates that in fact real O&M costs are becoming a more significant factor in utility budgets.

FIRST AND LAST YEAR COMPARISONS

Figures 84 and 85 illustrate the average trends in O&M costs and percent of total cost for support services, acquisition, treatment, and distribution components. Figure 84 shows that O&M cost increased for each category. Acquisition costs rose the most, 291%, while distribution costs remain the most significant cost component as also indicated in Figure 85, even though it may have declined as a percent of total cost.

SUMMARY

The data for these six small utilities indicate a general increase in water supply costs. The major causes appear to be payroll, energy, and inflation. This analysis demonstrates that O&M costs, which are significantly impacted by inflation, continue to grow as a portion of total cost. This information is important for planning future investments. The next chapter continues this analysis for the aggregate data set.

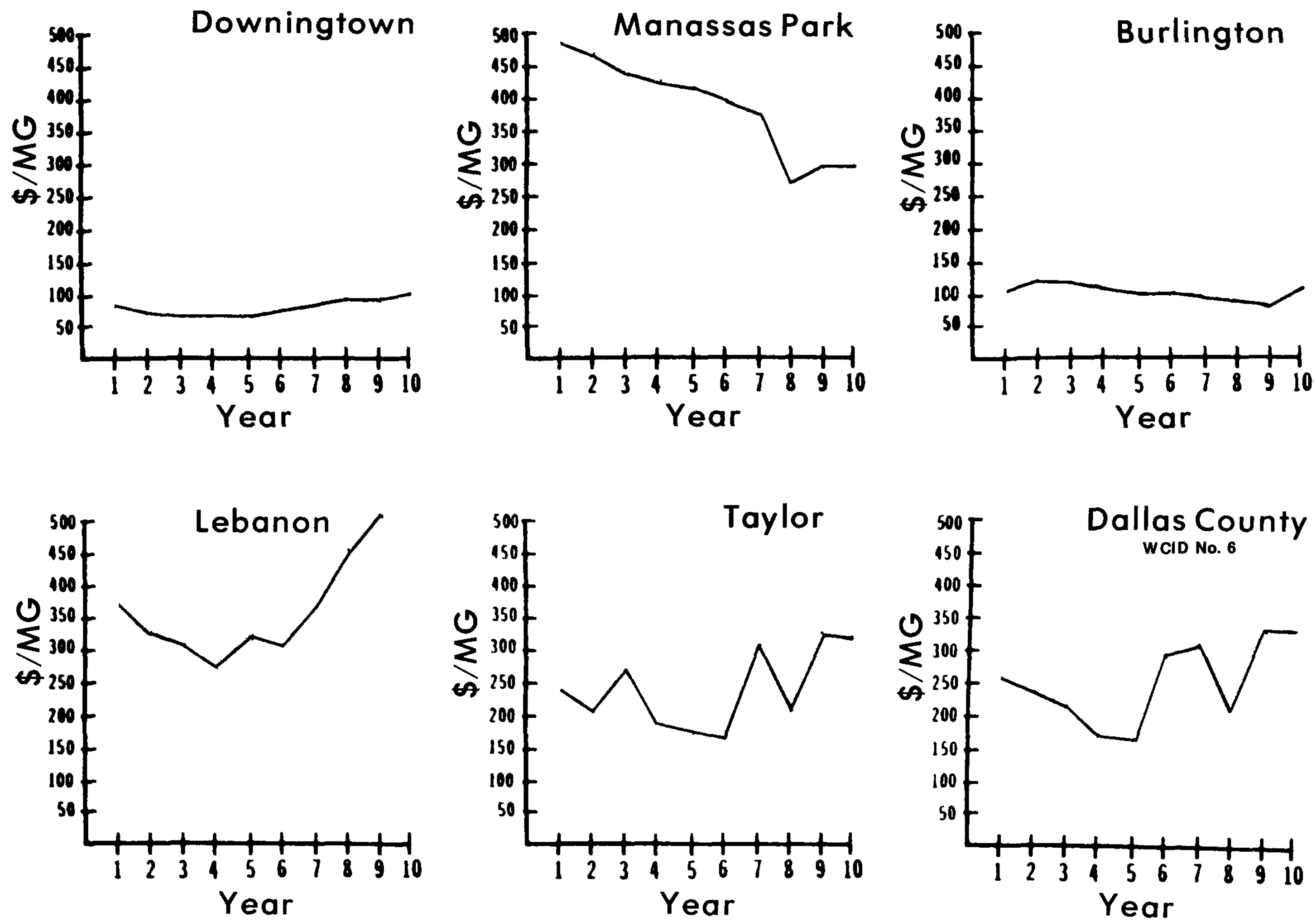

Figure 81. Capital cost per million gallons for six utilities.

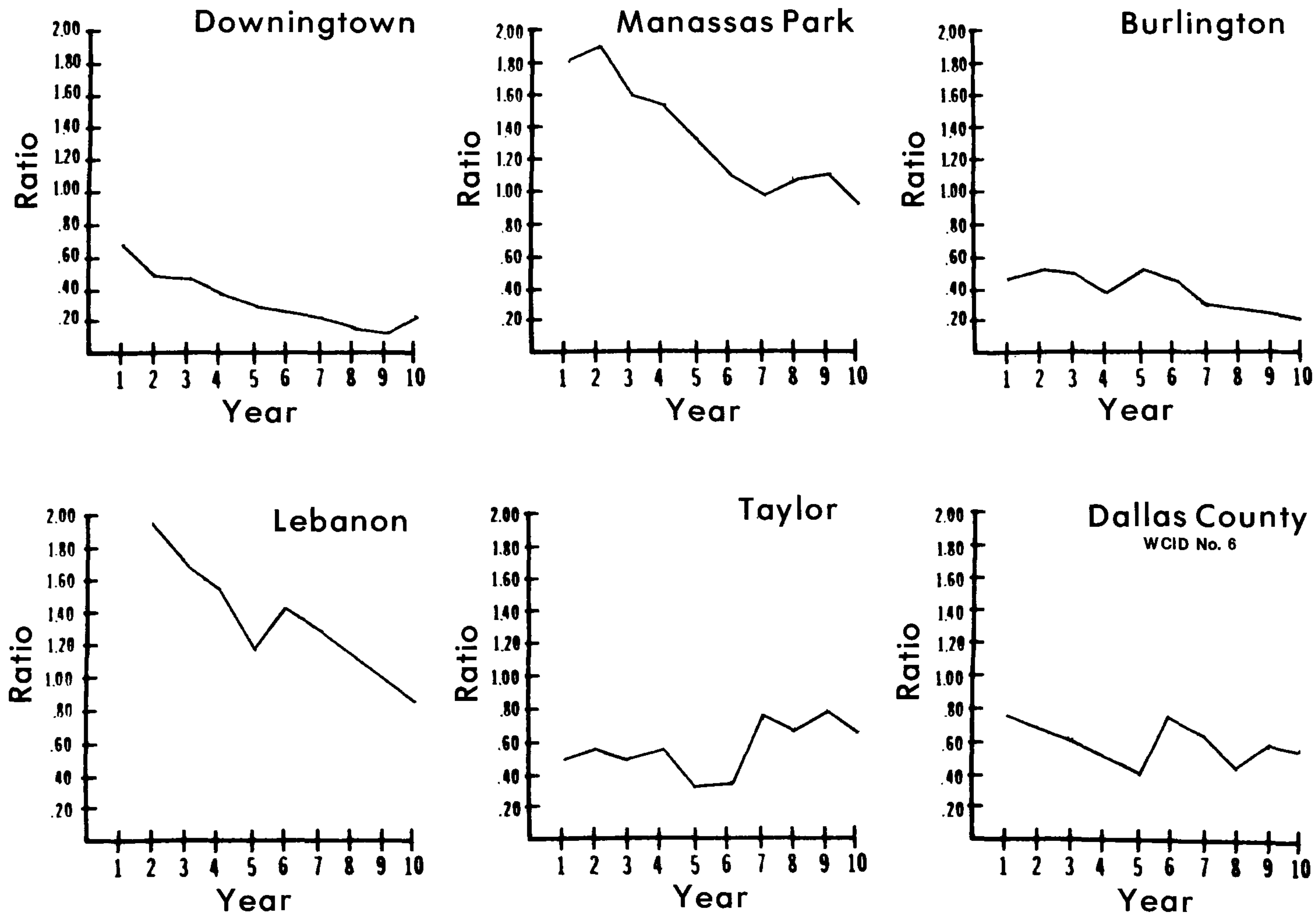

Figure 82. Ratio of capital to O & M cost for six utilities.

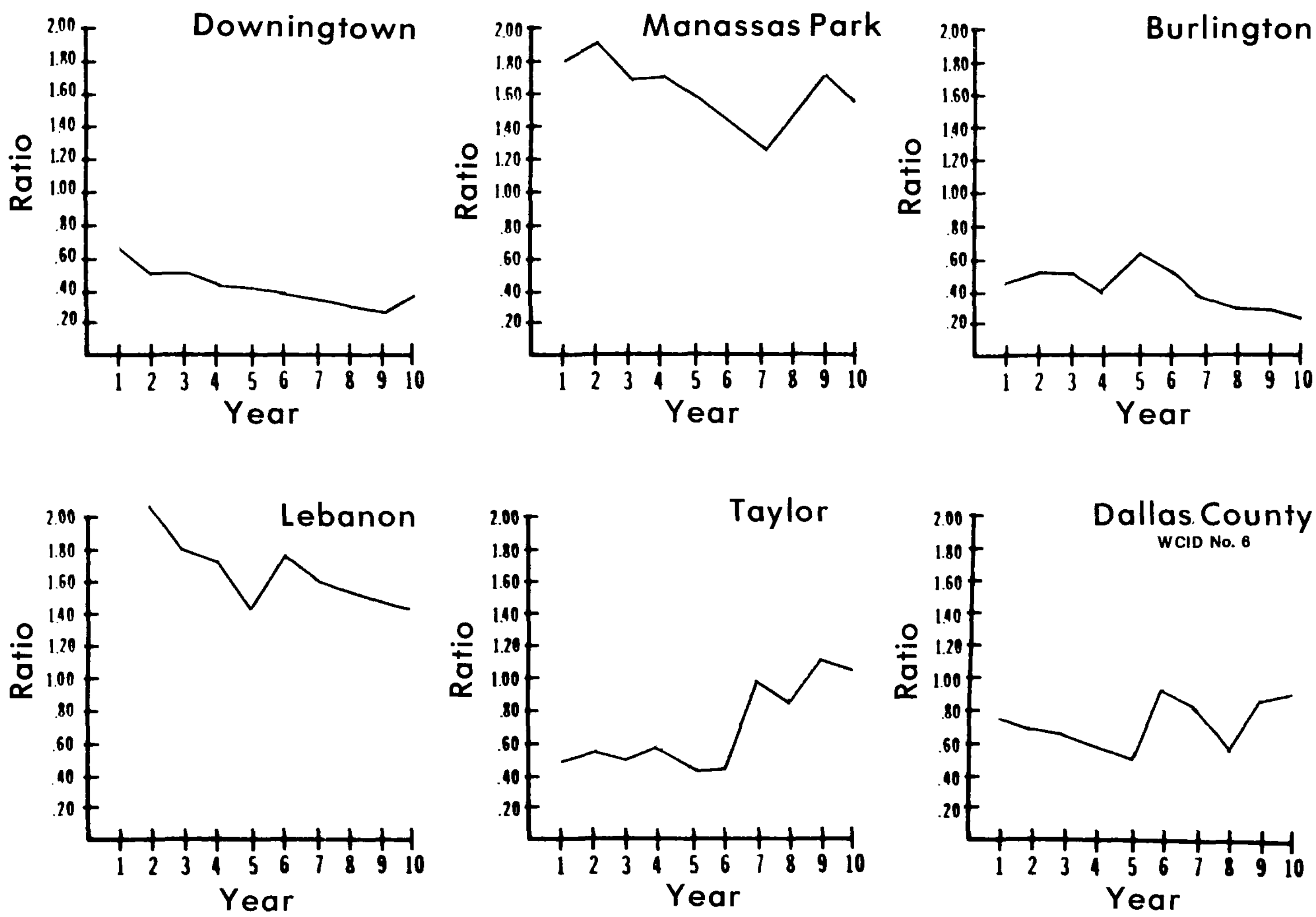

Figure 83. Ratio of capital to O & M cost deflated to year 1 for six utilities.

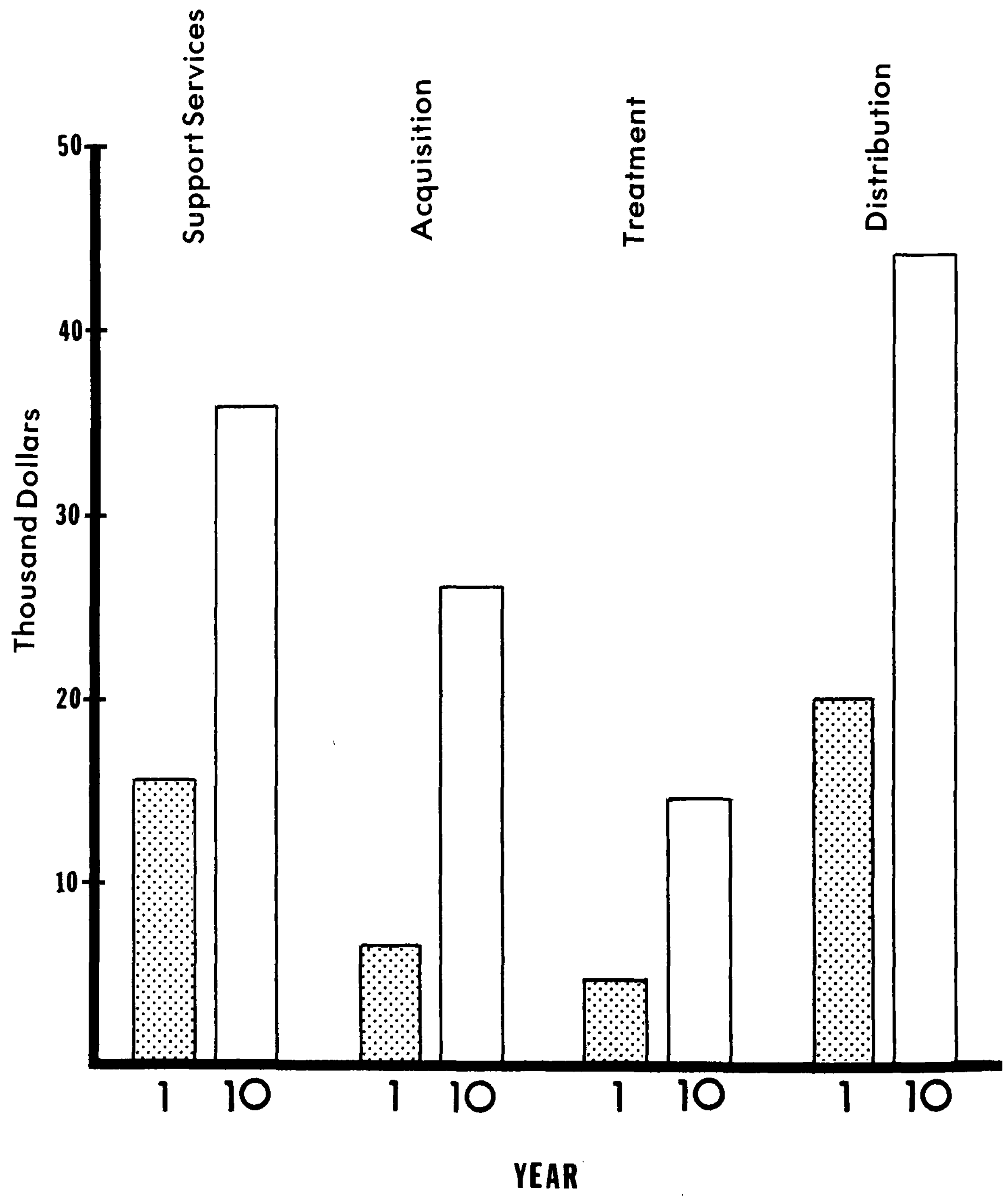

Figure 84. Average operating costs for six utilities by category.

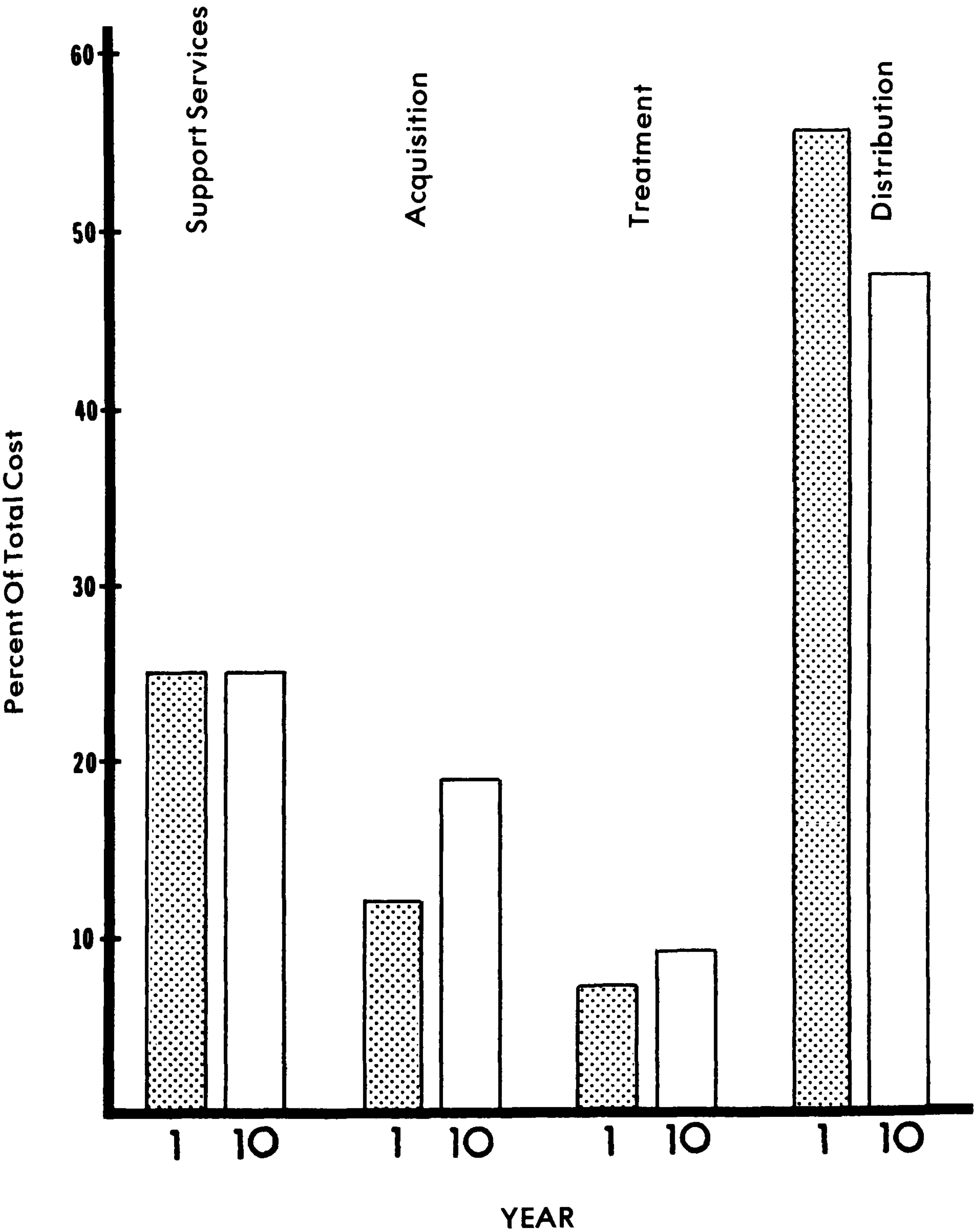

Figure 85. Utility operating costs: percent of total.

SECTION 5

AGGREGATE ANALYSIS

Averages of data on selected key variables provide information useful for decision-making. In this section, these averages are presented and analyzed. Tables 14 and 15 summarize the cost and output data over the 10-year period. There are missing values for some utilities. As a result, some cost components may not sum to total cost. However, trends based on the data in Tables 14 and 15 are indicative of both the level and pattern of expenditure. Figure 86 shows the trend in average revenue-producing water. In general, it has increased about 66% from 441.5 mil gal to 734.7 mil gal.

Average total operating and capital costs have risen over the study period, Figure 87. Operating costs increased from $75,786 to $198,150 (161%) while capital cost rose 117% from $49,386 to $107,058. This suggests that operating costs are more severely impacted by inflation. However, capital costs generaly reflected investments in prior years which are not affected by current price increases.

The trends of each O&M cost component (support services, acquisition, treatment, and distribution) are plotted in Figure 88. Distribution represents the most significant cost component, but support services are very close to distribution costs. Distribution costs increased only 164% from $17,386 to $45,824, while treatment costs rose 426% from $5,013 to $26,392. However, treatment costs comprise the smallest portion of O&M costs.

Figure 89 presents the change over time for payroll, power, and chemical costs while Figure 90 plots the costs versus revenue-producing water. These three items reflect a major portion of O&M costs. Payroll alone accounts for approximately 30% of total O&M expense. This explains part of the rapid increase in O&M since payroll costs have been significantly impacted by inflation (see Figure 91). Labor costs have more than doubled over the study period while productivity has increased slightly 9Figure 92). This is more evident from Figure 93 which shows the decline in man-hours per million gallons (MH/MG) as output (revenue-producing water) increased. This analysis suggests that over time, labor-saving equipment is being installed among the small water utilities.

As for power and chemical costs, Figures 89 and 90 indicate that energy cost is growing more rapidly than chemical cost. This is to be

Table 14. AVERAGE OPERATING AND CAPITAL COSTS FOR ALL UTILITIES FOR THE 10-YEAR PERIOD

	1	2	3	4	5	6	7	8	9	10
Total Operating Cost										
Thou $	75.876	107.377	92.520	92.216	100.964	126.091	136.244	149.487	176.780	198.150
$/mil gal	315.46	310.00	308.62	294.54	338.38	355.77	387.23	402.54	450.62	530.31
Depreciation										
Thou $	34.914	41.797	37.819	39.330	41.069	42.388	47.848	48.298	55.404	61.419
Interest										
Thou $	14.468	30.550	25.071	26.133	27.858	33.064	34.578	39.867	40.777	45.640
Total Capital Cost										
Thou $	49.386	72.348	62.890	65.464	68.927	75.452	82.425	88.166	96.181	107.058
$/mil gal	202.06	256.77	195.57	196.31	196.65	197.58	218.02	208.69	235.50	253.37
Total Operating and Capital Costs										
Thou $	125.173	156.648	156.839	157.680	181.119	202.024	219.432	238.401	273.733	306.010
$/mil gal	516.92	566.54	503.69	490.77	536.62	555.23	608.00	613.38	688.38	785.85
Revenue-Producing Water										
mil gal	441.50	468.50	503.64	563.50	568.29	640.29	689.00	708.86	749.57	734.71

Table 15. AVERAGE PAYROLL, CHEMICAL, AND ENERGY COSTS

	1	2	3	4	5	6	7	8	9	10
Total Payroll										
Thou $	23.857	26.547	28.166	30.809	36.131	41.354	45.272	49.625	55.113	58.846
$/mil gal	113.80	116.60	129.10	126.00	139.50	159.20	178.40	185.50	213.80	227.90
Man-Hours										
Hours	17221.00	17324.30	17131.30	18009.10	18450.10	18594.40	19436.90	20620.60	20461.00	20778.60
$/MH	2.02	2.28	2.38	2.58	2.91	3.30	3.50	3.45	4.09	4.31
MH/MG	66.80	60.00	62.00	57.70	57.90	50.70	53.80	53.00	56.30	57.80
Capital/Labor Cost Ratio										
	2.07	2.73	2.23	2.12	1.91	1.82	1.82	1.78	1.75	1.82
Total Power Cost										
Thou $	13.048	14.966	16.606	16.143	19.861	22.157	23.138	25.378	29.905	37.289
$/mil gal	53.23	48.92	45.69	44.85	50.48	49.23	52.15	52.00	58.38	68.77
Kilowatt Hours										
KWH (x 10^2)	4874.69	5268.67	4815.20	5171.40	8899.92	5682.38	4683.70	4795.50	4155.35	3893.89
KWH/MG	2327.00	2281.00	1791.00	1529.67	2784.33	1583.33	1378.33	1402.33	1416.67	1476.00
$/KWH										
Chemical Cost										
Thou $	9.516	9.489	9.414	10.713	11.153	12.078	12.273	10.566	13.809	19.314
$/MG	18.25	18.00	17.25	17.75	16.50	16.00	15.63	16.38	19.63	31.63

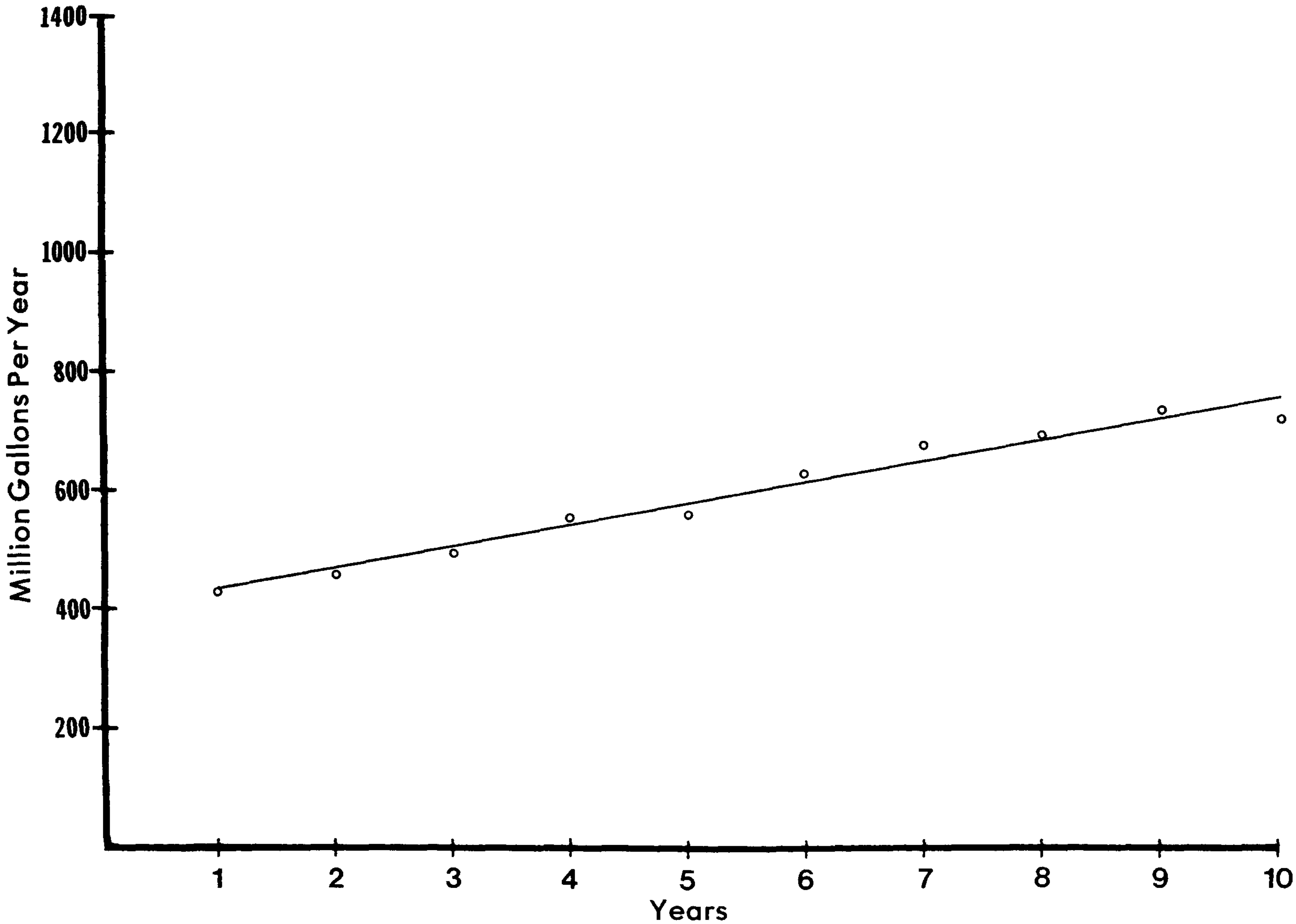

Figure 86. Average revenue producing water for small utilities.

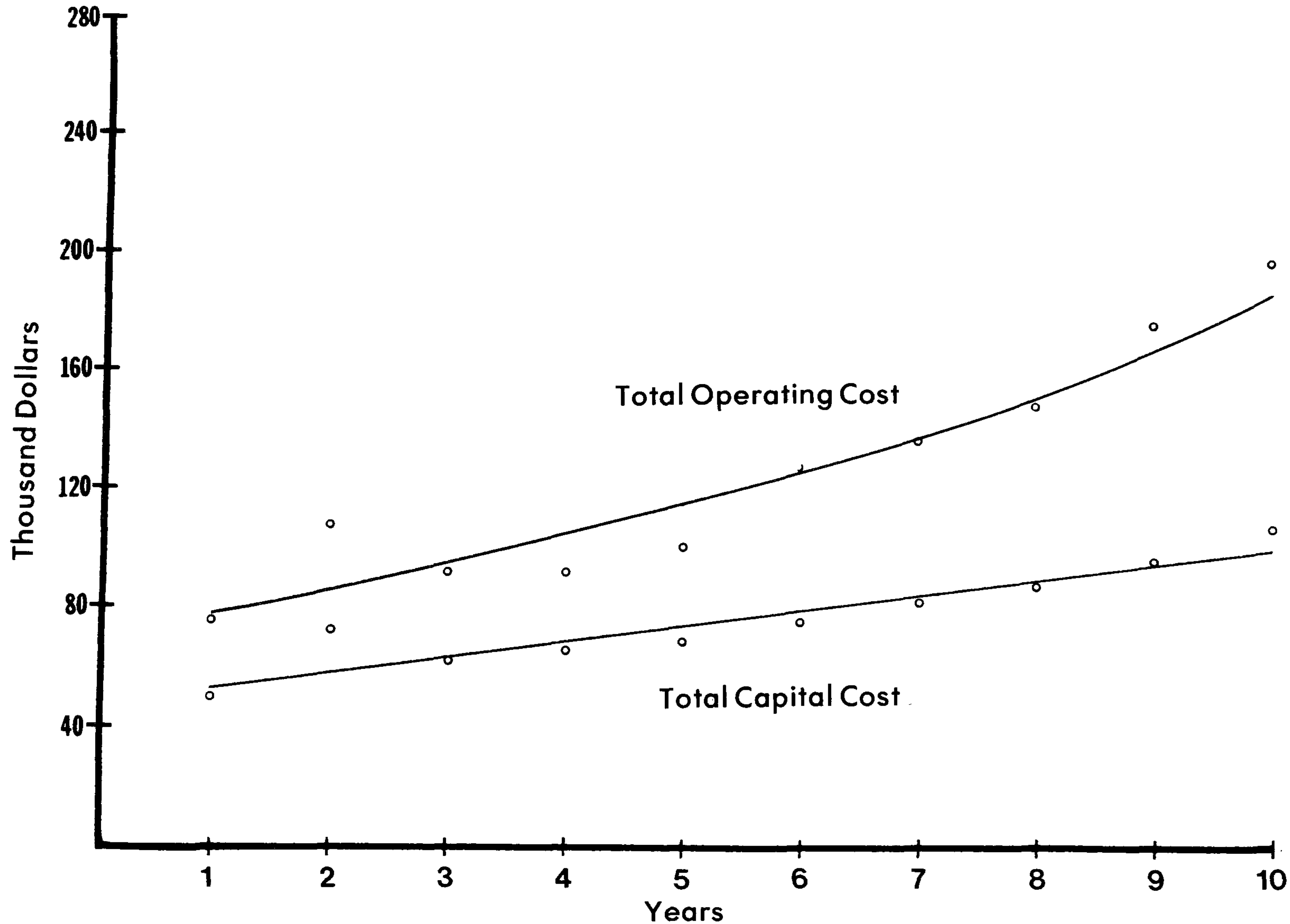

Figure 87. Average total operating and capital cost for small water utilities.

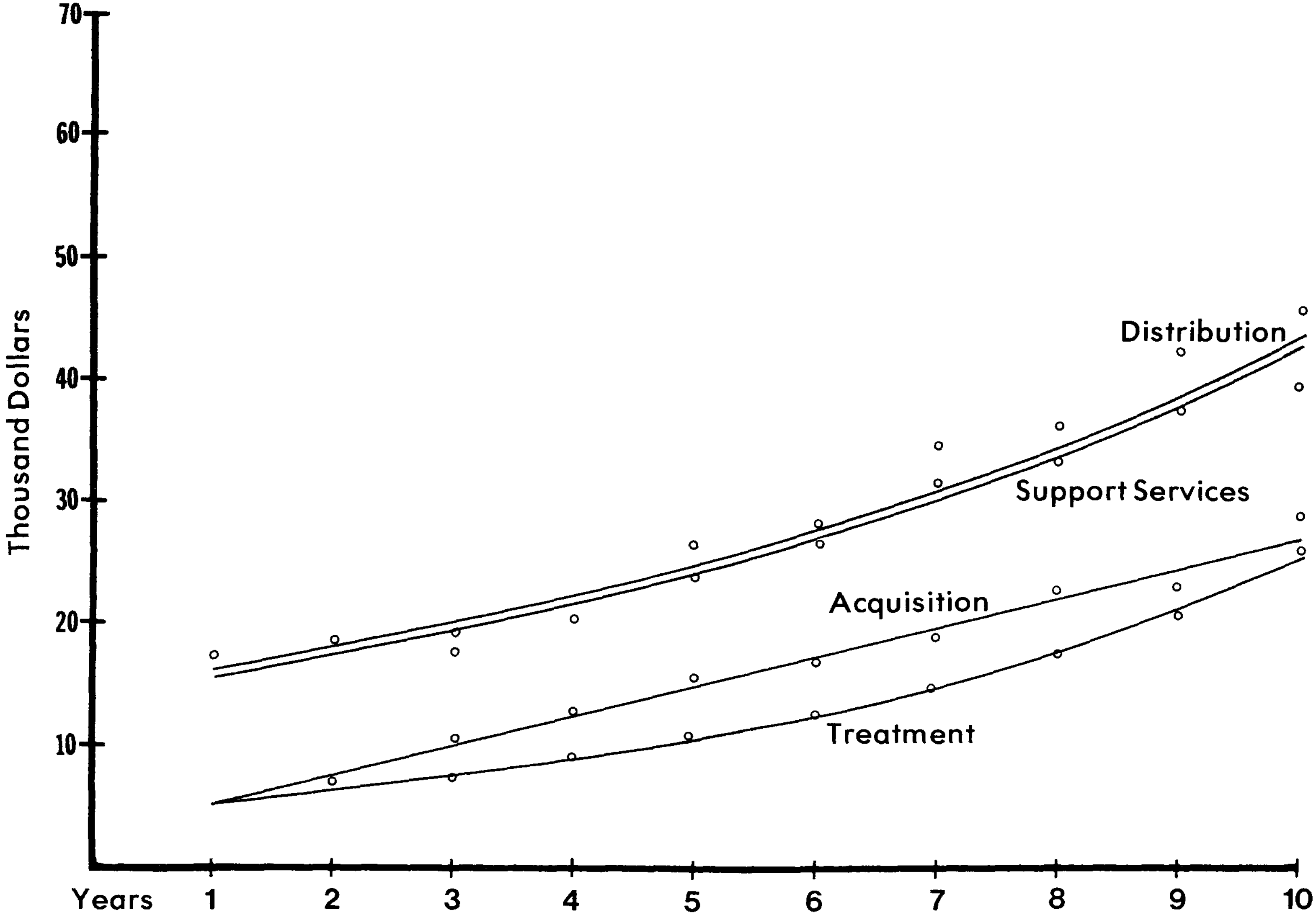

Figure 88. Average total operating expenditures for distribution, support services, acquisition and treatment.

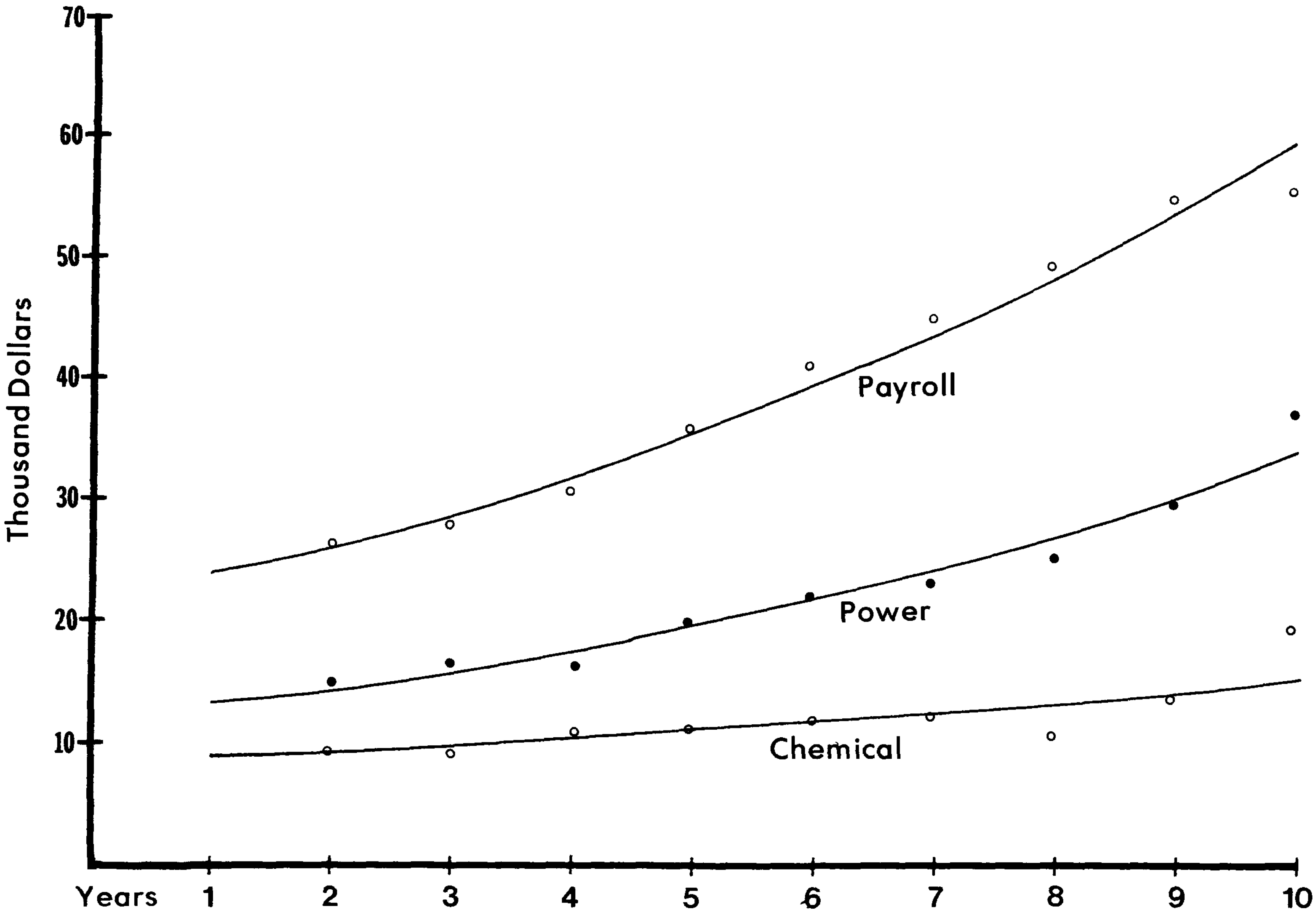

Figure 89. Average of total payroll, power, and chemical costs versus time for small water utilities.

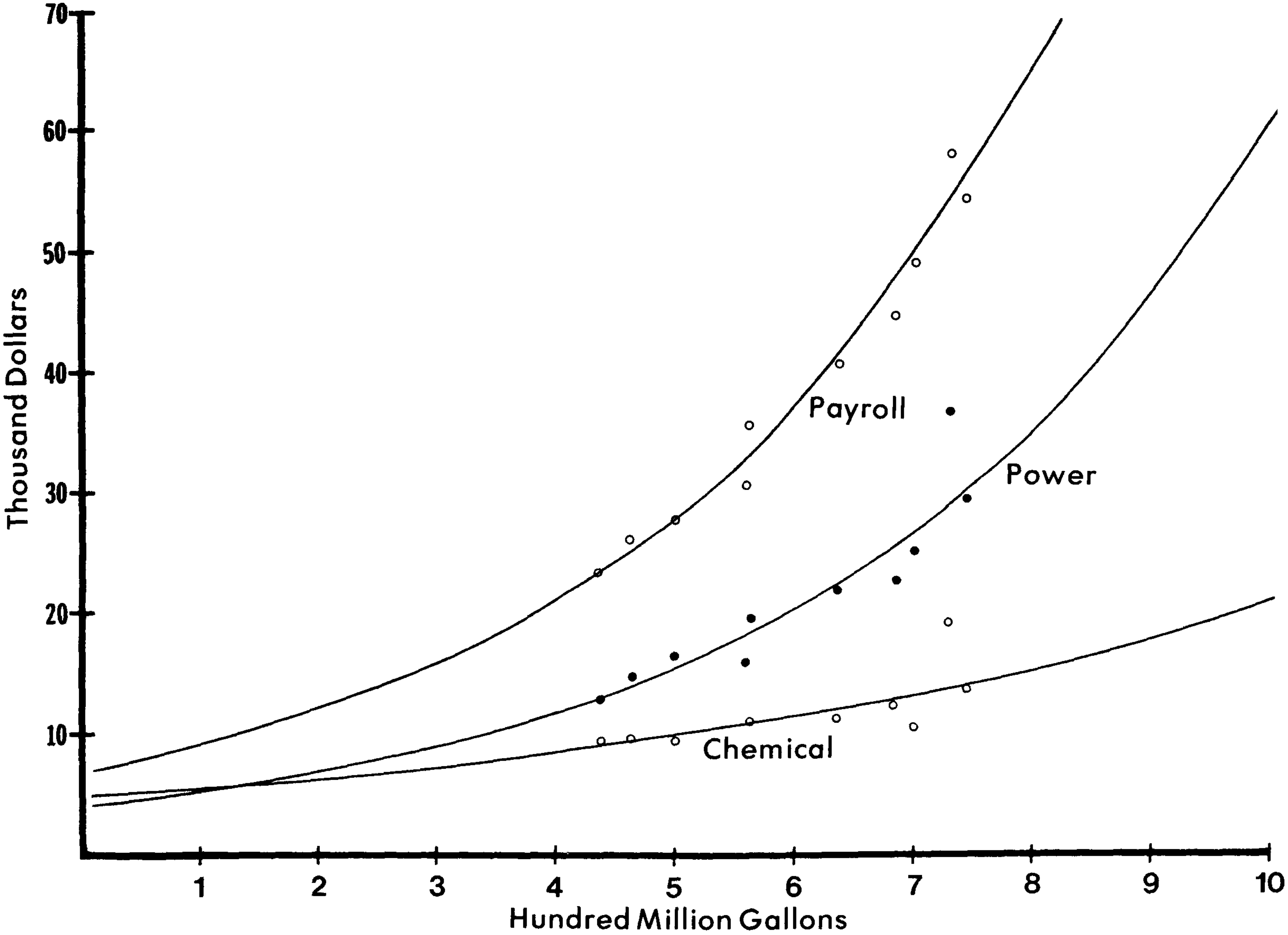

Figure 90. Average of total operating cost for payroll, power, and chemicals versus revenue producing water for small water utilities.

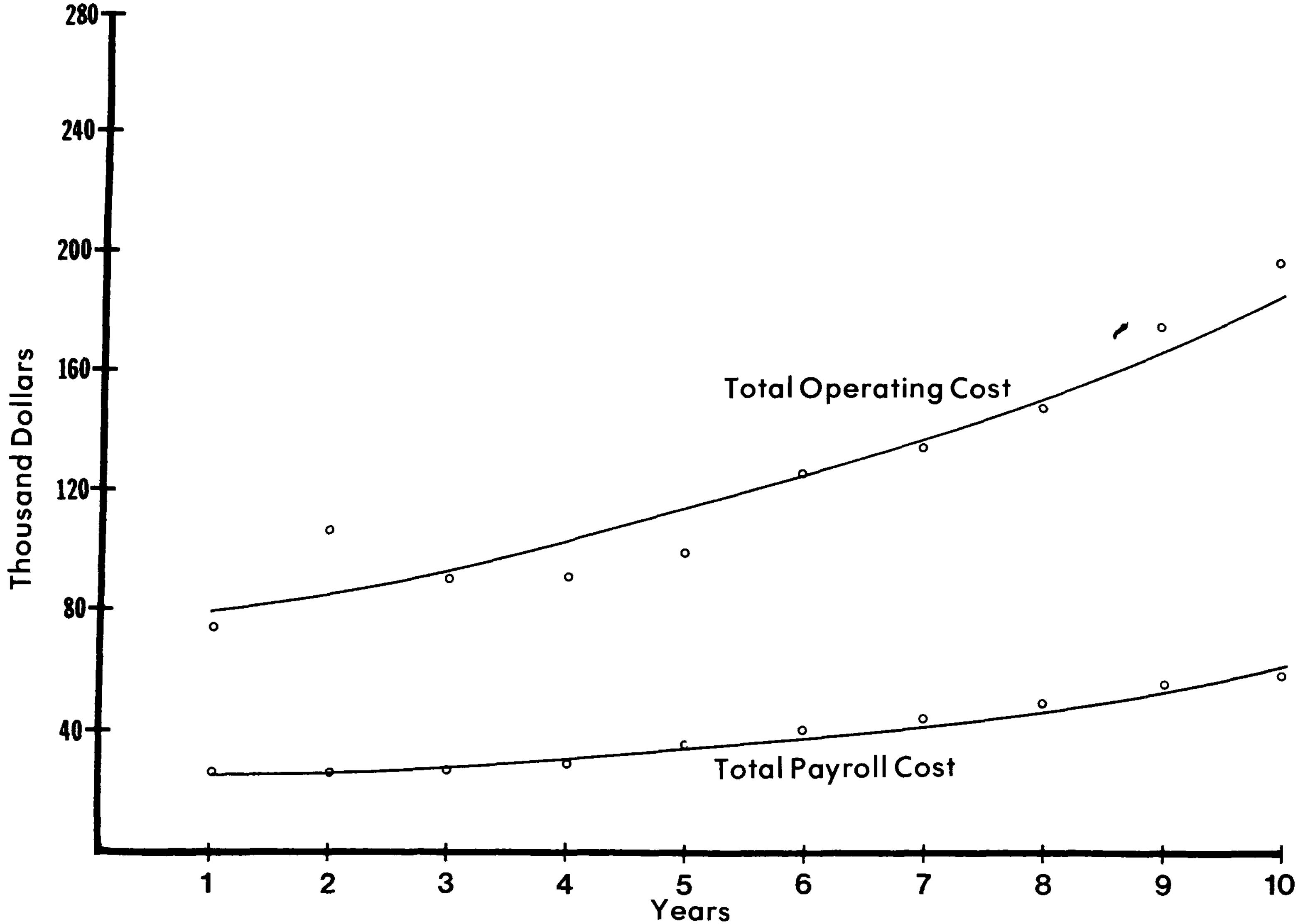

Figure 91. Average expenditure for operating and payroll versus time for small water utilities.

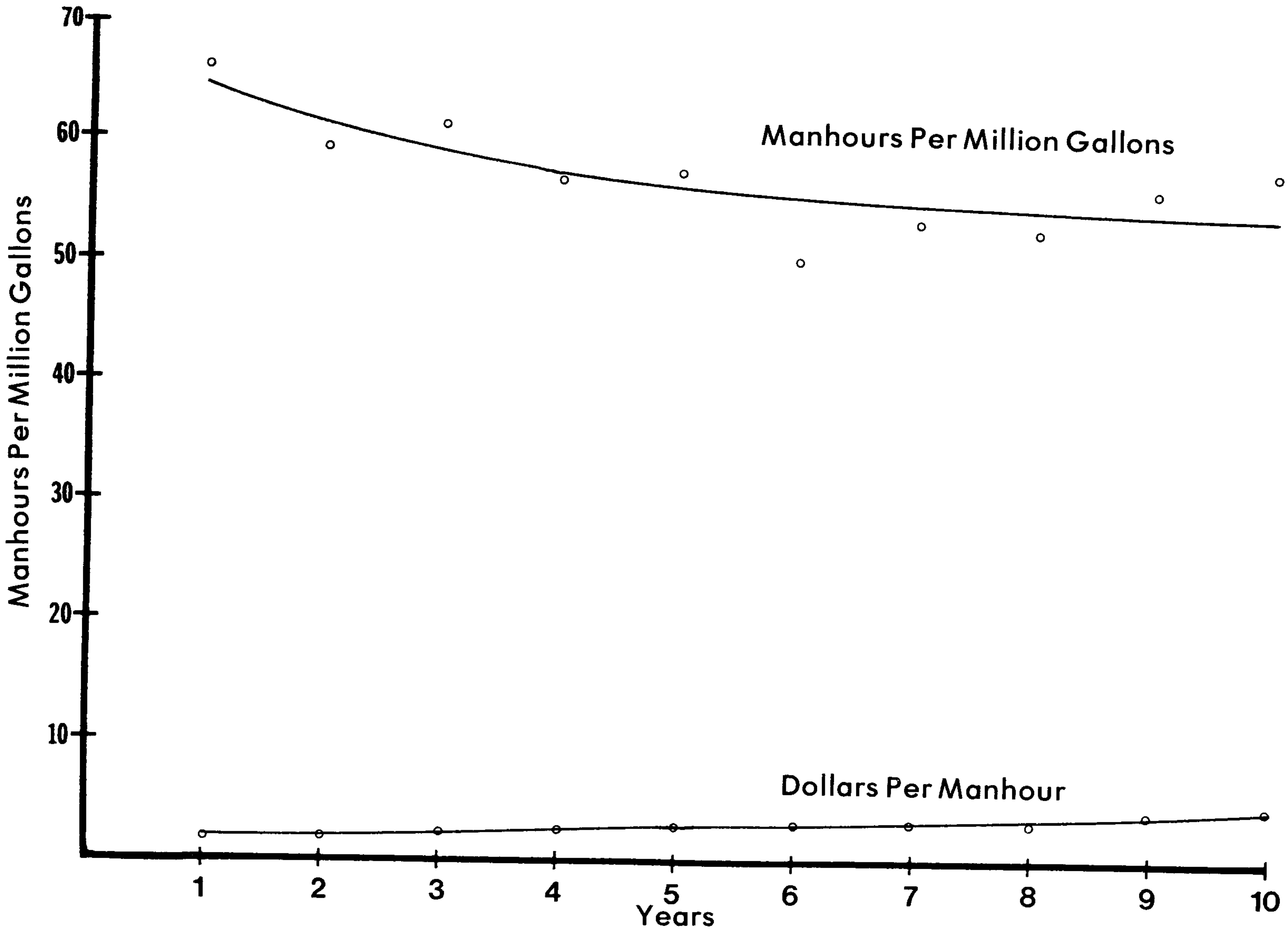

Figure 92. Average manhours per million gallons and dollars per manhour versus time for small water utilities.

expected with the rising cost of fuel and the low portion of O&M cost related to the treatment component. In general, all three components, payroll, power, and chemical expenditures, are rising rapidly over time which will have a significant impact on water rates and utility budgets.

Figures 94 and 95 present total unit operating and capital cost with respect to time and quantity, respectively. The obvious implication again is that O&M costs rose more rapidly than unit capital costs. However, capital costs are not affected as significantly by current price increases. Evaluation of this requires more detailed information on current capital value of the plant. A general indication of the impact of inflation on small water utilities can be obtained from Figures 96 and 97. While the current value of total unit cost rose 52%, the real value (current value deflated by the CPI) has actually declined by about 7.5% from the beginning of the study period. Therefore, inflation has been the primary influence on small water utility cost increases.

Table 16 presents empirical results for each component of O&M and capital cost. The form $C = aQ^b e^{sT}$ was estimated by pooling the data for each utility over the 10-year period [cost = cost/year, Q = revenue-producing water, mil gal/year, and T = time]. A missing values option was used in the computer statistical package. The parameter b provides an estimate of cost elasticity while s indicates the rate of growth in cost per year. From these equations, the impact on cost of increased output as well as the overall growth of cost over time can be evaluated. Appendix A provides similar information for each utility. The results for acquisition and treatment do not appear to be statistically significant. Acquisition and treatment expenditures are the lowest cost components which may partially explain their lack of significance. Some coefficients are significant, but in general their R^2's are low. The results for the remaining components and total cost appear statistically significant. As can be seen from the table, operating costs have grown at a rate almost twice that of capital costs, .073 to .047, respectively. Overall, total costs have risen 6.7% per year.

In summary, two trends are evident from this aggregate analysis. First, inflation is a principal influence on rising utility costs. Increased labor productivity has managed to trim down this rise, but not significantly. The inflationary impact is such that real unit costs (current value deflated by the CPI) have actually declined. And second, since payroll costs represent a significant portion of O&M costs and since labor wage rates usually are tied to the rate of increase in prices, any change in the labor market will have a pronounced effect in water utility costs. Information on movements in the labor market can be helpful to utility managers as they plan future investments which might affect the capital/labor trade-off.

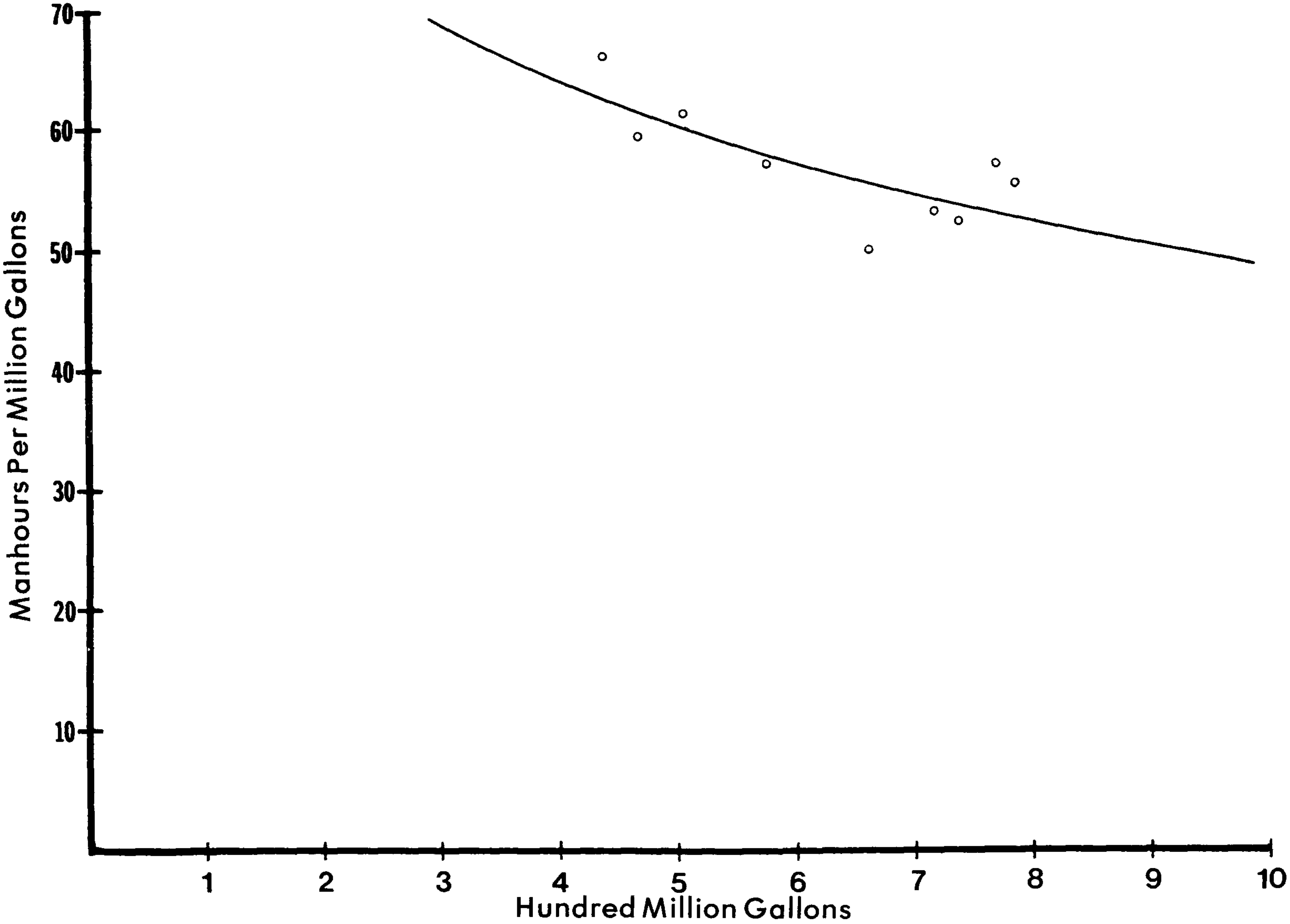

Figure 93. Average manhours per million gallons versus revenue producing water for small water utilities.

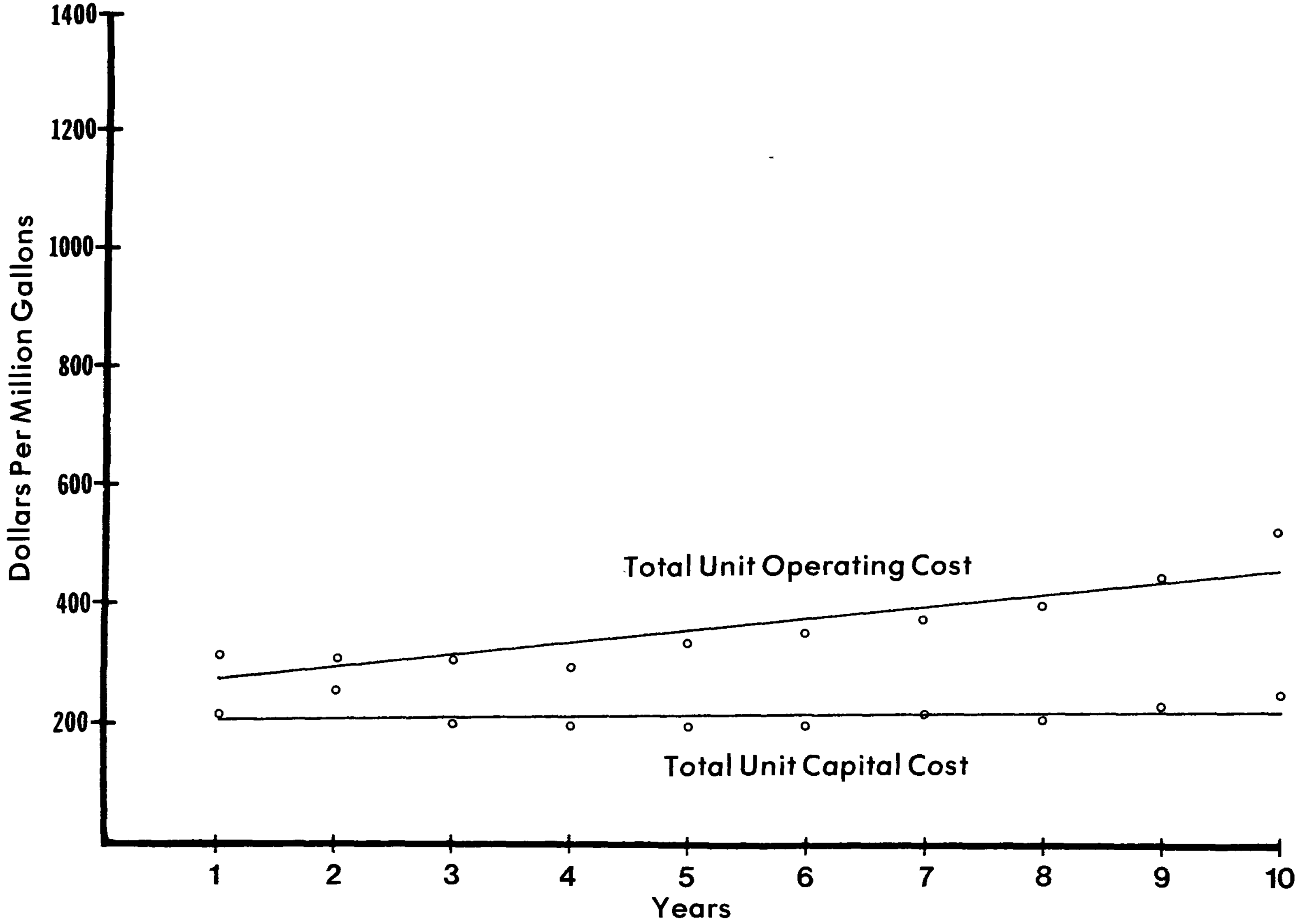

Figure 94. Average total unit operating and capital costs versus time for small water utilities.

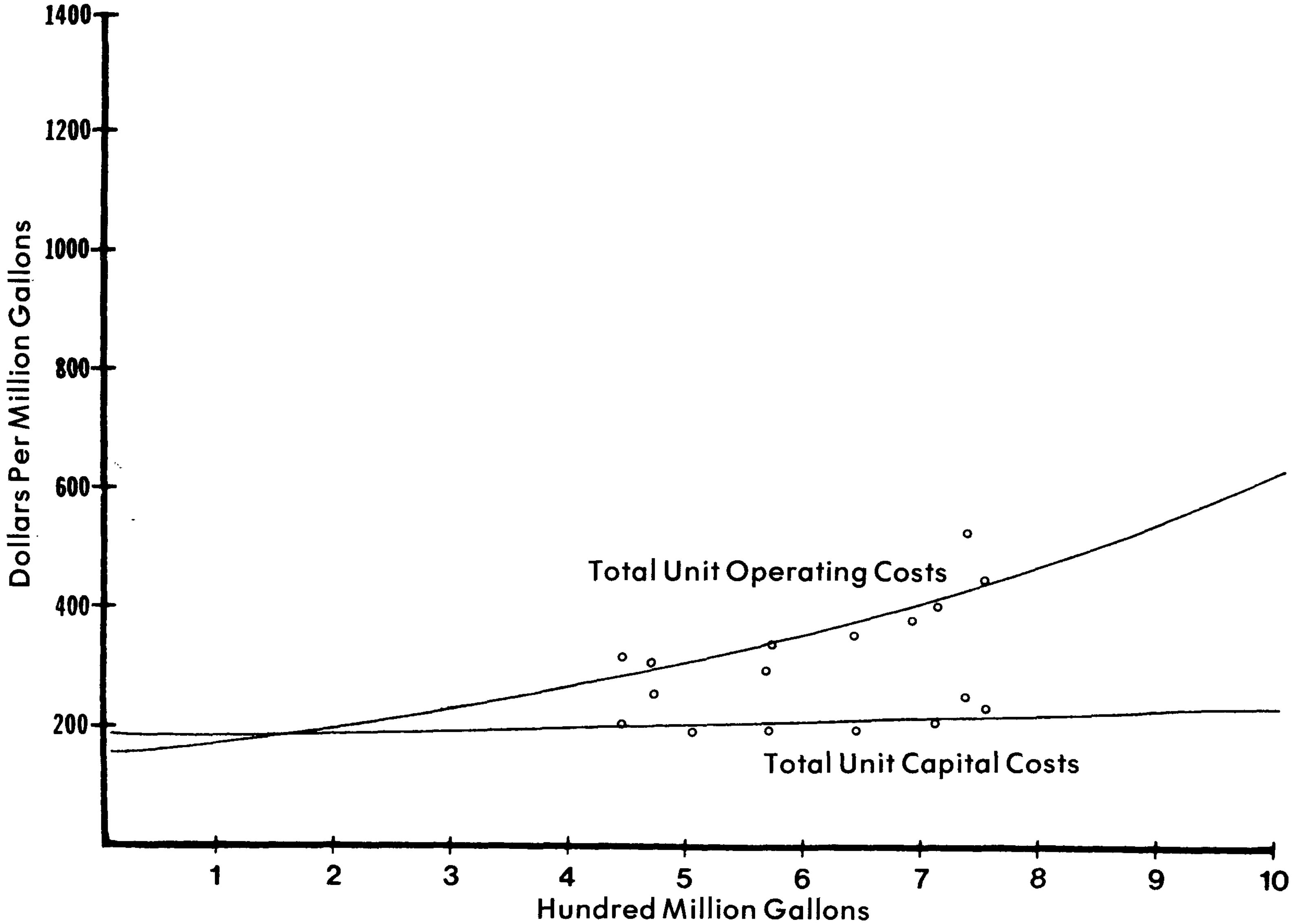

Figure 95. Average total unit operating and capital costs versus revenue producing water for small water utilities.

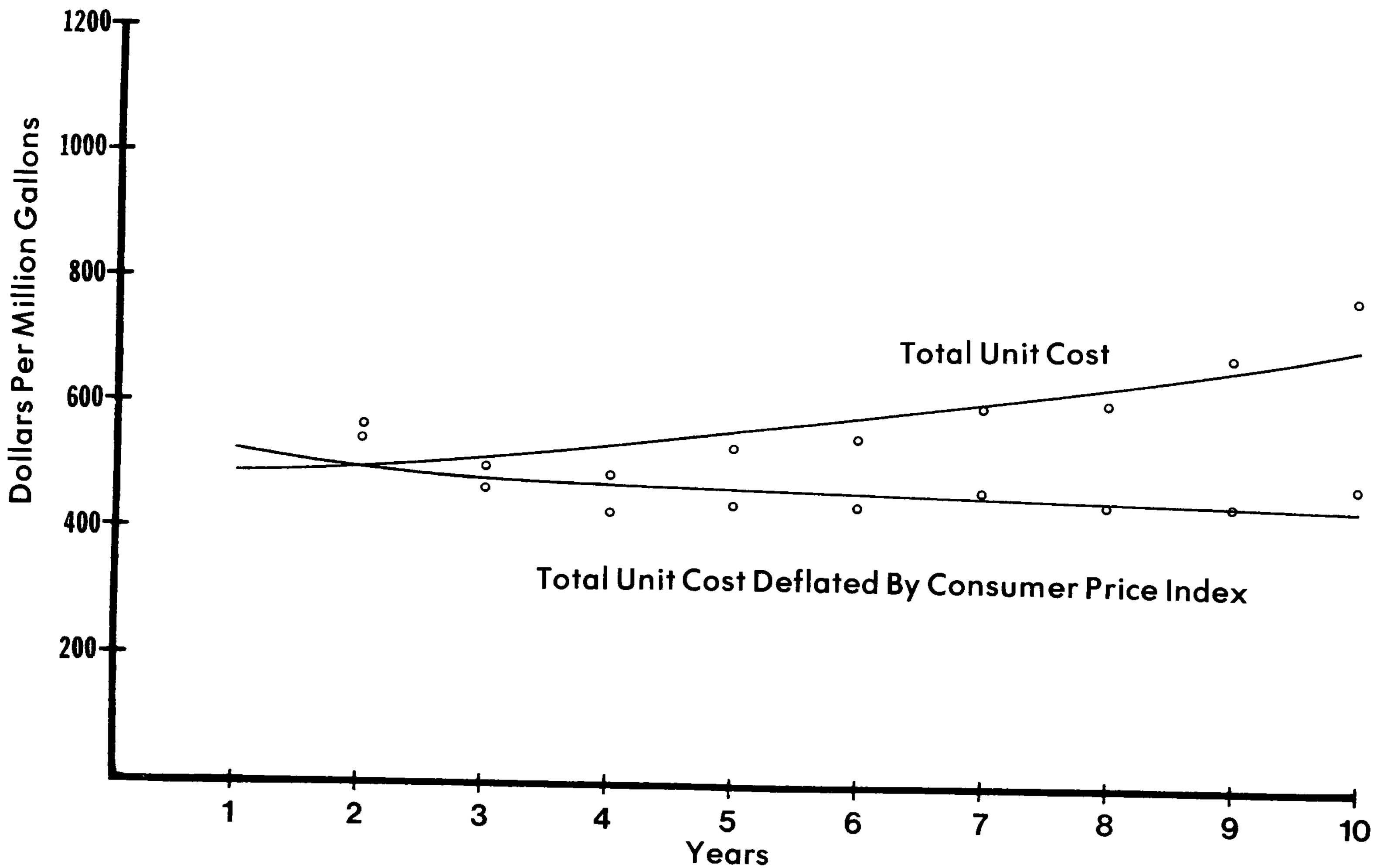

Figure 96. Average total unit cost versus time for small water utilities: historical and deflated.

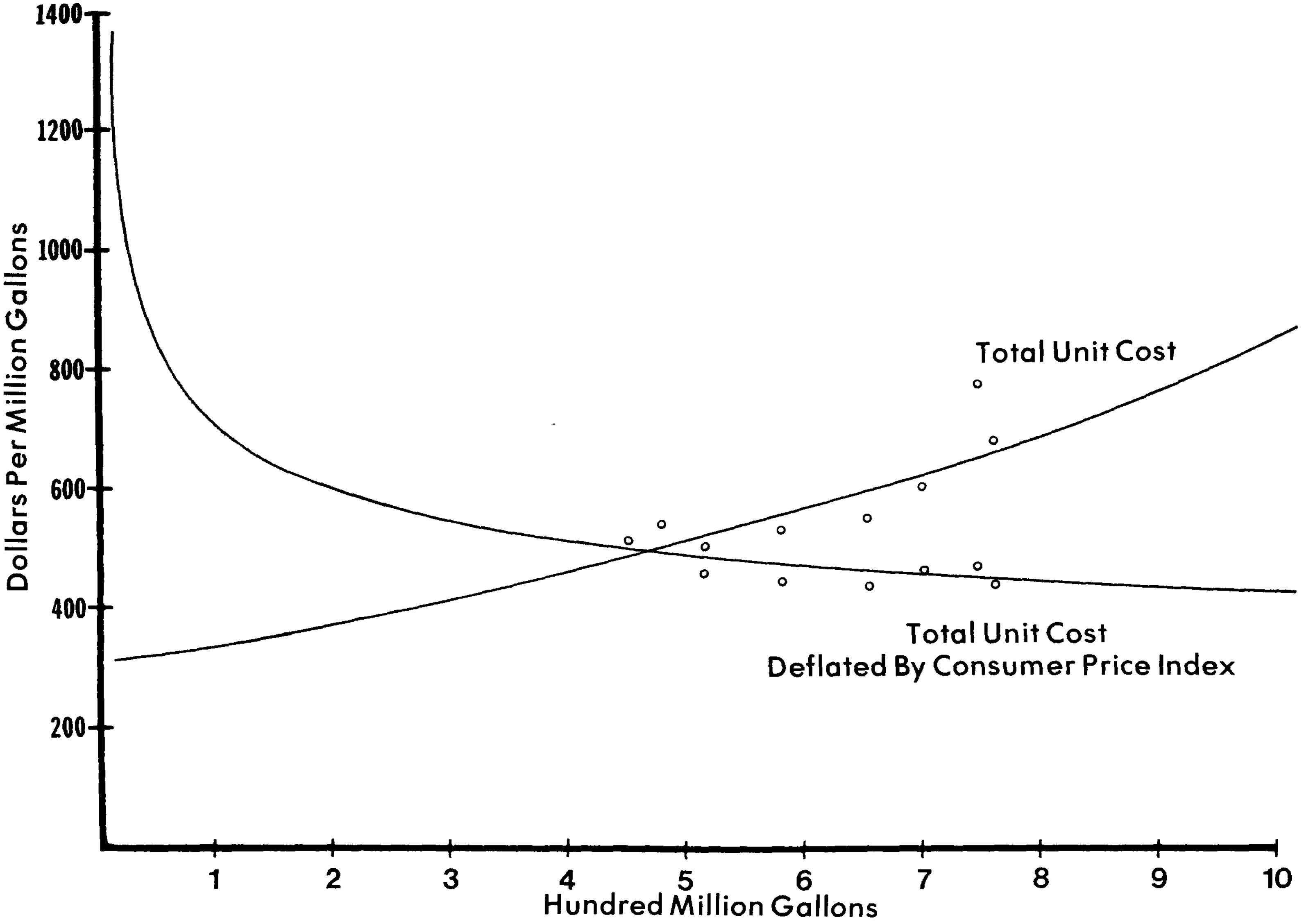

Figure 97. Average total unit cost versus revenue producing water for small water utilities: historical and deflated.

Table 16. EMPIRICAL RESULTS OF O&M AND CAPITAL COSTS

	Operating $C = aQ^b e^{sT*}$				Capital $C = aQ^b e^{sT*}$				Total $C = aQ^b e^{sT*}$			
	a	b	s	R^2	a	b	s	R^2	a	b	s	R^2
Acquisition	28.02	.885 (.204)	.124 .090	.156	278.20	.221 (.201)	N.S. 0.0	.007	34.62	.873 (.207)	.161 (.091)	.160
Treatment	3.43	1.177 (.209)	N.S.	.205	4.35	.863 (.202)	N.S. 0.0	.096	14.83	.975 (.209)	N.S. 0.0	.151
Distribution	130.51	.905 (.048)	.063 (.021)	.755	414.44	.722 (.043)	.043 (.021)	.634	513.30	.816 (.040)	.051 (.018)	.786
Support Services	132.07	.823 (.028)	.064 (.028)	.600	.08	1.680 (.133)	N.S. 0.0	.487	106.00	.883 (.063)	.069 (.028)	.637
Total	649.93	.802 (.027)	.073 (.013)	.842	409.68	.783 (.044)	.047 (.021)	.666	1112.05	.794 (.028)	.067 (.013)	.840

* T refers to time during the study; T = 1 in 1965.
Values in parantheses are standard errors.
All estimates are significant at the .05 level.
N.S. = not significant

A note of caution must be introduced. These unit costs do not reflect the increased value of capital over time. Considering increases in capital cost value, this would probably raise the deflated unit cost to either a flat or positive slope.

SECTION 6

COST MODEL DEVELOPMENT

ANNUAL OPERATING AND CAPITAL COSTS

A measure of the trade-off between operating and capital cost may be useful in examining the relative impacts on the utility from inflation, technological change, and growth. A theoretical description may aid in understanding this analysis.

Let:
- Q = revenue-producing water
- E = units of labor
- C = units of capacity
- TC = total cost, \$/year
- W = wage rate
- R = unit capital cost
- a,b,c = constants

Then a production function for Q may be expressed as:

$$Q = f\ (E,C) = aE^bC^c \qquad (1)$$

and total cost as

$$TC = g(Q) = WE + RC \qquad (2)$$

Equation 1 represents a general production relation for water supply with a Cobb-Douglas form. Equation 2 relates total utilityQcost to the basic capital and labor inputs. By multiplying through by Q = 1,

with a Cobb-Douglas form. Equation 2 relates total utility cost to the basic capital and labor inputs.

By multiplying through by $\frac{Q}{Q} = 1$, equation 2 becomes:

$$TC = W\frac{E}{Q}\ Q + R\frac{C}{Q}\ Q \qquad (3)$$

$\frac{E}{Q}$ and $\frac{C}{Q}$ represent productivity relations: labor units per unit of output and capital units per unit of output, respectively. If the two components can be considered separately and all operating costs can be related to labor costs, then equation 3 may be divided into two parts:

$$TOC = W\frac{E}{Q}\,Q \qquad (4)$$

$$TCC = R\frac{C}{Q}\,Q \qquad (5)$$

where TOC = total operating cost, \$/year, and
TCC = total capital cost, \$/year.

Each of these may be estimated using the data collected on small water utilities. TOC is a function of the labor wage rate, labor productivity, and total output. TCC is a function of the price of capital, productivity of capital, and total output. However, data on the price of capital are not readily available, so a proxy relationship may be employed which combines $RC\frac{K}{Q}$ into one variable -- depreciation cost per unit of output. This gives an indication of the investment required per unit of output. As this ratio increases, either capital productivity has declined or the price of capital has increased.

The empirical estimates of equation 4 and 5, based upon the small water utility data, are:

$$TOC = 30.35\ Q^{.918}\ L^{.572}\ W^{.677} \qquad R^2 = .938 \qquad (6)$$
$$(.020)\ (.038)\ (.069)$$

$$TCC = 3.98\ Q^{.994}\ (K)^{.834} \qquad R^2 = .911 \qquad (7)$$
$$(.023)\ (.036)$$

where $K = \frac{K}{RQ}$ and $L = \frac{E}{Q}$

Almost no multicollinearity was found among the variables. The standard error for each variable is given in parentheses.

From equation 6, it can be seen that TOC increases almost linearly with respect to increases in Q if productivity and labor cost remain constant. Data from the previous section indicate that labor cost (total payroll) has risen faster (147%) than productivity (16%), but the increase in productivity has tended to hold down the rise in operating costs since labor cost per million gallons rose 100%.

The first partial derivatives of equation 6 with respect to each independent variable are:

$$\frac{\partial TOC}{\partial Q} = 27.86\ Q^{-.082}\ L^{.572}\ W^{.677} > 0 \quad (8)$$

$$\frac{\partial TOC}{\partial L} = 17.36\ Q^{.918}\ L^{-.428}\ W^{.677} > 0 \quad (9)$$

$$\frac{\partial TOC}{\partial W} = 20.55\ Q^{.918}\ L^{.572}\ W^{-.323} > 0 \quad (10)$$

All are positive, indicating that costs increase as each variable rises. These equations indicate the effect on cost of a change in revenue-producing water, labor units per unit of water (man-hours/million gallons), or the wage rate. By taking the total differential of equation 6, information on the trade-off cost elasticities among Q, L, and W can be obtained. The total differential of 6 yields:

$$dTOC = 27.86\ Q^{-.082}\ L^{.572}\ W^{.677}\ dQ \quad (11)$$

$$+ 17.36\ Q^{.918}\ L^{-.428}\ W^{.677}\ dL$$

$$+ 20.55\ Q^{.918}\ L^{.572}\ W^{-.323}\ dW$$

Setting dTOC and dQ = 0 gives:

$$0 = 17.38\ Q^{.918}\ L^{-.428}\ W^{.677}\ dL + 20.55\ Q^{.918}\ L^{.572}\ W^{-.323}\ dW \quad (12)$$

Solving for $\frac{dL}{dW}$ creates:

$$\frac{dL}{dW} = -\frac{20.55\ Q^{.918}\ L^{.572}\ W^{-.323}}{17.36\ Q^{.918}\ L^{-.428}\ W^{.677}} \quad (13)$$

or $$\frac{dL}{dW} = -1.18\frac{L}{W}$$

This can be converted to a cost elasticity between L and W (ε_{LW}) by multiplying by $\frac{W}{L}$.

Therefore:

$$\varepsilon_{LW} = \frac{dL}{dW} \cdot \frac{W}{L} = -1.18 \quad (14)$$

This indicates that within a neighborhood of the mean of the data, a 1% increase in the wage rate must be accompanied by a 1.18% decrease in the number of man-hours necessary per million gallons in order to keep total operating cost constant. This number represents the trade-off elasticity between labor productivity and the wage rate.

Similar relationships can be developed for the other variables using the total differential equation 11. These are presented in Table 17.

Table 17. SUBSTITUTION ELASTICITIES AMONG W, L, AND Q

X \ Y	W	ε_{YX} L	Q
W	-	- 1.18	- .74
L	- .85	-	- .62
Q	- 1.36	- 1.60	-

These rates do not reflect trade-offs from large changes in a variable. Obviously, a 100% increase in W will not bring a 118% decrease in productivity. Some threshold level for minimum labor usage must prevail. There are levels below which each variable will not fall because a minimum amount is required to continue production. For example, if (L_1, W_1) and (L_2, W_2) represent two data points, and L_1 = 28 man-hours/million gallons, W_1 = 4.8 \$/man-hour, and W_2 = 5.28 \$/man-hour (10% increase), then the value of L_2 can be estimated using the - 1.18 elasticity. Thus, L_2 = 24.7, 11.8% below L_1. However, if W_2 increased 100% to \$9.6/man-hour, L_2 cannot decline to a negative value. Rather, a different approach might be employed to account for the decline in the trade-off elasticity as one approaches the threshold value of the variable.

Instead of taking the total differential of equation 6, use a logarithmic transformation:

$$\ln TOC = 3.413 + .918 \ln Q + .572 \ln L + .677 \ln W \qquad (15)$$

The total differential of 15 yields:

$$d \ln TOC = .918 \, d \ln Q + .572 \, d \ln L + .677 \, d \ln W \qquad (16)$$

setting $d \ln TOC = 0$ and $d \ln Q = 0$

$$\frac{d \ln L}{d \ln W} = - 1.18 \qquad (17)$$

which generates the same cost elasticity as before.

Let $Y_2 = \ln L_2$, $Y_1 = \ln L_1$, $X_2 = \ln W_2$ and $X_1 = \ln W_1$:

$$\frac{Y_2 - X_1}{X_2 - X_1} = \frac{d \ln L}{d \ln W} = - 1.18 \qquad (18)$$

or

$$Y_2 - Y_1 = (X_2 - X_1)(- 1.18) \qquad (19)$$

Restructured and converting out of logarithms:

$$L_2/L_1 = (W_2/W_1)^{- 1.18} \qquad (20)$$

or

$$L_2 - L_1 (W_2/W_1)^{- 1.18} = L_1 (\frac{W_1}{W_2})^{1.18} \qquad (21)$$

Therefore, with a 100% increase in W from \$4.8/man-hour to \$9.6/man-hour,

$$L_2 = 28 (\frac{4.8}{9.6})^{1.18} = 12.36 \frac{\text{man-hours}}{\text{million gallons}}$$

Man-hours/million gallons dropped more than 50%, but not the 118%. Extrapolation to large changes are not applicable with a point estimate of elasticity. Elasticity changes as one variable is traded off for the other. A similar approach is applicable for the other variables in equation 6.

From equation 7, the trade-off elasticities between the depreciation expense per unit and total output can be identified. The total differential of equation 7 is

$$dTCC = 3.96 Q^{-.006} K^{.834} dQ + 3.32 Q^{.994} K^{-.166} dK \qquad (22)$$

Setting dTCC = 0 and solving for $\frac{dK}{dQ}$ yields:

$$\frac{dK}{dQ} = - \frac{3.96 Q^{-.006} K^{.834}}{3.32 Q^{.994} K^{-.166}} = - 1.19 \frac{K}{Q} \qquad (23)$$

Multiplying by Q/K provides the cost elasticity ε_{KQ}:

$$\frac{dK}{dQ} \frac{Q}{K} = -1.19 \tag{24}$$

This provides a cost elasticity between K and Q which indicates that a 1% increase in Q must coincide with a 1.19% decline in depreciation expenditure per unit to keep TCC constant. Existence of scale economies provides one answer to the question of feasibility of a utility to accomplish this as Q rises. Table 18 shows the substitution rates among the variables.

Table 18. SUBSTITUTION ELASTICITIES AMONG K AND Q

Y / X	ε_{YX} K	Q
K	-	- .84
Q	- 1.19	-

The relationship of interest and depreciation can also be estimated:

$$I = .036\, D^{1.248} \qquad R^2 = .332 \tag{25}$$
$$(.577)$$

where I = interest expense per year, and
D = depreciation expense per year

To obtain a relationship for total cost, equations 6 and 7 must be combined:

$$TC = 30.35\, Q^{.918} L^{.572} W^{.677} + 3.98\, K^{.834} Q^{.994} \tag{26}$$

Taking the total differential yields:

$$dTC = 27.86\, Q^{-.082} L^{.572} W^{.677} \tag{27}$$

$$+ 17.36\, Q^{.918} L^{-.428} W^{.677}\, dL + 20.55\, Q^{.918} L^{.572} W^{-.323} dW$$

$$+ 3.32\, K^{-.166} Q^{.994}\, dK + 3.96\, K^{.834} Q^{-.006}\, dQ$$

Combining terms yields:

$$dTC = [27.86\ Q^{-.082}\ L^{.572}\ W^{.677} + 3.96\ K^{.834}\ Q^{-.006}]\ dQ$$

$$+ 17.36\ Q^{.918}\ L^{-.428}\ W^{.677}\ dL + 20.55\ Q^{.918}\ L^{.572}\ W^{-.323}\ dW$$

$$+ 3.32\ K^{-.166}\ Q^{.994}\ dK$$

Setting dTC, dQ, and dL = 0:

$$0 = 20.55\ Q^{.918}\ L^{.572}\ W^{-.323}\ dW + 3.32\ K^{-.166}\ Q^{+.994}\ dK \quad (28)$$

$$\frac{dK}{dW} = -\frac{20.55\ Q^{.918}\ L^{.572}\ W^{-.323}}{3.32\ K^{-.166}\ Q^{.994}} \quad (29)$$

Then, e_{KW} is:

$$\frac{dK}{dW} \cdot \frac{W}{K} = -\frac{20.55\ Q^{-.076}\ L^{.572}\ W^{.677}}{3.32\ K^{.834}} \quad (30)$$

This expression may be evaluated for each utility given an initial set of values for Q, L, W, and K. For example, if K = $84/mil gal, L = 58 man-hours/mil gal, W = $4.30/man-hour, and Q = 735 mil gal/year (average of small utility data for latest year), then

Table 19. SUBSTITUTION ELASTICITIES AMONG L, K, W, and Q

	ε_{YX}			
x \ y	L	K	W	Q
L	-	LK	-.85	LQ
K	KL	-	KW	KQ
W	- 1.18	WK	-	WQ
Q	QL	QK	QW	-

$$LK = \left(- \frac{17.36\ Q^{-.076}\ L^{.572}\ W^{.677}}{3.32\ K^{.834}} \right)$$

$$KL = - \frac{3.32\ K^{.834}}{17.36\ Q^{-.076}\ L^{.572}\ W^{.677}}$$

$$KW = \left(- \frac{3.32\ K^{.834}}{20.55\ Q^{-.076}\ L^{.572}\ W^{.677}} \right)$$

$$QL = \left(- 1.60 - \frac{3.96\ K^{.834}\ Q^{.994}}{17.36\ Q^{.918}\ L^{.572}\ W^{.677}} \right)$$

$$WK = \left(- \frac{20.55\ Q^{-.076}\ L^{.572}\ W^{.677}}{3.32\ K^{.834}} \right)$$

$$QK = \left(- 1.19 - \frac{27.86\ Q^{.918}\ L^{.572}\ W^{.677}}{3.32\ K^{.834}\ Q^{.994}} \right)$$

$$QW = \left(- 1.36 - \frac{3.96\ K^{.834}\ Q^{.994}}{20.55\ Q^{.918}\ L^{.572}\ W^{.677}} \right)$$

$$LQ = \left(- \frac{17.36\ Q^{.918}\ L^{.572}\ W^{.677}}{27.86\ Q^{.918}\ L^{.572}\ W^{.677} + 3.96\ K^{.834}\ Q^{.994}} \right)$$

$$KQ = \left(- \frac{3.32\ K^{.834}\ Q^{.994}}{27.86\ Q^{.918}\ L^{.572}\ W^{.677} + 3.96\ K^{.834}\ Q^{.994}} \right)$$

$$WQ = \left(- \frac{20.55\ Q^{.918}\ L^{.572}\ W^{.677}}{27.86\ Q^{.918}\ L^{.572}\ W^{.677} + 3.96\ K^{.834}\ Q^{.994}} \right)$$

Table 20. RELATIONSHIP BETWEEN ANNUAL COST AND REVENUE-PRODUCING WATER

	a	$TC = aQ^b$ b	R^2
Support Services	86.080	.914 (.091)	.351
Acquisition	314.435	.662 (.137)	.111
Treatment	1.761	1.326 (.163)	.261
Distribution	695.277	.806 (.042)	.660
Total	2143.401	.795 (.026)	.838

Values in parentheses are standard errors.

$$\varepsilon_{KW} = -\frac{340.81}{133.66} = -2.55 \quad (31)$$

Therefore, if the wage rate rises, then depreciation expense per million gallons must decrease in order to keep total cost constant. Table 19 provides the elasticity formulas for substitution among L, K, W, and Q. The $\varepsilon_{KL} = -2.15$ using the same set of values for K, L, W, and Q as before. Therefore, if man-hours per million gallons increases (labor productivity declines), then depreciation expense per million gallons must decrease (capital productivity increases) in order to keep total cost constant.

PRODUCTION COMPONENTS

The major water supply production components are support services, acquisition, treatment, and distribution. Each are important in the cost framework of a water utility. In this section, the total cost of each production component is related to revenue-producing water and selected subelements, such as chemical and power cost.

Using all the small water utility cost data inflated to 1975 by the CPI, the functional form

$$TC = aQ^b \quad (32)$$

can be estimated for each component as well as total cost. TC is total cost and Q is revenue-producing water. Table 20 summarizes the results. In general, the results are not extremely good except for distribution and total costs. Separate estimates by component and total for O&M and for capital costs were produced. However, no significant relationships were found. This may occur because distribution costs represent the major cost component while the other cost components are less significant in magnitude. Table 21 provides a breakdown of the percent of utility costs by component. It is obvious that distribution costs play a significant role in the cost structure of these small utilities.

Chemical cost and power cost are two other easily identifiable cost elements. Each may be related to quantity and selected dummy variables.

Table 21. PERCENT OF UTILITY COSTS BY COMPONENT

	Support Services	Acquisition	Treatment	Distribution
Operating Cost	33	19	15	33
Capital Cost	8	8	16	68
Total Cost	24	15	16	45

CHEMICAL COST

Chemical cost represents a significant portion of O&M treatment costs. The level of expenditure on chemicals is affected by the quantity and quality of the raw water; however, a slightly different approach is used here for small water utilities. This is necessary because some small utilities with lower water quality may not subject the raw water to substantial chemical treatment. As a result, the relationships presented here denote the differences among utilities on the basis of treatment techniques employed.

Let: X_1 = dummy variable
- 1 = utility has no treatment of raw water
- 0 = utility treats raw water

X_2 = dummy variable
- 1 = utility uses more than just chlorination to treat raw water
- 0 = utility either does not treat or only chlorinates raw water

Q = revenue-producing water, MG/yr

CC = total annual chemical costs

The following relations were found (t value in parentheses) using pooled cross-sectional and time-series data.

$$CC_1 = .121\ Q^{.848}\ 210.234^{X_1} \qquad R^2 = .679 \qquad (33)$$
$$(8.480) \quad (12.995)$$

$$CC_2 = 1.915\ Q^{.864}\ 20.730^{X_2} \qquad R = .543 \qquad (34)$$
$$(7.200) \quad (8.987)$$

Therefore, if $X_1 = 1$, $CC_1 = 25.44\ Q^{.848}$;

and if $X_1 = 0$, $CC_1 = .121\ Q^{.848}$.

Also, if $X_2 = 1$, $CC_2 = 39.70\ Q^{.864}$

and if $X_2 = 0$, $CC_2 = 1.915Q^{.864}$

From these equations, it is possible to examine the costs for four situations: no treatment, treatment with chlorination only, treatment with more than just chlorination, and treatment with chlorination and other processes.

POWER

Power costs also represent a major factor in water utilities. Energy expenditures depend not only on the quantity produced, but the net altitude to which water must be transported.

Let:
- H = dummy variable
- 1 = net altitude is greater than 150 feet
- 0 = net altitude is less than or equal to 150 feet
- Q = revenue-producing water, MG/yr
- PC = power cost per year

The following relation was found (t - value in parentheses) using pooled cross-sectional and time-series data.

$$PC = 62.978\ Q^{.675}\ 5.406^{H} \qquad R^2 = .234 \qquad (35)$$
$$(1.713) \quad (4.288)$$

Thus, if $H = 1$, $PC = 340.459\ Q^{.675}$

and if $H = 0$, $PC = 62.978\ Q^{.675}$

This identifies the difference between high and low altitude service areas.

Equations 33 - 35 enable the researcher to mix chemical and power situations to evaluate the comparative costs.

SPATIAL AND DEMOGRAPHIC COSTS

In addition to the effect on cost of altitude, the area served by the utility as well as the density of use can significantly impact transmission and distribution costs. The larger the area served, the greater an investment in pipelines and pumping stations is required.

The following relation between total unit costs of distribution and output and area was found (standard error in parentheses) using pooled cross-sectional and times-series data.

$$UC = 716.598\, \underset{(.127)}{Q^{-.238}}\ \underset{(.130)}{A^{.319}} \qquad R^2 = .362 \qquad (36)$$

Where UC = total unit costs of distribution, \$/mil gal;
Q = revenue-producing water, mil gal;
A = service area in square miles.

From equation 36, it is easy to see that unit costs will rise as area served increases. This has tremendous implication for the issue of regionalization of small utilities. The trade-off between increased Q which tends to lower unit costs and increased area served which tends to raise unit costs will affect the extent to which utilities can regionalize. These countervailing effects must be evaluated on a case by case basis to determine the cost effective area for a utility.

Density of use also impacts distribution costs. As density of use rises, costs will rise, but not as fast as the case when service area expanded.

Let: C = total distribution cost, \$/yr;
Q = revenue-producing water, mil gal; and
P_d = population density, people/sq mi.

Then:

$$C = 240.874\, \underset{(.043)}{Q^{.906}}\ \underset{(.026)}{P_d^{\,.076}} \qquad R^2 = .770 \qquad (37)$$

This relation indicates that total distribution costs tend to rise as density of use increases, but this is offset by the scale economies gained as total output rises.

TIME AND OPERATION, MAINTENANCE, AND CAPITAL COSTS

The implication from much of this analysis indicates that operating and maintenance costs have increased more rapidly over time than capital costs. Part of the explanation for this phenomenon is the stability of capital expenditures over time. This stability occurs because most capital expenditures are determined in a prior year when the plant was constructed, but the costs are distributed over future years in the form of depreciation and interest. As a result, with the current inflationary trend, a lag in the impact of rising capital costs will occur depending upon the frequency of plant replacement and expansion.

To understand the current trend, two relationships have been established.

Let: OC = total annual operating cost, \$/yr;
CC = total capital cost, \$/yr;
Q = revenue-producing water, mil gal; and
T = time in calendar years.
(Values in parentheses are standard errors.)

Then,

$$OC = e^{-134.602} \underset{(.026)}{Q^{.807}} \underset{(.012)}{e^{.072T}} \qquad R^2 = .850 \qquad (38)$$

$$CC = e^{-70.017} \underset{(.042)}{Q^{.786}} \underset{(.019)}{e^{.039T}} \qquad R^2 = .665 \qquad (39)$$

These equations suggest that OC is growing at a faster rate over time than CC. A clearer indication may be found by examining the ratio of OC to CC.

$$\frac{OC}{CC} = e^{-64.590} Q^{.021} e^{.033T} \qquad (40)$$

From this equation, the growth rate in operating costs to capital costs can be determined if Q remains constant over time. Increases in Q also tend to raise the ratio of OC to CC, but the impact of time on operating costs has a greater impact. Even if output did not increase, the ratio would increase 3.3% per year.

Therefore, over time current expenditures will tend to be dominated by operating and maintenance costs.

SECTION 7

ECONOMIC IMPACT OF THE SAFE DRINKING WATER ACT

In this section cost estimates will be developed for add-on technologies to be installed in a selected set of water supply utilities.[9] Finished and raw water samples were tested for each of the utilities included in the study. Tables 22, 23, and 24 contain the results of the chemical analysis for each of the utilities studied.

Data were collected for 10 years on four major operating-maintenance (O&M) components, three other significant O&M elements, and the capital costs associated with depreciation and interest for each of the 23 utilities. The O&M cost components are acquisition, treatment, support services, and distribution. Chemicals, payroll, and power are three elements contained in the other four components, but are considered separately because of their individual impacts on operating expenditures. Depreciation expense for each major cost component was also obtained in order to examine the relative capital intensiveness of the system.

Revenue-producing water is used as the basis for all calculations since it represents the means by which utilities obtain their operating revenue. It provides a comparative basis between utilities, but may be easily converted to total treated water. A complete inorganic profile was developed and a comparative analysis of treatment removal efficiencies was made for each system. In some cases the existing treatment plant was failing to adequately remove constituents from the raw water causing the utility to fail to meet the Safe Drinking Water Act MCL's. After examining the complete spectrum of chemical determinations for the raw and finished samples from each utility, a decision was made as to whether or not a treatment train should be hypothesized so that finished water quality would meet existing MCL's. Cost estimates were made for the proposed treatment train at each affected utility. For example, in Region III one utility was identified as having a nitrate removal problem. After examining data from the raw and finished samples, a hypothetical ion exchange system was assumed. Table 25 summarizes the cost calculations for an ion exchange unit to solve the utility's nitrate removal problems.

In a similar manner, cost estimates were developed for add-on technologies in the other utilities identified as having problems. Table 26 shows utility designation, the region, the quality problem for each impaced utility, and the types of treatment hypothesized for solution. Six utilities in all

Table 22. Results from Raw and Finished Samples - Reg. III

Sample Type	Utility	Serial No.	Date Coll.	Turbidity	Color	Total Dissolved Solids	Chloride	Sulfate	Nitrate	Barium	Arsenic	Selenium	Fluoride
Raw	A	40727	3/29/77	.32	3.0	229.0	10.0	20.0	4.0	.57	.005	.005	.1
Finished	A	40726	3/29/77	.12	3.0	89.0	10.0	15.0	1.0	.2	.005	.005	.2
Raw	B	3663	4/05/77	98.0	12.0	64.0	10.0	15.0	4.0	.2	.04	.012	.1
Finished	B	40758	4/05/77	.12	2.0	126.0	15.0	32.0	8.0	.2	.005	.005	.1
Finished	C	40721	4/05/77	.11	3.0	209.0	20.0	25.0	50.0	.2	.005	.005	.1
Finished	D	40722	4/05/77	.23	2.0	258.0	19.0	40.0	6.0	.3	.01	.005	.1
Raw	E	35492	3/31/77	4.5	5.0	40.0	10.0	15.0	2.0	.2	.005	.005	1.0
Finished	E	40729	3/31/77	.35	3.0	100.0	10.0	22.0	2.0	.2	.005	.005	1.0

Table 22. Results from Raw and Finished Samples - Reg. III (Cont.)

Sample Type	Utility	Serial No.	Date Coll.	Specific Conductance	pH	Chromium	Silver	Copper	Manganese	Lead	Iron	Cadmium	Zinc	Mercury
Raw	A	40727	3/29/77	354.0	7.8	< .005	< .03	.20	< .03	< .005	< .1	< .002	.03	< .0005
Finished	A	40726	3/29/77	152.0	7.55	< .005	< .03	.03	< .03	.005	< .1	< .002	.02	< .0005
Raw	B	3663	4/05/77	82.0	6.8	< .005	< .03	< .02	.27	.008	5.0	< .002	< .02	< .0005
Finished	B	40758	4/05/77	202.0	7.15	< .005	< .03	< .02	< .03	< .005	< .1	< .002	.03	< .0005
Finished	C	40721	4/05/77	327.0	8.05	< .005	< .03	< .02	< .03	< .005	< .1	< .002	.02	< .0005
Finished	D	40722	4/05/77	402.0	7.8	< .005	< .03	.08	< .03	< .005	< .1	< .002	< .02	.0005
Raw	E	35492	3/31/77	61.0	6.65	< .005	< .03	< .02	.10	< .005	.43	< .002	< .02	< .0005
Finished	E	40729	3/31/77	168.0	7.85	< .005	< .03	< .02	< .03	< .005	< .1	< .002	.02	< .0005

Table 23. Results from Raw and Finished Samples - Reg. V

Sample Type	Utility	Serial No.	Date Coll.	Turbidity	Color	Total Dissolved Solids	Chloride	Sulfate	Nitrate	Barium	Arsenic	Selenium	Fluoride
Raw	A	35474	2/18/77	4.0	70.0	226.0	27.0	37.0	8.0	< 0.2	0.005	< 0.005	0.3
Finished	A	35475	2/18/77	3.2	35.0	250.0	32.0	49.0	8.0	< 0.2	0.005	< 0.005	0.2
Raw	B	35484	2/18/77	21.0	6.0	504.0	39.0	104.0	< 1.0	0.21	< 0.005	< 0.005	0.4
Finished	B	35473	2/18/77	0.3	5.0	561.0	41.0	108.0	< 1.0	< 0.2	< 0.005	< 0.005	0.4
Raw	C	26463	2/14/77	0.4	4.0	555.0	65.0	45.0	< 1.0	< 0.2	< 0.005	< 0.005	4.0
Finished	C	26464	2/14/77	1.6	3.0	223.0	100.0	36.0	< 1.0	0.2	0.006	< 0.005	5.0
Raw	D	26452	2/14/77	1.0	6.0	1080.0	< 10.0	580.0	< 1.0	< 0.2	0.009	0.01	0.8
Finished	D	26471	2/14/77	1.5	6.0	1066.0	< 10.0	580.0	< 1.0	< 0.2	0.009	0.0125	0.8
Raw	E	25306	2/14/77	1.0	6.0	297.0	< 10.0	< 10.0	< 1.0	8.1	< 0.005	< 0.005	0.8
Finished	E	26470	2/14/77	1.0	3.0	297.0	< 10.0	< 10.0	< 1.0	7.8	< 0.005	< 0.005	0.8
Raw	F	25308	2/14/77	0.5	4.0	303.0	< 10.0	< 10.0	< 1.0	6.1	< 0.005	< 0.005	0.7
Finished	F	15307	2/14/77	0.12	3.0	310.0	< 10.0	< 10.0	< 1.0	7.6	< 0.005	< 0.005	1.3
Raw	G	25310	2/14/77	0.8	6.0	301.0	< 10.0	< 10.0	< 1.0	2.0	< 0.005	< 0.005	0.6
Finished	G	25309	2/14/77	0.26	3.0	305.0	< 10.0	< 10.0	< 1.0	2.1	< 0.005	< 0.005	1.3

Table 23. Results from Raw and Finished Samples - Reg. V (Cont.)

Sample Type	Utility	Serial No.	Date Coll.	Specific Conduc-tance	pH	Chromium	Silver	Copper	Manganese	Lead	Iron	Cadmium	Zinc	Mercury
Raw	A	35474	2/18/77	340.0	7.45	< 0.005	< 0.03	< 0.002	0.05	< 0.005	0.96	< 0.002	< 0.02	< 0.0005
Finished	A	35475	2/18/77	338.0	9.35	< 0.005	< 0.03	< 0.02	0.04	< 0.005	0.69	< 0.002	< 0.02	< 0.0005
Raw	B	35484	2/18/77	865.0	7.2	< 0.005	< 0.03	< 0.02	0.16	< 0.005	0.30	< 0.002	< 0.02	0.0005
Finished	B	35473	2/18/77	860.0	7.45	< 0.005	< 0.03	< 0.02	0.11	< 0.005	< 0.1	< 0.002	< 0.02	< 0.0005
Raw	C	26463	2/14/77	880.0	7.7	< 0.005	< 0.03	< 0.03	< 0.03	0.005	0.42	< 0.002	0.12	< 0.0005
Finished	C	26464	2/14/77	1020.0	7.45	< 0.005	< 0.03	0.03	< 0.03	0.005	< 0.1	< 0.002	0.02	< 0.0005
Raw	D	26452	2/14/77	1306.0	7.65	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	0.17	< 0.002	< 0.02	< 0.0005
Finished	D	26471	2/14/77	1306.0	7.4	< 0.005	< 0.03	0.04	< 0.03	< 0.005	0.14	< 0.002	0.03	< 0.0005
Raw	E	25306	2/14/77	510.0	7.55	< 0.005	< 0.03	< 0.02	< 0.03	0.023	0.21	< 0.002	0.02	< 0.0005
Finished	E	26470	2/14/77	510.0	7.55	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	0.1	< 0.002	< 0.02	< 0.0005
Raw	F	25308	2/14/77	536.0	7.5	< 0.005	< 0.03	< 0.02	< 0.03	0.055	0.11	< 0.002	0.04	< 0.0005
Finished	F	15307	2/14/77	534.0	7.75	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	< 0.1	< 0.002	0.02	< 0.0005
Raw	G	25310	2/14/77	560.0	7.5	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	0.1	< 0.002	< 0.02	< 0.0005
Finished	G	25309	2/14/77	556.0	7.8	< 0.005	< 0.03	0.03	< 0.03	0.10	0.11	< 0.002	0.02	< 0.0005

Table 24. Results from Raw and Finished Samples - Reg. VI

Sample Type	Utility	Serial No.	Date Coll.	Turbidity	Color	Total Dissolved Solids	Chloride	Sulfate	Nitrate	Barium	Arsenic	Selenium	Fluoride
Raw	A	18060	1/3/77	0.12	3.0	410.0	24.0	26.0	30.0	0.23	0.005	0.005	0.6
Finished	A	18061	1/3/77	0.13	2.0	379.00	22.0	22.0	23.0	< 0.2	0.005	--	0.6
Raw	B	18062	1/2/77	0.25	3.0	1325.0	260.0	315.0	1.0	0.2	< 0.005	0.012	4.3
Finished	B	18063	1/3/77	0.45	2.0	1360.0	270.0	330.0	< 1.0	< 0.2	< 0.005	0.01	4.3
Raw	C	18064	2/77	0.28	5.0	213.0	24.0	23.0	< 1.0	< 0.2	< 0.005	< 0.005	0.2
Finished	C	18065	2/77	1.2	4.0	209.0	25.0	20.0	1.0	< 0.2	< 0.005	< 0.005	0.3
Raw	D	18068	2/22/77	1.1	8.0	220.0	28.0	33.0	< 1.0	< 0.2	< 0.005	< 0.005	0.4
Finished	D	18069	2/22/77	1.8	6.0	229.0	29.0	35.0	< 1.0	< 0.2	< 0.005	< 0.005	1.0
Raw	E	18070	2/25/77	0.22	5.0	963.0	290.0	91.0	< 1.0	< 0.2	< 0.005	< 0.005	0.8
Finished	E	18071	2/25/77	0.22	2.0	970.0	270.0	91.0	< 1.0	< 0.2	< 0.005	< 0.005	0.9
Raw	F	Buys treated water from Dallas.											
Finished	F	18073	2/25/77	6.0	4.0	228.0	27.0	92.0	2.0	< 0.2	< 0.005	< 0.005	0.9
Raw	G	Buys treated water from Dallas.											
Finished	G	18075	2/25/77	0.17	3.0	115.0	12.0	28.0	< 1.0	< 0.2	0.005	< 0.005	0.8

Table 24. Results from Raw and Finished Samples - Reg. VI (Cont.)

Sample Type	Utility	Serial No.	Date Coll.	Specific Conductance	pH	Chromium	Silver	Copper	Manganese	Lead	Iron	Cadmium	Zinc	Mercury
Raw	A	18060	1/3/77	700.0	7.25	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	< 0.1	< 0.002	< 0.02	< 0.0005
Finished	A	18061	1/3/77	636.0	7.5	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	< 0.1	< 0.002	< 0.02	< 0.0005
Raw	B	18062	1/2/77	2150.0	8.2	0.012	< 0.03	< 0.02	< 0.03	0.015	< 0.1	< 0.002	0.05	< 0.0005
Finished	B	18063	1/3/77	2150.0	8.0	0.016	< 0.03	< 0.02	< 0.03	0.018	0.14	< 0.002	< 0.02	< 0.0005
Raw	C	18064	2/77	374.0	7.65	< 0.005	< 0.03	< 0.02	< 0.03	0.005	< 0.1	< 0.002	< 0.02	< 0.0005
Finished	C	18065	2/77	374.0	7.75	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	< 0.1	< 0.002	< 0.02	< 0.00085
Raw	D	18068	2/22/77	374.0	7.55	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	0.16	< 0.002	0.03	< 0.0005
Finished	D	18069	2/22/77	394.0	7.95	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	0.16	< 0.002	< 0.02	< 0.0005
Raw	E	18070	2/25/77	1667.0	8.4	< 0.005	< 0.03	< 0.02	< 0.03	0.018	< 0.1	< 0.002	< 0.02	< 0.0005
Finished	E	18071	2/25/77	1648.0	8.4	0.005	< 0.03	< 0.02	< 0.03	0.020	< 0.1	< 0.002	< 0.02	< 0.0005
Raw	F			Buys treated water from Dallas.										
Finished	F	18073	2/25/77	347.0	9.6	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	0.45	< 0.002	0.18	< 0.0005
Raw	G			Buys treated water from Dallas.										
Finished	G	18075	2/25/77	195.0	8.15	< 0.005	< 0.03	< 0.02	< 0.03	< 0.005	< 0.1	< 0.002	< 0.02	< 0.0005

Table 25. COST ESTIMATES FOR NITRATE REMOVAL BY ION EXCHANGE

Item	Quantity	
Flow Treated (MGD)	0.11	
Capital Cost		
Construction Cost ($)	74,909	
Site Work ($)	3,745	
Engineering ($)	8,809	
Land ($)	0	
Legal, Fiscal, Administration ($)	3,823	
Int. during Construction ($)	1,131	
Total	101,858	
Amortized Capital - 7%, 20 yr ($/yr)		9,615
Operating & Maintenance Cost		
Building & Process Energy @ 3¢/kw-hr ($/yr)	465	
Maintenance Material ($/yr)	2,798	
Labor @ 10$/hr ($/yr)	11,010	
Chemicals* ($/yr)	6,801	
Total Annual O&M Cost		21,774
Total Annual Cost		30,689

* Regenerant @ $28.00/ton

were identified as having water quality problems. For five of the six utilities, two types of treatment were considered. As mentioned earlier, Utility III-C represents a problem in nitrate removal, because the finished water nitrate level is very close to the allowable maximum contaminant level (MCL). The solid lines in Figure 98 depict the historical unit costs for Utility III-C. The dotted line represents the unit costs for the latest year including add-on technology. As can be seen, total unit cost to the consumer will increase by 194%. Costs are summarized in Table 27.

In Region V, water utilities V-B, V-E, V-F, and V-G were selected as representatives of problems that could be corrected by additional treatment facilities. Utility V-B, as can be seen, is experiencing manganese problems. Chemical oxidation or ozone was assumed as a treatment technique. Utilities V-E, V-F, and V-G are experiencing problems with barium removal. For barium removal the recommended treatment is Zeolite or lime softening. Table 27 contains the cost estimates for each alternative. Figure 99 shows the increases in unit costs that might result from applying chemical oxidation to Utility V-B. Of course, in this case manganese is not one of the contaminants in the Primary Standards but is being considered as a Secondary Standards contaminant.

Utility VI-B is experiencing problems with removing total dissolved solids and fluorides from the finished water. The treatment technique recommended and presented in Table 26 is activated alumina or reverse osmosis. Figure 100 shows the impact on unit cost from the addition of activated alumina.

This cost impact analysis is hypothetical, and as can be seen from Table 27, more than one type of treatment may be applied to solve the same problem but, depending on size, the costs associated with teach technology can be very different. In figures 99 and 100 the lowest cost technologies were chosen for cost comparison. To properly select a treatment system for any utility requires many more extensive design considerations than is possible here, and should include pilot testing. This analysis does provide, however, some realistic estimates of the potential costs that a small system might incur in attempting to meet the Safe Drinking Water Act requirements. Although current interest has centered on the costs associated with applying treatment technology for the removal of trihalomethanes and synthetic organics, the cost of meeting the existing interim standards in some small utilities may be high.

The solid line in Figure 101 shows the current average unit costs for all of the utilities studied over the 10-year time span. The average unit cost for meeting the standards for all of the utilities is shown by a dotted line in year 10. For the entire sample, the cost is increased by less than 5% but, as shown by Figure 98, cost increases for some utilities may be highly significant.

Table 26. UTILITIES SELECTED FOR COST IMPACT ANALYSIS

Region	Utility	Quality Problems	Hypothesized Treatment
III	1	Nitrate	Ion exchange
V	1	Manganese	Chemical oxidation; ozone
	2	Barium	Zeolite; lime softening
	3	Barium	" "
	4	Barium	" "
VI	1	Total dissolved solids & fluorides	Activated alumina; reverse osmosis

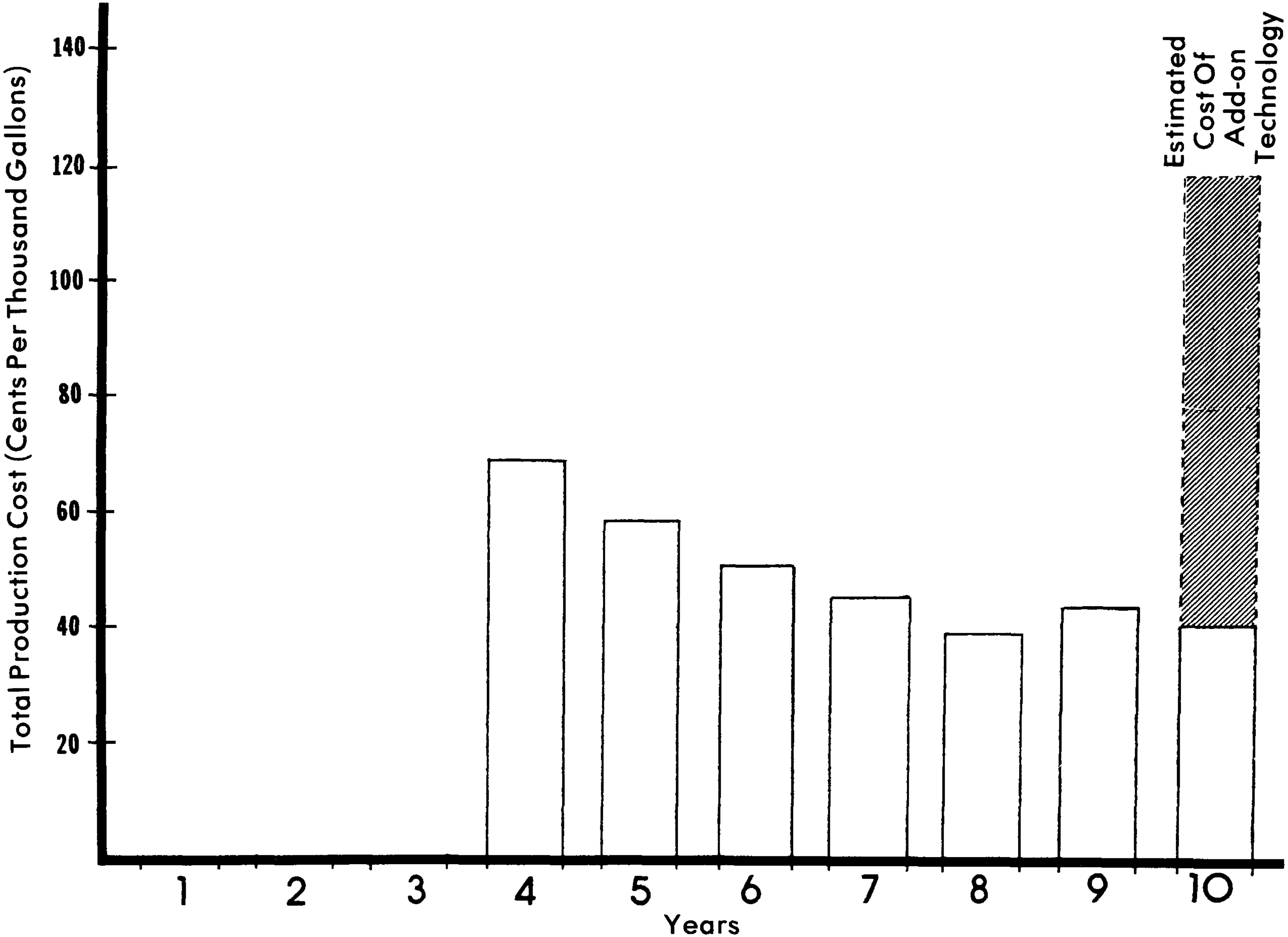

Figure 98. Unit production cost for Utility III-1 with add-on technology.
(Ion Exchange NO_3 Removal)

Table 27. ESTIMATED ECONOMIC IMPACTS FOR SMALL SYSTEMS

Item	Utility III-1	Utility V-1		Utility V-2		Utility V-3	
Water treated (MGD)	0.13	1.17		0.41		0.45	
Revenue-producing water (MGD)	0.11	0.67		0.27		0.34	
Proposed treatment technique	Ion exchange (nitrate Removal)	Chemical Oxidation	Ozonation	Ion-Exchange Softening	Lime Softening	Ion-Exchange Softening	Lime Softening
Construction cost for proposed treatment ($)	101,858	5,913	71,744	137,000	622,152	141,512	643,792
Amortized capital cost for proposed treatment ($) (7% ≥ 20 years)	9,615	559	6,773	12,934	58,727	13,358	60,769
Annual operations and maintenance cost for proposed treatment ($)	21,074	2,528	7,136	28,547	80,628	30,094	83,462
Total annual cost for proposed treatment ($)	30,689	3,087	13,909	41,481	139,355	43,452	144,231
Current annual total cost for water supply ($)	16,559	299,387	299,387	69,328	69,328	46,470	46,470
Projected annual total cost for water supply ($) (with proposed treatment)	47,248	302,474	313,296	110,809	208,683	89,922	190,701
Current unit cost for water supply (¢/1000 gal)	41.2	122.4	121.2	70.3	70.3	37.4	37.4
Projected new unit cost for water supply (with proposed treatment - ¢/1000 gal)	117.7	123.7	128.1	112.4	211.8	72.5	153.7

Table 27. ESTIMATED ECONOMIC IMPACTS FOR SMALL SYSTEMS (Cont.)

Item	Utility V-4		Utility VI-1	
Water treated (MGD)	0.066		1.08	
Revenue-producing water (MGD)	0.055		0.78	
Proposed treatment technique	Ion-exchange Softening	Lime Softening	Activated Alumina	Reverse Osmosis
Construction cost for proposed treatment ($)	86,518	368,816	180,722	1,129,902
Amortized capital cost for proposed treatment ($) (7% @ 20 years)	8,167	34,814	17,057	106,655
Annual operations and maintenance cost for proposed treatment ($)	12,612	49,170	24,937	204,412
Total annual cost for proposed treatment ($)	20,779	83,984	41,994	311,065
Current annual total cost for water supply ($)	13,078	13,078	231,006	231,006
Projected annual total cost for water supply ($) (with proposed treatment)	33,857	97,062	273,000	542,073
Current unit cost for water supply (¢/1000 gal)	65.1	65.1	81.1	81.1
Projected new unit cost for water supply (with proposed treatment - ¢/1000 gal)	168.7	483.5	95.9	190.4

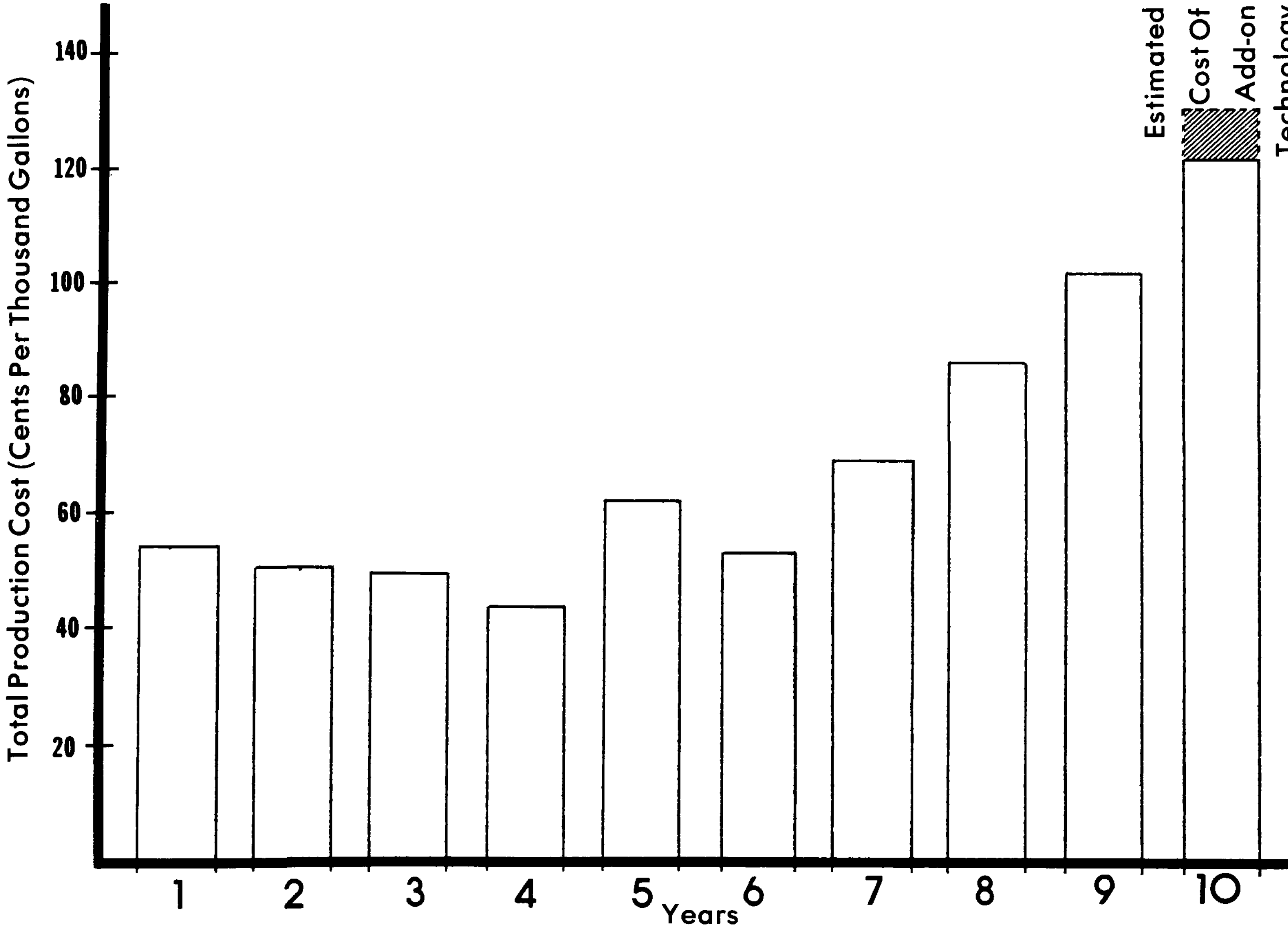

Figure 99. Unit production cost for Utility V-1 with add-on technology.
(Chemical Oxidation)

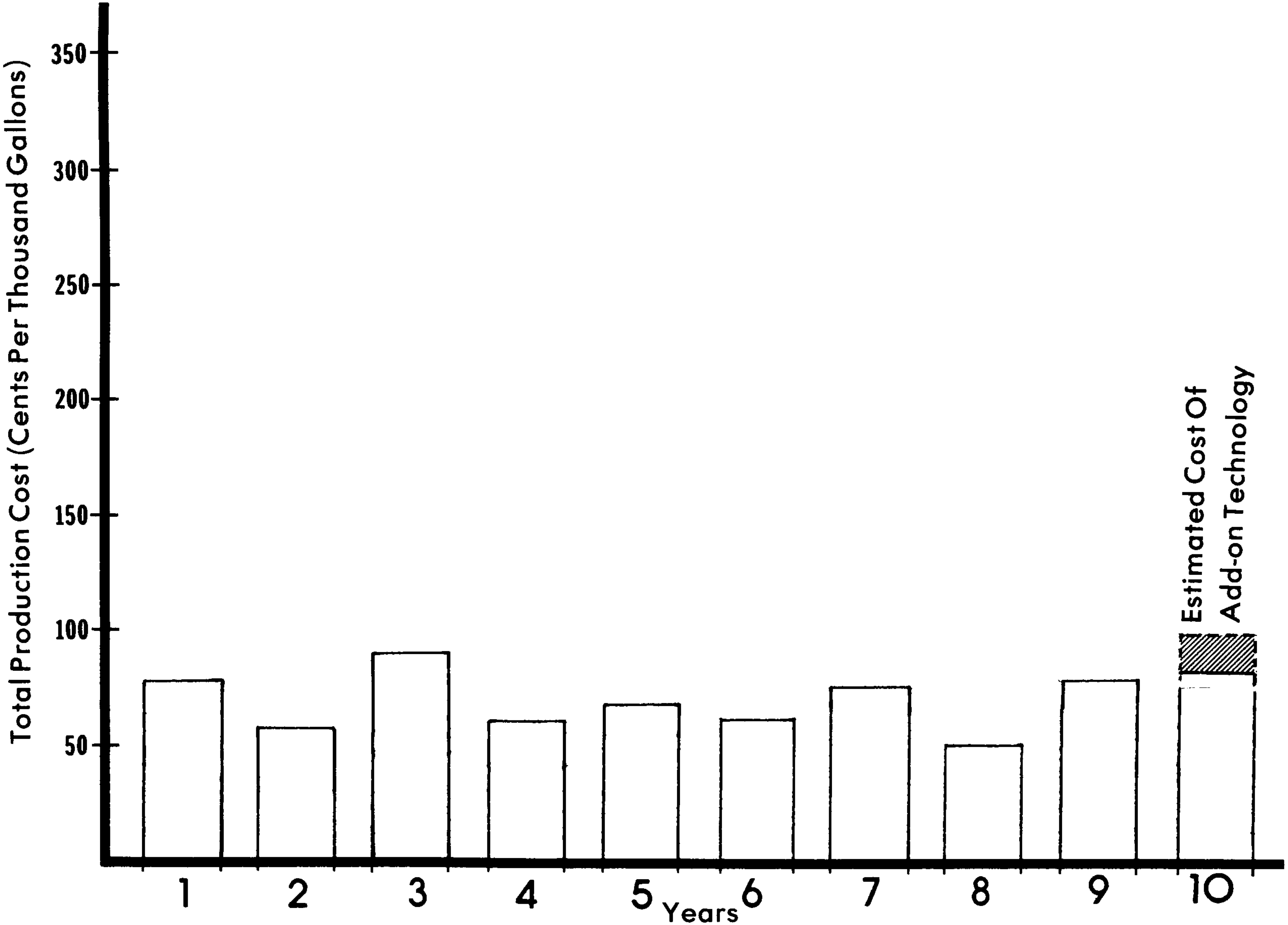

Figure 100. Unit production cost for Utility VI-1 with add-on technology. (Activated Alumina)

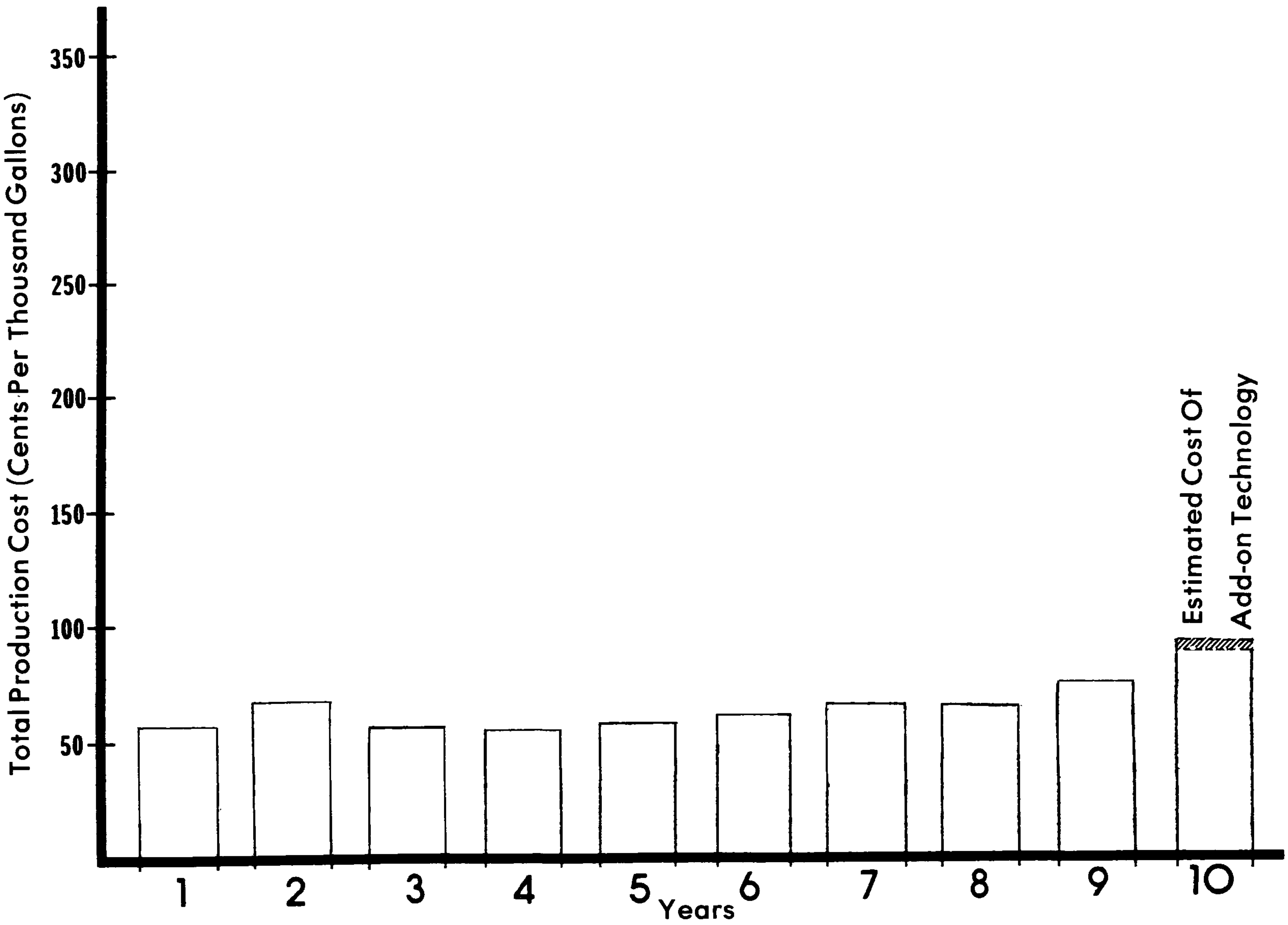

Figure 101. Average production cost for all utilities with estimated cost of add-on technology.

The above analysis is intended to put the small system problem into perspective. There are many more small than large systems in the U. S. Identifying those systems in and out of compliance will be a difficult task. Once the systems are identified and their particular problems categorized, a technological or management solution may be found.

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APENDIX

COST EQUATIONS

Table A-1. ANNUAL OPERATING COST VERSUS TIME

Utility Name	$C = b + mt$			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Algonquin, Ill.	- 8719655.364	4446.327 (327.107)	.959	$e^{-241.956}$	.128 (.011)	.946
Audubon Water Co. Norristown, Pa.	- 16626677.139	8459.448 (666.431)	.953	$e^{-436.780}$	.227 (.014)	.972
Batavia, OH	- 5021244.905	2565.486 (815.193)	.712	$e^{-116.979}$	.065 (.019)	.745
Bell Co. WCID 1 Killeen, TX	- 52422112.364	26793.309 (5639.643)	.738	$e^{-121.760}$	.068 (.014)	.741
Belton, TX	N.S.	N.S.		$e^{-260.717}$	.138 (.064)	.539
Burlington, Ill.	- 1144431.624	583.861 (150.422)	.653	$e^{-162.004}$	.087 (.023)	.634
Cockrell Hill, TX	N.S.	N.S.		N.S.	N.S.	
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 27157369.188	13821.770 (2282.783)	.821	$e^{-322.323}$	.169 (.018)	.914
Dallas Co. WCID #6	- 37390330.448	19037.721 (1271.021)	.966	$e^{-312.895}$	.165 (.007)	.984

(Continued)

Table A-1. (Continued)

Utility Name		$C = b + mt$			$C = Ke^{at}$	
	b	m	R^2	K	a	R^2
Denton, TX	- 68814298.903	35130.558 (338.105)	.932	$e^{-155.837}$	.086 (.006)	.960
Downingtown, Pa.	- 31529685.933	16058.933 (1569.591)	.929	$e^{-280.828}$	.148 (.009)	.968
Georgetown, TX	- 17750982.988	9050.655 (1453.769)	.866	$e^{-183.729}$	.035 (.008)	.844
Great Valley Water Co. Malvern, Pa.	- 36927874.145	18798.764 (1944.339)	.921	$e^{-316.660}$	.167 (.007)	.986
Honeybrook, Pa.	- 722132.286	370.000 (189.845)	.432	$e^{-84.119}$	.047 (.022)	.475
Killeen, TX	- 64875708.300	33187.300 (4060.406)	.905	$e^{-112.842}$	.064 (.009)	.886
Lake Zurich, IL	- 19518917.429	9929.607 (2139.552)	.812	$e^{-374.625}$	.120 (.046)	.782
Lebanon, OH	- 23630472.333	12041.933 (838.154)	.963	$e^{-240.042}$	.128 (.007)	.976

(Continued)

Table A-1. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Lowell, IN	− 20618114.333	10500.333 (1253.145)	.898	$e^{-278.550}$	.147 (.010)	.964
Manassas, VA	− 47485807.000	24166.000 (6258.450)	.882	$e^{-214.092}$	.115 (.029)	.890
Manassas Park, VA	− 2589957.436	1327.939 (260.771)	.764	$e^{-94.998}$	.053 (.010)	.782
Taylor, TX	− 9213282.121	4735.503 (1653.885)	.506	$e^{-71.474}$	.042 (.014)	.543
West Dundee, IL	N.S.	N.S.		N.S.	N.S.	

Table A-2. ANNUAL CAPITAL COST VERSUS TIME

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Algonquin, IL	- 992088.091	508.448 (145.825)	.603	$e^{-116.886}$	.064 (.020)	.572
Audubon Water Co. Norristown, PA	- 10858010.182	5520.255 (1147.055)	.743	$e^{-548.804}$	.283 (.052)	.785
Batavia, OH	136890.619	-58.943 (20.129)	.682	$e^{15.581}$	N.S.	
Bell Co. WCID 1 Killeen, TX	- 18890987.903	9690.158 (6475.338)	.219	$e^{-210.254}$	.113 (.069)	.250
Belton, TX	---	---		---	---	
Burlington, Ill.	- 54292.127	-26.418 (15.193)	.274	$e^{30.989}$	-.012 (.007)	.269
Cockrell Hill, TX	- 148524.286	79.464 (27.566)	.624	$e^{-10.225}$	.010 (.003)	.624
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 5511815.527	2821.818 (466.017)	.821	$e^{-108.370}$	.060 (.011)	.796
Dallas Co. WCID #6	- 18019016.776	9179.539 (1597.767)	.805	$e^{-254.646}$	.135 (.023)	.817

(Continued)

Table A-2. (Continued)

Utility Name	C = b + mt: b	m	R^2	$C = Ke^{at}$: K	a	R^2
Denton, TX	- 38998993.345	19941.564 (7160.471)	.492	$e^{-104.384}$	.059 (.022)	.480
Downingtown, PA	- 555558.455	298.636 (87.602)	.592	$e^{-7.508}$	.009 (.003)	.587
Georgetown, TX	- 2557961.524	1312.190 (382.549)	.662	$e^{-84.634}$	.048 (.014)	.666
Great Valley Water Co. Malvern, PA	- 19286007.321	9813.303 (514.046)	.979	$e^{-436.686}$	.227 (.015)	.965
Honeybrook, PA	- 852065.429	-427.071 (42.594)	.953	$e^{95.038}$	-.044 (.005)	.942
Killeen, TX	- 30072565.017	15309.850 (4295.521)	.645	$e^{-246.664}$	.131 (.028)	.764
Lake Zurich, IL	- 26579877.429	13519.357 (1582.427)	.936	$e^{-356.053}$	.186 (.024)	.924
Lebanon, OH	- 8393400.958	4323.594 (858.370)	.760	$e^{-55.755}$	.034 (.006)	.780

(Continued)

Table A-2. (Continued)

Utility Name	$C = b + mt$ b	 m	 R^2	$C = Ke^{at}$ K	 a	 R^2
Lowell, IN	N.S.	N.S.		$e^{-99.454}$	.056 (.049)	.140
Manassas, VA	8809352.600	-4256.100 (3764.717)	.389	$e^{33.642}$	-.011 (.009)	.394
Manassas Park, VA	1506421.473	-748.279 (86.762)	.903	$e^{55.330}$	-.023 (.003)	.897
Taylor, TX	- 12392977.576	6322.339 (1146.091)	.792	$e^{-176.523}$	.095 (.016)	.806
West Dundee, IL	- 246909.143	129.893 (27.888)	.813	$e^{-18.389}$	.014 (.003)	.813

Table A-3. REVENUE-PRODUCING WATER VERSUS TIME

Utility Name	b ($C = b + mt$)	m ($C = b + mt$)	R^2 ($C = b + mt$)	K ($C = Ke^{at}$)	a ($C = Ke^{at}$)	R^2 ($C = Ke^{at}$)
Algonquin, IL	- 3579.964	1.861 (.599)	.547	$e^{-39.569}$	.022 (.007)	.541
Audubon Water Co. Norristown, PA	- 28668.158	14.594 (.902)	.970	$e^{-382.818}$	.196 (.020)	.927
Batavia, OH	1782.352	-.879 (.390)	.388	$e^{36.759}$	-.017 (.007)	.402
Bell Co. WCID 1 Killeen, TX	- 572601.964	292.709 (25.572)	.942	$e^{-130.008}$	.070 (.006)	.945
Belton, TX	- 23759.667	12.200 (4.663)	.631	$e^{-71.082}$	.039 (.014)	.644
Burlington, IL	N.S.	N.S.		N.S.	N.S.	
Cockrell Hill, TX	9625.286	-4.821 (2.012)	.535	$e^{84.242}$	-.040 (.016)	.572
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 21600.224	11.061 (1.138)	.922	$e^{-106.308}$	.057 (.005)	.941
Dallas Co. WCID #6	- 46608.115	23.788 (2.354)	.927	$e^{-183.285}$	.096 (.010)	.918

(Continued)

Table A-3. (Continued)

Utility Name	C = b + mt b	m	R^2	$C = Ke^{at}$ K	a	R^2
Denton, TX	- 254345.188	130.170 (24.603)	.778	$e^{-117.619}$	.064 (.011)	.794
Downingtown, PA	34212.061	-17.152 (5.957)	.509	$e^{92.477}$	-.044 (.014)	.545
Georgetown, TX	56997.700	-28.700 (11.469)	.676	$e^{153.503}$	-.075 (.029)	.691
Great Valley Water Co. Malvern, PA	- 73943.655	37.636 (1.779)	.982	$e^{-391.274}$	.201 (.017)	.944
Honeybrook, PA	- 5879.857	3.000 (.499)	.878	$e^{-168.372}$	.087 (.015)	.876
Killeen, TX	- 174592.861	89.250 (7.202)	.956	$e^{-130.052}$	.069 (.006)	.947
Lake Zurich, IL	- 18496.655	9.488 (1.499)	.870	$e^{-84.020}$	.045 (.007)	.881
Lebanon, OH	14301.794	-7.085 (6.504)	.129	$e^{51.986}$	.023 (.019)	.160

(Continued)

Table A-3. (Continued)

Utility Name	$C = b + mt$			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Lowell, IN	− 16554.424	8.461 (.842)	.927	$e^{-137.358}$	.072 (.007)	.935
Manassas, VA	− 57410.300	29.300 (7.977)	.871	$e^{-133.648}$	.071 (.020)	.867
Manassas Park, VA	− 6348.600	3.267 (.679)	.743	$e^{-68.701}$	.037 (.007)	.764
Taylor, TX	− 31235.715	15.988 (5.787)	.488	$e^{-116.627}$	.062 (.020)	.558
West Dundee, IL	− 1785.571	.964 (.869)	.197	N.S.	N.S.	

Table A-4. MAN-HOURS/MIL GAL VERSUS TIME

Utility Name	$C = b + mt$			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Algonquin, IL	---	---		---	---	
Audubon Water Co. Norristown, PA	- 207.566	.123 (.071)	.750	$e^{-3.369}$	.004 (.002)	.750
Batavia, OH	9057.997	-4.545 (1.478)	.542	$e^{92.833}$	-.045 (.014)	.568
Bell Co. WCID 1 Killeen, TX	445.247	-.224 (.041)	.791	$e^{102.879}$	-.051 (.009)	.813
Belton, TX	N.S.	N.S.		N.S.	N.S.	
Burlington, IL	39.260	-.0107 (.103)	.001	N.S.	N.S.	
Cockrell Hill, TX	- 1376.226	.707 (.255)	.606	$e^{-76.602}$	.040 (.016)	.572
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 3808.700	1.972 (.776)	.447	$e^{-47.628}$	.026 (.010)	.460
Dallas Co. WCID #6	5067.914	-2.544 (1.060)	.419	$e^{84.008}$	-.041 (.018)	.390

(Continued)

Table A-4. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Denton, TX	2548.058	-1.277 (.360)	.611	$e^{81.527}$	-.040 (.012)	.595
Downingtown, PA	- 3705.469	1.895 (.526)	.619	$e^{-117.933}$	.062 (.018)	.595
Georgetown, TX	- 6438.182	3.286 (1.239)	.701	$e^{-143.783}$	.075 (.029)	.691
Great Valley Water Co. Malvern, PA	5896.611	-2.964 (.762)	.716	$e^{115.030}$	-.056 .014	.717
Honeybrook, PA	2127.789	-1.073 (.189)	.866	$e^{174.403}$	-.087 (.015)	.876
Killeen, TX	4824.308	-2.428 (.262)	.924	$e^{126.871}$	-.063 (.006)	.944
Lake Zurich, IL	---	---		---	---	
Lebanon, OH	- 8428.720	4.312 (1.316)	.573	$e^{-109.683}$	.058 (.019)	.524

(Continued)

Table A-4. (Continued)

Utility Name	$C = b + mt$			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Lowell, IN	---	---		---	---	
Manassas, VA	7370.784	-3.697 (2.200)	.585	$e^{103.131}$	-.050 .028	.608
Manassas Park, VA	5300.893	-2.654 (.491)	.785	$e^{77.439}$	-.037 (.007)	.764
Taylor, TX	14731.076	-7.416 (2.180)	.590	$e^{126.924}$	-.062 (.020)	.558
West Dundee, IL	---	---		---	---	

Table A-5. DOLLARS/MAN-HOURS VERSUS TIME

Utility Name	C = b + mt			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Algonquin, IL	---	---		---	---	
Audubon Water Co. Norristown, PA	- 574.510	.292 (.206)	.667	$e^{-269.021}$	.137 (.100)	.653
Batavia, OH	N.S.	N.S.		N.S.	N.S.	
Bell Co. WCID 1 Killeen, TX	- 270.349	.139 (.037)	.639	$e^{-64.217}$	.033 (.009)	.654
Belton, TX	N.S.	N.S.		N.S.	N.S.	
Burlington, IL	- 785.212	.400 (.068)	.813	$e^{-223.349}$	.114 (.014)	.892
Cockrell Hill, TX	- 817.372	.418 (.161)	.574	$e^{-120.664}$	.062 (.024)	.583
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 452.645	.231 (.044)	.771	$e^{-166.436}$	.085 (.017)	.758
Dallas Co. WCID #6	- 360.303	.184 (.010)	.977	$e^{-119.731}$	.061 (.003)	.918

(Continued)

Table A-5. (Continued)

Utility Name	C = b + mt			C = Ke^{at}		
	b	m	R^2	K	a	R^2
Denton, TX	- 401.117	.205 (.044)	.757	$e^{-150.481}$	.077 (.017)	.749
Downingtown, PA	- 1199.677	.612 (.090)	.852	$e^{-245.958}$	.126 (.018)	.854
Georgetown, TX	- 208.770	.107 (.098)	.286	$e^{-84.059}$	.043 (.043)	.250
Great Valley Water Co. Malvern, PA	- 563.649	.288 (.082)	.674	$e^{-106.984}$	.055 (.016)	.663
Honeybrook, PA	- 288.709	.149 (.028)	.846	$e^{-68.037}$	.035 (.007)	.853
Killeen, TX	- 432.653	.221 (.018)	.956	$e^{-162.926}$	.083 (.008)	.935
Lake Zurich, IL	---	---		---	---	
Lebanon, OH	- 385.025	.197 (.019)	.930	$e^{-178.362}$	.091 (.009)	.929

(Continued)

Table A-5. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Lowell, IN	---	---		---	---	
Manassas, VA	---	---		---	---	
Manassas Park, VA	- 332.900	.170 (.014)	.946	$e^{199.030}$	.101 (.009)	.944
Taylor, TX	- 182.865	.094 (.012)	.888	$e^{-89.251}$	.046 (.006)	.866
West Dundee, IL	---	---		---	---	

Table A-6. ANNUAL SUPPORT SERVICES O&M COST VERSUS TIME

Utility Name	C = b + mt			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Algonquin, IL	---	---		---	---	
Audubon Water Co. Norristown, PA	- 15915405.500	8086.500 (1833.148)	.907	$e^{-378.959}$	.197 (.046)	.904
Batavia, OH	---	---		---	---	
Bell Co. WCID 1 Killeen, TX	- 1814844.900	9224.300 (3471.874)	.702	$e^{-237.107}$	.126 (.013)	.969
Belton, TX	- 3896145.952	1989.143 (705.233)	.665	$e^{-128.423}$	.070 (.024)	.679
Burlington, IL	- 322722.806	164.315 (50.454)	.570	$e^{-242.672}$	.127 (.035)	.624
Cockrell Hill, TX	N.S.	N.S.		N.S.	N.S.	
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 4886074.848	2484.521 (410.685)	.821	$e^{-522.770}$	.270 .039	.857
Dallas Co. WCID #6	- 10690103.079	5448.497 (839.763)	.840	$e^{-224.580}$	.119 .014	.895

(Continued)

Table A-6. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Denton, TX	---	---		---	---	
Downingtown, PA	- 135948.400	6918.400 (1188.167)	.809	$e^{-405.332}$	.211 (.025)	.901
Georgetown, TX	- 6364309.357	3240.357 (309.513)	.948	$e^{-264.281}$	.139 (.012)	.960
Great Valley Water Co. Malvern, PA	- 9558403.212	4876.230 (674.925)	.867	$e^{-176.883}$	.095 (.012)	.880
Honeybrook, PA	- 203977.571	104.000 (22.069)	.816	$e^{-192.090}$	.101 (.024)	.784
Killeen, TX	- 13333820.556	6797.000 (901.155)	.890	$e^{-227.797}$	.121 (.020)	.840
Lake Zurich, IL	---	---		---	---	
Lebanon, OH	- 4658502.879	2377.247 (278.613)	.901	$e^{-188.282}$	.101 (.015)	.848

(Continued)

Table A-6. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Lowell, IN	---	---		---	---	
Manassas, VA	- 14419616.70	7315.200 2789.277	.775	$e^{-911.513}$	.467 (.224)	.685
Manassas Park, VA	- 1631550.236	836.539 (164.279)	.764	$e^{-95.452}$	.053 (.010)	.782
Taylor, TX	- 2764075.479	1420.697 (496.145)	.506	$e^{-72.681}$	.042 (.014)	.543
West Dundee, IL	---	---		---	---	

Table A-7. ANNUAL ACQUISITION O&M COSTS VERSUS TIME

Utility Name	$C = b + mt$			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Algonquin, IL	---	---		---	---	
Audubon Water Co. Norristown, PA	- 7533085.700	3826.200 (577.282)	.956	$e^{-420.877}$	.218 (.033)	.957
Batavia, OH	---	---		---	---	
Bell Co. WCID 1 Killeen, TX	- 26592055.400	13531.400 (2021.597)	.937	$e^{-237.107}$	.126 (.013)	.969
Belton, TX	- 27690284.238	14083.686 (4034.902)	.753	$e^{-394.121}$	.206 (.075)	.649
Burlington, IL	- 322722.806	164.315 (50.454)	.570	$e^{-242.672}$	.127 (.035)	.624
Cockrell Hill, TX	N.S.	N.S.		N.S.	N.S.	
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	---	---		---	---	
Dallas Co. WCID #6	- 19448856.697	9895.042 (506.851)	.979	$e^{-518.161}$	.268 (.034)	.889

(Continued)

Table A-7. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Denton, TX	---	---		---	---	
Downingtown, PA	- 2183015.533	1113.733 (248.253)	.716	$e^{-174.347}$	.093 (.017)	.786
Georgetown, TX	- 569257.310	290.476 (65.908)	.764	$e^{-161.956}$	.086 (.021)	.729
Great Valley Water Co. Malvern, PA	- 12965018.181	6596.854 (650.955)	.928	$e^{-436.801}$	.277 (.025)	.913
Honeybrook, PA	- 735051.286	374.214 (18.792)	.988	$e^{-253.094}$	.132 (.006)	.989
Killeen, TX	- 15097574.567	7792.567 (3018.152)	.488	$e^{-49.919}$	.317 .012	.504
Lake Zurich, IL	---	---		---	---	
Lebanon, OH	- 3900293.539	1986.048 (252.667)	.885	$e^{-297.405}$	.156 (.015)	.932

(Continued)

Table A-7. (Continued)

Utility Name	C = b + mt			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Lowell, IN	---	---		---	---	
Manassas, VA	- 2890028.300	-1462.800 (917.339)	.560	$e^{725.204}$	-.363 (.248)	.517
Manassas Park, VA	- 569859.891	292.182 (57.385)	.764	$e^{-96.524}$	.053 (.010)	.782
Taylor, TX	- 1197684.358	615.594 (215.001)	.506	$e^{-73.510}$	.042 (.014)	.543
West Dundee, IL	---	---		---	---	

Table A-8. ANNUAL TREATMENT O&M COSTS VERSUS TIME

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Algonquin, IL	---	---		---	---	
Audubon Water Co. Norristown, PA	1265813.500	-640.000 (378.201)	.589	$e^{497.187}$	-.248 (.123)	.671
Batavia, OH	---	---		---	---	
Bell Co. WCID 1 Killeen, TX	- 9803680.200	5021.600 (2160.293)	.643	$e^{-81.110}$	.047 (.021)	.628
Belton, TX	N.S.	N.S.		N.S.	N.S.	
Burlington, IL	- 319137.533	162.133 (58.220)	.492	$e^{1675.783}$	.852 (.111)	.880
Cockrell Hill, TX	---	---		---	---	
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 12889255.606	6558.715 (1149.667)	.803	$e^{-345.798}$	.181 (.020)	.909
Dallas Co. WCID #6	73395.230	-37.176 (6.776)	.790	$e^{1233.703}$	-.624 (.132)	.738

(Continued)

Table A--8. (Continued)

Utility Name	C = b + mt			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Denton, TX	---	---		---	---	
Downingtown, PA	- 9144177.564	4659.109 (283.807)	.971	$e^{-267.503}$	.141 (.011)	.950
Georgetown, TX	- 455406.048	232.381 (52.751)	.764	$e^{-162.193}$	.086 (.021)	.729
Great Valley Water Co. Malvern, PA	- 7276526.594	3701.085 (473.155)	.884	$e^{-466.009}$	.241 (.012)	.979
Honeybrook, PA	- 92615.143	47.536 (23.094)	.459	$e^{-73.047}$	.041 (.021)	.426
Killeen, TX	N.S.	N.S.		N.S.	N.S.	
Lake Zurich, IL	N.S.	N.S.		N.S.	N.S.	
Lebanon, OH	- 3935143.503	2004.158 (249.706)	.890	$e^{-281.408}$	.148 (.014)	.931

(Continued)

Table A-8. (Continued)

Utility Name	b	m	R^2	K	a	R^2
	$C = b + mt$			$C = Ke^{at}$		
Lowell, IN	---	---		---	---	
Manassas, VA	- 24839245.700	12640.700 (3427.788)	.872	$e^{-214.715}$	.115 (.027)	.900
Manassas Park, VA	---	---		---	---	
Taylor, TX	- 368598.982	189.455 (66.166)	.506	$e^{-74.707}$	.042 (.014)	.543
West Dundee, IL	---	---		---	---	

Table A-9. ANNUAL POWER & PUMPING COST VERSUS TIME

Utility Name	$C = b + mt$			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Algonquin, IL	- 35416.836	4764.418 (132.734)	.994	$e^{-146.374}$	.079 (.014)	.800
Audubon Water Co. Norristown, PA	- 2842542.982	1446.255 (156.117)	.915	$e^{-401.749}$	.208 (.014)	.965
Batavia, OH	---	---		---	---	
Bell Co. WCID 1 Killeen, TX	- 33155590.067	16890.667 (2793.371)	.820	$e^{-241.321}$	.128 (.015)	.900
Belton, TX	---	---		---	---	
Burlington, IL	- 164786.860	84.352 (28.845)	.517	$e^{-103.918}$	.056 (.020)	.493
Cockrell Hill, TX	---	---		---	---	
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 1773339.873	905.382 (138.302)	.843	$e^{-150.694}$	.081 (.011)	.881
Dallas Co. WCID #6	509149.279	-255.097 (83.445)	.539	$e^{87.764}$	-.040 .013	.535

(Continued)

Table A-9. (Continued)

Utility Name	C = b + mt: b	m	R^2	C = Ke^{at}: K	a	R^2
Denton, TX	- 474153.884	48535.405 (1434.996)	.997	$e^{-120.971}$	.067 (.007)	.922
Downingtown, PA	- 3109338.000	1583.382 (177.135)	.909	$e^{-177.024}$	.095 (.008)	.946
Georgetown, TX	---	---		---	---	
Great Valley Water Co. Malvern, PA	- 8617507.352	4383.479 (476.987)	.913	$e^{-460.295}$	.239 (.006)	
Honeybrook, PA	- 739629.571	376.500 (17.723)	.989	$e^{-262.128}$	.137 (.007)	.988
Killeen, TX	- 3350970.483	1707.983 (310.736)	.811	$e^{-200.792}$	.107 (.015)	.879
Lake Zurich, IL	---	---		---	---	
Lebanon, OH	N.S.	N.S.		$e^{-40.5697}$	.026 (.023)	.138

(Continued)

Table A-9. (Continued)

Utility Name	C = b + mt			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Lowell, IN	− 2004853.781	1021.255 (114.512)	.908	$e^{-275.047}$	.144 (.013)	.936
Manassas, VA	---	---		---	---	
Manassas Park, VA	369032.236	−184.339 (51.969)	.611	$e^{70.596}$	−.031 (.009)	.600
Taylor, TX	− 1591268.885	811.612 (179.128)	.720	$e^{-218.059}$	.115 (.037)	.553
West Dundee, IL	− 78251.913	9630.623 (515.521)	.980	$e^{-208.540}$	.110 (.015)	.892

Table A-10. ANNUAL TRANSMISSION AND DISTRIBUTION O&M VERSUS TIME

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Algonquin, IL	---	---		---	---	
Audubon Water Co. Norristown, PA	- 1424750.700	724.700 (452.639)	.562	$e^{-296.936}$	.155 (.095)	.570
Batavia, OH	---	---		---	---	
Bell Co. WCID 1 Killeen, TX	- 49147433.300	25000.300 (5600.108)	.869	$e^{-253.554}$	.135 (.025)	.908
Belton, TX	N.S.	N.S.		N.S.	N.S.	
Burlington, Ill.	- 337724.612	173.030 (80.121)	.368	$e^{-95.996}$	.053 (.027)	.316
Cockrell Hill, TX	- 1507568.714	771.036 (130.028)	.876	$e^{-112.806}$	.062 (.012)	.846
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 9381871.539	4778.448 (837.237)	.803	$e^{-252.901}$	.134 (.017)	.888
Dallas Co. WCID #6	- 7324658.521	3731.303 (722.699)	.769	$e^{-238.198}$	.126 .020	.826

(Continued)

Table A-10. (Continued)

Utility Name	C = b + mt b	m	R^2	$C = Ke^{at}$ K	a	R^2
Denton, TX	---	---		---	---	
Downingtown, PA	- 6607476.842	3367.606 (629.043)	.782	$e^{-210.185}$	.112 (.017)	.849
Georgetown, TX	- 10361728.881	5287.298 (1199.607)	.764	$e^{-159.082}$	.086 (.021)	.729
Great Valley Water Co. Malvern, PA	- 7127962.085	3624.612 (530.088)	.854	$e^{-544.697}$	.281 (.030)	.918
Honeybrook, PA	N.S.	N.S.		N.S.	N.S.	
Killeen, TX	- 36485419.256	18617.700 (2983.430)	.848	$e^{-161.953}$	.088 (.014)	.842
Lake Zurich, IL	---	---		---	---	
Lebanon, OH	- 11136818.830	5674.576 (503.264)	.941	$e^{-246.999}$	.131 (.012)	.936

(Continued)

Table A-10. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Lowell, IN	---	---		---	---	
Manassas, VA	- 11116973.400	5672.900 (1576.890)	.866	$e^{-129.295}$	.071 (.019)	.865
Manassas Park, VA	- 388583.018	199.236 (39.119)	.764	$e^{-96.917}$	.053 (.010)	.782
Taylor, TX	- 4883018.842	2509.806 (876.539)	.506	$e^{-72.109}$	.042 (.014)	.543
West Dundee, IL	---	---		---	---	

Table A-11. ANNUAL TOTAL EXPENDITURES VERSUS TIME

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Algonquin, IL	- 9711743.455	4954.776 (357.046)	.960	$e^{-215.841}$	.115 (.011)	.929
Audubon Water Co. Norristown, PA	- 27484687.321	13979.703 (1776.189)	.886	$e^{-473.871}$	.246 (.015)	.970
Batavia, OH	- 4884354.286	2506.543 (815.714)	.702	$e^{-70.862}$	.042 (.013)	.725
Bell Co. WCID 1 Killeen, TX	- 71313100.267	36483.467 (7611.477)	.742	$e^{-122.923}$	.069 (.017)	.664
Belton, TX	- 45179928.667	23021.400 (11032.612)	.521	$e^{-226.569}$	.121 (.056)	.535
Burlington, IL	- 1090139.497	557.442 (162.271)	.596	$e^{-110.426}$	.061 (.018)	.579
Cockrell Hill, TX	- 1671727.857	886.214 (872.657)	.171	$e^{-11.843}$	.012 (.011)	.173
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 32669184.715	16643.588 (2417.036)	.856	$e^{-237.662}$	.127 (.010)	.949
Dallas Co. WCID #6	- 55409347.224	28217.261 (2319.156)	.949	$e^{-290.381}$	.153 (.010)	.969

(Continued)

Table A-11. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Denton, TX	---	---		$e^{-131.727}$	.074 (.011)	.856
Downingtown, PA	- 32085244.388	16357.569 (1595.487)	.929	$e^{-212.113}$	.114 (.007)	.966
Georgetown, TX	- 20308944.512	10362.845 (1387.956)	.903	$e^{-159.572}$	.087 (.013)	.884
Great Valley Water Co. Malvern, PA	- 56213881.467	28612.067 (2206.737)	.955	$e^{-348.475}$	.183 (.005)	.994
Honeybrook, PA	N.S.	N.S.		N.S.	N.S.	
Killeen, TX	- 94948273.317	48497.150 (5716.439)	.911	$e^{-136.420}$	.076 (.008)	.932
Lake Zurich, IL	- 46098794.857	23448.964 (3023.047)	.923	$e^{-362.334}$	.190 (.031)	.882
Lebanon, OH	- 32023873.291	16365.527 (1247.675)	.956	$e^{-132.645}$	.074 (.005)	.965

(Continued)

Table A-11. (Continued)

Utility Name	C = b + mt			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Lowell, IN	- 22299988.491	11375.327 (2344.660)	.746	$e^{-199.080}$	.107 (.024)	.713
Manassas, VA	- 38676454.400	19909.900 (6574.082)	.821	$e^{-50.153}$	(.011)	.816
Manassas Park, VA	- 1083535.964	579.661 (292.709)	.329	$e^{-8.286}$	.010 .005	.325
Taylor, TX	- 21606259.697	11057.842 (1167.970)	.918	$e^{-109.893}$	.062 (.007)	.911
West Dundee, IL	N.S.	N.S.		N.S.	N.S.	

Table A-12. UNIT COSTS ($/mil gal) VERSUS TIME

Utility Name	$C = b + mt$			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Algonquin, IL	- 91963.904	46.971 (6.991)	.849	$e^{-176.272}$	.093 (.014)	.848
Audubon Water Co. Norristown, PA	- 72397.631	37.071 (14.960)	.434	$e^{-91.053}$	.049 (.023)	.368
Batavia, OH	- 101487.461	52.078 (11.640)	.833	$e^{-74.932}$	.042 (.009)	.845
Bell Co. WCID 1 Killeen, TX	N.S.	N.S.		N.S.	N.S.	
Belton, TX	- 95874.482	48.986 (41.095)	.262	$e^{-155.488}$	.082 (.057)	.338
Burlington, IL	- 52205.136	26.699 (7.700)	.600	$e^{-112.005}$	.060 (.017)	.612
Cockrell Hill, TX	- 65340.145	33.466 (11.259)	.639	$e^{-96.085}$	.052 (.018)	.628
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 90074.239	46.031 (6.994)	.844	$e^{131.354}$	.070 (.009)	.888
Dallas Co. WCID #6	- 81931.482	41.932 (8.275)	.762	$e^{-107.096}$	.058 (.011)	.762

(Continued)

Table A-12. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Denton, TX	N.S.	N.S.		N.S.	N.S.	
Downingtown, PA	- 119138.834	60.855 (8.426)	.866	$e^{-304.590}$	.158 (.017)	.912
Georgetown, TX	- 107620.838	54.740 (15.603)	.804	$e^{-302.510}$	.156 (.050)	.767
Great Valley Water Co. Malvern, PA	35556.67	-17.647 (14.007)	.166	$e^{42.798}$	-.018 (.017)	.128
Honeybrook, PA	93235.808	-47.027 (8.552)	.858	$e^{185.142}$	-.091 (.015)	.879
Killeen, TX	N.S.	N.S.		N.S.	N.S.	
Lake Zurich, IL	- 161054.352	82.002 (14.622)	.803	$e^{-272.578}$	.141 (.028)	.834
Lebanon, OH	- 142781.328	72.809 (15.416)	.736	$e^{-184.630}$	.097 (.020)	.746

(Continued)

Table A-12. (Continued)

Utility Name	$C = b + mt$ b	m	R^2	$C = Ke^{at}$ K	a	R^2
Lowell, IN	N.S.	N.S.		$e^{-61.722}$	.035 (.028)	
Manassas, VA	115561.763	-57.799 (15.527)	.874	$e^{83.495}$	-.039 (.010)	.873
Manassas Park, VA	35756.501	-17.804 (6.914)	.453	$e^{60.415}$	-.027 (.010)	.460
Taylor, TX	---	---		---	---	
West Dundee, IL	N.S.	N.S.		N.S.	N.S.	

Table A-13. TOTAL CHEMICAL COST VERSUS TIME

Utility Name	C = b + mt: b	C = b + mt: m	C = b + mt: R^2	$C = Ke^{at}$: K	$C = Ke^{at}$: a	$C = Ke^{at}$: R^2
Algonquin, IL	---	---		---	---	
Audubon Water Co. Norristown, PA	---	---		---	---	
Batavia, OH	---	---		---	---	
Bell Co. WCID 1 Killeen, TX	N.S.	N.S.		N.S.	N.S.	
Belton, TX	N.S.	N.S.		N.S.	N.S.	
Burlington, IL	- 337724.612	173.030 (80.121)	.368	$e^{-95.996}$	.053 (.027)	.316
Cockrell Hill, TX	---	---		---	---	
Colony MUD #1 Lewisville, TX	---	---		---	---	
Culpepper, VA	- 4821653.096	2451.642 (679.229)	.620	$e^{-454.837}$	.235 (.046)	.766
Dallas Co. WCID #6	- 73395.230	-37.176 (6.776)	.790	$e^{1233.704}$	-.624 (.132)	.738

(Continued)

Table A-13. (Continued)

Utility Name	$C = b + mt$			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Denton, TX	- 6969701.673	3561.382 (831.118)	.697	$e^{-133.867}$	.073 (.016)	.729
Downingtown, PA	- 593732.127	303.818 (113.098)	.474	$e^{-107.514}$	.059 (.021)	.489
Georgetown, TX	---	---		---	---	
Great Valley Water Co. Malvern, PA	- 6825233.714	3468.214 (590.953)	.851	$e^{-558.763}$	.288 (.018)	.977
Honeybrook, PA	- 146844.714	74.643 (20.062)	.735	$e^{-497.061}$	.255 (.067)	.741
Killeen, TX	N.S.	N.S.		N.S.	N.S.	
Lake Zurich, IL	---	---		---	---	
Lebanon, OH	---	---		---	---	

(Continued)

Table A-13. (Continued)

Utility Name	$C = b + mt$			$C = Ke^{at}$		
	b	m	R^2	K	a	R^2
Lowell, IN	249302.370	-123.624 (122.216)	.113	$e^{61.532}$	-.027 (.025)	.127
Manassas, VA	---	---		---	---	
Manassas Park, VA	---	---		---	---	
Taylor, TX	- 611760.994	312.285 (59.399)	.776	$e^{-168.506}$	.090 (.017)	.774
West Dundee, IL	- 226254.300	115.100 (29.495)	.835	$e^{-251.184}$	.131 (.029)	.874

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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16. ABSTRACT

A study to determine the economics of water delivery was completed in 12 selected Class A (revenues greater than $500,000/year) water utilities and is reported in The Cost of Water Supply and Water Utility Management, Vols. I and II, EPA-600/5-77-015a and 015b, November 1977. The effort provided valid data on large water systems but raised questions about the costs associated with small utilities.

As a follow-up to the earlier effort, a study of 23 small water utilities was undertaken to determine the economics of their water delivery. Data were collected from seven to nine small utilities in each of three U.S. Environmental Protection Agency Regions. This Volume (Volume I) is an in-house analysis of the data collected under Contract No. 68-03-2071 and includes a summary of selected data from the study. All utilities are analyzed in aggregate and factors affecting the cost of water supply are examined. An evaluation of the hypothetical 1980 impact of the Safe Drinking Water Act of 1974 is also provided.

Volume II contains the basic data from each of the 23 utilities studied and contains the results of the contractor's effort. Services of each utility were divided into three functional areas common to all water supply delivery systems: acquisition, treatment, and delivery. These areas provided a common basis for collecting and comparing data. Costs were categorized as either operating or capital expenditures.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Benefit Cost Analysis; Cost Analysis; Cost Centers; Cost Comparison; Cost Estimates; Economic Analysis, Economic Factors; Forecasting; Incremental Costs; Interest; Productivity; Regression Analysis; Regulations, Revenue; Statistical Analysis; Taxes; Water Distribution; Water Production; Water Supply; Depreciation; Primary Standards	Small Systems; Chemical Cost; Labor Cost; Operating & Maintenance Cost; Revenue Producing Water; Safe Drinking Water Cost; Secondary Standards; Water Delivery	13B 14A

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