The Effects of Water Conservation on New Water Supply for Urban Colorado Utilities

by

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ABSTRACT

In this study a model is developed and used with various scenarios to make a comparison of the costs and benefits of a water conservation program for various sizes and types of Colorado cities. Colorado water law and the scarcity of water encourages cities to acquire more water than they need and to resist conservation because of implied threats that they may lose water they are not currently using. Based on surveys of selected cities, costs of water acquisition from transfers, storage, imports and purchase are evaluated and projected into the future. These costs are compared with the costs of various conservation programs that will modify demand and thus reduce need for additional water.

The results of this study show that for all types of cities and all growth rates, conservation is the more economic approach to be utilized for urban water utilities in Colorado in meeting future water demands.

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Chapter 1

INTRODUCTION

The availability of adequate water supplies is crucial to the Colorado economy and quality of life. Historically, Coloradoans have gone to great lengths to ensure that water will be available where it is needed by developing vast diversion networks--both local and trans-mountain. But as new sources become unavailable or increasingly expensive, a closer look has been taken at more efficient management of the sources already available.

Several Colorado cities and towns have experienced shortages during recent droughts and many more anticipate an inadequate water supply within the next few decades due to growth. Obviously, if future needs are to be met without needlessly robbing any area of the state of the use of precious water resources, municipalities must practice efficient planning and use of water supplies.

Municipal water conservation has been encouraged to reduce the demand for water. The benefits of conservation include the postponement of capital expenditures and a reduction in operation and maintenance costs. However, delays in acquisition of water rights could be a disadvantage if increased competition for the purchase of rights in the future decreases availability and increases water costs. It is also possible that during droughts when yields of most rights are reduced, a non-conserving city could have more water to meet demands than a conserving city.

This study evaluates the options which Colorado municipalities can consider to meet their water demands. This objective is met by determining the water use characteristics of Colorado municipalities, analyzing the cost and availability of water throughout the state, and incorporating this information into scenarios comparing alternative supply strategies. The scenarios are based on hypothetical communities typical of Colorado and serve as the basis for both an economic analysis of differing water management policies and an analysis of the effects of drought on conserving and non-conserving communities.

Chapter 2

WATER USE CHARACTERISTICS OF COLORADO MUNICIPALITIES

Water use varies from community to community because of differences in climate, population mix, and types of industry. Joseph analyzed water data from the 17 western states and found that, of the estimated average day per capita residential use of 125 gallons, about 70 gallons per capita per day (gpcpd) or 55% was for interior uses, while 55 gpcpd or 45% was used outdoors (1). White, et al., found per capita use values of Northern Colorado's metered towns to be in this range, but the unmetered towns generally had a higher usage (2). These studies estimate that residential use accounts for approximately 64% to 72% of total municipal use.

A Survey of Colorado Municipalities

In order to define the variability of water system characteristics throughout the state, 132 municipalities were contacted in April, 1982 and asked to participate in this study. Seventeen communities completed a detailed questionnaire (see Appendix A) covering general information, current water supplies, future plans for expansion, supplies during drought, and water conservation methods employed. There were few responses to some questions and other answers did not provide complete information. Supplemental information was acquired when necessary through additional contacts with the water system managers. (See

Appendix B for the names and addresses of water managers in the towns involved in the survey.)

The data obtained from this survey was combined with information gathered by other researchers on Colorado towns. A list of the communities involved and the source of information is presented in Table 2-1. The locations of the communities are illustrated in Figure 2-1.

Current and projected population figures were provided by the study towns and adjusted where necessary based on other sources of information. These figures were combined with census data for population in previous years and for the number of people per household (3). The municipalities are divided according to size of population in Table 2-2.

The communities can be divided into five different groups based on population and growth.

Type I-- large metropolitan city or suburb with over 30,000 people expecting significant growth in the next two decades.

Type II--formerly rural town which is becoming more urban; present population of 9000-50,000 has doubled over the last decade and significant growth is expected over the next two decades.

Type III--small mountain or plains town (population 1000-10,000) expecting to double in size or more over the next two decades.

Type IV--small mountain or plains town of 2500 or less expecting only a small increase or a decrease in population over the next two decades.

Type V--very small town of less than 1000 expecting to double in the next two decades.

Water Supplies and Water Use

Estimates of water use in towns of each type are presented in Table 2-3. The estimates for residential use include single-family residences

TABLE 2-1

Colorado Communities Selected for Study

Community	Source of Information (sources listed below)
Aguilar	a
Akron	a
Boulder	b, c
Brighton	b
Broomfield	a
Cheraw	a
Crested Butte	a
Englewood	a
Ft. Collins	b, c
Granby	a
Greeley	b
La Jara	a
Layfayette	b
Longmont	b, d
Loveland	b
Meeker	a
Montrose (Project 7)	a
Nucla	a
Pritchett	a
Rangely	a
Steamboat Springs	a
Walsh	a
Westminster	a, c
Yuma	a

Sources:

a. Survey conducted April 1982

b. White, A. U., et al., "Municipal Water Use in Northern Colorado: Development of Efficiency-of-Use Criterion," Water Resources Research Institute Completion Report No. 105, Colorado State University, Fort Collins, Colo., Sept. 1980.

c. McCoy, G. A., "A Study of Municipal Water Management Policies and Effects on Water Supplies in Northern Colorado," thesis presented to the University of Colorado, Boulder, Colo., in 1982, in partial fulfillment of the requirements for the degree of Master of Science.

d. Rocky Mountain Consultants, Inc., Longmont Water Study: 1979-2040, City of Longmont, Colo., Nov. 1979.

FIGURE 2-1

Location of Communities Selected for Study

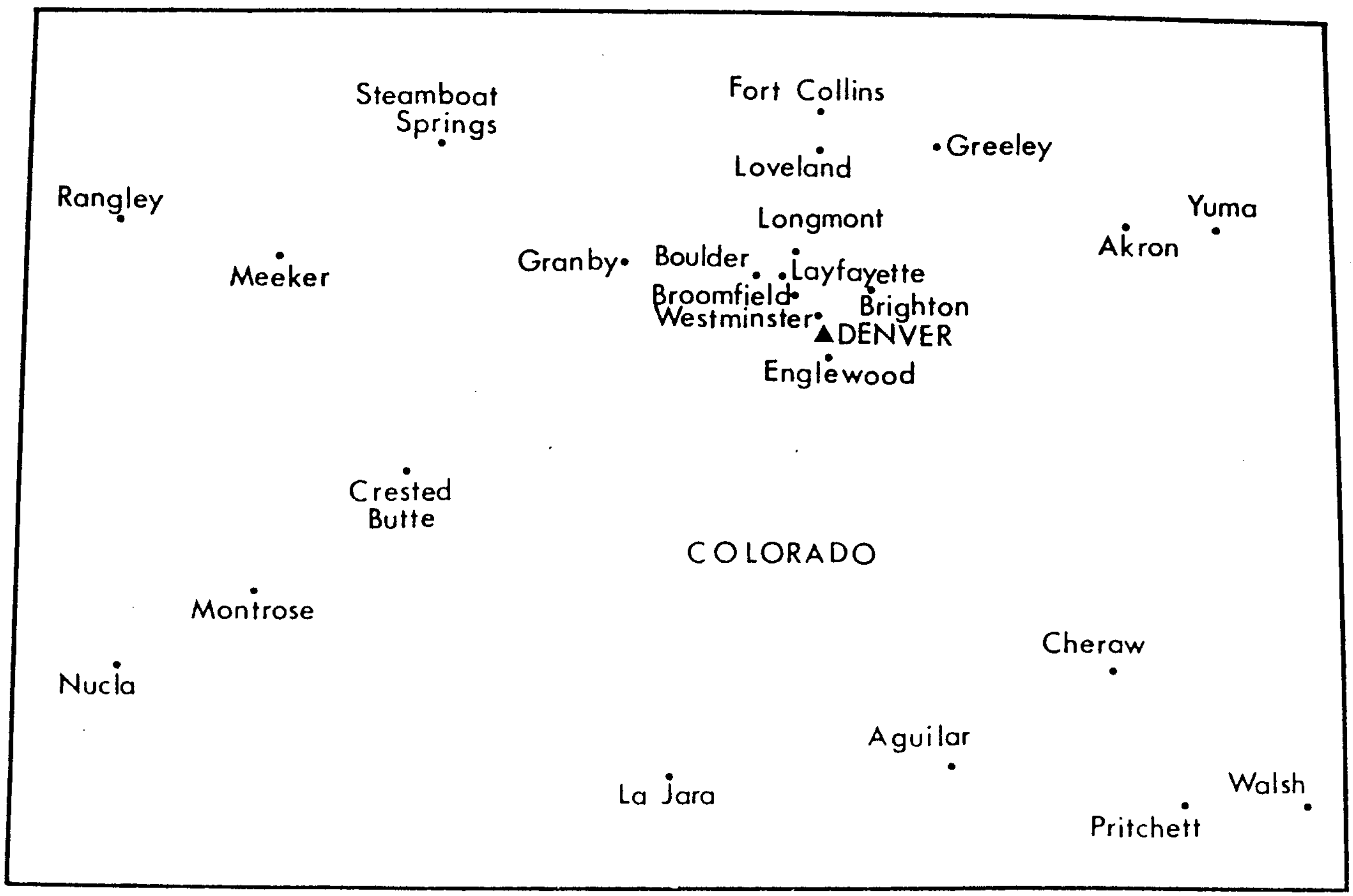

TABLE 2-2

Population, Growth Rate, and Number of Persons per Household for Selected Cities

Community	Population				Percent Growth Rate			Capita/ Household
	1970	1982	2000	2020	1970-1982	1982-2000	2000-2020	
Over 50,000								
Boulder	66,900	83,000	113,900	N/A*	+ 24	+ 37	N/A	2.14
Fort Collins	43,000	85,000	150,000	N/A	+ 98	+ 76	N/A	2.25
Greeley	N/A	70,400	120,000	N/A	N/A	+ 70	N/A	2.24
Westminster	19,400	63,000	122,200	182,200	+225	+ 94	+ 49	2.69
10,000-50,000								
Brighton	8,180	13,300	24,000	N/A	+ 63	+ 80	N/A	2.96
Broomfield	7,260	20,800	30,000	35,000	+187	+ 44	+ 17	3.02
Englewood	33,300	30,000	45,000	60,000	- 10	+ 50	+ 33	2.32
Longmont	23,000	49,000	76,100	132,000	+113	+ 55	+ 73	2.75
Loveland	15,900	32,800	56,000	N/A	+106	+ 71	N/A	2.61
2,500-10,000								
Layfayette	3,500	9,000	15,000	N/A	+157	+ 66	N/A	2.62
Meeker	1,600	2,600	18,000	N/A	+ 63	+592	N/A	2.51
Rangely	1,590	2,500	15,000	20,000	+ 57	+500	+ 33	2.74
Steamboat Springs	2,260	5,100	10,500	N/A	+126	+106	N/A	2.45
Yuma	2,260	2,800	5,500	7,500	+ 24	+ 96	+ 36	2.49

TABLE 2-2 (continued)

Community	Population 1970	1982	2000	2020	Percent Growth Rate 1970-1982	1982-2000	2000-2020	Capita/ Household
1,000-2,500								
Akron	1,780	1,700	1,700	N/A	- 4	0	N/A	2.11
Crested Butte	N/A	1,200	1,900	N/A	N/A	+ 58	N/A	2.44
Granby	N/A	1,400	3,000	N/A	N/A	+114	N/A	2.28
Nucla	N/A	1,000	N/A	N/A	N/A	N/A	N/A	2.79
Less than 1,000								
Aguilar	N/A	810	900	920	N/A	+ 11	+ 2	2.25
Cheraw	N/A	220	500	650	N/A	+127	+ 30	2.68
La Jara	N/A	856	1,800	3,000	N/A	+110	+ 67	3.03
Pritchett	N/A	150	declining		N/A	negative	N/A	2.15
Walsh	N/A	900	900	N/A	N/A	0	N/A	2.39

*N/A - Not Available

TABLE 2-3

Water Use and Percentage of
Residences Metered for Selected Municipalities

Municipality	Total Use/ Cap. (gpcpd)	Use/Res. Tap* (gptpd)	Percent Metered
Type I			
Boulder	192	320	100
Englewood	275	500	10
Ft. Collins	225	600	0
Greeley	296	660	35
Westminster	140	380	100
Type II			
Brighton	242	720	0
Broomfield	141	430	100
Longmont	243	670	0
Loveland	246	640	0
Layfayette	129	340	100
Type III			
Crested Butte	200	460	5
Rangely	185	510	100
Steamboat Springs	260	640	0
Yuma	260	650	100
Type IV			
Akron	185	390	100
Aguilar	120	270	100
Granby	250	610	10
Meeker	234	590	100
Nucla	155	430	100
Walsh	440	1,050	0
Type V			
Cheraw	205	550	100
La Jara	200	610	0

*Includes multi-family housing

and multi-family housing. The metered towns in each category generally appear to have lower water use than unmetered towns. This is particularly apparent for the larger cities.

The vast majority of the towns surveyed feel that the water rights they hold are sufficient to meet their needs well into the future. Steamboat Springs and Crested Butte are confident their rights will meet water needs until the year 2000. Englewood, since it is surrounded by other suburbs and has a limited areal growth potential, is in the unique position of owning all the rights that it will ever need.

Not all cities are so well supplied, however. Rapidly-expanding Broomfield and Westminster will meet the limits of their supplies in 1985 and 1990 respectively. Longmont will need additional supplies in 1990 (4). Meeker expects to need new supplies by 1984.

Most of the communities surveyed have established a rate structure which covers the full cost of their water system. Often the funds for system expansion are derived from water service fees or, in addition, tap fees. However, five of the smaller towns only attempt to cover operation and maintenance of the current system.

Additions to Water Systems

Water utilities seeking to increase their water supply have among their main options the possibilities of developing new supplies, purchasing existing rights, and/or condemning rights. Thirteen cities ranked these alternatives according to their preference.

The most popular solution by far was to develop new supplies (wells, reservoirs, etc.) Eleven of the thirteen municipalities, or 85%, chose this as their first or only solution. The remaining two, Walsh and

Granby, indicated they would attempt to purchase existing rights first before turning to new development.

Most of the cities which indicated a second choice felt that purchase of existing rights was the route to follow. Only two suggested that demand-reduction options or reuse for irrigation were appealing alternatives to purchase. Other options such as donation of water rights by developers were mentioned.

The cities were unanimous in their rating of condemnation as the last possible alternative. Four communities stated that they would not even consider condemnation. Westminster would work out cooperative agreements with irrigation companies rather than condemn. Of the fourteen communities responding, most were non-commital on whether they would attempt condemnation. Nine towns or 64% said they did not know if they would consider condemning rights. As one town official put it, condemnation is an unpleasant alternative and he "hoped they don't have to" condemn. Only one town, in the heavily-populated Front Range, would definitely consider condemnation, but only if the water right were not currently being used.

Most of the municipalities questioned are not actively seeking water rights for purchase. Only four of the fifteen communities responding (27%); Broomfield, Nucla, Steamboat Springs, and Westminster; have a standing policy to purchase water rights as soon as they become available. Yet, all of the communities are unanimous in their prediction that, neglecting the effects of inflation, water rights will cost more in the future.

Nine towns or 60%, including all but one of the fast-growing Type III towns, did not know whether or not there were water rights for sale in their area. Presumably, these towns rely on developing new water, waiting for sellers of rights to approach them, or obtaining usable rights through developer donation policies to fulfill their future water needs. Four towns, including two with policies to acquire water when available, stated that there were no rights to be purchased in their area at the present.

Two towns are currently in the process of purchasing existing rights. The officials of one of the towns would not elaborate on the transaction. The other city, Westminster, is planning to purchase 10,000 acre-feet of irrigation rights at a price of $2000-$3000 acre-foot.

The majority of towns surveyed do not have a developer donation policy. Only four towns; Broomfield, La Jara, Meeker, and Westminster; require new development or annexatons to the municipality to give water rights to the city. Westminster only requires residential developments to do this. Rangely's policy only requests, but does not require donations.

The surveyed communities are all confident that new water supplies can be developed. Several towns are currently proceeding with a project or have completed one in the recent past. Crested Butte has completed a test well for $40,000 and is contemplating drilling a 0.5 MGD well at a cost of $250,000 for a total cost of $520/acre-foot. This is comparable to Longmont's 1979 estimate of the cost to drill shallow wells in the St. Vrain basin of $500/acre-foot (4). Westminster estimates that drilling deep wells yielding 1000 acre-feet/year will cost $3000/acre-foot.

In 1973, Steamboat Springs enlarged their reservoir storage at a cost of $450/acre-foot. Currently, Broomfield has plans to increase their raw water storage from 3200 acre-feet to up to 7000 acre-feet for a cost of $3.6 million or more than $950/acre-feet. Nucla plans to expand reservoir storage as well. To enlarge Standley Lake by 5000-10,000 acre-feet, it will cost Westminster $1500/acre-foot. Rangely has extensive plans for future storage projects including Rangely Dam, Wolf Creek Dam and the Yellow-jacket Project at the White River headwaters.

Many towns have plans to construct more treatment facilities as well. Information on planned water and wastewater treatment plants is available in Table 2-4.

Water Conservation

A variety of techniques have been used by Colorado municipalities to reduce water consumption. However, only a very few communities have extensive programs aimed at significantly lowering water use. The majority of towns use methods which require little effort, such as inserting educational pamphlets with bills, or methods which are a part of ordinary system operation, such as leak repair or metering new construction in metered towns. The most popular methods were metering, leakage reduction, and education. Predictably, the communities most needing to conserve because of limited supply practiced more of the conservation techniques.

Three of the unmetered towns surveyed have begun requiring metering in new construction, and one town has just completed a metering program. Englewood and Granby are both approximately 10% metered as a result of their requirements for meters in new construction. Crested Butte, which has required metering since 1979, is 5% metered.

TABLE 2-4

Size and Cost of Planned Treatment Facilities

Town	Size of Facility	Cost
Water Treatment		
Broomfield	4 MGD	$ 1,500,000
Cheraw	0.1 MGD	39,000
Crested Butte	0.5 MGD	300,000
Englewood	8 MGD	1,000,000
Meeker	0.05 MGD	78,400
Rangely	4.32 MGD	3,300,000
Westminster	10 MGD	5,100,000
Wastewater Treatment		
Broomfield	1.8 MGD	2,000,000
Englewood	13.3 MGD	20,000,000
Rangely	1 MGD	450,000
Westminster	2 MGD	8,400,000

Rangely, which completed metering in 1981, has shown a drop in water use. In 1981, 168 MG were distributed as compared to 196 MG in 1980--a drop of 17% in use. However, even though temperatures were very slightly higher in 1981 than 1980, Rangely received 0.22 inches more precipitation during the irrigation season in 1981. The towns of Meeker and Steamboat Springs, both located in the same general geographic area, showed drops of 11% and 12% respectively in water use from 1980 to 1981. Therefore, a 5-6% drop in water use can likely be attributed to Rangely's metering program.

Four of the surveyed towns, Broomfield, Crested Butte, Rangely, and Westminster, appear to have particularly comprehensive well-developed conservation programs. Westminster's program has been successful in significantly lowering water use without noticeably affecting lifestyle and has served as a model for conservation programs in other cities. Although the town of Meeker does not have an exceptional conservation program, they do require water-saving devices to be installed in new construction--a method which can be effective in reducing future water demands in a town expecting rapid growth.

Although conservation can reduce water use, the water saved cannot always be stored for use during future shortages. When asked if they would have enough storage to save unused water if a conservation program reducing use by 30% were instituted, only two out of seven towns (29%) replied that sufficient storage was available.

Municipal Supplies During Drought

Many of the surveyed municipalities experienced lowered yields of direct-flow rights during the 1976-1977 and the 1981 droughts, but few experienced any supply problems because of this. The situation could change during future droughts, however, as Colorado continues to increase in population.

The yields of the cities which provided information on drought flows are presented in Table 2-5. Broomfield, although it did not supply figures on water yield, experienced a water shortage and was forced to rent water from Denver at $125/acre-foot. To avoid future problems, they instituted a conservation program, purchased water rights, and leased water.

Crested Butte experienced a frozen raw water transmission line and was forced to replace the line and bury it deeper. Rangely was able to obtain an adequate water supply after channeling the streambed so that pumps could capture the low flow. Use restrictions, releases of stored water, and senior water rights' calls on the river also helped Rangely through the crisis.

In 1977, a series of workshops for water officials around the state were held to determine the effects of the drought of the previous two years (5). Norwood, Nucla, Naturita, and Dove Creek--all of which are located in the southwestern corner of the state in the Dolores-San Miguel River drainage basin--experienced severe water shortages when rivers dried up. It was felt by the affected municipalities that there is not enough municipal storage in the Colorado basin to prevent shortages during drought.

It was reported at the workshops that Grand Junction used the increased revenues from raised water rates to install more pumps to take water from the Gunnison River. Craig, which is dependent on direct flows

TABLE 2-5

Yields of Direct Flow Rights During Drought Years

Town	Percent of Normal Yield 1976	1977	1981
Aguilar	80	80	80
Rangely	--	50	80
Steamboat Springs	44	35	--
Westminster	97	64	69
Yuma	70	74	75

Source: April, 1982 survey

in the Yampa river, found it necessary to use water from the Colorado Division of Wildlife reservoirs when their municipal supplies ran low.

Only a few towns have a contingency plan to deal with shortages due to drought. Of sixteen towns surveyed, only seven (44%) had a drought contingency plan. The plans of these towns--Aguilar, Broomfield, Crested Butte, Englewood, La Jara, Rangely, and Westminster--depend mostly on education and increasingly more stringent restrictions. Crested Butte has found the most effective way of enforcing restrictions is to impound the hoses and sprinklers of offenders. Westminster relies heavily on educational programs to ensure cooperation during a drought.

A few towns, located mostly in metropolitan areas, can rely on rental water to help in a crisis. Only three of fifteen towns are able to rent water from another source, and five do not know if rental is possible. Broomfield can rent water for $45-100/acre-foot. Westminster is able to rent water from the Vidler Tunnel Company and Coors for $100/acre-foot.

Comparison of Residential Water Use for Conserving and Non-Conserving Municipalities

The water use estimates of the previous section indicated that metered communities had lower residential water use than unmetered communities. However, residential water use estimates based on values for consolidated municipal use are dependent on assumptions of the number of people per household, the percentage of municipal use which is non-residential, and other factors. Therefore, these estimates may not be accurate.

In order to more accurately determine the differences in residential water use between conserving and non-conserving municipalities, an analysis of water use was conducted for three communities which follow different water management policies. Fort Collins is an unmetered community which has, at times, instituted lawn watering restrictions; Boulder is a metered community with a uniform rate structure and has only asked for voluntary water use reduction; and Westminster is metered with an inclining block rate and seeks water use reduction through pricing. All of the cities have plumbing codes designed for reducing in-home water use.

Boulder

Population. In 1970, the population within the City of Boulder was 66,870; by 1980, the population had grown to 76,677--an increase of 14 percent in 10 years (3). Boulder plans on limiting growth to 2 percent per year through the year 2000. In addition to the people served water within the city, there were, in 1980, an estimated 9000 people served outside the city.

The 1980 U.S. Census for Boulder indicated that, on the average, there were 2.4 persons per dwelling unit (3). A mail survey in 1980 of a sample of Boulder's single family water customers indicated a population density of 2.7 persons per household (6). If 2.5 persons/unit are assumed and multiplied by 30,287 units (as estimated by Boulder's City Planning Department) the resulting population is very close to the 1980 census. In the unincorporated areas outside the city that receive city water service, the Boulder County Planning Department estimates the density at 3.0 persons per dwelling.

Water use. Boulder's historic water use is shown in Table 2-6. The most appropriate estimate of average use appears to be 0.21 acre-feet, based on periods of normal or above normal precipitation. This figure does not reflect simply residential use, but is based on total treated water consumed for all purposes--industrial, commercial, system leakage, etc.

Boulder's water accounting ledgers date back to January of 1974 with several gaps existing in the monthly reports. These were filled in on the basis of average consumption during the same period in other years. With the gaps filled, the average annual use per dwelling unit was determined by dividing total monthly water use by the total numbers

TABLE 2-6

CITY OF BOULDER HISTORIC TREATED WATER USE

Year	Estimated Service Population	Total Water Use (Acre-Feet)	Estimated Average Use Per Person (A.F.)	Annual Precipitation (in.)
1970	--	--	--	16.65
1971	--	14,326	--	18.69
1972	--	14,724	--	18.43
1973	--	15,690	--	20.21
1974	82,900*	17,300	.21	15.11
1975	84,600	16,920	.20	18.24
1976	84,300	16,952	.20	14.66
1977	83,600	16,025	.19	14.50
1978	84,000	17,809	.21	23.11
1979	84,500	17,915	.21	23.72
1980	85,200	19,875	.23	11.95

*City accounting records begin in 1974.

of billed accounts and then summing. The result of the calculation--155,000 gallons per year per household inside the city and 179,000 gallons per year per household outside--is shown in Table 2-7. Further breakdowns into household and sprinkling uses are also shown.

It was assumed that daily patterns and rates of domestic use are essentially the same in winter as in the summer. Therefore, winter daily use in the months of January, February, and March was considered to be equal to the average daily domestic consumption year-round.

Annual lawn sprinkling consumption was isolated from total domestic use by averaging the mean annual winter consumption over a twelve-month period and subtracting it from the total mean annual use. It should be noted that lawn sprinkling use was not determined from the seasonal period because of the uncertainty in the number of days a homeowner actually waters.

Using the total annual sprinkling use figure of 67,400 gallons/year, as shown in Table 2-7, and an average lawn size of 6100 square feet (7), the average annual lawn sprinkling application, for inside-city residents, is 18 inches. According to the consumptive use graph (Figure C-2) in Appendix C, 18 inches of consumptive use corresponds to an 82% probability of being exceeded. On the graph, 22 inches of consumptive lawn sprinkling has a 50% chance, on the average, of being exceeded, and it appears as though this is the median value for Boulder's ideal lawn sprinkling use. These factors point to the possibility that the average homeowner in Boulder, because of the metering rate, applies 4 inches less water than the lawn actually requires, or 82% of the requirement. The other possibility is that the average lawn size is overstated. See p. 30 for further discussion of lawn size in Boulder.

TABLE 2-7
BOULDER'S WATER CONSUMPTION
FOR SINGLE FAMILY RESIDENCES
(1974-1981)

Mean Annual Water Use/Dwelling	
Inside City	155,000 gal.
Outside City	179,000 gal.
Average Daily Domestic Use/Dwelling	
Inside City	240 gal.
Outside City	280 gal.
Mean Annual Sprinkling Use/Dwelling	
Inside City	67,400 gal.
Outside City	76,800 gal.
Average Daily Sprinkling Use/Dwelling	
Inside City	185 gal.
Outside City	210 gal.
Average Daily Domestic Use/Capita	
Inside City *	96 gal.
Outside City **	93 gal.
Average Daily Sprinkling Use/Capita	
Inside City *	74 gal.
Outside City **	70 gal.
Estimated Total Daily Use/Capita	
Inside City	170 gal.
Outside City	163 gal.

* Assuming 2.5 persons per dwelling
** Assuming 3.0 persons per dwelling

Fort Collins

Population. Fort Collins has often been described as the nation's fastest growing city in the under 100,000-population category. The U.S. Census estimates the 1970 population at 43,337; by 1980, it had grown to 64,632--an increase of 49 percent (3). Estimates made by the City of Fort Collins place the 1980 population at 71,100, however, for an increase of 64 percent. A mail survey of Fort Collins (6) and the 1980 census both indicate that Fort Collins' single family housing density is 2.7 persons per dwelling. Fort Collins serves outside-city customers estimated to be 10 percent of the city population.

Water use. Values for water use in Fort Collins are presented in Table 2-8. It should be noted that the actual water use per capita could

TABLE 2-8

FORT COLLINS HISTORIC TREATED WATER USE*

Year	Service Area Population	Total Water Use (Acre-Feet)	Average Use Per Person (A.F.)	Annual Precipitation (in.)**
1970	48,400	11.257	.23	14.29
1971	50,800	12,048	.24	13.98
1972	54,200	14,007	.26	9.91
1973	56,400	14,358	.25	14.07
1974	59,300	16,810	.28	11.62
1975	60,400	15,186	.25	17.07
1976	61,700	15,160	.25	10.56
1977	64,200	15,216	.24	12.15
1978	67,100	16,426	.24	14.91
1979	69,000	14,168	.21	22.14
1980	71,100	17,339	.24	14.57

*Source: City of Fort Collins

** 23-year average 14.4 inches

be as much as 10 percent higher if U.S. Census population estimates are used instead of Fort Collins' estimates.

It is difficult to establish a good estimate of residential water use in Fort Collins because the major portion of the customers are flat-rate. All commercial, industrial, and outside-city accounts are metered. Multi-family housing, except for duplexes, is also metered. The unmetered customers consist of single family and duplex residents within the city. In order to determine flat-rate customer usage, all metered consumption had to be deducted from the city's total treated usage.

The difficulty of establishing the average use per account was compounded by the city's policy to retain records for only three years plus the current year. There were many gaps within the records which made some of the existing information unusable, and therefore estimates were made by synthesizing the available data as explained below.

Review of the city's water billing ledger shows that 1978 was the only year with a complete record. From the middle of 1979 through the first half of 1980, the number of flat-rate customer accounts was unknown. This meant the record for the winter months of January, February, and March was unusable for 1980 and that total annual consumption for 1979 and 1980 was also unattainable per flat-rate account. However, the average in-house use could be determined for the years 1978, 1979, and 1981 by using the January-February-March figures for those years.

In order to estimate flat-rate consumption, system losses as well as miscellaneous unmetered city uses had to first be estimated and deducted from the total annual water usage. Fort Collins' estimate of water unaccounted-for is 10 percent of the total water treated annually.

Accordingly, a 10 percent loss was deducted for the years 1978 and 1979 and then divided evenly over each of the twelve month periods (see Table 2-9). Because the total water use for 1981 was not available, the average miscellaneous loss for 1978 and 1979 was assumed for 1981. Each month's unmetered use was separated from the total monthly consumption by subtracting all metered consumption (inside and outside city) from the total amount treated. Miscellaneous losses were then deducted and the resulting figure was the total monthly flat-rate consumption. This was then divided by the number of flat-rate customers billed to give the average winter use per account.

For the three years reported in Table 2-9, the mean monthly use is 93,600 gallons per dwelling per year or 7,800 gallons per month per dwelling, or, on the average, 260 gpd/tap. If the density of 2.7 persons per household is assumed, then the average daily in-house use is 95 gpcpd. This, coincidentally, is the same as that estimated for Boulder.

In order to accurately determine outside water use, the average monthly flat-rate use must be computed and then summed over the year. As mentioned previously, 1978 was the only year that had complete information. However, because Fort Collins received 14.91 inches of precipitation in 1978, which is very close to the average year, it is assumed that sprinkling use in 1978 is representative of a normal year.

The total annual 1978 flat-rate water use per dwelling was 234,100 gallons. If the average annual in-house use of 93,600 gallons per dwelling is subtracted from the total 1978 flat-rate consumption, the

TABLE 2-9

DOMESTIC USE FOR FORT COLLINS

Year	Month	Flat Rate Accts	Metered Consumption in City (mg)	Metered Consumption Outside City (mg)	Total Treated Consumption (mg)	Total Unmetered Consumption (mg)	Misc. Losses (mg)	Total Flat Rate Consumption (mg)	Av. Use per Flat Rate Account (gal.)
1978	Annual	--	1,563	361	5,352	3,428	535	--	--
	Jan	12,120	83	18	237	136	45	91	750
	Feb	12,191	92	15	217	110	45	65	530
	Mar	12,251	88	16	277	180	45	135	1,100
1979	Annual	--	1,376	340	4,616	2,900	462	--	--
	Jan	12,838	86	20	250	144	39	105	820
	Feb	12,882	66	20	244	158	39	119	920
	Mar	12,963	86	18	260	156	39	117	900
1981	Annual	--	N/N	N/N	N/N	N/N	N/N	N/N	
	Jan	14,806	99	21	258	138	42*	112	650
	Feb	14,839	101	19	241	121	42*	79	530
	Mar	14,921	85	20	271	166	42*	124	830
Mean Monthly Value									7800

N/N Not Known

* Averaged 1978-1979 Values

resulting figure--attributed to lawn sprinkling--is 140,500 gallons per year per dwelling. Table 2-10 summarizes Fort Collins' flat-rate residential use.

TABLE 2-10
SINGLE FAMILY RESIDENTIAL USE
For Fort Collins (Flat Rate Customers)

Mean Annual Water use/dwelling	234,100 gal.
Average daily domestic use/dwelling	260 gal.
Mean Annual Sprinkling use/dwelling	140,500 gal.
Average daily sprinkling use/dwelling	390 gal.
* Average daily domestic use/capita	95 gal.
* Average daily sprinkling use/capita	140 gal.
Estimated total daily use/capita	240 gal.

* Assuming a density of 2.7 capita/dwelling

In June of 1979, the city of Fort Collins made a computer tabulation of lot size for all flat-rate accounts (8). An average irrigable area per residence of 6370 square feet was estimated by using aerial photos. If the mean annual sprinkling use per dwelling is 140,500 gallons, then the average annual application is 35 inches.

The probability graph of consumptive use (Figure C-2) in Appendix C shows that 21 inches of consumptive use is the approximate mode of the data points for Fort Collins. This consumptive use figure is consistent with Danielson's findings that the rates of evaporation for Fort Collins and Northglenn for the years 1977 and 1978 were 21.1 and 19.7 inches respectively (9). If 21 inches is the accepted average annual use, then Fort Collins flat rate users are applying 14 inches more water than is actually needed.

Westminster

Population. Since the mid-1950's, Westminster has experienced a housing boom that has resulted in a tremendous population increase. In 1970, the city's population was 19,400; by 1980, it had grown to 50,200, an increase of 160 percent. As for density, based on the 1980 census and the total number of dwelling units, the city has estimated that, on the average, there are 2.7 persons per dwelling.

Water use. The city of Westminster has metered its water customers since 1964. The records have been retained, but the manner in which the billings were recorded has made it difficult to use the resulting information. Until the beginning of 1980, each month's consumptive use was added to the previous eleven months, making the task of determining individual monthly use extremely tedious. At the beginning of 1980, the accounting system was revised so that total monthly average use per user type could be readily determined.

To assess Westminster's average monthly domestic use, the entire city's single family consumptive use for January, February, and March was averaged over the years 1979-1981. The mean monthly domestic use, averaged over the entire city, was 5800 gallons per dwelling unit. This equates to an average daily use of 200 gallons per dwelling or approximately 75 gpcpd, as compared with 95 gpcpd for both Boulder and Fort Collins. Westminster's single family water consumption is presented in Table 2-11.

TABLE 2-11
WESTMINSTER'S WATER CONSUMPTION
For Single Family Residences

1980 average water use/dwelling	136,000 gal.
Average daily domestic use/dwelling	200 gal.
1980 sprinkling use/dwelling	64,000 gal.
* Average daily domestic use/capita	75 gal.
Average daily sprinkling use/capita	65 gal.
Estimated total daily use/capita	140 gal.

* Assuming 2.7 persons/dwelling

The city of Westminster has never made a survey to determine average lawn sizes. Therefore, any estimation of the number of inches annually applied to Westminster lawns is subject to conjecture. However, Westminster's 1980 lawn sprinkling use--64,000 gallons per unit as shown in Table 2-11--is close to Boulder's mean sprinkling use of 67,400 gallons per unit (see Table 2-7). As previously determined, Boulder's annual use figure is associated with an average application of 18 inches. If Westminster lawns are approximately the same average size as Boulder's, the application rate would range between 17 and 18 inches.

Meter Route Study

In the preceding section, water usage was given as an average per residence based on total residential use in each city. In this section, water meter routes for Boulder and Westminster are investigated to see if there is a correlation between water usage under differing water management policies for areas with similar socioeconomic character.

The criteria used in selecting meter routes was based on the assumption that (1) family incomes can be equated to average house value assessment, (2) households are relatively close in size, (3) domestic water use habits are similar, and (4) lot sizes are reasonably equal.

Boulder. The water use data for the metered period under investigation is for the years 1974 through May of 1981. The routes, 79 and 82, were chosen on the premise that they would be representative of an actual homeowner's water use behavior for a median-income family in Boulder. The routes are located in Table Mesa in the southern sector of the city.

By tabulating the monthly billing data from each of the route books and averaging the winter months' consumption (January, February, and March), it was calculated that the mean monthly usage was 7600 gallons per account. If 2.5 persons per dwelling are assumed, then the average daily per capita use is 100 gallons, or 5 gpcpd more than the 95 gpcpd calculated in the city-wide analysis of Boulder.

Lawn sprinkling use was determined by subtracting the total domestic use of 7600 gallons per month from the mean annual use of 178,300 gallons per account, resulting in lawn sprinkling consumption of 87,100 gallons per account. This figure is 19,700 more than the 67,400 gallons found in the city-wide analysis.

In 1969, Hanke reported that the average effective irrigable area in route 79 was 0.1271 acres or 5600 square feet (7). This gives an annual lawn watering application of 25 inches, which is 3 inches more than the

22-inch median consumptive use. If the lawn size is taken as 6100 square feet, however, the application rate would be 23 inches. Seet page 21.

Westminster. Three of Westminster's meter routes, Nos. 22, 23, and 25, were chosen for comparison to routes 79 and 82 in Boulder. Using the data for the years 1976-1980, a mean annual use of 160,000 gallons per account was calculated--24,000 gallons more than was determined from the city-wide analysis. The average domestic use, defined by winter consumption, was found to be 6900 gallons per month per account--900 gallons in excess of the figure for city-wide usage previously quoted.

Results of Route Studies. Table 2-12 displays the results of the meter route studies for Boulder and Westminster. Boulder's total use per dwelling is 10 percent greater than Westminster's, with lawn sprinkling consumption being 11 percent greater and household use 9 percent greater. Figures for flat-rate users in Fort Collins are included in Table 2-12 so that a comparison of non-metered and metered cities can be made.

From this study, it is clear that Westminster's conservation program, and particularly its inclining block pricing policy, is influencing homeowners in Westminster to use less water than comparable homeowners in Boulder or Fort Collins.

Conclusions to Chapter Two

The levels of planning and water management vary greatly for water utilities across the state. Metropolitan and other fast-growing areas have been the most likely to develop water management plans which integrate policies for increasing supply with demand reduction.

TABLE 2-12
COMPARISON OF SINGLE FAMILY WATER USE

For Meter Routes in Boulder, Westminster, and Unmetered Users in Fort Collins

Dwelling Item	Boulder Meter Routes 79 & 82 (gal.)	Westminster Meter Routes 22, 23, & 25 (gal.)	Fort Collins (gal.)
Annual Use/Dwelling	178,000	160,000	234,100
Annual Lawn Sprinkling Consumption/Dwelling	87,000	77,000	140,500
Monthly Domestic Use/ Dwelling	7,000	6,900	7,800
Average Daily Domestic Use/Dwelling	250	230	390
Average Daily Domestic Use/Capita	100*	85**	95**

* Assuming 2.5 persons/dwelling
** Assuming 2.7 persons/dwelling

Generally, municipalities in Colorado seem reluctant to commit to comprehensive conservation programs unless forced to do so by supply shortages or rapid growth. Many towns only began awakening to the need for more efficient management of existing supplies during recent droughts. As shown by the survey of Colorado towns, however, supply solutions, particularly development of new supply, are the preferred methods of meeting future water demands and preparing for future droughts.

It appears that management policies are the most significant factor affecting water use. The study of three cities with differing management policies implies that a policy of metering water customers combined with an inclining rate structure results in a reduction in lawn sprinkling use of 40 to 50 percent.

Chapter 3

COST AND AVAILABILITY OF WATER SUPPLIES

The cost and availability of water for municipal use and development is influenced by many factors--the hydrologic conditions in the area, the number and type of competitors for water supplies, the expectation or occurrence of drought, the degree of treatment required, etc. This chapter will discuss the availability and cost of water in Colorado in order to provide a basis for the assumptions used in the scenarios of Chapter 5.

Water Supplies

Purchase of Existing Rights

Most municipalities contacted know little about the current state of water rights sales, and those who do are generally hesitant to release information. There is no public record of the purchase price of water rights, and sales are usually only recorded when application is made to the courts for a transfer of the purchased right. Since competition for the available supply is very keen in some areas, information on the sale of rights is likely to be kept confidential in order to avoid price inflation of other rights in the area.

Since there is no established water rights market or market value, municipalities must evaluate purchase prices based on past purchases or knowledge of sales to others. However, it is difficult to determine the value of a right by comparison with other direct-flow rights or with shares in a different ditch company since priority dates differ, some rights or shares are enhanced in value by storage, and the times of year when diversion can be made differs.

Although the State Water Engineer's Office was not able to supply any detailed information on the value of water rights in Colorado, they did state that a price of $5000/acre-foot was a likely upper limit for the purchase price of a prime right in today's market (10). More detailed information can only be obtained from the municipalities themselves.

In 1981, water managers in northeastern Colorado were interviewed in order to obtain estimates of water rights values. Even though northeastern Colorado water values may differ from less abundantly supplied or less populated areas, they will be taken as representative of colorado due to lack of data for other areas.

In 1981, water from the Colorado-Big Thompson (CBT) Project sold for $1300-$2200/share with an average $1850/share price. The annual O & M assessment is $5-$5.50/share. The firm yield of a CBT share is 0.60 acre-foot per share, but yields have averaged 0.75 acre-foot per share since 1957. It has been the policy of the conservancy district to provide a full acre-foot per share in dry years. This policy has led many water managers in northeastern Colorado to equate one share of CBT water with one acre-foot.

By 1981, CBT water had increased by 285% over the amount of $480/share paid by Boulder in 1974. The market appears to have varied somewhat according to hydrologic conditions. When annual precipitation was well below average in 1976 and a CBT share yielded a full acre-foot, the price jumped from $466/share to $1150/share. Longmont also reports that the price of CBT water has risen over the years. In 1960, CBT units were purchased for $50. Purchases in subsequent years rose in price as follows: 1965 - $100; 1970 - $300; 1975 - $500; 1979 - $2200 (4).

The Windy Gap Project also will provide water for northeastern Colorado. The project will produce an average of 48,000 acre-feet of water each year at a project cost of $46.8 million. The estimated annual cost of delivering the water is $12.5 million or $262/acre-foot. If an infinite project life and a discount rate of 11% are assumed, the total capitalized cost is $2345/acre-foot.

Information was also collected on local ditch rights. Values of ditch stock vary according to their reliability. Boulder has purchased shares in Farmer's Ditch Company which have an average yield of 60 acre-feet/share, but a firm yield of only 20 acre-feet/share. Based on an average year, Farmer's costs $233.50/acre-foot, but this rises to $700/acre-foot when calculations are based on the more important dry year yield. Farmer's has no reservoir storage and withdrawals are made only during the irrigation season.

North Poudre Irrigation Ditch Company, near Fort Collins, has a dependable yield of 5.3 acre-feet/share. In 1981, company shares sold for $1500/acre-foot. This is an increase of 207% from 1974.

The values of water rights in the Denver area are also increasing quite rapidly. Some water rights in Clear and Ralston Creeks recently increased more than 30% in a year. In 1980, shares in Farmer's Highline Canal Company sold for $2300/acre-foot. These shares sold for $580/acre-foot in 1975.

The Farmer's Reservoir and Irrigation Company (FRICO), which diverts from Clear Creek, yields 7.5 acre-feet/share and includes 8.2 acre-feet of storage with each share. Because of the reliability created by storage, FRICO shares sold for $3200/acre-foot in 1981--up from $600/acre-foot in 1975.

These values for ditch stock are comparable to the prices paid by cities for direct-flow rights. As mentioned in Chapter 2, Westminster is currently in the process of purchasing irrigation rights at a cost of $2000-$3000/acre-foot. In 1979, Longmont evaluated water rights of 8000 acre-feet of direct flow and 2500 acre-feet of storage obtained through developer donation at $2860/acre-foot (4).

Developer Donation Policies

Although developer donation policies can add significantly to a municipality's water supply, it should not be expected to provide for all future needs. Longmont's water policy, which requres a donation of two acre-feet of direct-flow per acre of annexed land, has provided an average of 1.96 acre-foot of usable water and a 0.6 acre-foot of water storage per acre (4). It is estimated that residents of Longmont use approximately 2.3 acre-feet of water per developed acre.

Some cities with developer donation policies allow payment in lieu of donation. Fort Collins' in-lieu-of rate has reflected the changes in price of water rights. In 1974, the rate was $400/acre-foot. This increased by 550% to $2200/acre-foot in 1980. The rate dropped in 1981, however, to $1900/acre-foot in response to the drop in price of CBT units as the Windy Gap Project comes closer to being completed. The in-lieu-of rate is kept above the current price of local ditch stocks to help maintain their value.

The true cost of a water right is equal to the cost of purchase plus the costs of transferring the right to a different location and/or a different use. Therefore, donated rights are not free, but will cost the city in legal fees and engineering and administrative costs. Recent transfers of 7000 acre-feet of agricultural rights by Westminster took three years to proceed through the courts and cost $160,000 or $23/acre-foot. Longmont has recently begun transferring the donated rights that have accumulated over the years. The estimated cost of these transfers is $66-$75/acre-foot (4).

Development of Water Supplies

As revealed in the survey discussed in Chapter 2, all of the Colorado municipalities questioned feel that new water supplies are available through development. Available information indicates that the costs of building new reservoirs have increased, however, since the better dam sites are already built on and increasing environmental concerns are being addressed. The costs of developing reservoir storage for several past and present projects are presented in Table 3-1.

Price Trends of Water Supplies

Municipalities, such as Westminster, which have followed the policy of purchasing water when available have found that water rights have been a good investment because they have grown faster in value than the rate of inflation. As shown in Figure 3-1, water rights slowly increased in price until the mid-1970's, when water prices skyrocketed. Part of this increase can be explained by inflation as indicated by the rise in the Consumer Price Index plotted in Figure 3-2. The averages of the real values (adjusted to constant 1982 dollars) for the water rights of Figure

TABLE 3-1

Costs of Providing Reservoir Storage

Project Constructor	Reservoir	Cities Supplied	Year Completed	Annual Yield for Municipal Purposes (ac-ft)	Cost ($/ac-ft)	Real Cost** (1982 $/ac-ft)
Bureau of Reclamation [a]	Jackson Gulch	none	1950	10,000 (for irrigation)	$ 390	$2,847
Conejos Water Conservancy District [a]	Platoro	Antonito, Manassa, Sanford	1951	15,000	320	2,280
No. Fork Conservancy District [a]	Paonia	Somerset, Paonia, Hotchkiss	1962	18,300	430	1,891
Bureau of Reclamation [a]	Vega	none	1962	32,100 (for irrigation)	500	2,200
Steamboat Springs [b]	N/A*- enlargement	Steamboat Springs	1973	N/A	450	900
Aurora [c]	Spinney Mountain	Aurora	1982	20,000	2,250	2,250
Fort Collins [c]	Joe Wright	Fort Collins	In progress	4,800	2,080	2,080
Westminster [b]	Standley- enlargement	Westminster	Proposed	5-10,000	1,500	1,500
Thornton [d]	Gross- enlargement	Thornton	Proposed	71,000	1,600	1,600
Denver [e]	Two Forks	Denver & suburbs	Proposed in 1980	88,000	2,700	3,100

Table 3-1 (continued)

Project Constructor	Reservoir	Cities Supplied	Year Completed	Annual Yield for Municipal Purposes (ac-ft)	Cost ($/ac-ft)	Real Cost** (1982 $/ac-ft)
St. Vrain & [f] Left Hand Conservancy District	Coffintop	Longmont	Proposed in 1979	8,000	3,500	4,300
St. Vrain & [f] Left Hand Conservancy District	Geer Canyon	Longmont	Proposed in 1979	14,600	3,080	3,800

*N/A - Not Available

**Real costs were determined by adjustment with the Engineering News-Record Construction Cost Index.

Sources:

a. Water Conservation Agencies of the State of Colorado, Colorado Water Conservation Board, Denver, Colo., 1963.

b. April, 1982 survey

c. McCoy, G. A., "A Study of Municipal Water Management Policies and Effects on Water Supplies in Northern Colorado," thesis presented to the University of Colorado, Boulder, Colo., 1982, in partial fulfillment of the requirements for the degree of Master of Science.

d. Brimberg, J., "Water Board Wooing Suburbs," Denver Post, Vol. 91, No. 12, Aug. 12, 1982, pp. 1C & 8C.

e. Brimberg, J., "Reservoir Tract to Increase," Denver Post, Vol. 90, No. 206, May 25, 1982, pp. 1B & 4B.

f. Rocky Mountain Consultants, Inc., Longmont Water Study: 1979-2040, City of Longmont, Colo., Nov. 1979.

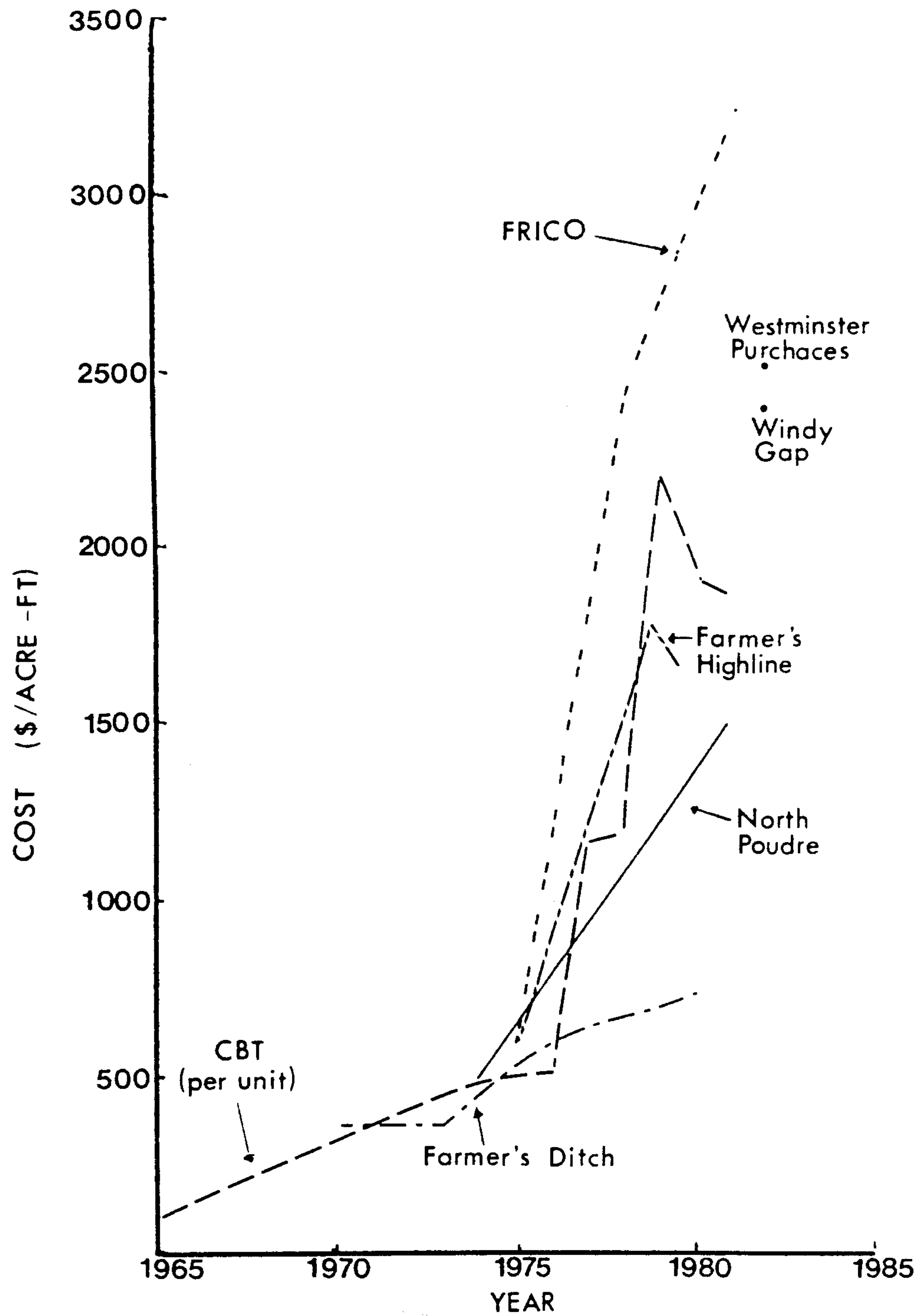

FIGURE 3-1

Raw Water Costs for Colorado

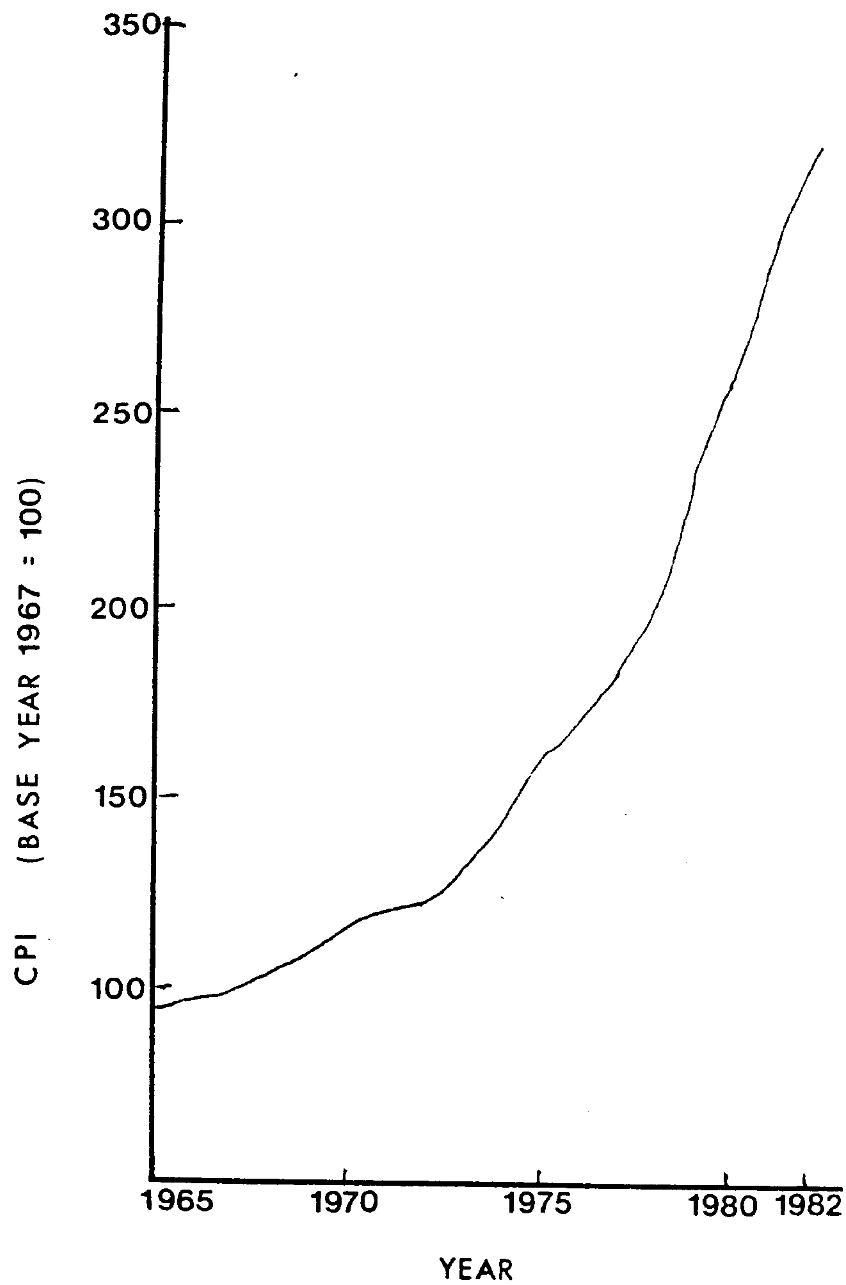

FIGURE 3-2

Consumer Price Index

3-1 are shown in Figure 3-3. It is likely that three factors--population growth, drought, and conversion of water rights from agricultural use to municipal use-- have combined to cause this increase in the real value of water rights.

A close look at Figure 3-3 reveals an almost perfectly linear relationship (note the dotted line) between the 1965-1970 real price levels and the 1982 value. This paper will assume that this linear increase will continue, on the average, into the future. Deviations from this trend can be expected to occur during periods of drought when prices will rise, only to return to the trend in the years following the drought.

The costs of reservoir construction have remained fairly constant at around $2250/acre-foot (in 1982 dollars.) However, as shown in Table 3-1, the costs of proposed reservoirs are higher--averaging $3700/acre-foot. This higher level reflects the efforts currently required to reduce environmental impacts as well as the larger requirements of labor and material needed to make poorer dam sites usable. It will be assumed that this higher price level will continue.

Drought Supplies

Drought is defined more by its effects than by its causes. According to Warrick, "Drought is a water shortage...which results in an otherwise unscheduled modification of water supply management practices (11)". Since a large shortage in annual precipitation, particularly for several consecutive years, will affect water management practices, precipitation records can be used generally to define periods of drought when use of a more accurate method is not feasible.

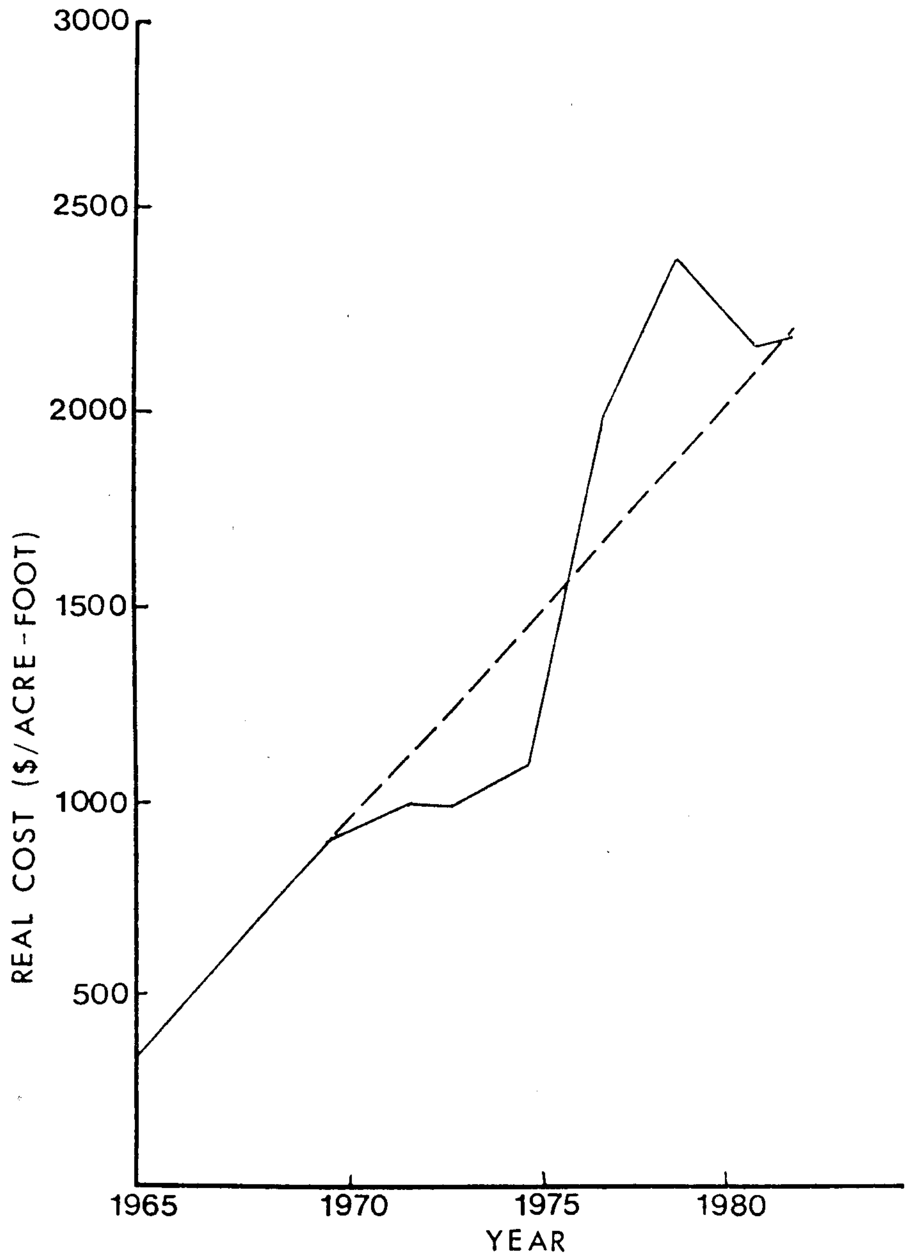

FIGURE 3-3

Real Costs of Raw Water
In Colorado
(1982 Dollars)

Figure 3-4 plots the historical precipitation series for several Colorado communities. Also shown are the mean precipitation and the levels at which precipitation is 10% and 30% below the mean. A single drought year with precipitation at 30% below normal could have serious repercussions.

Although a single year with precipitation at 10% below normal is not likely to cause major problems, several consecutive years with precipitation at this level or less can be devastating. As shown in Tables 3-2 and 3-3, the average precipitation in southeastern Colorado was 90% and 92% of normal in 1976 and 1977 respectively. This reduced precipitation caused the Arkansas River to flow at 50-60% of normal in 1976 and at only 18-20% of normal in 1977. Table 3-4 shows reservoir levels dropped to 10-50% of normal.

The number of times precipitation has dropped to less than 70% of normal in six Colorado municipalities can be determined from Figure 3-4. Also shown, as indicated by the shaded areas in the figure, are the occurrences of two or more consecutive years of precipitation at 90% of normal. The number of occurrences of these events are tabulated in Table 3-5.

These records can allow generalizations concerning the occurrence of drought in Colorado. Each year there is a 2-12% chance that precipitation will be 30% less than the mean. There is an approximate 39% chance that precipitation will be 10% less than the mean in any one year.

If the annual precipitation of one year is less than 90% of the mean, there is an average 15% chance that the precipitation in the succeeding

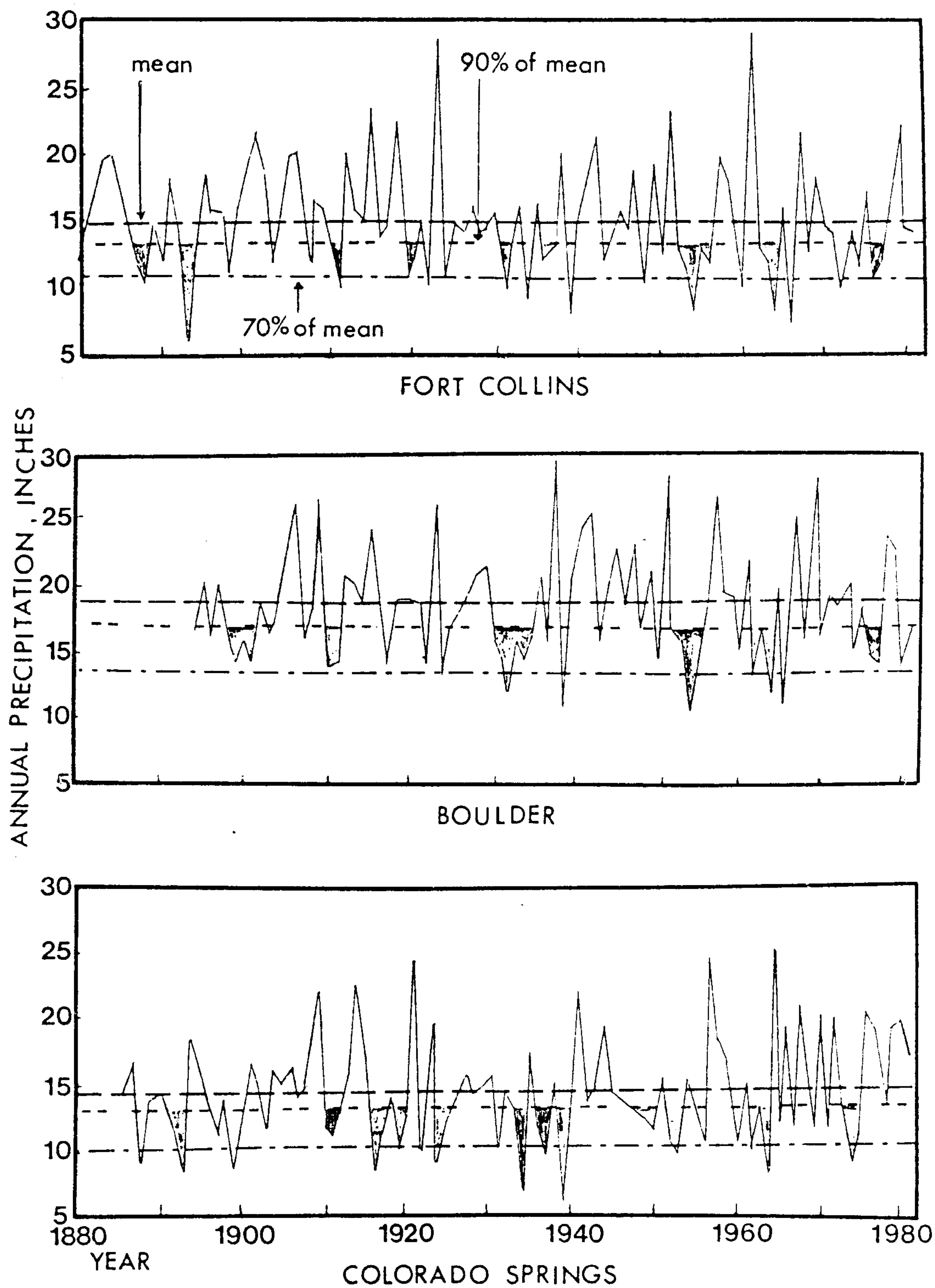

FIGURE 3-4

Annual Precipitation For
Selected Colorado Municipalities

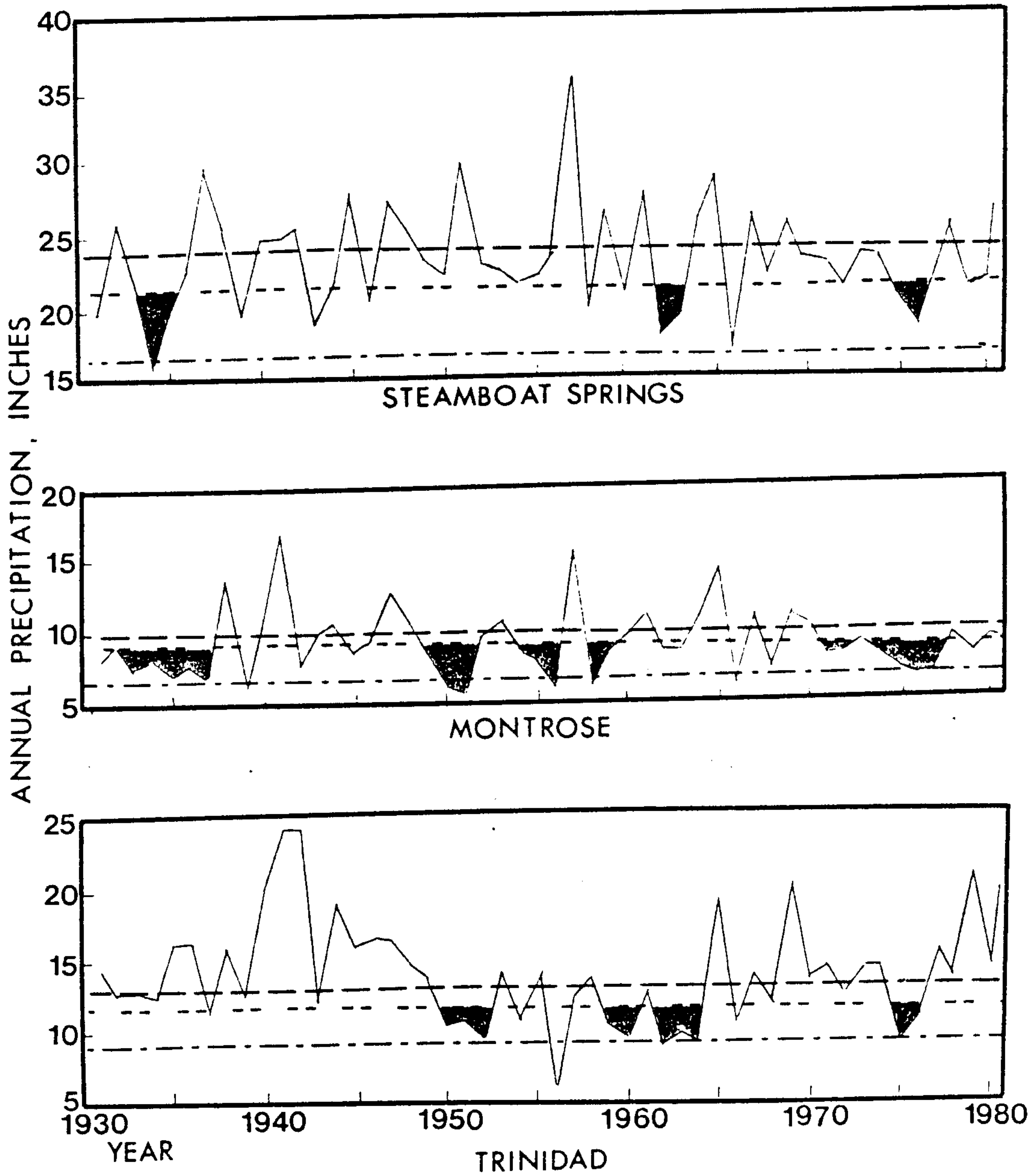

Figure 3-4 (continued)

TABLE 3 - 2

Precipitation During Drought Years

State Region	Station	Percent of Normal 1976	1977
Northeast	Akron	72	80
	Ft. Collins	77	71
	Julesburg	54	118
	Parker	78	120
	Average	88	88
Southeast	Colorado Springs	130	119
	Las Animas	76	87
	Trinidad	81	120
	Average	90	92
South Central	Alamosa	89	113
	Center	76	77
	Average	88	81
West	Aspen	85	90
	Crested Butte	61	80
	Grand Junction	62	66
	Grand Lake	97	115
	Ignacco	91	74
	Montrose	72	75
	Norwood	73	90
	Steamboat Springs	75	92
	Average	77	85

Source: Howe, C. W., et al., "Drought-Induced Problems and Responses of Small Towns and Rural Water Entities in Colorado: The 1976-1978 Drought," Colorado Water Resources Research Institute Completion Report No. 95, Colorado State University, Fort Collins, Colo., June 1980, pp. 13-17.

TABLE 3-3

Streamflow During Drought Years

State Region	River	Percent of 50-Year Avg. 1976	1977
Northeast	Cache La Poudre	NN*	NN
	Upper S. Platte	84	36
	Overall	90	90
Southeast	Cucharas	NN	36
	Arkansas	50-60	18-20
South Central	Rio Grande	NN	20
Southwest	Dolores & San Juan	70	10-20
West Central	Colorado	60	16
Northwest	White	90	8
	Yampa	50-60	16

*NN - Near Normal

Source: Howe, C. W., et al., "Drought-Induced Problems and Responses of Small Towns and Rural Water Entities in Colorado: The 1976-1978 Drought," Colorado Water Resources Research Institute Completion Report No. 95, Colorado State University, Fort Collins, Colo., June 1980, p. 10.

TABLE 3-4

Reservoir Levels During Drought Years

State Region	Area	Percent of Normal 1976	1977
Northeast	Park & Douglas Counties	60	70
	Metropolitan	NN*	NN
Southeast	Trinidad & Pueblo	NN	NN
	Walsenburg	50	50
	North of Arkansas River	10	10
South Central		N/A**	30-45
West Central		N/A	NN-20
Northwest		Below Normal	
Southwest	La Plata River	N/A	25
	Animas & Florida Rivers	NN	NN

*NN - Near Normal

**N/A - Not Available

Source: Howe, C. W., et al., "Drought-Induced Problems and Responses of Small Towns and Rural Water Entities in Colorado: The 1976-1978 Drought," Colorado Water Resources Research Institute Completion Report No. 95, Colorado State University, Fort Collins, Colo., June 1980, pp. 19-23.

TABLE 3-5

Occurrences of Below Normal Precipitation
for Selected Colorado Municipalities

Municipality	Years of Record	No. of Times Annual Precipitation < 70% of Mean	No. of Times Annual Precipitation < 90% of mean	No. of Times First Year < 90% of Mean was Followed by Precipitation < 90% of Mean in at least				
				1 yr.	2 yrs.	3 yrs.	4 yrs.	5 yrs.
Fort Collins	101	12	38	13	4	2	1	0
Boulder	87	6	38	15	9	5	2	1
Colorado Springs	96	12	35	15	2	0	0	0
Steamboat Springs	50	1	16	4	1	0	0	0
Montrose	50	6	28	14	6	3	1	0
Trinidad	50	4	14	6	2	0	0	0

year will also be less than 90% of the mean. There is a 6% chance that three successive years with precipitation less than 90% of normal will occur. There is only a 2% chance that a year with precipitation at 90% of normal will be followed by three or more equally dry years.

Although there is variation among the climates of Colorado's regions, these generalizations concerning drought recurrence will be assumed to be applicable to the entire state. Since the regions of the state are often hydrologically dependent on one another, either naturally or by human intervention, drought in one area can affect the rest of the state. This information will be used to simulate drought cycles in the scenarios of Chapter 5.

Chapter 4

EFFECTS OF CONSERVATION

Recently, as attention has turned to demand modification, researchers have attempted to define the effects of water conservation programs and municipal policies on water demand. Considerable work has been done to determine the actual quantitative change in demand after implementation of a program or installation of a conservation device. A bibliography listing studies which evaluate the effectiveness of various conservation methods is provided at the end of this report.

Several different conservation programs can be developed based on this research. Their effects can range from a negligible reduction to as much as a 63% reduction with crisis rationing. These methods have different levels of public acceptability. The scenarios developed in Chapter 5 will exhibit the savings possible through the implementation of the programs described below.

Conservation Programs

Program 1--Metering. Metering all of the residential taps in a community can reduce household water use by about 30%[1]. Most of this reduction will be in the sprinkling demand, although domestic use can be expected to drop slightly as well. A 30% drop in residential use will

[1] All estimates of use reduction and cost contained in these program descriptions are based on a compilation of the estimates given by the researchers listed in the bibliography mentioned above, unless otherwise noted.

cause a 22% drop in municipal use if residential use accounts for 72% of municipal use.

Metering can also lower the peak use. The peak day to average day use ratio before metering can be assumed to be 2.6.[2] If metering caused peak use to drop by 12%, the new peak-to-average ratio would be 2.3.

Installing a meter in a new home during construction is significantly less expensive than retrofitting. Installation in new construction costs $125/meter whereas the average cost of installing a meter in existing construction is $420/meter. Annual costs for meter maintenance, reading, and billing are $7.50/meter. (See Appendix D for development of metering costs.)

<u>Program 2--Pricing</u>. The amount of water used is dependent upon the price paid. However, the effect of small price increases can wear off with time. A change in price structure has a more definitive, lasting effect.

If the price structure is changed from declining block to inclining block with a summer penalty charge for large peak users, demand for water will drop. Average use would be lowered about 3%. The peak-to-average use ratio would drop by 8%--from 2.3 to 2.1. It is assumed that the new rates produce the same amount of total revenue from water rates as the old rates.

<u>Program 3--Education</u>. A strong continuing education program can lower water use slightly by changing customer habits and attitudes. The main value of a public education program is not the drop in water use it brings by itself, but is the creation of a conservation ethic which enhances the effectiveness of other conservation programs.

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[2] For the years 1971-1979, Fort Collins had a mean peak-to-average use ratio of 2.55 (8).

A strong education program could include monthly bill inserts, a bi-monthly newsletter during the six-month irrigation season which provides information on efficient sprinkling and landscaping techniques, radio announcements, speakers for civic groups, and a water conservation education series for elementary school children. These efforts can be expected to produce a 1% drop in residential use--by reducing both domestic and sprinkling use--at a cost of $10/household/year.

Program 4--Small kit distribution. Conservation devices distributed by the utility to customers can reduce water use. A small kit --containing two plastic bags and clips for placing in the toilet tank, a shower flow restrictor, dye tablets for detecting toilet leaks, and a pamphlet telling how to use the devices--can be manufactured and mass-mailed for about $1.25/kit. The results of the program are shown in Table 4-1.

TABLE 4-1

Results of Program 4

Device	Household Domestic Water Savings (percent)	Households Installing (percent)	City-wide Domestic Water Savings (percent)
Plastic toilet bags	4	35	1.4
Shower restrictors	10	15	1.5
Dye tablets	25	2*	0.5
	Total domestic savings		3.4%

*Percent of households finding toilet leaks and repairing them.

After the initial installation, it can be expected that some of the devices will be removed because of malfunction or dissatisfaction with performance. The savings lost due to this can be recovered if kits are continually mailed to new residents in existing homes as they open water billing accounts. It is assumed that continued installation of new devices more than balances the removal or deterioration of previously installed devices.

Program 5--Large kit distribution. Kits can be distributed door-to-door by school or civic groups for minimal cost. These kits would include two toilet dams, a shower flow restrictor, a faucet aerator, and dye tablets. An educational pamphlet included in the kit would explain how to install the devices, and the kit distributors could provide additional information or installation if needed. The results of this program are displayed in Table 4.2.

TABLE 4-2

Results of Program 5

Device	Household Domestic Water Savings (percent)	Households Installing (percent)	City-wide Domestic Water Savings (percent)
Toilet dams	8	65	5.2
Faucet aerators	3	60	1.8
Shower restrictors	10	30	3.0
Dye tablets	25	3*	0.75
	Total domestic savings		3.4%

*Percent of households finding toilet leaks and repairing them.

Program 6--Building code modification. Installation of water-saving devices can be much more effective in new construction. If building codes were changed to require installation of shallow-trap toilets, flow-restricting showerheads, and faucet aerators on all taps, domestic water use could be lowered by 20% or more. These fixtures would cost approximately $35/house more than ordinary fixtures.

Program 7--Drought contingency. A contingency plan to be implemented during droughts or emergencies can produce large temporary drops in use. This plan would consist of restrictions on the times and types of water use and a strong informational program to make the public aware of the crisis.

In a typical metered city, light restrictions can reduce water use by 10%. Due to the larger sprinkling use in unmetered cities, the same restrictions can produce a 20% decrease in use. Further restrictions can bring reductions of 25-40% in metered or unmetered cities. The level of reduction reached can be increased if a continuous education program has created a conservation ethic. Severe rationing can achieve a 60% reduction in use but can probably only be implemented in metered cities.

It will be assumed that the restrictions program will pay for itself through penalties and special watering permits. The lowered revenues caused by the temporary drop in water use should be taken into account.

Water and Wastewater Savings

As domestic and sprinkling use drops, the amount of treated water required drops, thereby saving chemicals and energy. Likewise, as domestic use drops, the amount of wastewater generated is reduced, possibly saving money as well. A reduction in sprinkling use could also reduce the quantity of wastewater if sewer infiltration is high.

The cost of power and chemicals for water treatment can be assumed to be proportional to the amount of water treated. Therefore, if the average cost were $275/MG,[3] a city which experienced a 10% drop in demand from 5 MGD to 4.5 MGD would save $137.50 daily or $50,190 yearly.

The treatment savings from a reduction in wastewater are not as easily calculated, however, since the cost of wastewater treatment is more dependent on the strength of the wastewater, rather than the quantity. Therefore, a reduction in water use could possibly increase wastewater treatment costs.

The California Department of Water Resources has evaluated the changes which took place in seventeen wastewater treatment plants due to the flow reductions occurring during the 1976-1977 drought (12). The energy use of the wastewater plants dropped to a maximum reduction of 20% at a 50% reduction in wastewater flow. Use of chemicals ranged from a 30% reduction to a 50% increase in use. The change in overall O & M costs ranged from a decrease of 5% to an increase of 4%.

The major savings from wastewater reduction appears to be from delaying capital expenditures for treatment expansions, not from reduced operation and maintenance costs. Further calculations will assume no change in O & M costs as a result of reduced wastewater flows due to implementation of a domestic water conservation program.

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[3] Communications with Pam Mulhall at the city of Westminster and with Jim Carnady, Boulder water treatment plant operator, revealed that Westminster's average cost for treating drinking water was $283/mg and Boulder's cost was $266/mg.

Legal Considerations

It has been suggested that the appropriation doctrine encourages waste by requiring a water right to be used in order to be retained.[4] However, this assumption ignores two important aspects of the law.

First, a water right must be applied to a beneficial use in order to be established and maintained. The courts have ruled many times that a senior appropriator may not take water and waste it when a junior appropriator could put it to beneficial use.

Secondly, some municipalities fear that water rights which will be needed to serve growing populations in the future will be considered abandoned if not taken and put to any use now--no matter how wasteful. This fear is not justified. Abandonment consists of actual non-use and the intent to permanently discontinue use. Municipalities are allowed to hold water rights in excess of their present needs in order to prepare for future growth--not for speculation. The Colorado Supreme Court has ordered that the informed, good-faith opinions of government agencies on the need for future water supplies must be recognized. Therefore, if a city intends to use its excess water in the future and has a well grounded comprehensive plan for use of its rights, there is little chance of losing its water rights through more efficient use.

If a city has established a conditional decree, development of the water right must be pursued with due diligence and full use of the rights made before the decree is made final. Again, intent is important. If a municipality wishes to institute a conservation program at the same time as developing a conditional decree, it is necessary to have a detailed

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[4] A comprehensive review of Colorado water law is provided by Radosevich (13).

TABLE 2-3

Water Use and Percentage of
Residences Metered for Selected Municipalities

Municipality	Total Use/ Cap. (gpcpd)	Use/Res. Tap* (gptpd)	Percent Metered
Type I			
Boulder	192	320	100
Englewood	275	500	10
Ft. Collins	225	600	0
Greeley	296	660	35
Westminster	140	380	100
Type II			
Brighton	242	720	0
Broomfield	141	430	100
Longmont	243	670	0
Loveland	246	640	0
Layfayette	129	340	100
Type III			
Crested Butte	200	460	5
Rangely	185	510	100
Steamboat Springs	260	640	0
Yuma	260	650	100
Type IV			
Akron	185	390	100
Aguilar	120	270	100
Granby	250	610	10
Meeker	234	590	100
Nucla	155	430	100
Walsh	440	1,050	0
Type V			
Cheraw	205	550	100
La Jara	200	610	0

*Includes multi-family housing

comprehensive plan in order to document actual progress and intent for future work on the system as a whole.

Some cities have felt that water may not always be as readily available for purchase or development in the future when competition becomes more intense for the available supply. This is likely to be true, but municipalities are in the unique position of requiring water for a preferred use--domestic supply. They have the power of eminent domain and can institute condemnation proceedings against unwilling agricultural or industrial water rights sellers. Therefore, while other water users may be unable to find new supplies, cities will always be able to obtain sufficient water if they are willing to pay the financial and political price.

When water is used more efficiently, return flows are reduced as the percentage consumed rises. It is questionable whether the downstream users who relied on the return flow have any legal recourse, however. If the water was imported from another watershed, the importer has the right to reuse and dispose of the water without concern to other appropriators. If the water was natural to the stream, it is likely that, unless the right has been transferred, the return flow has never been quantified. Since return flows vary from year to year anyway, the reduction in water availability may never be attributed to the increased efficiency.

A water user is allowed some freedom to make changes in his use. An appropriator is allowed to capture seepage on his land and reuse it, but only on the same land. A farmer could switch to a more water intensive crop or cropping pattern. A change in the point of return to the stream can be made without concern to junior appropriators, since they have no right of control over the water works of an upstream appropriation. Under these conditions, a downstream junior appropriator would have little control over the effects of the change in usage on him. However, releases of raw water from storage may be required to meet the needs of senior appropriators.

The most likely view the courts will take in the future toward more efficient water use was summarized recently in Fellhouer vs. People (14). The concept of maximum utilization of the state's water resources was found to be implicit in the state Constitution. The court stated:

> As administration of water approaches its second century, the curtain is opening upon the new drama of 'maximum utilization' and how constitutionally that doctrine can be integrated into the law of vested rights. We have known for a long time that the doctrine was lurking in the background as a result of the accepted, though oft violated, principle that the right to water does not give the right to waste it.

In the future, efforts to develop new water supplies will work hand-in-hand with efforts to use the existing supply more efficiently.

Chapter 5

SCENARIOS OF THE EFFECT OF WATER CONSERVATION ON MUNICIPAL WATER SUPPLIES

Since the management choices of water utilities are limited by monetary constraints, demand reduction alternatives must be compared to the supply solutions in order to determine the policies which will provide the water needed in the future at the least cost. This determination can be made by using the scenario technique.

This chapter will develop scenarios, for each of the city types described in Chapter 2, to illustrate the possible long-term advantages and consequences of following each of the programs developed in Chapter 4. The costs and benefits occurring over a 30-year period (until 2013) from implementing Programs 1 through 6 will be estimated and presented in terms of present worth for comparison. Additional scenarios, utilizing Program 7, will be developed to illustrate the effects of drought on conserving and non-conserving cities of each type.

Characteristics of the Scenario Municipalities

Population and Growth Characteristics

Table 5-1 presents the current population, density, and growth rates for the hypothetical cities of each type. Type III is characterized by two different examples--III-A and III-B-- which have different growth rates in order to reflect the wide variation in growth rates of the cities on which they are based. (See Table 2-2.) The population densities are assumed to remain constant until 2013.

TABLE 5-1

Population Characteristics and Growth Rates for Hypothetical Municipalities

City Type	1982 Population	Population Density per household	City-wide Domestic Water 1982-2002	2002-2013
I	70,000	2.25	2.7	0.9
II	25,000	2.80	2.4	1.2
III-A	3,000	2.50	3.5	0.8
III-B	3,000	2.50	8.9	0.9
IV	1,100	2.40	0.2	0.2
V	550	2.80	3.9	1.2

Water Supplies

The policy of each of the communities is to possess sufficient water rights to meet the projected annual demand ten years in the future. Water rights are purchased as needed to fulfill this policy. None of the communities have a developer donation requirement.

City Types I, II, and III currently own direct-flow rights which will meet their needs until 1993 at present per capita use levels. The Type IV community expects its supply to meet its needs for at least 30 years until 2013 or later. The Type V town will meet the limits of its current direct-flow supply in 2003 at present levels of per capita water use.

When determining water requirements, the hypothetical cities include a storage reserve factor (RF) to meet demands during drought periods. Storage is also provided to meet seasonal demands. (See Appendix E for calculation of the RF and the seasonal storage requirement.)

The amount of water storage currently available to each of the hypothetical municipalities is sufficient to meet the reserve requirement for some time into the future--until 1993 for City Types I, II, and V; until 1988 for Type III; and until well past 2013 for Type IV. Each of the hypothetical cities, except the Type IV community, is currently planning a storage project to be completed when the storage requirement just equals the amount of storage available. The amount of water and storage currently owned by each of the hypothetical communities is shown in Table 5-2.

TABLE 5-2

Current Water Supplies and Storage

Water Supplies (acre-feet)	City Type					
	I	II	III-A	III-B	IV	V
Direct Flow	34,081	11,246	1,506	2,496	536	401
Storage	50,510	16,688	1,899	2,574	761	414

Treatment Facilities

At present per capita use rates, the capacity of the water treatment plants of all the communities will be met in 1988. Each of the municipalities has begun considering designs for a new treatment plant, to begin producing water in 1988, which will meet treated water needs until 2013.

The wastewater treatment facilities of all the hypothetical municipalities are expected to reach capacity in 1993 at present rates of wastewater generation. New plants, which will meet projected needs until 2013, are presently being planned for completion in 1993.

Current water use and wastewater flows for each of the hypothetical cities are presented along with the present plant capacities in Table 5-3. The maximum water treatment plant capacity is 2.6 times the expected average day demand in 1988. The design capacity of the wastewater treatment plants is 2.25 times the expected average day flow in 1993 (15). The average day wastewater flow will be taken as 145 gpcpd.[5]

Scenarios of Future Water Management Alternatives

In order to compare the water management alternatives available to each of the hypothetical communities, an economic analysis spanning 30 years will be carried out. The analysis is based on the premise that a stream of costs will be generated whether or not the communities practice any of the conservation programs developed in Chapter 4.

Since expenditures will occur on an irregular basis throughout the study period, they will be expressed in terms of present worth (defined as the amount of money, which if set aside in the first year of the analysis, would be equal to the future expenditures at the given discount rate). In order to reduce the dependency of the analysis outcomes on the

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[5] Hopp and Darby estimate that wastewater flows average 145 gpcpd (16). This figure is in agreement with Longmont's experience. In 1979, the Longmont wastewater plant treated an average of 150 gpcpd. It was estimated that residential use accounted for 100 gpcpd, industrial and commercial use made up 40 gpcpd, and infiltration was 10 gpcpd (4).

TABLE 5-3

Water Use, Wastewater Flows, and Plant Capacities
for Hypothetical Municipalities
in 1982

City Type	Average Municipal Water Use (MGD)	Peak Municipal Water Use (MGD)	Average Municipal Wastewater Flow (MGD)	Peak Municipal Wastewater Flow (MGD)	Maximum Water Treatment Capacity (MGD)	Maximum Wastewater Treatment Capacity (MGD)
I	23.33	60.6	10.15	22.8	71.1	30.6
II	7.94	20.6	3.63	8.2	23.8	10.6
III-A	0.95	2.5	0.44	1.0	3.0	1.4
III-B	0.95	2.5	0.44	1.0	4.1	2.5
IV	0.45	1.2	0.16	0.4	1.2	0.4
V	0.17	0.4	0.08	0.2	0.5	0.3

discount rates, three differing rates--low (9%), medium (11%), and high (13%)-- will be used.

In the following analysis, adjustments for inflation will not be included. Instead, all expenditures will be expressed as real costs in 1983 dollars.

Alternatives will be compared from the economic viewpoint of the municipality since there must be sufficient economic advantage to the municipality to implement the programs. Therefore, the water and energy savings of the customers will not be included. Also, the costs to downstream users from reduced return flows due to conservation will not be included in the analysis, since these costs are not borne directly by the city.

Water Use Reduction and Costs Due to Implementation of Water Conservation Programs

Initially, none of the hypothetical cities have metered residential customers. Therefore, their average daily water use is comparable to that of the actual unmetered cities on which each type is based, as shown in Table 5-4. Program 0 involves no changes to the current system operation and assumes that the present levels of water use will continue into the future.

City Types III, IV, and V could complete metering in one year, by the end of 1983. Use reductions from metering would not reach their peak until a year later, at the end of 1984, since demand will not be lowered until customers have become accustomed to paying water bills based on actual water use. If other programs are introduced at the beginning of 1985, reductions in water use should reach their maximum potential by the end of 1985.

TABLE 5-4

Effects of Water Management Programs
on Average Daily Residential Water Use

Program(s) Implemented and Water Savings over Base Program 0	Average Daily Residential Water Use Per Household (gptpd) after Program Implementation in City Type					
	I	II	III-A	III-B	IV	V
Program 0	540	640	570	570	700	610
Program 1	378	448	399	399	490	427
Savings	162	192	171	171	210	183
Programs 1 & 2	367	435	387	387	475	414
Savings	173	205	183	183	225	196
Programs 1 & 3	374	444	395	395	485	423
Savings	166	196	175	175	215	188
Programs 1 & 2 & 3	363	431	383	383	470	410
Savings	177	209	188	188	230	200
Programs 1 & 4	372	440	392	392	483	419
Savings	168	200	178	178	217	191
Programs 1 & 2 & 4	361	428	380	380	469	407
Savings	179	212	190	190	231	203
Programs 1 & 5	359	424	378	378	469	403
Savings	181	216	192	192	231	207
Programs 1 & 2 & 5	348	412	366	366	455	391
Savings	192	228	203	203	245	219
Programs 1 & 6*	342	403	359	359	452	382
Savings	198	237	211	211	248	228
Programs 1 & 2 & 6*	332	391	348	348	438	370
Savings	208	249	222	222	262	240

*The savings from Program 6 (building code modification) apply only to new construction.

City Type II will require two years, until the end of 1984, to complete metering. The maximum reduction in use from metering will be reached at the end of 1985. City Type I will finish metering in three years, by the end of 1985, and will see a maximum use reduction from metering at the end of 1986. If other programs are put into effect in these two city types, they will produce their maximum results by the end of 1987 and 1986 for City Types I and II, respectively.

The costs of program implementation are summarized in Table 5-5. Program 0 obviously has no implementation cost. Program 2 is assumed to have no additional cost (other than possible political costs) if it is put into effect at the same time as Program 1.

Future Additions to Water Supplies

If the hypothetical communities institute conservation programs, they will reduce their need to acquire additional water supplies to meet future demands. Since the conservation programs are aimed at reducing water use by residential customers, it will be assumed that other types of municipal use are unaffected by the programs and remain equal to 72% of the municipal use under Program 0.

As an example of the reductions in water supplies which are possible, Figure 5-1 diagrams the required direct-flow supplies for City Type I with no conservation, with metering, and with a strong conservation program. These figures are followed by Table 5-6 which summarizes the cost of additions of direct-flow rights under each program for each city type. Table 5-7 shows the size and cost of storage additions for each city type under each program.

City Type IV is not represented in Table 5-6 or 5-7 since its current water supplies and storage will meet its needs until after 2013.

TABLE 5-5

Costs of Program Implementation

For Program(s)	Present Worth ($) in 1983 For City Type I	II	III-A	III-B	IV	V
0	0	0	0	0	0	0
1 - At 9%	$13,357,000	3,937,000	575,000	779,000	194,000	96,000
11%	12,969,000	3,857,000	565,000	735,000	194,000	94,000
13%	12,630,000	3,790,000	558,000	701,000	194,000	92,000
2+	0	0	0	0	0	0
3 - At 9%	3,406,000	1,018,000	168,000	324,000	44,000	29,000
11%	2,698,000	819,000	136,000	252,000	37,000	23,000
13%	2,179,000	673,000	113,000	201,000	31,000	19,000
4 - At 9%	45,630	13,760	2,020	2,410	720	380
11%	40,340	12,380	1,850	2,200	660	340
13%	36,060	11,240	1,300	2,030	610	310
5 - At 9%	344,000	103,550	15,300	17,830	5,320	2,550
11%	318,330	97,580	14,690	17,110	5,100	2,440
13%	295,000	92,060	13,380	15,600	4,650	2,230
6 - At 9%	267,330	74,770	17,010	69,450	300	3,260
11%	218,720	61,440	14,280	57,130	240	2,710
13%	181,100	51,310	12,160	47,650	200	2,300

+If Program 2 is put into effect at the same time as Program 1, there is no additional cost.

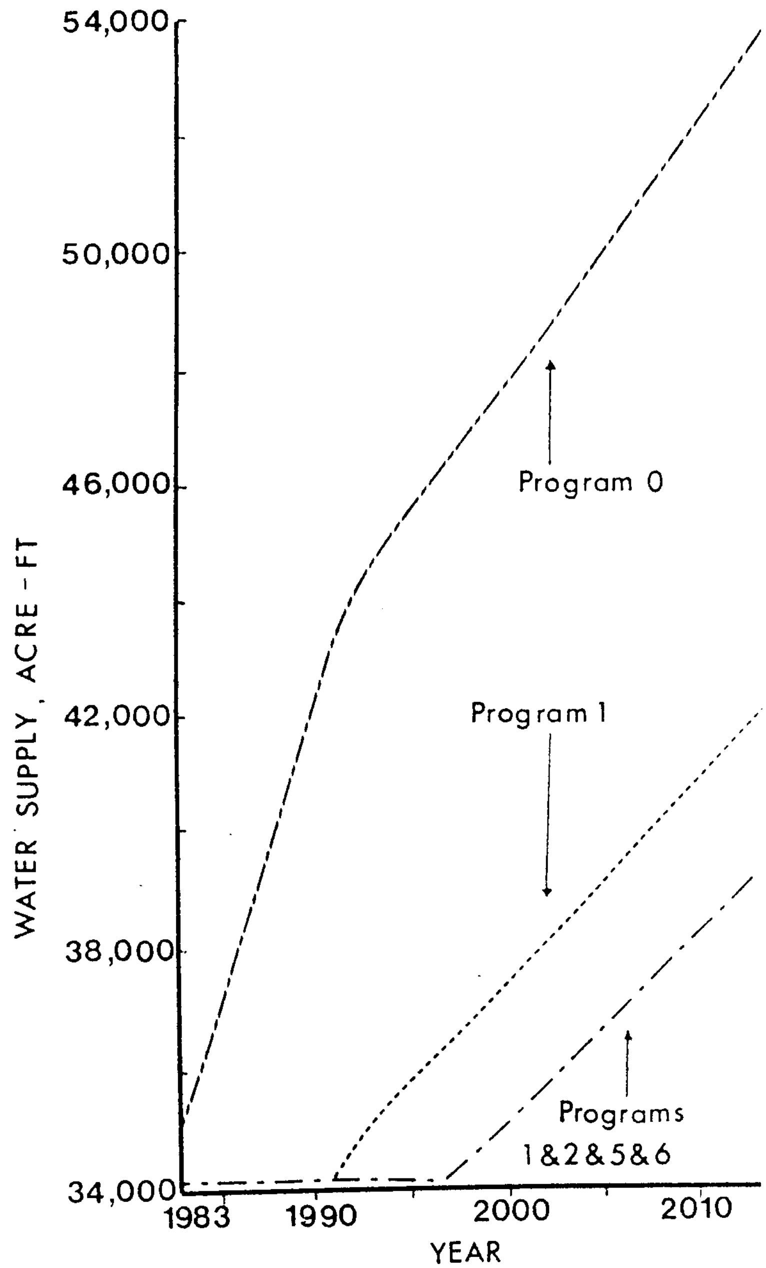

FIGURE 5-1

Municipal Water Supply
Under Programs 0, 1, and
1 & 2 & 5 & 6 for
City Type I

TABLE 5-6

Costs for Additions to Direct-Flow Rights

Under Program(s)		Amount of Direct-Flow Rights Held in 2013 (ac-ft) and Present Worth (10^3 \$) in 1983				
		For City Type				
		I	II	III-A	III-B	V
0 --	Amount	53,635	18,274	2,517	7,065	515
Present Worth	At 9%	27,059	8,934	1,487	7,161	95
	11%	23,494	7,590	1,309	6,373	68
	13%	20,756	6,583	1,170	5,699	50
1 --	Amount	42,050	14,327	1,973	5,539	404
Present Worth	At 9%	7,137	2,487	512	4,429	1
	11%	5,305	1,780	407	3,832	1
	13%	4,012	1,295	329	3,351	0
1 & 2 --	Amount	41,263	14,060	1,935	5,432	401
Present Worth	At 9%	6,040	2,156	453	4,242	0
	11%	4,388	1,514	356	3,661	0
	13%	3,241	1,079	284	3,194	0
1 & 3 --	Amount	41,764	14,245	1,960	5,503	401
Present Worth	At 9%	6,738	2,383	497	4,366	0
	11%	4,971	1,695	394	3,774	0
	13%	3,732	1,225	318	3,298	0
1 & 2 & 3 --	Amount	40,977	13,978	1,922	5,396	401
Present Worth	At 9%	5,652	2,059	436	4,181	0
	11%	4,066	1,437	275	3,606	0
	13%	2,973	1,018	145	3,143	0

TABLE 5-6 (continued)

Under Program(s)	Amount of Direct-Flow Rights Held in 2013 (ac-ft) and Present Worth (10^3 \$) in 1983 — For City Type I	II	III-A	III-B	V
1 & 4 & 6 -- Amount	40,669	13,808	1,895	5,239	401
Present Worth					
At 9%	5,366	1,903	384	3,930	0
11%	3,566	1,321	297	3,382	0
13%	2,809	931	243	2,942	0
1 & 2 & 4 & 6 -- Amount	39,914	13,562	1,859	5,139	401
Present Worth					
At 9%	4,415	1,633	345	3,322	0
11%	3,085	1,006	264	3,227	0
13%	2,187	769	206	2,800	0
1 & 5 & 6 -- Amount	40,152	13,633	1,874	5,215	401
Present Worth					
At 9%	4,664	1,695	351	3,881	0
11%	3,276	1,158	256	3,336	0
13%	2,336	802	218	2,898	0
1 & 2 & 5 & 6 -- Amount	39,397	13,386	1,838	5,115	401
Present Worth					
At 9%	3,794	1,442	312	3,273	0
11%	2,596	967	256	3,180	0
13%	1,801	657	218	2,756	0

TABLE 5-7

Costs for Water Storage Additions

Under Program(s)		Year of Completion, Size of Project* (ac-ft) and Present Worth** (10^3 \$) in 1983 — For City Type I	II	III-A	III-B	V
0 --	Year+	1993	1993	1988	1988	1993
	Size	14,200	4,178	1,211	5,989	178
	Year	2003	2003	2003	2003	2003
	Size	6,065	2,643	258	803	75
Present Worth						
	At 9%	26,196	8,274	3,082	14,931	328
	11%	21,287	6,657	2,778	13,520	266
	13%	17,426	5,403	2,515	12,286	218
1 --	Year	2001	2003	1994	1990	1999
	Size	5,801	2,029	783	4,882	116
Present Worth						
	At 9%	4,550	1,339	1,123	9,881	108
	11%	3,280	931	919	8,701	81
	13%	2,378	652	755	7,679	61
1 & 2 --	Year	2002	2004	1995	1990	1999
	Size	4,754	1,682	732	4,739	106
Present Worth						
	At 9%	3,421	1,019	963	9,591	99
	11%	2,422	695	774	8,446	74
	13%	1,726	478	625	7,454	55
1 & 3 --	Year	2001	2003	1994	1990	1999
	Size	5,417	1,919	766	4,833	113
Present Worth						
	At 9%	4,249	1,267	1,089	9,782	105
	11%	3,063	880	899	8,614	79
	13%	2,221	616	739	7,602	59

TABLE 5-7 (continued)

Under Program(s)		Year of Completion, Size of Project* (ac-ft), and Present Worth** (10^3 \$) in 1983 For City Type I	II	III-A	III-B	V
1 & 2 & 3 --	Year	2003	2005	1995	1990	1999
	Size	4,371	1,573	714	4,691	103
Present Worth						
	At 9%	2,885	874	939	9,494	96
	11%	2,005	586	755	3,361	72
	13%	1,404	396	609	7,378	54
1 & 4 & 6 --	Year	2004	2006	1995	1991	2000
	Size	3,887	1,347	671	4,438	91
Present Worth						
	At 9%	2,354	687	883	8,241	78
	11%	1,606	452	710	7,125	57
	13%	1,105	300	573	6,530	42
1 & 2 & 4 & 6--	Year	2006	2007	1996	1991	2000
	Size	2,884	1,028	622	4,306	82
Present Worth						
	At 9%	1,470	481	751	7,996	70
	11%	968	311	593	6,913	51
	13%	641	202	470	5,994	38
1 & 5 & 6 --	Year	2006	2007	1996	1991	2000
	Size	3,030	1,056	636	4,398	85
Present Worth						
	At 9%	1,545	494	768	8,167	73
	11%	1,017	319	606	7,061	53
	13%	674	208	481	6,122	39

TABLE 5-7 (continued)

Under Program(s)	Year of Completion, Size of Project* (ac-ft), and Present Worth** (10^3 $) in 1983 For City Type I	II	III-A	III-B	V
1 & 2 & 5 & 6--Year	2008	2009	1996	1991	2001
Size	2,032	738	587	3,950	75
Present Worth					
At 9%	872	291	708	7,335	59
11%	553	181	559	6,341	42
13%	354	114	444	5,498	.31

*The projects are sized to provide sufficient storage to meet needs until 2013.

**Storage projects are assumed to cost $3700/ac-ft in the year in which they are completed.

+If no conservation methods are practiced, as under Program 0, two projects will be required to meet needs until 2013.

Therefore, the Type IV commuity will have no expenditures for additional water supplies.

Future Treatment Expansions

Since each of the hypothetical communities are facing the prospect of constructing a new water treatment plant in 1988 and a new wastewater treatment plant in 1993 if present use levels continue, they have begun considering metering and conservation as management alternatives. The water and wastewater treatment facilities which would be required under Programs 1 through 6 are described in Tables 5-8 and 5-9.

The O & M costs for water treatment under each program are delineated in Table 5-10. As previously discussed in Chapter 4, wastewater treatment O & M costs are assumed to remain constant as wastewater flows are reduced. Cost information for the treatment plant components, on which the present worth values in Tables 5-8 through 5-10 are based, can be found in Appendix F.

The peak wastewater flow is assumed to remain at 2.25 times the average flow. Each program reduces the average day wastewater flow (equal to 145 gpcpd under Program 0) by the same amount that it reduces domestic flow. Decreases in wastewater flow due to possible reductions in infiltration are not taken into account.

Overall Benefits and Costs of the Management Alternatives

Conservation can provide savings for all of the city types studied by reducing capital expenditures and prolonging the time until they must be made, and by reducing operation and maintenance costs. A summary of the savings from conservation, which were developed in the previous section, is presented in Table 5-11.

TABLE 5-8

Additions to Water Treatment Facilities

Under Program(s)		Year of Completion, Size of Project* (MGD) and Present Worth** (10^3 $) in 1983 For City Type I	II	III-A	III-B	IV	V
0 --	Year	1988	1988	1988	1988	1988	1988
	Size	42.72	13.84	2.39	10.89	0.04	0.56
Present Worth							
	At 9%	7,730	3,743	1,200	3,242	142	323
	11%	7,059	3,410	1,096	2,961	130	295
	13%	6,456	3,119	1,002	2,708	119	270
1 --	Year	2000	2001	1996	1991	> 2013+	1994
	Size	11.51	3.52	0.91	6.78	--	0.27
Present Worth							
	At 9%	1,205	494	236	1,841	0	183
	11%	884	356	186	1,592	0	150
	13%	653	258	148	1,380	0	123
1 & 2 --	Year	2004	2007	1998	1992	> 2013	1996
	Size	5.75	1.62	0.64	6.02	--	0.22
Present Worth							
	At 9%	526	192	142	1,542	0	139
	11%	359	124	108	1,309	0	110
	13%	247	81	83	1,115	0	87
1 & 3 --	Year	2000	2002	1997	1991	> 2013	1994
	Size	10.98	3.37	0.89	6.72	--	0.27
Present Worth							
	At 9%	1,153	439	186	1,841	0	183
	11%	846	311	144	1,592	0	150
	13%	625	221	112	1,380	0	123

TABLE 5-8 (continued)

Under Programs		Year of Completion, Size of Project* (MGD) and Present Worth** (10^3 $) in 1983					
		For City Type					
		I	II	III-A	III-B	IV	V
1 & 2 & 3 --	Year	2005	2008	1999	1992	> 2013	1996
	Size	5.26	1.38	0.62	5.96	--	0.21
Present Worth							
	At 9%	462	159	129	1,542	0	139
	11%	310	101	96	1,309	0	110
	13%	209	64	72	1,115	0	87
1 & 4 & 6 --	Year	2001	2003	1997	1992	> 2013	1995
	Size	9.13	2.86	0.77	6.23	--	0.24
Present Worth							
	At 9%	954	369	168	1,571	0	160
	11%	687	256	130	1,334	0	129
	13%	498	179	89	1,136	0	104
1 & 2 & 4 & 6-	Year	2007	2009	1999	1992	> 2013	1996
	Size	3.63	0.88	0.51	5.53	--	0.19
Present Worth							
	At 9%	307	66	120	1,452	0	131
	11%	198	41	90	1,233	0	103
	13%	129	26	67	1,050	0	81
1 & 5 & 6 --	Year	2001	2005	1998	1992	> 2013	1995
	Size	8.07	2.32	0.73	6.18	--	0.23
Present Worth							
	At 9%	867	277	148	1,571	0	160
	11%	625	186	113	1,334	0	129
	13%	453	126	86	1,136	0	104

TABLE 5-8 (continued)

Under Programs	Year of Completion, Size of Project* (MGD) and Present Worth** (10^3 $) in 1983					
	For City Type					
	I	II	III-A	III-B	IV	V
1 & 2 & 5 & 6-Year	2008	2011	2000	1993	> 2013	1997
Size	2.66	0.55	0.47	5.48	--	0.18
Present Worth						
At 9%	228	45	149	1,332	0	120
11%	145	27	109	1,111	0	93
13%	93	16	80	929	0	72

*The projects are sized to meet peak loads until 2013.

**Project costs are presented in greater detail in Appendix E.

+Additional treatment facilities are not required until after the end of the study period in 2013.

TABLE 5-9

Additions to Wastewater Treatment Facilities

Under Program(s)		Year of Completion, Size of Project* (MGD) and Present Worth** (10^3 $) in 1983 For City Type I	II	III-A	III-B	IV	V
0 --	Year	1993	1993	1993	1993	1993	1993
	Size	12.27	4.32	0.71	3.44	0.02	0.17
Present Worth							
	At 9%	4,299	2,188	585	1,959	49	206
	11%	3,585	1,824	488	1,633	40	172
	13%	2,998	1,526	408	1,366	34	144
1 --	Year	1995	1996	1995	1993	> 2013+	1995
	Size	9.31	3.29	0.56	3.03	--	0.14
Present Worth							
	At 9%	3,154	1,484	427	1,798	0	159
	11%	2,536	1,171	343	1,499	0	128
	13%	2,047	929	277	1,254	0	103
1 & 2 --	Year	1996	1996	1995	1994	> 2013	1995
	Size	8.72	3.09	0.53	2.95	--	0.13
Present Worth							
	At 9%	2,731	1,417	408	1,600	0	147
	11%	2,156	1,118	328	1,310	0	118
	13%	1,710	887	265	1,076	0	96
1 & 3 --	Year	1995	1996	1995	1993	> 2013	1995
	Size	9.07	3.21	0.55	3.00	--	0.13
Present Worth							
	At 9%	3,082	1,455	415	1,768	0	147
	11%	2,478	1,149	334	1,474	0	118
	13%	2,000	911	270	1,233	0	96

TABLE 5-9 (continued)

Under Program(s)		Year of Completion, Size of Project* (MGD) and Present Worth** (10^3 \$) in 1983 For City Type I	II	III-A	III-B	IV	V
1 & 2 & 3 --	Year	1996	1997	1995	1994	> 2013	1996
	Size	8.49	3.00	0.52	2.92	--	0.13
Present Worth							
	At 9%	2,651	1,252	401	1,583	0	135
	11%	2,092	971	323	1,296	0	107
	13%	1,659	756	260	1,065	0	85
1 & 4 & 6	Year	1997	1998	1996	1994	> 2013	1996
	Size	6.97	2.45	0.42	2.49	--	0.11
Present Worth							
	At 9%	2,183	1,039	322	1,487	0	107
	11%	1,693	791	254	1,218	0	67
	13%	1,318	605	202	1,001	0	67
1 & 2 & 4 & 6-	Year	1997	1998	1997	1994	> 2013	1997
	Size	6.47	2.30	0.40	2.42	--	0.10
Present Worth							
	At 9%	2,087	993	285	1,452	0	98
	11%	1,618	756	221	1,189	0	76
	13%	1,260	578	172	977	0	59
1 & 5 & 6 --	Year	1998	1999	1997	1995	> 2013	1997
	Size	5.91	2.11	0.38	2.44	--	0.10
Present Worth							
	At 9%	1,778	884	274	1,340	0	98
	11%	1,354	661	212	1,077	0	76
	13%	1,035	497	165	870	0	59

TABLE 5- 9 (continued)

Under Program(s)		Year of Completion, Size of Project* (MGD) and Present Worth** (10^3 $) in 1983 — For City Type I	II	III-A	III-B	IV	V
1 & 2 & 5 & 6	Year	1999	2000	1997	1995	> 2013	1997
	Size	5.40	1.93	0.37	-2.39	--	0.09
Present Worth							
	At 9%	1,525	766	264	1,312	0	92
	11%	1,140	562	205	1,055	0	71
	13%	856	415	160	852	0	55

*The projects are sized to meet peak loads (2.25 times the average load) until 2013.

**Project costs are presented in greater detail in Appendix E.

+Additional treatment facilities are not required until after the end of the study period in 2013.

TABLE 5-10

Water Treatment Facility
Operation and Maintenance Costs*

Under Program(s)		Present Worth (10^3 \$) in 1983 of O & M Costs For City Type I	II	III-A	III-B	IV	V
0 --At	9%	27,864	9,197	1,237	2,252	411	227
	11%	23,252	7,693	1,024	1,766	352	187
	13%	19,848	6,581	868	1,422	307	158
1 --At	9%	23,199	7,556	912	1,699	308	167
	11%	19,833	6,474	762	1,341	266	139
	13%	17,321	5,668	653	1,087	235	118
1&2 --At	9%	22,773	7,406	890	1,652	301	163
	11%	19,497	6,354	744	1,305	260	136
	13%	17,051	5,570	638	1,059	230	116
1&3 --At	9%	23,054	7,512	905	1,684	297	166
	11%	19,720	6,439	757	1,329	257	138
	13%	17,233	5,640	648	1,078	227	118
1&2&3 --At	9%	22,627	7,362	882	1,638	290	161
	11%	19,384	6,319	738	1,294	251	135
	13%	16,962	5,542	633	1,050	222	115
1&4&6 --At	9%	21,794	7,048	843	1,581	282	154
	11%	18,649	6,040	704	1,247	243	128
	13%	16,306	5,289	601	1,010	214	109
1&2&4&6--At	9%	21,404	6,919	823	1,538	276	151
	11%	18,344	5,936	687	1,214	238	125
	13%	16,062	5,205	587	984	209	107
1&5&6 --At	9%	21,635	6,924	827	1,561	276	151
	11%	18,389	5,941	691	1,231	238	126
	13%	16,099	5,209	590	997	210	107
1&2&5&6--At	9%	21,073	6,795	806	1,518	270	147
	11%	18,085	5,837	674	1,197	233	123
	13%	15,855	5,126	576	971	206	104

*More detailed information on O & M costs may be found in Appendix E.

TABLE 5-11

Savings from Conservation Implementation

Under Program(s)		Reductions in Utility Costs* (10^3 \$) Over Base Program 0 For City Type					
		I	II	III-A	III-B	IV	V
1	--At 9%	53,903	18,976	4,381	9,897	294	561
	11%	46,839	16,462	4,078	9,288	256	489
	13%	41,073	14,410	3,801	8,730	225	435
1&2	--At 9%	57,697	20,146	4,735	10,918	301	631
	11%	49,855	17,369	4,385	10,222	262	550
	13%	43,509	15,117	4,068	9,583	230	486
1&3	--At 9%	54,872	19,280	4,499	10,104	305	578
	11%	47,599	16,700	4,167	9,470	265	503
	13%	41,673	14,599	3,876	8,890	233	444
1&2&3	--At 9%	58,871	20,630	4,804	11,107	312	648
	11%	50,820	17,760	4,442	10,387	271	564
	13%	44,277	15,436	4,118	9,730	238	499
1&4&6	--At 9%	60,497	21,290	4,991	12,735	320	680
	11%	52,191	18,314	4,600	11,947	279	589
	13%	45,448	15,908	4,255	11,215	246	518
1&2&4&6	--At 9%	63,465	22,244	5,267	13,347	326	729
	11%	54,464	19,124	4,836	12,477	284	633
	13%	47,205	16,432	4,461	11,676	251	555
1&5&6	--At 9%	62,659	22,062	5,223	13,355	326	697
	11%	54,016	18,909	4,792	12,214	284	604
	13%	46,887	16,310	4,423	11,458	250	531
1&2&5&6	--At 9%	65,656	22,997	5,352	14,775	332	761
	11%	56,158	19,600	4,892	13,369	289	659
	13%	48,525	16,884	4,485	12,475	254	578

*Utility costs include the costs which are affected by conservation programs--costs for additions to direct-flow rights, storage, and water and wastewater treatment facilities and costs for water treatment plant O & M.

The benefit-cost ratios for the various programs are displayed in Table 5-12. An incremental benefit-cost ratio was also calculated in order to determine the advantages (or disadvantages) of implementing programs in addition to metering and changing rate structures.

Metering is cost-effective in all of the study communities, even in the slow-growing City Type IV, where it eliminates the need for additional treatment facilities during the study period. Metering is particularly effective in the fast-growing City Type III-B. Even though capital expenditures for City Type III-B are not put off for very long (only two years for direct-flow rights and three years for water treatment facilities), they are reduced in magnitude enough to produce a B/C ratio of 12.64 at a discount rate of 11%.

The use of increasing block rates in conjunction with any of the other programs increases the benefits received. Since Program 2 has no implementation cost if it is initiated at the same time as Program 1, it is very effective as a conservation measure, if it can gain public acceptance.

An education program used in conjunction with Programs 1 and/or 2 can be cost-effective, but the extra money spent for public education will not bring equal returns. Even though an educational program cannot pay for itself with monetary returns, it can still be valuable in enhancing the effectiveness of other programs. Therefore, if a strong educational program is to be used, it should only be used in conjunction with other programs, and not by itself.

The combination of water-saving device distribution and building code modification is astoundingly effective. Both the overall benefits and the incremental returns over metering are quite high. The

TABLE 5-12

Benefits and Costs of Conservation Implementation

Under Program(s)			Benefit-Cost Ratio* (B/C) and Incremental Benefit-Cost Ratio** (▲B/▲C) For City Type I	II	III-A	III-B	IV	V
1-- B/C	At	9%	4.04	4.82	7.62	12.70	1.52	5.84
		11%	3.61	4.27	7.22	12.64	1.32	5.20
		13%	3.25	3.80	6.81	12.45	1.16	4.73
1&2-- B/C	At	9%	4.32	5.12	8.23	14.02	1.55	6.57
		11%	3.84	4.50	7.76	13.91	1.35	5.85
		13%	3.44	3.99	7.29	13.67	1.19	5.28
1&3-- B/C	At	9%	3.27	3.89	6.06	9.16	1.28	4.62
		11%	3.04	3.57	5.94	9.59	1.15	4.30
		13%	2.81	3.27	5.78	9.86	1.04	4.00
▲B/▲C	At	9%	0.28	0.30	0.70	0.64	0.25	0.60
		11%	0.28	0.29	0.65	0.72	0.25	0.60
		13%	0.28	0.28	0.65	0.80	0.25	0.47
1&2&3--B/C	At	9%	3.51	4.16	6.47	10.07	1.31	5.18
		11%	3.24	3.80	6.34	10.52	1.17	4.82
		13%	2.99	3.46	6.14	10.79	1.06	4.50
▲B/▲C	At	9%	0.35	0.48	0.41	0.58	0.41	0.59
		11%	0.35	0.48	0.42	0.65	0.41	0.61
		13%	0.35	0.47	0.44	0.73	0.41	0.68
1&4&6--B/C	At	9%	4.43	5.29	8.40	14.97	1.64	6.82
		11%	3.97	4.66	7.92	15.04	1.43	6.07
		13%	3.54	4.13	7.45	14.94	1.26	5.48
▲B/▲C	At	9%	21.04	26.14	32.05	39.49	24.49	32.80
		11%	20.66	25.09	32.36	44.82	25.56	32.79
		13%	20.15	23.95	32.73	50.02	25.93	31.80
1&2&4&6 B/C	At	9%	4.64	5.53	8.87	15.69	1.67	7.32
		11%	4.12	4.87	8.32	15.71	1.46	6.52
		13%	3.67	4.27	7.80	15.55	1.29	5.87
▲B/▲C	At	9%	18.40	23.80	27.96	33.80	18.63	26.92
		11%	17.79	23.77	27.96	38.01	24.44	27.21
		13%	17.02	21.00	28.33	42.13	25.93	26.44

TABLE 5-12 (continued)

Under Program(s)			Benefit-Cost Ratio* (B/C) and Incremental Benefit-Cost Ratio** (▲B/▲C) For City Type I	II	III-A	III-B	IV	V
1&5&6-- B/C	At	9%	4.49	5.36	8.60	15.42	1.63	6.85
		11%	4.00	4.71	8.07	15.09	1.42	6.09
		13%	3.58	4.15	7.58	14.99	1.26	5.50
▲B/▲C	At	9%	14.31	17.31	26.06	39.62	5.69	23.41
		11%	13.36	15.39	24.65	39.41	5.24	22.33
		13%	12.21	13.25	24.35	43.13	5.15	21.19
1&2&5&6 B/C	At	9%	4.70	5.59	8.81	17.06	1.66	7.47
		11%	4.16	4.88	8.24	16.52	1.45	6.65
		13%	3.70	4.29	7.69	16.32	1.28	5.99
▲B/▲C	At	9%	13.01	15.99	19.10	55.89	5.52	22.38
		11%	11.74	14.03	17.50	54.97	5.06	21.17
		13%	10.54	12.32	16.33	45.72	4.95	20.31

*For the B/C ratio, benefits are set equal to the savings over Base Program 0 and costs are the costs of program implementation.

**For the ▲B/▲C ratio, the incremental benefits are the savings over Program 1 or Programs 1 & 2, whichever is applicable.

inexpensive Program 4 is particularly appealing because economic returns range from 17.02 to 50.02 times greater than the costs of program implementation for the study towns.

These results indicate that conservation is a good management policy which can significantly reduce future expenditures for water rights, storage, treatment facilities, and operation and maintenance. Demand-reduction methods are particularly cost-effective in communities which are experiencing large amounts of growth.

While conservation alternatives were cost-effective for the slow-growing hypothetical community used in this study, the B/C ratios were close to 1. This indicates that metering may not be a wise program in Colorado municipalities like the Type IV city if the costs of metering are higher than those assumed or if the savings from the program are less than those calculated for City Type IV.

The Effects of Drought on Conserving and Non-Conserving Municipalities

A common criticism of water conservation programs is that they lower the ability of a municipality to deal with drought. A city which does not follow a conservation policy, but acquires liberal amounts of water, could have a more adequate supply during drought years than a conserving city which has reduced its need to acquire water.

During times of drought, a non-conserving city also has a wider range of options to reduce demand than the conserving city. Use restrictions implemented in an unmetered city produce a greater reduction than in metered cities due to the larger unmetered sprinkling use. Non-conserving cities can implement programs during a prolonged drought, such as distribution of water-saving devices, which the conserving city has used all along.

In order to test the validity of the assumption that non-conserving cities have a more adequate supply during times of drought than conserving cities, an analysis of the effects of drought on City Type II was made. Twenty drought traces of thirty years each were generated based on probabilities of occurrence which are typical of Colorado. (Details of this analysis are contained in Appendix G.)

The water supplies which resulted from this analysis were compared to the expected demand of four different Type II municipalities which follow different management policies--an unmetered city with no use restrictions in effect during droughts, an unmetered city using restrictions, a conserving city with no restriction program, and a conserving city which uses restrictions during droughts. A restriction program such a Program 7 (see chapter 4), can be expected to reduce drought year sprinkling use by 20% in an unmetered city and 10% in a metered community.

The water demands, as calculated for each of the hypothetical cities described above, were subtracted from the drought year supplies to determine the amounts by which direct-flow supplies fell short. The maximum amount of storage which would be required to meet demands in the event of drought is presented in Table 5-13.

The required storage is always less than the storage available to City Type II in the earlier scenarios, so the communities never run short of water during these drought traces, if their reservoirs are able to refill between drought occurrences. However, the drought storage reserve of the conserving, unrestricted city comes within 130 acre-feet of depletion during a three-year drought and could not be expected to provide sufficient water if a four-year drought should occur. The same is true for the conserving, restricted city (only 1620 acre-feet remain after a three-year drought), but both of the metered communities have sufficient stored water available to survive a prolonged drought.

TABLE 5-13

Drought Reserve Requirements for City Type II

Management Policies	Maximum* Amount of Storage (ac-ft) Required to Supplement Direct-Flow Rights for a Drought Lasting		
	1 year	2 years	3 years
Unmetered unrestricted	5,192	8,920	14,211
Unmetered restricted	3,793	6,391	10,161
Conserving unrestricted	5,728	10,021	15,984
Conserving restricted	5,213	9,087	14,493

*The largest deficits of direct-flow supply which occurred in twenty drought traces of thirty years each were used to compute the required storage. See Appendix G.

It should be noted that the shortages of direct-flow supplies for the conserving city are consistently larger in magnitude than the shortages of the unmetered city. It may be concluded that, if a city follows conservationist management policies and reduces its acquisitions of direct-flow rights, it should increase the storage reserve factor used to calculate the amount of storage required. Therefore, a conserving city will require less total storage than an unmetered city (due to the reduction in total use), but must increase the ratio of water storage to actual water use for adequate protection against drought. A conserving city following the same water and storage acquisition policies as an unmetered city (by purchasing sufficient rights to meet needs ten years in the future and by obtaining storage to meet a reserve factor based on a three-year drought) would indeed have a less adequate water supply than an unmetered city during a prolonged drought.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The preferred method of meeting water demands for Colorado municipalities has been to acquire or develop additional water supplies. Many communities have made only haphazard attempts to reduce demand--often only when the occurrence of drought made it necessary. However, this study has shown that demand-reduction, through metering or conservation programs, can provide significant savings for almost any type of community by postponing water supply acquisitions, deferring capital investments in treatment and storage facilities, and reducing water treatment operation and maintenance costs.

Many arguments have been made against the implementation of intensive conservation programs. This study has refuted most of these arguments, even though some were found to have merit. The major argument given by water officials against conservation, particularly against metering, concerns the expense. However, as demonstrated by the scenarios, metering can be cost-effective for any type of city--large or small, fast- or slow-growing. Even cities which have sufficient water supplies to meet needs beyond the foreseeable future can gain benefits from reductions in the amount of water treated which justify the money spent for metering.

The combination of building code modification and water-saving device distribution was found to return the implementation costs many times over in any type of community. The only program which was not cost-effective in any of the city types studied was an intensive, continual educational program. Because community education on water use could ease the introduction of other programs and increase their effectiveness, an education program might still be implemented along with other programs, if the over-all benefits of the program remain higher than the total costs.

Arguments have been made that the delays in water acquisitions brought about by conservation can be disadvantageous because of the continually increasing real costs of purchasing water rights and greater competition among purchasers. However, the scenarios demonstrated that, for municipalities which maintained sufficient water supplies to meet the projected needs ten years in the future, conserving cities had less need to purchase additional supplies at higher prices in the tighter market of the future than non-conserving cities. Even cities which planned to purchase large amounts of water now, at lower prices than in the future, and conserve later could not realize savings as large as those obtained by cities which institute conservation programs immediately, because the major savings came from reductions in the amount of water required, stored, and treated (particularly in the fast-growing cities) and not from the deferment of expenditures.

A third argument considered by this study is that non-conserving cities, which have acquired large water supplies to meet future demands, are in a better position to deal with drought than conserving cities.

This assumption was shown to have some validity. A conserving city which plans future storage facilities based on the same storage reserve factor as an unmetered city will be more vulnerable to shortages during prolonged droughts. The storage reserve factor for conserving cities must be increased to compensate for the reduction in holdings of direct-flow rights. However, the total amount of storage and water rights required to assure an adequate supply for a conserving municipality during droughts is still substantially less than that required for a non-conserving community.

Because a water right must be put to beneficial use in order to avoid questions of abandonment, and the development of a conditional right must be pursued with due diligence in order to perfect the right, it has been suggested that conservation can jeopardize a municipality's water rights holdings. However, this need not be true. Water rights can be protected by developing and following a comprehensive water-management plan which details expected water demands and the plans for providing sufficient supplies.

These arguments against the implementation of conservation programs, along with other less major objections, have been considered, and those with merit have been weighed against the benefits of conservation. These benefits include not only economic advantages, but a reduction in the pressure on the agricultural sector to transfer water to municipal storage projects.

It is concluded that metering and intensive conservation programs are valuable water-management alternatives. They provide a better solution to the problems of meeting future municipal water demands than a sole reliance on supply solutions for most communities (small towns with a static population may not find this to be true), if the proper precautions are taken to assure adequate drought supplies and to mitigate any possible adverse effects.

Recommendations

This study has concluded that demand-reduction techniques are a cost-effective alternative to supply solutions for meeting the present and future demand for municipal water. Specific actions which may be taken by a community seeking to develop better water-management policies follow.

1. Current water right holdings should be evaluated to determine the normal year and dry year yields. The determination of dependable drought yields should be based on at least the two lowest consecutive flows on record, and preferably on the three lowest.
2. Water billing and accounting procedures should be designed to provide water use data. This data is required for determination of the amount of future water supply additions and of the effectiveness of any conservation programs which are implemented.
3. Local weather and streamflow data should be analyzed to determine the probability of drought occurrence. This information, combined with water use data and information on expected additions to water supplies, can be used to calculate a storage reserve factor which will provide sufficient protection against shortages during drought.

4. The city's water budget should be designed to account for projected future needs by estimating future acquisition costs of water rights and reservoir storage. This is particularly important, because cost of conveyance in the future may exceed the benefits. In addition, water right transfer costs should be recognized as a budgetary expense.
5. Because water rights do increase in value each year and Colorado water law does require close husbandry of water rights, a municipality considering reducing its demand would be well advised to keep a close accounting of yields of water right donations and potential transfer losses.
6. Unmetered municipalities should conduct an economic analysis on the feasibility of metering. It is likely that all but a few small, slow-growing communities will find metering to be cost-effective. If studies indicate that customers will accept it, an increasing block rate structure with penalties for high peak use should be instituted.
7. Metered communities should modify building codes to require the installation of water-saving devices in new construction or when remodeling. This program should be combined with distribution of water-saving devices to existing homes.
8. An intensive educational program should only be used in conjunction with other very cost-effective conservation programs. Educational programs should be implemented for the purpose of increasing the public's awareness and developing a conservation ethic, and not to produce large reductions in use.

9. A detailed water management plan should be developed and followed. Projected water demands, expected additions to water supplies and storage, and plans for the implementation of conservation programs should be included.

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APPENDIX A

SAMPLE SURVEY QUESTIONNAIRE

WATER AGENCY QUESTIONAIRE

Name of your Water Agency:____

Name of and title of person completing this questionaire:____________________

____Telephone #:__________

Geographic area of your utility:____________________________________

I. GENERAL INFORMATION

1) Population served by your utility

a) at present____________________

b) Estimate of population to be served by year 2000__________

c) Estimate of population to be served by year 2020__________

2) Total treated water distributed in million gallons per year, (do not include water wholesaled to others)

1974______________	1978______________
1975______________	1979______________
1976______________	1980______________
1977______________	1981______________

3) Total water revenues in dollars/year

1974______________	1978______________
1975______________	1979______________
1976______________	1980______________
1977______________	1981______________

4) Describe your water rate structure (flat rate, block, special charges, etc.) Please include actual prices.

____

____

____

____

5) What is the principal behind the rate structure? (Check one)

_____ Coverage of operation and maintenance costs

_____ Full cost coverage

_____ Full cost coverage and system expansion

_____ Other. Please explain: ____

____

____

6) Estimate the cost of delivery of treated water in dollars per 1000 gallons. ____________________

7) What percentage of your residential water taps are metered? (Check one)

a) _______ 0% _______ 10% _______ 25% _______ 50% _______ 75% _______ 100%

b) Do you require metering or yokes on new homes?

_______ yes _______ no

8) What is the total volume of storage facilities within your system? Show units, million gallons or acre-feet.

raw water ____________________ treated water ____________________

9) Are there currently plans for expansion of water treatment plants?

________ yes ________ no

If yes, what is the estimated capacity of the expansion and its cost?

________________________ mgd ____________________ dollars

10) Same, but wastewater treatment plant

________________________ mgd ____________________ dollars

II WATER SUPPLY

1) What total water rights does your agency own? Please estimate the amount and comment on their availability for use or reliability. Please, attach a complete list of all rights and their amount if it is available.

a) Direct flow rights: ☐ Don't know (see below*)

b) Storage rights:

*If a consultant or law firm handles your water rights and can answer this question, please give the name, address and telephone number of someone we can contact.

2) Is the average yield of these rights sufficient to meet current peak demands?

________yes ________no

If yes, estimate when your expanded demands (from growth, etc.,) will reach limit of current supply.

____

3) Is it possible for your agency to rent water rights from others on a
a) short-term basis?

________yes ________no ________don't know

If yes, what amount of water may be rented and from whom?

____at what unit price?____________

b) Can you rent (lease) water to others?

________yes ________no ________don't know

If yes, what amount could be rented?____________at what unit price?____________

4) Does your agency have a requirement that developers must supply water rights?

Explain:

5) Can water be made available to you through development of new supplies
a) (wells, reservoirs, etc.)?

________yes ________no

b) If yes, are there currently plans to proceed with a project?

________yes ________no

If yes, briefly explain project--include estimated cost and water yield:

____

____

____

____

6) Are there currently water rights available for sale to you?
a)

________yes ________no ________don't know

If yes, what are the amounts, present uses, and cost of the rights?

____

____

b) If yes, do you plan to buy any of these rights?

__________yes __________no

If yes, what amount and at what price?______________________________

____

If not, explain why not?_______________________________________

____

7) Is your agency currently condemning any water rights?

__________yes __________no __________don't know

If yes, please describe the amount and current use of the rights.__________

____

If no, would you consider condemnation in the future? Explain:__________

____

____

8) Please rate the following methods of adding to your water supply from highest preference to lowest. (rank from 1 to 4 with 1 most preferable).

__________Developing new supplies (reservoirs, wells, etc.)

__________Purchasing existing rights

__________Condemning rights

__________Other (please explain)_________________________________

____

9) Does your agency have a standing policy for the acquisition of additional water rights or supplies?

__________yes __________no

If yes, explain:____

____

____

10) Do you feel that (<u>excluding the effects of inflation</u>), the addition of water to your supplies, through development, purchase of rights, etc., will (check one)

______cost more in the future

______cost less in the future

______cost the same in the future

11) Please estimate as close as you can, the average cost of acquiring water per acre-foot during the following years in your area (fill in an many years as possible).

a) direct flow rights

1950-____________ 1977- ____________
1960-____________ 1978- ____________
1970-____________ 1979- ____________
1975-____________ 1980- ____________
1976-____________ 1981- ____________

b) stored water

1950-____________ 1977- ____________
1960-____________ 1978- ____________
1970-____________ 1979- ____________
1975-____________ 1980- ____________
1976-____________ 1981- ____________

III. SUPPLY DURING DROUGHT

1) Were any supply problems encountered in your agency during the 1976-1977 or 1981 droughts?

________yes ________no

If yes, please answer the following. Please elaborate on their nature and severity:

____

____

____

____

Have steps been taken to prevent these problems during future droughts? Explain:

____

____

____

____

2) During the 1976-1977 and/or the 1981 droughts, did you rent additional water rights?

________yes ________no

If yes, how much water and at what price?

__________ __________

3) What % of normal yield did your water rights yield in:

1976-________%

1977-________%

1981-________%

4) Would you be likely to initiate condemnation during a future severe drought?

__________yes __________no __________don't know

IV. WATER CONSERVATION

1) What long-term conservation measures does your agency currently employ? Check all that pertain to your utility.

_____Promoting use and installation of in-home conservation devices

_____Require conservation devices in new construction

_____Water recycling of any kind

_____System improvement; i.e., fixing leaks

_____Public education on conservation

_____Metering

_____Price increases

_____Other (please explain)____

____

____

2) Are any of the above planned for the future? Please list time you plan to use in order of importance.____

____

____

3) Does your agency have a drought contingency plan?

__________yes __________no

if yes, does it include any of the following? (Check those that apply).

_____change in pricing policy (explain below)

_____water restrictions (explain below)

_____obtaining additional supplies

_____public education

_____Other (explain below)

Explanations:____

____

____

4) If you have a drought contingency plan, has it been used in the past?

__________yes   __________no

If yes, what measures proved to be the most effective in lowering consumption?

____

____

What measures met with the best public response? least response?

____

____

5) Please estimate the cost of your conservation programs on a yearly basis. $/customer

Long-term____

Drought____

6) If you initiated a long-term conservation program that resulted in a significant reduction in use, say 30%, would your agency have sufficient facilities to store the unused water for times of shortage?

__________yes   __________no

Any other comments, suggestions or questions that you would care to give us.

____

____

____

____

Thank you very much for your assistance. If you would like a copy of our report in return for your cooperation, please let us know. (check one)

______yes, I'm happy to help - send me a copy of the report:

Name:__________________________

Address:________________________

____

____

______no, I don't need a copy.

APPENDIX B

CITY OFFICIALS PARTICIPATING IN SURVEY

Town	Water Official
Aguilar	Joe Marquez Water Superintendent Aguilar, CO 81020 941-4360
Akron	Richard Elliott Town Manager P. O. Box P Akron, CO 80720 345-2624
Broomfield	Mike Bartleson, Jan Carlson, George Miners # 6 Garden Center Broomfield, CO 80020 469-3301
Cheraw	Robert E. Solomon Water Superintendent Box 16 Cheraw, CO 81030 853-6506
Crested Butte	Susan Cottingham Planning Director Box 39 Crested Butte, CO 81224 349-5338
Englewood	Stuart Fonda Director of Utilities 3400 S. Elati Englewood, CO 80110 761-1140
Granby	D. Mulloy Plant Operator Zero & Jasper Street P. O. Box 17 Granby, CO 80446 887-2448

APPENDIX B (continued)

Town	Water Official
La Jara	J. Adelmo Medina Water Superintendent P. O. Box 32 La Jara, CO 81140
Meeker	Frank Marsh Public Works Director Box 38 Meeker, CO 81641 878-5896
Nucla	Carl Duane Pender Public Works Box 219 Nucla, CO 81424-0219 864-7351
Pritchett	Reva Phillips Town Clerk Box 56 Pritchett, CO 81064 523-6444
Project 7-Montrose	Dick Margetts Manager P. O. Box 1725 Montrose, CO 81401 249-4511
Rangely	James Koontz Water Supply Superintendent P. O. Box 1067 Rangely, CO 81648 675-2221
Steamboat Springs	Joe Zimmerman Water Superintendent Box 1174 Steamboat Springs, CO 80477 879-1805
Walsh	Harold Stoddard Manager Box 296 Walsh, CO 81090 324-5411

APPENDIX B (continued)

Town	Water Official
Westminster	Kelly DiNatale Water Resource Engineer City of Westminster 3031 W. 76th Avenue Westminster, CO 80030 429-1546
Yuma	Doug Lasater Public Works Director Box 265 Yuma, CO 80759 848-5101

Appendix C

CALCULATION OF POTENTIAL CONSUMPTIVE USE REQUIREMENTS FOR LAWNS IN COLORADO

The expected evapotranspiration of plants can be estimated from the following equation:

$$ET_p = C \cdot ET \qquad [1]$$

where ET is the potential evapotranspiration determined from the Jensen and Haise equation, and ET_p is the evapotranspiration expected for a particular crop. The C is a coefficient accounting for the type of crop, moisture, and soil condition. Danielson empirically determined the value of C for urban lawns to be about 0.90 (9).

The Jensen and Haise equation is rewritten here:

$$ET = (.014T - .37)Rs \qquad [2]$$

where Rs represents the estimated solar radiation in inches per day and T represents mean air temperature in °F.

The average daily solar radiation on a horizontal surface is usually given in KJ/M^2 and needs to be converted to in./day to fit equation [2] above. Converted values are given in Table C-1. Since the record had only been constructed for Denver, the same solar data had to be applied to both Fort Collins and Boulder.

The ET was determined for the seasonal lawn irrigating period of May-September. Equation [1) was modified to account for the effective

TABLE C-1

Solar Radiation for Stapleton Airport*
Denver, Colorado (in./day)

Year	May	June	July	August	September
1953	.372	.421	.391	.367	.336
1954	.363	.433	.391	.363	.315
1955	.385	.380	.430	.351	.320
1956	.382	.434	.399	.350	.338
1957	.332	.404	.395	.370	.329
1958	.398	.433	.402	.385	.323
1959	.351	.430	.435	.356	.306
1960	.418	.443	.420	.386	.330
1961	.364	.411	.413	.384	.283
1962	.418	.417	.430	.391	.315
1963	.424	.443	.424	.347	.332
1964	.400	.427	.430	.378	.321
1965	.374	.394	.398	.379	.261
1966	.414	.419	.423	.364	.318
1967	.355	.384	.421	.359	.321
1968	.412	.457	.397	.359	.328
1969	.377	.366	.413	.375	.304
1970	.417	.446	.426	.368	.324
1971	.367	.438	.387	.401	.312
1972	.399	.431	.385	.376	.292
1973	.382	.462	.389	.380	.285
1974	.443	.433	.426	.365	.298
1975	.371	.424	.440	.385	.313

NOTE: (1) Average daily global radiation on a horizontal surface was estimated from cloud cover and hours of sunshine. units - KJ/M^2 (SERI)

(2) To convert KJ/M^2 to cal/cm^2 (Langleys) multiply by .02390

(3) To convert cal/cm^2 to in./day divide by 1500
Reference: Jensen, M. E. and Haise, H. R., "Estimating Evapotranspiration from Solar Radiation," _Irrigation and Drainage Division, American Society of Civil Engineers_, Vol. 89, Dec. 1963, p. 37.

*Source: Solar Energy Research Institute, Golden, Colo.

monthly precipitation using the method of Linsley and Franzini (17). The effective precipitation is a measure of the amount of precipitation that may be expected to enter the soil, excluding losses due to runoff.

The effective precipitation was determined by use of Figure C-1. The graph is utilized by considering that all precipitation up to 1 inch is totally absorbed by the plant root system. Any precipitation in excess of 1 inch is proportional to the last full increment.

For example, if 2.7 inches of precipitation was recorded then the effective precipitation is determined by: (1) subtracting the first 1 inch; (2) taking the mean percentage of the precipitation between 1.0 and 2.0 inches (.90); (3) determining the average percentage between 2.0 inches and 2.7 inches (.73) and then multiplying (.7 inches x .73 = .50 inches) to determine the amount of effective precipitation of the last increment of rainfall; and (4) summing all proportions

$$(1.0 + .9 + .5 = 2.40 \text{ inches})$$

to determine the total effective precipitation of 2.40 inches.

It must be noted that precipitation in excess of 6 inches is not considered as being effective. It was also assumed that total monthly precipitation occurred as one event since daily precipitation records are not readily available.

In order to determine consumptive use, equation (1) is rewritten as

$$Cu = ET_p - Pe \qquad [3]$$

where Cu is the consumptive water use, in inches, for a particular crop and P_e represents the effective precipitation in inches. The seasonal

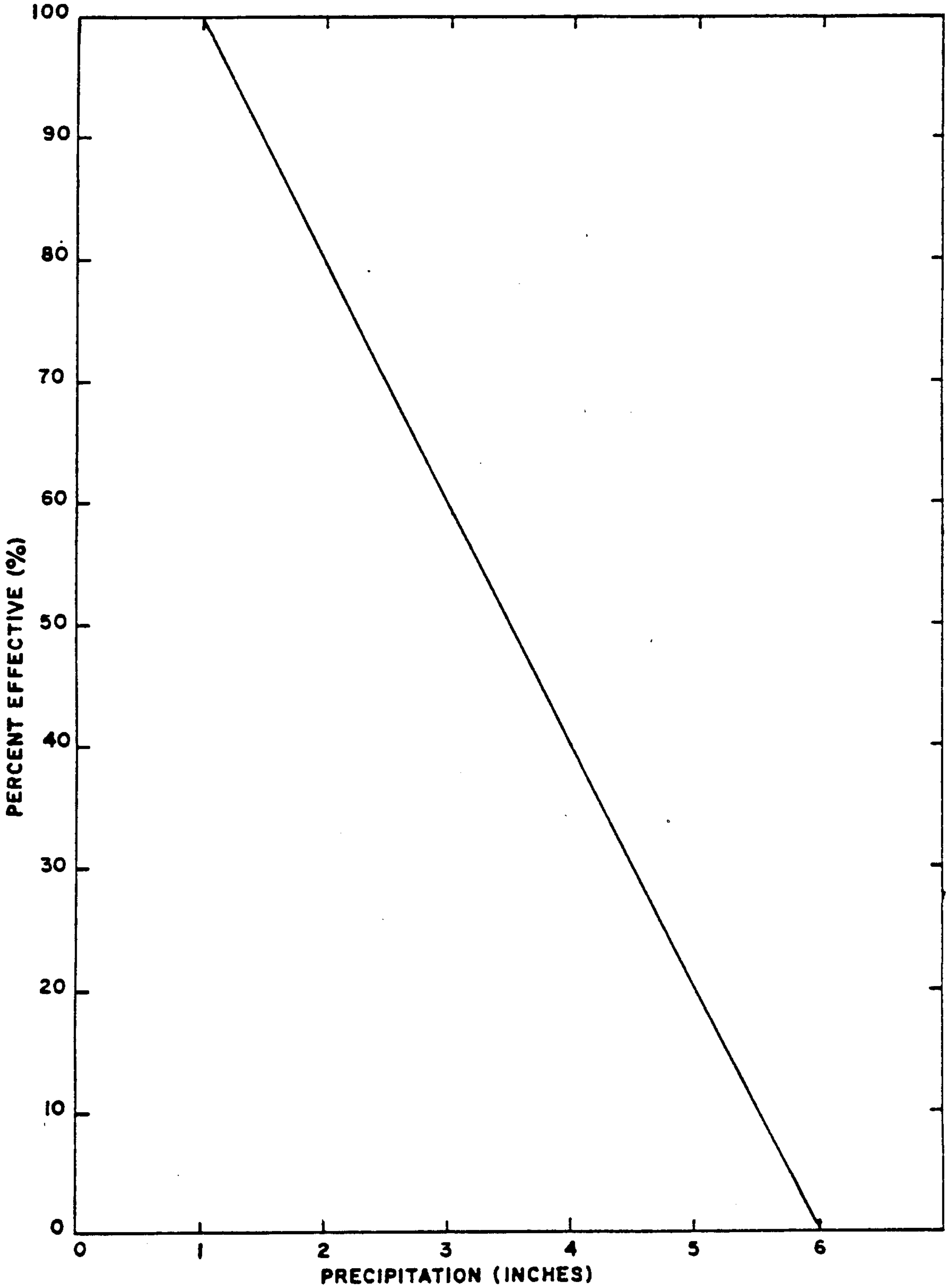

FIGURE C-1

Effective Precipitation Ratio

Cu was calculated for Boulder and Fort Collins for the years 1953-1975. The results are plotted on normal probability paper according to Cunnane's plotting position formula as shown in Figure C-2.

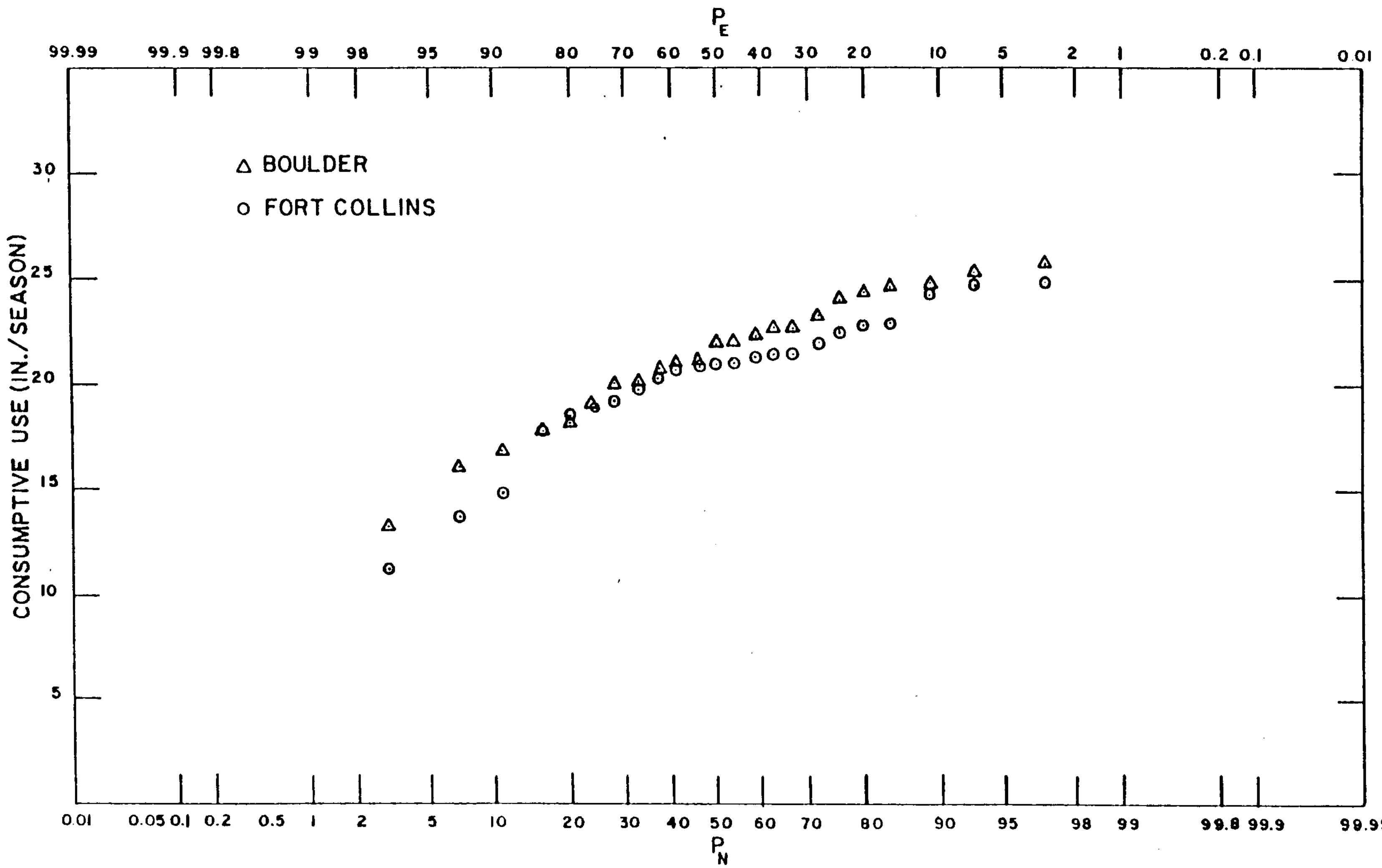

FIGURE C-2 LAWN WATER REQUIREMENT FOR BOULDER AND FORT COLLINS

Appendix D

METERING COSTS

Metering is relatively simple and inexpensive for meters installed during construction. The city of Fort Collins charges $100 for metering new taps and Boulder charges $150. Therefore, the average of $125/meter for new taps was used in the scenarios of Chapter 5. It should be noted that the cost of materials (yoke, meter, meter pit, and cover) is less than $100.

Installing meters on existing taps is more complicated since it requires the following procedures:

--location of buried service line

--installation of meter pit

--cutting service line (and in some cases replacing it)

--installing a meter

--landscaping the ground to its original contour

The basic cost for meter installation in existing homes is estimated to be $380. This is based on the recent costs of bulk metering in three Colorado municipalities--in Denver the cost is $295/meter (18), in Brighton the cost is $350/meter (19), and in Loveland the cost is $380/meter (20).

It is estimated that 40 percent of the house service lines will have to be replaced during a mass-metering program at $100/ replacement. (The average replacement cost for house service lines in Denver is $113 [18]) This brings the average cost to $420/tap.

Meter reading, billing, and maintenance costs are estimated to be $7.50 per meter per year. The Denver Water Board estimates these costs to be $7.25/meter (18) and Fort Collins estimates costs at $7.40/meter (8).

Appendix E

CALCULATION OF STORAGE REQUIREMENT

When determining water requirements, the hypothetical cities include a storage reserve to meet demands during drought periods. Because three successive dry years in a row occur, on the average, three times in fifty years, but four successive dry years usually occur less than once in fifty years, the cities plan for a worst case of three severely dry years in a row.*

The reserve factor (RF) is the percentage of the normal annual demand which must be held over from one year to the next in order to have sufficient supplies during periods of drought. The RF is equal to the difference in water rights yields between normal and dry years plus the water lost during storage due to reservoir seepage and evaporation.

During the first year of a severe drought the cities' water rights yield can drop to 75% of normal. (See Tables 2-5 and 3-3.) During the second year, the yield drops to 60%. Yields in the third year are only 50% of normal.** Therefore, the

---

*The City of Denver plans for three consecutive dry years. Boulder prepares for only two dry years in a row. Fort Collins plans for five back-to-back dry years. Longmont's decisions are based on five consecutive dry years (4).

**A study by Smith has shown that, in very dry years, the average in-basin stream flows are approximately 50% of normal (21). Morris speculates that Denver's water rights yield no more than 48% in very dry years (18).

carry-over required is 0.25 + 0.40 + 0.50 = 1.15 times the normal annual demand.

It is estimated that 15% of water stored in reservoirs in northeastern Colorado is lost to evaporation and seepage. If this estimate is applied to Colorado as a whole, then an additional 17%=(0.15 x 1.15) of the normal annual demand must be stored. Therefore, the RF is equal to 0.17 + 1.15 = 1.32 times the normal annual demand.

Since many municipalities own direct-flow rights which were previously used for irrigation, they are not allowed to divert water during the non-irrigation season under these decrees. The direct-flow rights which do allow year-round diversion often are not sufficient to meet winter demands. Therefore, some storage must be devoted to capturing excess water during the irrigation season for use during the winter months.

Each of the hypothetical municipalities has designed their storage projects to provide enough water to supply the municipal winter demand (assumed to be equal to the domestic demand ÷ 0.72) for four months each year.* This amount plus the amount of storage needed to provide drought supplies, equal to the RF, make up the total storage requirement.

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*In 1980, Longmont derived 3.7 months of their 6 month winter supply from storage (4).

APPENDIX F

CALCULATION OF WATER AND WASTEWATER TREATMENT COSTS

Water and wastewater treatment plant construction costs and O & M costs for water treatment facilities were determined by using cost curves developed for the U.S. Environmental Protection Agency (121, 122). These curves provide cost information for unit processes. Costs for individual processes for each plant size were totaled, then costs which were more directly related to the total cost of the project--such as land, general contractor profit, and administration costs--were added on. These totals were converted into current dollars by using the ENR Construction Cost Index.

So that costs would be comparative, standard treatment plant designs were selected. Water treatment plants with less than 1 MGD capacity consist of a package raw water pumping station, a package complete treatment plant, a steel backwash/clearwell tank, package high-service pumping, and sludge dewatering lagoons. Water treatment plants larger than 1 MGD capacity include chemical feed systems, rapid mix, flocculation, rectangular clarifiers, gravity mixed-media filters, surface wash systems, backwash systems, an above-ground clearwell, and sludge lagoons. For plants larger than 40 MGD, a gravity thickener and basket centrifuge were substituted for the sludge lagoons.

Design examples of the water treatment plants are shown in Tables F-1 and F-2. Costs for the hypothetical plants used in this study are presented in Table F-3.

Costs for wastewater treatment plants were arrived at in the same manner. Wastewater facilities with an average day flow less than 0.75 MGD (peak flow less than 1.7 MGD) are designed around three facultative treatment lagoons in series. Bar screens, a grit chamber, an effluent-polishing rock filter, and chlorination were also included. Larger plants (70.75 MGD) consist of pretreatment, circular primary and secondary clarifiers, diffused-air activated sludge tanks, chlorination, a gravity thickener, anerobic two-stage digestion, vacuum filtration, and sludge landfilling. A flotation thickener for secondary sludge was added to plants with average day flows greater than 2 MGD.

Design examples of the wastewater treatment plants are presented in Tables F-4 and F-5. Costs for the hypothetical wastewater plants used in this study are delineated in Table E-6.

For simplification, the average O & M cost for the hypothetical water treatment plants--equal to $300/Mgal treated for power and chemicals--was used in this study. This value is comparable to the expenditures for power and chemicals experienced by Colorado municipalities. McCoy reports that Westminster's costs are $283/Mgal and Boulder's costs are $266/Mgal (58).

TABLE F-1

Cost Calculation for a 0.504 MGD (350 gpm) Package Complete Water Treatment Plant

Component	Design Parameter	Construction Cost ($)	Annual O & M Cost ($/yr)
Package raw water pumping facilities	490 gpm	23,280	2,800
Package complete treatment plant--5 gpm/ft^2	350 gpm	183,690	38,000
Steel backwash/ clearwell tank	100,000 gal	35,000	
Package high-service pumping station	490 gpm	18,500	4,200
Sludge dewatering lagoon	15,000 ft^3	3,720	1,500
Subtotal		264,190	46,500
Chemicals; alum, 11 tons/yr @ $70/ton; polymer, 274 lb/yr @ $2/lb; chlorine, 1.6 tons/yr @ $300/ton			1,810
Total Annual Cost			48,310
Sitework, interface piping, roads @ 5%		13,210	
Total Construction Cost		277,400	
General contractor's overhead and profit @ 12%		33,288	
Subtotal		310,688	
Engineering @ 10%		31,069	
Subtotal		341,757	
Land 0.45 acres @ $2000/ac		900	
Legal, fiscal, and administrative services		9,300	
Total capital cost		351,957	
Conversion from 1978 dollars to late 1982 dollars		475,660	65,290

TABLE F-2

Cost Calculation for a 40 MGD Conventional Water Treatment Plant

Component	Design Parameter	Construction Cost ($)	Annual O & M Cost ($/yr)
Alum feed system--40 mg/l	556 lb/hr	71,440	2,138
Sodium hydroxide feed system--15 mg/l	5,000 lb/day	47,300	3,156
Polymer feed system--0.2 mg/l	67 lb/day	22,400	3,158
Rapid mix--45 sec., G = 600	2,785 ft^3	44,210	13,575
Flocculation--35 min., G = 50	130,000 ft^3	447,070	13,341
Rectangular clarifiers--1000 gpd/ft^2	40,000 ft^3	2,247,330	16,511
Gravity filtration--5 gpm/ft^2	5,560 ft^2	1,747,730	86,156
Filter media--mixed media	5,560 ft^2	148,200	0
Surface wash	5,560 ft^2	160,850	5,809
Backwash pumping--18 gpm/ft^2	10,010 gpm	122,530	10,095
Wash water surge basin	200,000 gal	440,000	0
Chlorine feed system--2 mg/l	670 lb/day	68,980	12,384
Clearwell storage--above ground	2,500,000 gal	400,000	0
Finished water pumping	40 MGD	180,000	155,959
Gravity thickener	850 ft^2	73,520	1,804
Basket centrifuge	115,000 gpd	334,810	100,303

TABLE F-2 (continued)

Component	Design Parameter	Construction Cost ($)	Annual O & M Cost ($/yr)
Dewatered sludge hauling--20 miles	20,000 yd^3/yr	81,510	17,523
Administrative, laboratory, and maintenance building	40 MGD	216,200	110,200
Subtotal		6,854,080	552,110
Chemicals; alum, 1533 tons/yr @ $70/ton; polymer, 16,425 lb/yr @ $2/lb; sodium hydroxide, 602 tons/yr @ $200/ton; chlorine, 82 tons/yr @ $300/ton			285,250
Total Annual Cost			837,360
Sitework, interface piping, roads @ 5%	342,700		
Total Construction Cost	7,196,780		
General contractor's overhead and profit @ 10%	719,680		
Subtotal	7,916,460		
Engineering @ 10%	791,650		
Subtotal	8,708,110		
Land, 13 acres @ 2000/ac	26,000		
Legal, fiscal and administrative costs	67,030		
Total capital cost	8,801,140		
Conversion from 1978 dollars to late 1982 dollars		11,894,430	1,131,660

TABLE F-3

Water Treatment Facility Costs

Maximum Plant Capacity (MGD)	Capital Cost ($)	Annual O & M Costs ($/yr)
0.04	219,010	16,000
0.18-0.19	400,470	57,000
0.21-0.22	425,449	62,000
0.23-0.24	450,169	64,000
0.27	473,450	68,000
0.47	642,819	87,000
0.51	475,657	70,000
0.55-0.56	497,390	73,000
0.62	511,906	78,000
0.64	517,660	80,000
0.73	539,030	85,000
0.77	561,360	88,000
0.88-0.89	621,810	94,000
0.91	724,160	98,000
1.2	--	114,000
1.38	1,368,740	120,000
1.62	1,516,900	128,000
2.35	1,846,200	152,000
2.66	1,967,380	162,000
2.86	2,067,460	171,000
3.00	--	175,000
3.37	2,257,530	185,000
3.52	2,330,140	190,000
3.63	2,428,870	194,000
4.10	--	210,000
5.26	3,077,490	240,000
5.50	3,153,620	245,000
5.75	3,211,990	250,000
6.00	3,349,610	257,000
6.20	3,411,580	264,000
6.75	3,668,770	278,000
8.07	4,089,570	311,000
9.13	4,498,840	341,000
10.90	4,988,580	373,000
11.51	5,213,270	388,000
13.84	5,745,750	430,000
23.80	--	653,000
42.72	11,894,430	1,211,000
71.10	--	1,607,000

TABLE F-4

Capital Cost Calculation for a 0.25 MGD
(0.56 MGD Peak Flow)
Facultative Wastewater Treatment Lagoon System

Component	Cost ($)
Bar screens and gut chamber	17,000
Land	43,610
Lagoons--three in series	350,000
Rock filter	27,380
Chlorination system	31,500
Maintenance building	10,000
Subtotal	479,490
Piping @ 10%	47,950
Electrical @ 5%	23,970
Instrumentation @ 3%	14,380
Site preparation @ 5%	23,970
Subtotal	589,760
Engineering and construction supervision @ 15%	88,470
Contingencies @ 15%	88,470
Total capital cost	766,700
Conversion from 1976 dollars to late 1982 dollars	1,200,700

TABLE F-5

Capital Cost Calculation for a 3.1 MGD
(7.0 MGD Peak Flow)
Activated Sludge Wastewater Treatment Plant

Component	Cost ($)
Pretreatment	91,000
In-plant pumping	85,000
Circular primary clarifier	300,000
Diffused-air activated sludge	530,000
Circular secondary clarifier	400,000
Chlorination system	90,000
Gravity thickener	67,000
Flotation thickener	110,000
Anerobic 2-stage digestion	320,000
Lime stabilization	220,000
Vacuum filtration	490,000
Landfilling	43,560
Land	6,000
Administration and maintenance building	47,000
Subtotal	2,799,560
Piping @ 10%	279,960
Electrical @ 8%	223,960
Instrumentation @ 5%	139,980
Site preparation @ 5%	139,980
Subtotal	3,583,440

TABLE F-5 (continued)

Component	Cost ($)
Engineering and construction supervision @ 15%	537,520
Contingencies @ 15%	537,520
Total Capital Cost	4,658,470
Conversion from 1976 dollars to late 1982 dollars	7,295,460

TABLE F-6

Wastewater Treatment Facility Capital Costs

Maximum Plant Capacity (MGD)	Cost ($)	Maximum Plant Capacity (MGD)	Cost ($)
0.02	114,890	2.44	3,770,000
0.09	306,260	2.45	3,786,430
0.10	328,400	2.49	3,838,580
0.11	355,010	2.92	4,085,910
0.13	414,310	2.95	4,129,040
0.14	446,670	3.00	4,186,130
0.17	487,220	3.03	4,256,000
0.37	883,340	3.09	4,343,430
0.38	915,710	3.21	4,461,130
0.40	950,940	3.29	4,549,120
0.42	987,410	3.44	4,637,110
0.52	1,129,000	4.32	5,179,090
0.53	1,146,880	5.40	6,052,860
0.55	1,168,330	5.91	6,475,610
0.56	1,200,700	6.47	6,974,680
0.71	1,385,000	6.97	7,295,460
1.93	3,312,600	8.49	8,125,690
2.11	3,510,020	8.72	8,371,720
2.30	3,617,390	9.07	8,669,020
2.39	3,691,680	9.31	8,872,890
2.42	3,746,430	12,27	10,177,860

Appendix G

ANALYSIS OF THE EFFECTS OF DROUGHT

In order to determine the effects which drought can have on Type II communities which follow differing water-management policies, twenty drought traces were generated based on probabilities typical of Colorado. (See Chapter 3.) These traces were used to determine the water supplies likely to be available to Type II communities which are unmetered and those which follow a strong conservation program (a combination of Programs 1 & 2 & 5 & 6), whether or not they use restrictions during droughts. The cities always own sufficient direct-flow rights to meet the needs of a normal year ten years in the future.

It was assumed that water rights yield 75% of normal during the first year in which precipitation is 90% of normal. If the first drought year is followed by a second year with precipitation 10% below normal, water rights yield only 60% of normal. Any successive years with precipitation at 90% of normal will see the yield of water rights drop to 50%. If the precipitation in any of the drought years drops to 70% of normal, the water rights' yield is further reduced by 20%, i.e., the first year's yield would be 60%, the second year's yield would be 48%, and the third and any successive year's yield would be 40% of normal.

Since sprinkling use in an unmetered city can be 116-167% of the lawn consumptive use during a normal year, sprinkling use is assumed to stay the same if no restrictions are used in the unmetered city.* Because sprinkling use in the conserving city is equal to the lawn consumptive use or less, the amount of water used for sprinkling is assumed to increase by 16% in a drought year, as the evapotranspiration rate rises, if restrictions are not implemented. Restrictions in the conserving city will cause a 10% drop in drought year sprinkling use, making it equivalent to 1.044 times normal year use. The water demands, as calculated above, were subtracted from the drought year supplies to determine the amounts by which direct-flow supplies fell short.

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*Danielson found that irrigation in Fort Collins, an unmetered city, was 1.16 times the lawn consumptive use in 1978, even though application of only 70% of the consumptive use was required for a healthy lawn (9). It is estimated that irrigation in an unmetered city could equal as much as 167% of the consumptive use in a normal year. A sprinkling application depth of 22 inches will keep northern Colorado lawns healthy in years of normal precipitation and average evapotranspiration. This requirement increases by as much as 16%, to 25.5 inches, in drought years. Therefore, a restricted, unmetered city would apply 93-134% of the lawn's needs, while a restricted, conserving city would apply only 90% of the lawn's needs.