AN ASSESSMENT OF WATER USE AND POLICIES IN NORTHERN COLORADO CITIES

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COLORADO WATER RESOURCES RESEARCH INSTITUTE

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ABSTRACT

Municipal water management policies and water use patterns were examined in twenty-five northern Colorado Front Range communities. Towns were classified on the basis of population; extent of metering, if any; and source of water supply, groundwater or surface water. Water use patterns were analyzed for a four-year period, 1975 to 1978. The effects of metering, water use restrictions and the 1976-1977 drought period on municipal water use were also determined.

Metering of all residential customers was found to be the practice in eleven of the twenty-five communities. Per capita water use was lower in the metered towns than in the unmetered towns, but the actual per capita use varied greatly among the individual towns. Metering was particularly effective in reducing per capita outdoor water use. Lawn watering restrictions were widely practiced in the unmetered towns and judged to be generally less effective than metering without restrictions in reducing average and peak outdoor water use.

Interviews were conducted with town water managers regarding municipal water management policies. Water rates, pricing policies, revenues from water sales and tap-on fees varied greatly in both the metered and unmetered towns. The majority of the towns required water rights contributions from new developments. Exclusive of these water rights donation requirements, planning for future raw water supply needs and estimates of the dependable yield of water rights owned were judged to be inadequate in many towns. The possible benefits and costs of increased efficiency of water use on municipal return flows and water rights were determined and evaluated.

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INTRODUCTION

Water is a scarce resource in Colorado. The allocation and use of this scarce resource is governed by the doctrine of prior appropriation, a system of water law dating to the mining claims of the mid-1800's. The right to divert water from a stream, to store water in a reservoir for later use, and, to some extent, to pump groundwater is governed by this doctrine. Municipalities, as well as irrigators and other water users must posess water rights in order to legally take water for use. Under Colorado water law, the ownership of water rights, is not a guarantee that water will be available for use. Older, or senior, water rights have first claim to use of the water in a stream and there may not always be sufficient water remaining to meet the needs of those holding more junior water rights. This is especially true in dry years when precipitation and streamflows are below normal and the demand for water, especially by irrigators, is greater than normal.

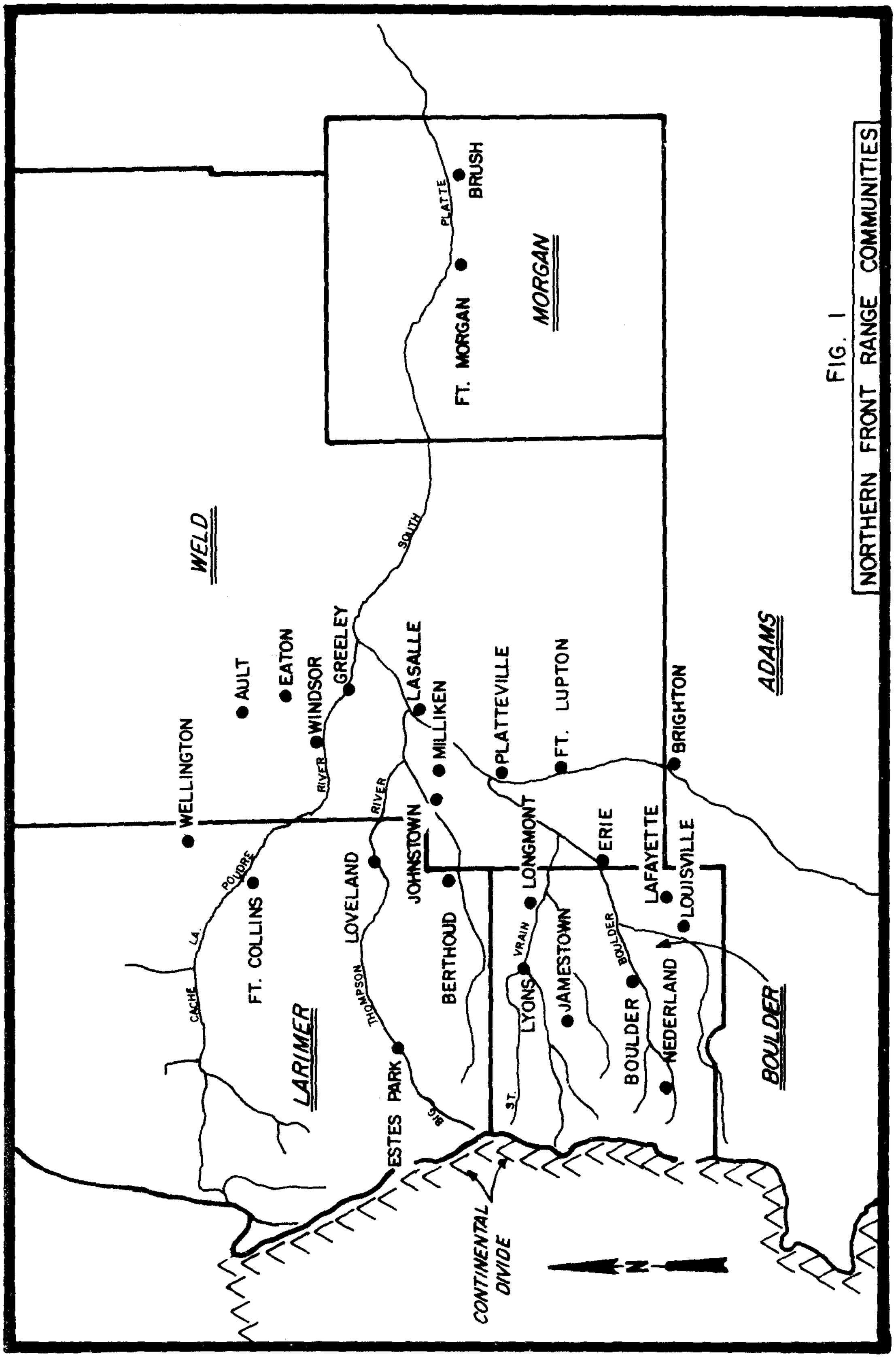

FIG. 1

NORTHERN FRONT RANGE COMMUNITIES

TABLE 2

AVERAGE ANNUAL PRECIPITATION

Town	Average Precipitation (inches)
Greeley	12.2
Longmont	12.7
Fort Morgan	13.2
Fort Collins	14.9
Loveland	15.8
Estes Park	15.9
Boulder	18.9

development. Approximately 75 percent of the runoff occurs during the months of April, May and June, requiring that reservoirs be constructed to store the flows for year round use.

The urban counties of the Front Range have been experiencing unprecedented population growth for the last 20 years. During the decade 1960 to 1970, the population of the United States increased 13.4 percent; Colorado's population increased 24.8 percent and the population of the Front Range urban counties increased 33.8 percent (Foss, 1978). Fort Collins is at present one of the fastest growing cities in the nation and indications are that the Front Range will continue to experience rapid growth, at least through the year 2000.

This rapid population growth has been accompanied by an increase in the demand for water for municipal use. Practically all the useable streamflows along the Front Range have been appropriated for municipal or agricultural use. The population growth has forced municipalities into competition with agriculture for the limited water resources of the region. Alternatives to resolving this conflict, such as increasing raw water supplies through trans-mountain diversions or the capture of flood flows in reservoirs, are becoming increasingly more costly and difficult to construct. Environmental concerns and competing Western Slope interests have succeeded in delaying several such projects, some indefinitely. These delays, in an inflationary period, will result in greater increased costs in the future if the projects proceed to construction.

Front Range water utilities, charged with the task of providing adequate water for new growth, are facing a difficult task. The cost of raw water acquisition is rising steadily. State public health records indicate that groundwater used by many utilities fails to meet certain federal drinking water quality standards.

Competition among municipalities for agricultural water rights is increasing. Water rates in many towns do not reflect the true costs of acquiring raw water or constructing new facilities. The ability of small municipalities to meet water demand during an extended drought has not been demonstrated.

One of the objectives of this study is to compare water use patterns among the northern Front Range municipalities and attempt to determine the factors that affect water use. Municipal water management procedures, especially in regards to water rights acquisition policies, will be also evaluated.

CHAPTER II

MUNICIPAL WATER USE: CONSUMPTION PATTERNS

This study will examine municipal water use patterns with special emphasis on the residential sector. The discussion of demand modification and conservation will emphasize residential use mainly because industrial and commercial water usage is a small part of the total urban demand. (For an in-depth study of industrial and commercial water usage along the northern Front Range, the study by Patterson (1977) is recommended.) The review of the literature that follows provides the basis for analyzing the water use data collected and comparing use patterns. Residential indoor or domestic usage and outdoor or sprinkling residential water use are discussed in detail.

A. Municipal Water Consumption

A municipal water utility generally supplies water of potable quality to all of the water users within its service district. Some individual users may have their own water supply. There are four major categories of municipal water use:

residential, commercial, industrial and public (includes system losses). Not all of these uses require water of potable quality. For example, many industrial processes and both residential and public lawn irrigation do not require water that meets drinking water standards, yet these uses consume high quality water that has been treated and distributed by the municipal utility.

There is a large variation, nationally and locally, in the percentage of municipally supplied water that is used for residential purposes. In 1970, water delivered for residential and public uses (including water system losses) accounted for 74 per cent (130 gallon per capita per day, gcd) of the municipal withdrawals in nine western regions versus 65 per cent (100 gcd) of the public supply withdrawals in the eastern regions of the United States (Murray, 1973). Even greater variation can be found locally. The percentage of municipally supplied water that is used for residential purposes is dependant upon many factors such as average annual precipitation and temperature and other climatological variations which affect irrigation requirements of lawns; variations in pricing and metering among residential, commercial and industrial users; population density of the community; and, of course, the number of large water-using industries.

When discussing municipal water use it is common practice to divide the total municipal water use by the population served to arrive at a gallons per capita per day (gcd) estimate that can be used in comparing consumption among communities. All water use is charged to the residents regardless of the purpose for which it is used, the rationale being that water used by business and industry provides jobs and water used for municipal purposes such as park watering, firefighting and street washing are in the interests of the general citizenry (Anderson, 1979). When analyzing residential use, however, it is necessary to estimate usage based only on residential demand.

B. Residential Water Consumption

From just after World War II until the mid 1960's residential water use nationally, on a gcd basis, showed a steady increase (AWWA Committee Report, 1973). This trend of increasing average residential water use has been attributed to a pronounced change in the water use habits of the American public. Automatic clotheswashers and dishwashers, garbage disposals and other water-using appliances became a part of many households. The widespread popularity of single-family detached housing and its attendant landscaping increased sprinkling demands.

It appears that per capita residential demand has leveled off in recent years. The use of household water-using appliances has probably reached its maximum. The price of water has been increasing in recent years as metering and pricing policies reflect increasing supply and distribution costs. The price of single family detached housing is increasingly beyond the financial capabilities of many Americans. As the housing trend shifts toward a greater percentage of apartments and condominiums, per capita water use may decline as landscape irrigation requirements decrease. The extent to which per capita water demand changes over time is dependant on the individual community (Weakley, 1977).

1. Domestic Water Use

A relatively constant portion of residential water use is that used inside the home. This in-house use (commonly called domestic use) consists of the water used for baths, showers, cooking, clothes and dishwashing, toilet flushing, etc. Milne (1976) estimated average domestic use to be 70 gcd. A number of studies have analysed the specific water use contributions made by household fixtures and appliances. Table 3, compiled by Flack, Weakley, and Hill (1977) gives a range of values for each domestic water use function. The bathroom (toilet, bath/shower and sink) accounts for 70% of the total domestic water consumption. Average domestic water use was estimated to be 62 gcd. A Johns Hopkins University study in the 1960's reported that per capita domestic water use remained relatively constant regardless of the method of water billing (metered or flat rate) and differences in climate (Linaweaver et al., 1967).

2. Outdoor Water Use

Outdoor water use, that water which is used for lawn and garden irrigation, car washing and other outdoor purposes such as swimming pools, etc., constitutes a significant portion of residential water demand. Due to the nature of lawn growth this large component of demand occurs over a relatively short time span of 3 to 6 months annually and is the primary contributor to peak loading of a water system. The Johns Hopkins Study found that peak hour sprinkling demands can be as much as 2,251 gpd/dwelling unit (Linaweaver et al., 1967). This peak loading factor creates the need for greater treatment, storage and distribution capacities than if average demand was the design criteria for the sizing of waterworks facilities.

TABLE 3

PER CAPITA DOMESTIC WATER USE*
(gcd)

Water Use Function	References								Range	Mean	% of Use
	Linaweaver, et al. 1963	Bailey, et al., 1969	Kreissl, 1971	Reid, 1965	Felton, 1974	Metcalf & Eddy, 1976	Nelson, 1975	Sharpe, 1975			
Water Closet	25.0	25.0	25.0	24.0	14.7	25.0	34.0	25.0	14.7-34.0	24.7	40
Bath/Shower	20.0	20.0	20.0	20.0	8.7	19.0[a]	20.0	20.0	8.7-2.00	18.4	30
Lavatory Sink	3.0	2.0	-	-	4.9	-	3.0	3.0	2.0-4.9	3.2	5
Laundry	9.0	10.0[e]	8.8	8.5	11.6	14.0[b]	15.0[b]	10.0	8.5-15.0	9.6	15
Dishwashing	-	3.8	-	3.8	1.1	-	-	4.0	1.1-4.0	3.2	5
Drinking/Cooking	7.0[b]	3.0	10.0[d]	2.7[c]	3.5[c]	2.0	4.0	3.0	2.0-10.0	3.0	5
Total	64.0	63.8	63.8	59.0	44.5	60.0	76.0	65.0	44.5-76.0	62.1	100

[a]Includes lavatory sink

[b]Includes dishwashing

[c]Includes garbage disposer

[d]Includes garbage disposer and dishwasher

[e]Includes utility sink

*Source, Flack, Weakley and Hill, 1977.

It is important to separate the outside water use component of residential water use from the domestic portion because outside use exhibits greater variation, both seasonally and daily, and responds differently to conservation measures than domestic use. The traditional method of estimating outdoor use has been the winter base rate method. This method assumes that domestic water consumption remains constant throughout the year and that there is no outside water use during the winter months. The water use rate during the winter months is used as the domestic use rate for the entire year. Outside, or sprinkling use, is that use rate greater than the winter base rate. Two month, three month and six month (November through April) winter base rates have been used (Danielson 1979).

The Johns Hopkins study (Linaweaver et al., 1967), the Boulder study (Hanke, 1969) and the Denver metering studies (Green, 1972; Bryson, 1973; Flechas, 1980) all used the winter base rate method for estimating outside water use. Linaweaver et al. used the three winter months (December, January, and February) in determining the base rate. Cotter and Croft (1974), in a New Mexico study, attempted to measure outside water use with meters installed on outside faucets. The data obtained from the meters was unreliable and the winter base rate method was chosen as an acceptable alternate means of estimating outdoor water use. A two month winter base rate was used as it was thought more appropriate for the arid Southwest.

More recently, a lawn watering experiment at the University of Wyoming (Barnes, Borelli and Pochop, 1979), using metered faucets and lysimeters also concluded that the winter base rate method was valid for estimating outdoor use. Of the two communities studied, Laramie and Wheatland, Wyoming, summer domestic useage was 55 gcd for Laramie and 75 gcd for Wheatland while winter useage was 76 gcd in Laramie and 77 gcd for Wheatland. Using the winter base rate method underestimates lawn watering use by a about 20 per cent for Laramie but is fairly accurate for Wheatland (Barnes et al., 1979).

In a similar study of lawn watering in Fort Collins and Northglen, Colorado, Haw (1978) found that either: 1) domestic water use increased during the winter in Northglen or, 2) there was a certain amount of outside winter water use, or both.
Haw (1978) concluded that the winter base rate method is a practical way to determine outdoor water use, but based on his findings, could be improved by assuming that domestic water use in the winter is approximately 15 to 20 per cent higher than in the summer months. Haw (1978) did not explain the

reason for lower summer domestic water use than winter domestic use but increased outdoor activities resulting in less time spent in the house during the summer is a probable factor.

The ratio of outdoor water use to domestic use represents a simple means of comparing outdoor or lawn sprinkling use among different regions of the country, or among communities in a geographic area. The outdoor water use ratio is defined as the outside water use divided by the total water use (Haw, 1978). In the Johns Hopkins study, the average annual outside water use ratio for 10 study areas in the Western United States was 0.43 (Linaweaver et al., 1967). Haw (1978) found the outside use ratio for July, August and September, 1977, to be 0.68 for Northglen, Colorado. Using the figures of Linaweaver et al. (1967) and assuming lawn watering for six months of the year, Haw estimated the average outside water use ratio to be 0.60 for the ten study areas in the western United States. Barnes et al. (1979) found the outside water use ratio to be 0.74 for Laramie and 0.85 for Wheatland with individual residences ranging from 0.50 to 0.96. Outside use was measured from approximately the last spring freeze to the first fall freeze. Based on the above findings, an outside water use ratio in the range of 0.60 to

0.75 would fairly represent sprinkling use in a typical northern Colorado front range community.

3. Lawn Sprinkling Requirements

The outdoor water use ratio as indicated by the above studies, shows that over 60 per cent of annual Colorado residential water use is used outdoors, primarily for lawn irrigation. As previously stated, lawn sprinkling creates heavy summer demand and the attendant costs associated with meeting that demand. In addition to water distribution costs, the cost of raw water acquisition is greatly increased. In semi-arid Colorado, operating under the Colorado doctrine of prior appropriation, the acquisition of water rights is not only a costly but a complex procedure.

a. Measurement of lawn water requirements. Lawn sprinkling, since it represents such a significant portion of total residential water demand, has been the subject of much research. The optimum amount of water needed to maintain a lawn in satisfactory condition should theoretically equal the evapo-transpiration, E-T, losses from the lawn (Bryson, 1973). The E-T rate is a function of temperature, humidity, duration and percent of sunlight, wind velocity and soil conditions (Cotter and Croft, 1974). The amount of water needed to maintain a lawn can vary greatly from region to region and even locally if climatic and soil conditions vary.

A number of equations have been developed to predict lawn evapo-transpiration. The Penman equation was used by Linaweaver et al. (1967) to estimate potential evapo-transpiration in the few cities where temperature, solar radiation, humidity and wind data were available. The Thornwaite equation was used in other cities and requires temperature and daytime hours to estimate evapo-transpiration (Linaweaver et al., 1967).

The modified Blaney-Criddle and Jensen-Haise evapo-transpiration equations were compared to actual measured E-T by Haw (1978). The Blaney-Criddle equation is based on mean monthly air temperature and mean monthly precentage of daytime hours. The Jensen-Haise equation uses mean daily air temperature and daily solar radiation as its climatic variables. Using lysimeters to measure actual E-T, Haw (1978) found that the modified Blaney-Criddle equation consistently predicted the E-T rate at a level below the measured E-T. Similar findings were reported by O'Neill (1977). Haw reported that the Jensen-Haise equation was able to predict weekly E-T with reasonable accuracy.

b. Examples of lawn sprinkling rates. If optimum lawn quality is achieved when water application rates are equal to the lawn evapo-transpiration, watering quidelines can be developed that would maximize the efficiency of outdoor water use. Haw (1978) and Danielson et al. (1979) investigated the relationship between measured E-T, actual water applied and lawn quality ratings for Fort Collins and Northglen, Colorado. In a similar study, O'Neill (1977) and Barnes et al. (1979) performed essentially the same experiment in Wyoming. Unfortunately, a great deal of subjective input was required as lawn appearance was judged on a scale from one to ten, with ten being excellent. The appearance was subjectively judged on the basis of color, thickness, dryness and presence of weeds in the lawn (Barnes et al., 1979).

Barnes found that lawn water application rates were 125 per cent of the average seasonal E-T rates in Laramie, Wyoming and 175 per cent in Wheatland. Individual homeowners who maintained the lowest application rates were near the irrigation consumptive use requirements of the grass. A considerable amount of overwatering was done by a few homeowners to raise the average application rate above the E-T values. Low correlation was found between the appearance rating and the amount of water applied to the lawn. Barnes concluded that watering is not the only maintenance practice required for an attractive lawn. The fact that one house in Laramie had an appearance rating of 9.4 and a water application rate equal to 93 per cent of the E-T rate while another house had a rating of 6.7 and an application rate equal to 193 per cent of the E-T rate confirms that overwatering is not a substitute for other lawn maintenance practices (Barnes et al., 1979).

Danielson et al. (1979) compared lawn water application rates and lawn quality for Fort Collins, which is unmetered, and Northglen, which is metered. Danielson found that lawn water application rates were appreciably lower at Northglen, even though the water requirements of grass at Northglen were somewhat higher than in Fort Collins. Water application was approximately 135 per cent of potential evapotranspiration at Fort Collins and about 80 per cent at Northglen.

Danielson also found that lawn quality ratings reflected the amount of water applied, i.e., ratings at Northglen were consistently lower than those at Fort Collins. Seasonal average ratings over the two seasons were 7.4 for Fort Collins and 6.5 for Northglen. At Fort Collins, where total water application was in excess of measured evapo-transpiration, Et_M, most of the time, there was a rather uniform quality rating for all lawns. At Northglen, where total application was normally below Et_M, lawn quality increased with water application rate. At total application (irrigation plus rainfall) rates equal to Et_M, the better managed Northglen lawns had quality ratings of about 8.

c. Factors affecting sprinkling use. The amount of water used for sprinkling varies significantly among regions of the country (Linaweaver, et al., 1967). This regional variation is primarily attributable to climatic factors (Grima, 1972). Economic variables relating to the price of water, the type of billing system and the consumer's income also exert an influence on the amount of water used for sprinkling (Howe and Linaweaver, 1967). Studies of Perth, Australia by McMahon and Weeks (1973) and Hanke and Mehrez (1979) reported that average maximum daily temperature was the climatic variable most related to monthly watering use. Danielson (1979) noted that total per capita use declined as household size increased, suggesting that domestic water use is affected by family size, because it is doubtful that family size affects sprinkling demand.

CHAPTER III

RESIDENTIAL WATER USE: DEMAND MODIFICATION

Residential water demands can be reduced through a variety of methods. A review of pertinent literature indicates that demand modification can be aimed at the domestic or outdoor portion of residential water use, or both. These measures can be instituted by the water utility or the individual homeowner. Some conservation measures have been proven effective while others remain to be shown to be cost-effective, politically feasible or publicly acceptable.

A. Metering

Metering is the most widely used structural means of regulating the demand for municipal water. In 1964 it was estimated that over 90 per cent of the water services in the United States were metered (Fleming, 1964). An unmetered flat-rate water billing system cannot provide an economic incentive for curbing water consumption as the user pays the same amount for water regardless of the amount that is used. Metering, on the other hand, provides the means for the consumer to be billed for the amount of water that is used. Metering can be an effective management tool, not only in reducing average demand, but also in lowering peak loads on the system. It also provides a means for instituting water rationing measures in water supply emergencies.

1. Effects of Metering

The effect of metering on demand is well documented. Linaweaver, et al. (1967) found that metering did not affect domestic water use but significantly reduced sprinkling use. Table 4 shows a comparison of metered versus flat rate average annual use. Sprinkling use in 10 metered areas in the Western United States averaged 186 gallons per day per dwelling unit (gpd/du) versus 544 gpd/du for 4 flat rate areas in Denver, Colorado. Sprinkling use was noted to be very inefficient in areas served by a flat-rate billing system with both maximum day and peak hour demands being twice that found in metered areas (Linaweaver et al., 1967).

The case study of Boulder found that both domestic and sprinkling use dropped significantly when residents went from a flat-rate to metered billing system (Hanke, 1969). Hanke attributed the 36 per cent decrease in domestic use to the repair of

TABLE 4

JOHNS HOPKINS' COMPARISON OF METERED VERSUS FLAT-RATE AVERAGE ANNUAL USE*

Area	Domestic use (gpd/du)	Sprinkling use (gpd/du)	Leakage (gpd/du)	Total use (gpd/du)
Denver (4 flat-rate areas)	238	544	44	826
Flat-Rate areas (8)	236	421	35	692
Metered areas (10 in Western U.S.)	247	186	25	458

*Source: Linaweaver et al. (1967) (adapted from Bryson, 1973)

domestic leaks and changes in behavioral water use patterns. Sprinkling use, corrected for weather conditions, dropped more than 50 per cent. This reduction in water use was noted to be persistent--no significant increase was noted in the follow up years (Hanke & Boland, 1971).

Green (1972), in a study of the feasibility of universal metering in Denver, examined 3 of the 4 flat-rate areas included in the Johns Hopkins' report (Linaseaver et al., 1967). Table 5 shows that flat-rate use ranged from 68 to 211 gpd/du greater than metered use for the same areas.

TABLE 5

GREEN'S COMPARISON OF METERED VERSUS FLAT-RATE AVERAGE ANNUAL USE FOR THE YEARS 1965 to 1968*

Neighborhood	Flat-rate use (gpd/du)	Metered use (gpd/du)	Difference (gpd/du)
3rd & Jasmine (High income area)	1127	916	211
11th & Glencoe (Middle income area)	520	452	68
5th & Tennyson (Low income area)	643	448	195
Total study area	763	605	158

*Source: Green (1972) from Bryson (1973).

Bryson (1973), in another study of Denver, also found a significant difference in sprinkling use between metered and unmetered areas. Assuming a 10 per cent system loss, the estimated average annual lawn irrigation rate was 3.6 feet of water for flat-rate residences versus 1.9 feet for metered residences as shown in Table 6. Bryson estimated a savings of 190 gpd/du would be achieved if Denver's one and two family flat-rate residences were metered. In a 1976 survey of 28 cities in northern Colorado it was found that largely unmetered communities used about 30 per cent more water than completely metered communities (Brauer, et al., 1967).

TABLE 6

COMPARISON OF METERED AND FLAT-RATE RESIDENTIAL WATER USAGE FOR THE YEARS 1969 TO 1972

Usage	Metered	Flat-Rate Using 6% System Loss	Flat-Rate Using 10% System Loss
Average domestic use (gpd/du)	261	205	164
Average total use (gpd/du)	601	638	564
Average sprinkling use (gpd/du)	340	433	400
Average lawn, garden & shrub area (sq.ft.)	8700	5400	5400
Average annual depth of water applied (feet)	1.9	3.9	3.6

Source: Bryson, 1973.

Flechas, in a more recent Denver metering study, estimated a savings of 313 gpd/du if Denver's flat-rate customers were metered (Flechas, 1980). This estimate is greater than Bryson's 1973 estimated savings of 190 gpd/du. Morris and Jones (1980) in a related study estimated that savings of 282 gpd/du could be achieved if Denver's flat-rate customers were metered and charged $0.43 per 1,000 gallons. The Flechas and Morris-Jones studies were based on water use in utilities surrounding the Denver water department's primary flat-rate service area.

2. Benefits and Costs of Metering

There are many benefits derived from metering. Equity in customer charges, increased efficiency in water useage, and savings in the cost of water acquisition treatment and pumping are achieved (Flack, 1970). Results of the studies discussed above suggest that metering, by reducing demand, could reduce or postpone the need for the acquisition of increasingly expensive water rights and the development of new water supplies. In addition, system losses could be more readily detected and consumption patterns among various types of users determined, allowing for better system planning. On a long-term basis the permanent reduction in average and peak demand can result in significant savings due to deferred expansion of treatment and storage facilities, reduced capacities in the distribution system and lower wastewater treatment costs.

On a regional basis, the demand reduction achieved through metering could reduce the loss of irrigated agricultural land due to municipal acquisition of irrigation water rights and reduce the amount of trans-mountain diversion, resulting in benefits to the agricultural economy of the state on both sides of the Continental Divide (Anderson et al., 1977). The environmental damage caused by water development projects is difficult to quantify in dollar terms but can be significant in terms of social and recreational opportunities and wildlife habitat. State and local agencies may have to completely finance new water projects. Environmental concerns over the impacts of water development projects have resulted in lengthy delays. These delays have doubled or even tripled the costs of water development. The Denver Water Board's Foothills Project is a leading example (Wiley, 1979).

Metering, in addition to the benefits cited above, is a valuable administrative tool for the water utility. In addition to providing data for future planning, metering enables the utility to institute special demand reduction policies such as rationing or innovative pricing schemes. Incentive programs, such as an increasing block rate pricing structure, where water customers are charged an increasing rate for increasing increments of consumption, can be implemented (Anderson et al., 1977).

Though the benefits of metering are many, the cost of installing meters in a previously unmetered community can be substantial. Metering can greatly increase the operation and maintenance budget of a water utility as installation, maintenance, meter reading and billing must be performed. Bryson (1973) estimated it would cost over 27 million dollars or approximately $300 per residence, to meter nearly 90,000 residences in Denver. Based on estimates made by the Fort Collins Water and Sewer Department in 1977, it would take approximately three years at the cost of approximately $2.8 million to fully meter that city at its then population of 60,000 (Anderson et al., 1977). Morris and Jones (1980) in a Denver metering study, have estimated the cost of metering Denver's flat rate customers. Using economies of scale but assuming that 24 percent of the residential service pipes will be replaced due to leakage, the average cost per meter is $408 installed (1979 dollars). The Denver Water Department recently estimated that metering would cost from $200 to $900 per meter (Denver Water Department, personal communication, 1980).

Taking an anti-metering perspective, Anderson (1974), states that capital investment in meters adds no water to the system and a better investment of funds would be in the capture of flood flows or importation of additional water. He notes that using meters and doubling water rates would reduce water use by only about one-fourth with the basic impact being esthetic, e.g., dead lawns, trees and shrubbery. In a follow up study Anderson asserts that the water savings in metered communities are rather modest considering the high prices that must be charged to achieve those savings and questions whether their populations are being well served (Anderson, 1979). A similar view was expressed by the Denver Water Department in a rebuttal to the Morris-Jones study cited earlier (Denver Water Department, 1980). Anderson admits that the metered communities do not have to develop as large a raw water supply or water treatment facility, but due to the low consumptive use in cities he believes that savings in a basin-wide sense would be small.

Morris and Jones (1980) have examined ways to meet Denver's water demand over the next thirty years. After evaluating five alternatives, they concluded that demand reduction, through a series of conservation programs, including metering, was the most cost-effective method. Table 7 shows the costs and yields of alternate programs studied by Morris. Flack et al., (1977) concluded that metering was cost-effective even at low water and wastewater prices if cost of installation is reasonable, i.e. less than $500 per meter.

3. Political Feasibility

Public acceptability and the political costs and benefits to decision-makers often weigh far more heavily in determining the ultimate adoption or rejection of a water project than does economic or technological feasibility (Snodgrass & Hill, 1977),

TABLE 7

COST AND YIELDS OF WATER SUPPLY PROGRAMS FOR DENVER*

	Yield bgy[1]	Cost[2]	Environmental Costs[3]	Risk
Demand reduction	36.7	$0.35	slight	low
Phase I Foothills	15.2	1.13	already	low
Small water projects	27.0	1.12	great	moderate
Recycled water	12.2	1.84	none[3]	high
Eagle River diversions	57.1	2.49	greatest	high

[1]Billions of gallons per year.

[2]Cost per thousand gallons as a weighted average of component projects.

[3]Except for unknown public health risk.

*Source: Morris & Jones, 1980.

(White et al., 1980). Metering can be especially susceptible to public criticizm. Utility decision-makers are understandably hesitant to request a large bond issue as well as higher water prices if voters thought there were other means to manage the water supply situation. Hill, in an analysis of interviews of water users in Lafayette and Louisville, Colorado, concluded that preferences for conservation alternatives tended to be low despite the generally high familiarity with such alternatives (Flack et al., 1977). The use of the "technological fix" to solve resource problems, e.g., increasing raw water supply or improving distribution facilities appear to be preferred by the average consumer more than conservation measures which require changes in behavior.

B. Pricing Policies

As mentioned above, metering allows the implementation of various pricing policies to modify demand. In an unmetered community customers can only be charged on a flat-rate basis where the charge for water is constant and not affected by the amount used. In the past water prices were set to generate sufficient revenue to cover costs of adequate service to the utility's customers (Flack et al., 1977). This was generally true for both unmetered and metered communities. In recent years the role of pricing under a metered system has expanded. In addition to generating sufficient revenues to cover operation and maintenance costs, various pricing schemes have been proposed to reduce both average and peak demands.

Central to the discussion of pricing policies is the concept of the price elasticity of demand. This elasticity reflects the change in demand that occurs for every change in price given a price-demand relationship. As prices for a commodity increase or decrease, consumers will use lesser or greater quantities of water.

Different uses of water have been shown to have different price elasticities. Howe and Linaweaver (1967), Grima (1972), Burns et al. (1975) and Danielson (1979) have all found that the price elasticity is greater for sprinkling use than for domestic use. It appears that water price increases reduce outdoor uses more than in-houses uses (Flack et al., 1977). It has been noted that a limit can be reached on the demand reduction achievable through price increases, especially with regard to domestic use. Anderson (1974) compared the water use in the cities of Boulder and Broomfield, Colorado, two metered communities with similar population characteristics and substantially different water prices. He asserted that even with fairly large increases in the price of municipal water the quantity delivered per capita declines very slowly once a certain level is reached. Residential water users are, apparently, unwilling to limit water use below a certain quantity, in spite of a substantial price increase (Anderson, 1974).

The most common metered pricing structure is declining block rate pricing (Flack and Roussos, 1978). Under a declining block rate structure water is supplied at lower unit prices as consumption increases. Generally, the cost of providing water has been averaged over the year even though there are significant seasonal variations in demand. Off-peak users subsidize peak users (Hanke, 1975); winter users subsidize summer users and high density dwellers subsidize suburban dwellers, whose lawns tend to be larger (Flack and Roussos, 1978).

Flack and Roussos (1978) in a study of Denver, distributed capital costs throughout the year to the extent they contribute to extra-capacity costs. The costs of treatment and storage facilities, designed on the basis of maximum day, were apportioned on the basis of 37 per cent base costs and 63 per cent extra-capacity costs. Pumping, transmission and distribution costs were designed on the basis of maximum hour and apportioned on the basis of 22 per cent base costs and 78 per cent extra-capacity costs. This indicates a relatively high marginal cost of supply while the declining block rate structure implies a declining marginal cost.

The policy of setting the price of water equal to its marginal cost means summer peak water should be priced higher than winter water because of the increased capacity and high cost marginal capacity required (Morgan, 1979). In practical terms this corresponds to a peak-rate or seasonal pricing scheme (Hanke, 1975; Flack and Roussos, 1978 and Morgan, 1979). Peak demand rates would concentrate on the irrigation component of water use, which is also the most sensitive to price changes (Weakley, 1977).

Roussos estimated that a 10 per cent reduction in total demand could be achieved in the city of Denver if peak demand pricing was implemented (Roussos, 1976). Sewell and Roueche (1974), in a case study of Victoria, British Columbia, found that a 6 per cent decrease in peak demand and an 18 per cent decrease in off-peak demand would result from seasonal pricing. Similar results were noted by Hanke and Davis (1974) with a reported 2.6 per cent decrease in total demand and an 8.3 per cent decrease in peak demand in Boulder.

Other rate structures such as spatially differentiated prices and inclining block rates have been suggested. Under an inclining block rate (also called inverted or reverse block rate) unit prices increase with consumption. It holds promise as a water conservation method but has problems such as excess revenue generation and its political acceptability (Flack et al., 1977). There are few cases of the increasing block rate being implemented. In Colorado, only Westminster has a year-round increasing block rate price structure. Flack and

Roussos (1978) have judged peak-rate pricing to be the most viable alternative rate structure. A utility contemplating peak-rate pricing must be able to efficiently administer the billings for it to be cost-effective. Feldman (1974) has proposed a remote readout, peak pricing meter that allows simplified billing.

C. Water-Saving Devices

The installation of water-saving devices is a conservation measure that can be implemented by the utility or the individual homeowner. In the past, water consumption was not a consideration in the design of domestic water using fixtures due to the low cost and ready availability of water. Practically every type of household water use fixture can and has been redesigned to use less water (Flack et al., 1977). A number of manufacturers now make devices that reduce the volume of water used per toilet flush and restrict flows through faucets and shower heads. In addition, manufacturers now market toilets and household appliances, such as automatic washers, that use smaller amounts of water than previous models.

A great deal of research has been directed at the possible water savings that could be achieved through the installation of such water-saving devices.

Flack et al. (1977) evaluated much of the previous research regarding these possible savings. It was concluded that the use of water-saving devices was technologically developed, socially and politically acceptable and cost effective at current water prices. It was estimated that the retroactive fitting of these devices on the average existing dwelling unit would save 42 gpd/du based on 4.0 persons/d.u. The installation of new water-saving devices and appliances in the average new residence, as required by a modified building code, could save an estimated 72 gpd/du (Flack et al., 1977).

There have been few controlled, long-term experiments completed on the actual impact of water-saving devices on residential water use. Building codes designed to achieve in-house conservation are relatively new. The retroactive fitting of water-saving devices on older homes have usually been in response to water shortage conditions.

The Washington Suburban Sanitary Commission (WSSC), in 1972 revised the building code in its district and also distributed, door to door, bottles for the displacement of water in toilets. Other water saving devices were also available upon request. A public-education program aimed at achieving residential water conservation was also undertaken at the same time. The results have been unclear: per capita domestic use has decreased and the program judged a success. It is difficult, however, to determine how much of the demand reduction was a result of the water-saving devices and how much was attributable to the public education program (WSSC, 1974).

Morgan analyzed the water use effects of installation of a free water conservation kit in Oxnard, California, and found a 3 per cent reduction in the water use of installers over noninstallers (Morgan and Pelosi, 1980). He concluded this was a profitable undertaking even at low water prices.

Most programs dealing with the distribution and installation of water-saving devices have also included a public-education program with an appeal to conserve water. This has made it difficult to analyse the cost-effectiveness of implementing either measure alone. By flushing the toilet two less times per day, about the same per capita savings can be achieved as with the retroactive fitting of water-saving devices. A long-term, controlled study evaluating the effects of retro-active fitting of water-saving devices and building code modifications on residential water use, with and without other conservation measures, is needed.

Changes in building codes and the use of water-conserving appliances in new homes have been judged to be more cost-effective than retroactive fitting of older homes (Flack et al., 1977).

D. Pressure and Leakage Reduction

The reduction of watermain pressures and the detection and repair of distribution system leaks are two measures that can be undertaken by a water utility to reduce water use. Leaks can also be repaired, in-house, by residential water users. In-house pressure reducers are classified as water-saving devices and have been discussed by Flack et al. (1977) and others. In-house leakage detection and repair can occur in response to incentives (Hanke and Boland, 1971).

As the flow rate through a closed conduit, such as a water pipe, is dependent upon the pressure, the reduction of system distribution pressures has been proposed and practiced as a water conservation measure. The Washington Suburban Sanitary Commission has predicted that a 33 per cent reduction in water flow in their system could be achieved by reducing all line pressures over 60 psi to pressures in the range of 50-60 psi (WSSC, 1974). A study in Johannesburg, South Africa, found that a rise of over 60 per cent in the system water pressure caused a 30 per cent increase in consumption in a residential township (Gebhardt, 1975). The results of leakage tests in South Africa showed that losses were proportional to pressure.

The detection and repair of leaks in both utility water distribution systems and individual homes can result in significant water savings. The estimation of the amount of leakage that occurs in a distribution system is made difficult due to the existence of unaccounted public uses such as fire-fighting, street-washing, hydrant flushing and parks irrigation. In a metered system these uses are quantified by taking the amount of metered use from the total water produced (Flack and Weakley, 1977). In a flat-rate system it is even more difficult to estimate the leakage as the unaccounted for water rise cannot be accurately determined (McPherson, 1976).

The unaccounted for water use is generally estimated in the range of 10-15 per cent of the total water produced. Keller (1976), in a survey of water utilities, found an average unaccounted for use of 10.9 per cent in 1970. Howe (1971) in another survey found average unaccounted use to be 12 per cent. Howe (1971) estimated that at very modest costs of water it pays to repair most leaks above 3,000 gpd/main mile. The East Bay Municipal Utility District has reported that through a leak detection and repair program losses of four MGD have been eliminated (Laverty, 1976).

The repair of household leaks can also result in water savings. Metering will provide an incentive in repairing some household leaks (Hanke and Boland, 1971). The most common types of household leaks are from toilets and faucets (Flack et al., 1977). It has been reported that one leaky faucet can waste up to 2,200 gallons per year (Cooperative Extension Service, 1977).

Incorrect meter readings which under-register the flow rate, though not a source of leakage, can result in significant amounts of unaccounted for water. It has been reported that one city had an apparent 37 per cent loss of water through the distribution system, but recalibration of the treatment plant meter reduced this apparent loss to 20 per cent (Keller, 1976). Inaccurate customer meters can be an important cause of revenue loss (Howe, 1971). One survey has shown that 20 per cent of meters that have been in use over nine years would not register flows below 0.75 gpm, a flow rate which accounts for 25 per cent of a household's use (Hudson, 1964).

E. Public Education

Public education programs have increased in popularity among utility districts. Public education regarding water conservation has, in the past, been reserved primarily for dealing with water shortages due to drought conditions or other emergency situations. The 1970's have seen a number of utilities institute regular public education programs on conservation.

One of the first water utilities to institute a public education program was the Washington Suburban Sanitary Commission (WSSC) in the early 1970's. The primary emphasis of the program was to reduce sewage flows to its waste-water treatment facilities. The program was initiated in 1971 with customer flyers sent out with the water bills and expanded the next year with the development of the WSSC Water-Saving and Waste-Reduction Handbook which was sent to all customers. Other developments in the program included a series of water-saving workshops aimed at property managers; a slide-speaker program for civic and service organizations; assembly of product-data on water-saving appliances; broadcast of a set of twelve television and radio public service spot announcements; and the adoption of plumbing code changes. This first stage of public education led to a drop in water use from 101.6 gpcd to 100.2 gpcd, for a net minimum saving in the WSSC system of 1.7 mgd (Brigham, 1976). A bottle kit, consisting of toilet displacement bottles and a leak detection kit, was distributed free to all customers and consumption was reported to have dipped further to 97.0 gpcd. The public education program was continued with the production of a water conservation film, "Drip", an outdoor water-saving handbook and school-education programs (Brigham, 1976). The effects of the program have been difficult to quantify but the program has been judged a success (WSSC, 1974; Brigham, 1976).

Another public education program was instituted by the East Bay Municipal Utility District (EBMUD) in the San Francisco Bay area in 1972. The principal direction of EBMUD's water conservation efforts was toward widespread public education of the value of water and the means for its conservation (Lattie and Vossbrink, 1977). Inserts were included with the bimonthly water bills; a speakers bureau of 60 employee volunteers was formed to give slide-show presentations; and a series of posters, buttons, keychains, and other reminder items carrying conservation messages were distributed. Radio and television water conservation public service announcements were co-produced with two other Bay area water agencies (Lattie and Vossbrink, 1977). In addition prints of the conservation cartoon, "Water Follies", produced by the Denver Water Department, were purchased and distributed by EBMUD to schools and civic groups.

An innovative school program, Project Water, was started in 1974 by EBMUD. It was designed to form a water-conscious generation of customers (Lattie and Vossbrink, 1974). This project gained good cooperation from teachers and schools; workbooks and teacher's guides for all grade levels had been prepared and printed by 1976. "The Adventures of Captain Hydro", a blend of cartoons and lessons proved to be immensely popular.

The results of the EBMUD's water conservation program alone is difficult to quantify. Since the EBMUD had a public education program well under way when the 1976-1977 drought hit, materials were immediately at hand to help the public in its efforts to cut use. The conservation information program had helped precondition customers to the importance of proper water use (Harnett, 1978). During a long period of excessively hot days in June of 1976, the water consumption levels did not come close to the record daily consumption set during a less severe hot spell in 1972, when the conservation program had just begun (Lattie and Vossbrink, 1977).

F. Water Use Restrictions

Restrictions on water use have been widely practiced, especially by utilities in the western United States. They are designed to reduce or limit average and/or peak demand. Restrictions are generally short-term methods of reducing demand usually practiced during drought periods (Flack et al., 1977). In recent years restrictions have been imposed annually by many utilities during the summer months, when capacity is limited, whether or not there were drought conditions. With few exceptions, local governments when faced with a need to reduce local water consumption will initially institute a program involving water restrictions (Anderson et al., 1977).

1. Types of Restrictions

Restrictions on water use may be voluntary or mandatory and may specify time or place of use or through rationing, limit the actual amount of water that may be used through some type of rationing. The most common type of restriction is the mandatory restriction on the times that lawn sprinkling is allowed. Rationing is a severe form of restriction in that the total amount of water used per customer is limited. Metering is required if rationing is to be implemented.

2. Effects of Restrictions

The Denver Water Department, on June 1, 1977, imposed mandatory outdoor watering restrictions on all of its customers. Watering was allowed for 3 hours every third day with special exceptions. A water calendar designating the allowed times and places of sprinkling was well publicized in the media (Miller, 1978). A $10 fine was instituted for the first violation with a larger fine and installation of a water restrictor the penalty for a second violation.

The goal of Denver's water conservation program was to reduce water use during the hot summer months by 20 per cent. A 21 per cent (8 billion gallons) savings was actually achieved. During the mandatory conservation program department employees made 5,500 field stops to warn residents of violations but only wrote 238 tickets assessing the $10 charge for violators who ignored the first warning. It was not necessary to enforce the more severe penalties (Miller, 1978).

Hanke and Mehrez, in a study of Perth, Australia, used data from a 30-year period, 1946-1975, to estimate the probable impact of "light restrictions" on water use (Hanke and Mehrez, 1979). "Light restrictions" consisted of a ban on outside sprinklers (garden hoses are still allowed) and a limit on the number of hours of outdoor watering. It was found that the imposition of water use restrictions had a significant effect on water use. Hanke and Mehrez estimated monthly water use with "light restrictions" to be from 85.7 to 89.4 per cent of what it would be without restrictions. A survey in 1972 of 17 communities in the eastern and southeastern United States showed that short term voluntary restrictions could reduce consumption by as much as 60 per cent (Century Research Corporation, 1972).

It has been noted that the effectiveness of restrictions depends upon whether or not the public perceives the situation as being a crisis (Baumann et al., 1976; Hoffman et al., 1979). One study of northern Colorado towns indicated that after water use restrictions were imposed water use in many towns stayed the same or actually increased (Brauer et al., 1976). It appears that restrictions may lose effectiveness if overused or implemented when the public does not perceive of a shortage.

The California drought of 1976-77 forced a great number of utilities to implement water use restrictions, especially in northern California and the San Francisco Bay area in particular. The Bay area depends on snow melt from the Sierra Nevada for 53 percent of its water, on groundwater for 27 per cent and on local surface supplies for 20 per cent (Gilbert, 1978). Precipitation for the year ending July, 1976, averaged less than half the normal amount statewide, making that year the third driest on record. The following year ending in July, 1977, was the driest on record with statewide precipitation averaging less than one-third the normal amount (Hoffman et al., 1979). This record drought caused serious problems for many water agencies, especially suburban utilities such as those in Marin County which were dependent on local surface supplies (Gilbert, 1978). Unprecedented efforts were undertaken by local, state and federal agencies to reallocate the available supplies and conserve water (Hoffman et al., 1979).

As shown in Table 8, the San Francisco Bay area water districts varied widely in their approaches to reducing demand. One of the suppliers did nothing, three requested voluntary cutbacks and four imposed mandatory rationing.

The actual savings achieved were impressive. The Marin Municipal Water District (MMWD) achieved a 62 per cent reduction and the EBMUD a 40 per cent reduction, both in excess of the amount required. The three districts asking for voluntary conservation experienced cutbacks that were 10 to 15 per cent larger than their requests (Hoffman et al., 1979).

TABLE 8

POLICIES ADOPTED BY WATER SUPPLIERS DURING THE DROUGHT*

Name	Type	Residential Rationing Program
Marin Municipal Water Dist. (MMWD)	public-retailer	mandatory 57 percent per capita
East Bay Municipal Utility Dist. (EBMUD)	public-retailer	mandatory 35 percent per household
Contra Costa County Water Dist. (CCCWD)	public-retailer	mandatory 30 percent variable percent
San Francisco Water Dept. (SFWD)	public-retailer	mandatory 25 percent variable percent
Sunnyvale Water Dept. (SWD)	public-retailer	voluntary 25 percent
Santa Clara Valley Water Dist. (SCVWD)	public-wholesaler	voluntary 25 percent
San Jose Water Works Co. (SJWWC)	private-retailer	voluntary 25 percent
Great Oaks Water Co. (GOWC)	private-retailer	no program

*Source: Hoffman et al., 1979

Consumer response to the northern California drought has been analyzed by a number of researchers. All agree that once the water supply situation is regarded as a true crisis the public is willing and able to achieve reductions in water use of up to 50 per cent (Hoffman et al., 1979, Harnett, 1978; Robie, 1978). The education of the public on the need for and the means to achieve urban water conservation and the use of the media to convey a sense of crisis are important factors in the effectiveness of restrictions.

Hoffman et al. (1979) found no evidence that voluntary conservation programs were perceived by the public as less fair than mandatory programs. Of all the mandatory rationing programs it was found that the variable percentage plan was judged the least equitable. This plan allocated water to consumers on the basis of prior use and was criticized by substantial segments of the general public. It was thought to be unfair in that it penalized customers who had previously conserved while rewarding those who had previously overconsumed (Hoffman et al., 1979).

EBMUD allocated each household 225 gpd with an additional allowance of 35 gpd for each person in excess of three (Harnett, 1978). EBMUD's rationing plan received high marks for fairness but was criticized because it did not adequately distinguish between families with large outdoor water use requirements and those with none (Hoffman et al., 1979).

Bruvold (1979) interviewed one hundred residents in each of nine selected San Francisco Bay area water districts during the summer of 1977. The conservation programs fell into three categories: mild, moderate and rigorous. Districts falling into the mild category sought a 0-25 per cent voluntary reduction with few, if any, regulations or penalties associated with the conservation program. Districts falling into the moderate category sought a reduction of from 25 to 30 per cent, with certain regulations and penalties associated with their conservation programs. Districts falling into the rigorous category required a reduction of 30 per cent or more and adopted definite regulations and penalties to enforce their mandatory conservation programs.

A specific question on regionalization of the water conservation programs was asked by Bruvold. With the exception of one district, San Leandro, about 60 per cent of all respondents favored local water conservation programs, with about 40 per cent favoring one regional Bay area program. The areas that experienced the most stringent conservation programs were the most favorable toward regionalization.

3. Costs Associated with Implementing Restrictions

As with any type of conservation program there are both benefits and costs associated with imposing water use restrictions. Restrictions on water use are generally less socially and politically acceptable than other conservation methods. Restrictions actually inconvenience the water consumer whereas other conservation policies such as water-saving devices and metering do not directly inconvenience the customer. The political costs of water use restrictions may be large. The imposition of restrictions may foster distrust of elected officials (Flack et al., 1977).

A major cost of restrictions, from the standpoint of the water utility, is that restrictions may be too successful and may substantially reduce revenues from water sales. An analysis of the 1977 mandatory summer watering restriction program instituted by the City of Denver Water Department shows that the costs for labor, materials, outside services, professional services and interdepartmental expenses totaled $101,800. The program produced income of $109,800 from permits and penalties. The program was not judged a "financial success" because the 21 per cent reduction in overall water use dropped revenue from the sale of treated water from

$33.4 million in 1976 to just over $31 million in 1977 (Miller, 1978).

One result of the water use reductions achieved through restrictions is that some water agencies have had to adjust their rates upward to compensate for the decline in water consumption (Robie, 1978). The East Bay Municipal Utility District was forced to add surcharges during and after the California drought to cover part of the revenues lost from reduced water sales. Drought relief funds were also necessary to help defray costs of the conservation program and expanding the water supply (Schinzinger and Fagin, 1979).

Table 9 compares the costs of demand reduction, through restrictions and other means, and supply augmentation programs for four districts in the Bay area employing mandatory rationing during the California drought. Capital costs to the districts represent expenditures associated with interdistrict transfers and the associated engineering efforts. Operating costs to augment supply represent the cost of water purchased through these transfers. Operating costs associated with demand reduction include costs for additional staff, overtime wages, data processing, publicity and information efforts and water conservation kits.

TABLE 9

COMPARISON OF DEMAND REDUCTION AND SUPPLY AUGMENTATION COSTS TO THE DISTRICTS*

Water District and Policy Type	Capital Costs $	Operating Costs $	Estimated Cost of Shortage to Consumers $	Yield acre-ft.	Unit Cost $ acre-ft.
EBMUD 1977					
demand reduction	0	633,780	8,510,000	102,408[1]	89
supply augmentation[2]	4,250,000	1,400,000	0	36,000	156
SFWD (retail only) 1977					
demand reduction	0	419,000	1,510,000	31,455[1]	61
supply augmentation[3]	0	590,000	0	5,137	115
CCCWD (retail) 1977					
demand reduction	0	73,000	990,000	7,875[1]	135
supply augmentation[4]	325,000	18,150	0	1,100[5]	312
MMWD 1977					
demand reduction	0	632,500	5,500,000	20,062	308
supply augmentation[6]	1,200,000	1,600,000	0	3,988	702

[1] 1977 water consumption minus 1976 consumption

[2] Middle River pumping project

[3] Water purchases from SWP, Presidio, and some well testing

[4] Five new wells

[5] Estimated annual yield after February 1978

[6] Construction and operation of pipeline; water purchases

*Source, Hoffman et al., 1979

The cost of the shortage to consumers is an estimate of the landscaping losses incurred by residential customers. There was no additional cost related to increased water rates because in almost every case consumption fell more than rates increased. A survey of landscapers in one water district's service area produced a wide range of estimates of landscaping losses per single family dwelling unit--from zero to $400. It was found that the highest losses in the Bay area occurred in the areas that had the strictest rationing and the largest lots (Hoffman et al., 1979).

Hoffman computed direct costs on a unit basis for the water yield attributable to supply augmentation and demand reduction. Direct costs to augment supply ranged from 1.75 to 2.3 times the direct costs to reduce demand. Hoffman also noted that substantial costs were incurred by the districts as a result of lost revenues because of reduced water and hydropower sales. The losses caused by reduced water sales represented an opportunity cost of $4.3 million for EBMUD, while those caused by lost power sales amounted to $2.5 million for the San Francisco Water Department.

G. Horticultural Changes

The implementation of horticultural changes is often overlooked as a means of reducing sprinkling demand. Species of grasses and plants that are native to a semi-arid region such as Colorado require much less water than imported species, such as Kentucky Bluegrass. The planting of native species such as Buffalo Grass, Blue Grama or Yellow Bluestem sharply reduces watering requirements (Uno, 1974). The degree to which the public accepts these species changes is the primary determinant in the amounts of water that will be saved (Flack, 1976). The high costs of seed and low germination rates for natural grasses compared with bluegrass, can be a deterrent to wide acceptance (Flack et al., 1977).

Dernoeden (1976) has shown that bluegrass can be "hardened" or made more drought tolerant by restricting irrigation when transpiration rates are low. He was able to apply water to various varieties of bluegrass only once every three weeks while it maintained what he described as a quality appearance. He recommended that the application of nitrogen in the spring be avoided as nitrogen stimulates shoot growth and causes other reductions in drought hardiness. Complete fertilizers should be applied in the fall to stimulate root and rhizome development.

Dernoeden also found that grass will stay green longer using less water when cut to a height of about one and one-half inches than if it is cut shorter. Frequent and severe mowing should be avoided.

Lawn water requirements can be reduced by treating the subsoil with peat moss, sewer sludge, compost material or other enriching, moisture holding material. Mulching around trees and gardens will also help retain soil moisture (Anderson et al., 1977). The use of gravel and rock areas in place of lawn areas can directly reduce water use (Flack et al., 1977; Anderson et al., 1977). In a New Mexico study it was found that 88 per cent more water was applied to yards made up of 90 to 100 per cent plant materials than yards made up of only 50 to 70 per cent plants (Chavez, 1973).

Inefficient watering techniques can contribute to excess sprinkling use. A New Mexico study reported that water requirements could be reduced by as much as 47 per cent through efficient watering techniques (Cotter and Croft, 1974). Cotter and Croft noted that the majority of residents did not employ systematic water application procedures and tended to use more water than needed to maintain the landscape. However, the residents expressed an interest in obtaining information about improving watering practices. It appears that a well-coordinated public education program on irrigation practices and horticultural changes could reduce sprinkling demand.

CHAPTER IV

RESEARCH PROCEDURE

To meet the stated objectives of this report, it was necessary that data be collected from each water utility regarding sources of water supply; treatment and storage capabilities; water use; water rights acquisition; revenues; costs and management policies. A survey questionnaire, filled in by the author during a personal interview with the municipal water utility managers, was designed. The first part of the interview concentrated on sources of raw water supply. A precise listing was requested, if available, of direct flow rights including dates of appropriation and adjudication, adjudicated amounts and estimates of "safe yields" from the direct flow rights. Other sources of water supply, such as storage rights; units of Colorado--Big Thompson Project water; groundwater; and irrigation ditch company stock were also listed. The second part of the interivew dealt with the operations of the water utility. Information was sought on the population served, including: total population; number of households; and types of water users, i.e.; residential, commercial and industrial. In addition, data was collected on water treatment and storage capacities; the extent of metering, if any; water rates; tap-on fees; annual revenues from water sales; and annual operation and maintenance (O & M) costs. A specific question was directed at any future plans, such as treatment plant expansions or metering. The third part of the interview consisted of the collection of monthly water use data for the years 1975-1978. The utility manager was also requested to estimate peak day water useage for each year, the percentage of total water use that was attributable to the residential sector, and system leakage losses.

It was found that much of the requested water use information was not available or unreliable for many of the communities. Accurate estimates of system losses and single-family residential water use were not possible for the majority of the unmetered communities. The metered communities, for the most part, did not distinguish between single-family and multi-family dwelling units. Separation of single-family residential use and estimates of their per capita use, for both metered and unmetered communities, was performed in those cases where the required data was available.

Only 9 of the 25 communities had complete, seemingly accurate monthly gross pumpage data for the entire 1975-78 study period. Gross municipal water use, in acre-feet per year (af/yr) and million gallons per day (MGD) was estimated from water treatment plant pumpage information. Gross municipal gallon per capita per day (gpcd) useage was estimated by dividing water treatment plant pumpage by the total service population. Gross municipal use was broken into average, winter and summer categories. Winter and summer periods were each six months, with the summer period, May through October, approximating the lawn irrigation season along the Front Range.

CHAPTER V

WATER RESOURCES OF THE NORTHERN FRONT RANGE

A. Definition of Water Terms and Legal Concepts

A complete explanation of the Colorado system of water law is not possible in this discussion. Certain terms which are common to the examination of water resource development in this state are briefly defined.

Acre-feet (af) and cubic feet per second (cfs) are common terms for water measurements. Water rights are usually measured in cubic feet per second. One cfs for 24 hours is called a second-foot day and is equivalent to approximately 2 acre-feet.

There are two types of water rights in Colorado. Direct flow rights allow the holder of the right to divert streamflow, up to the decreed rate, for its appropriated purpose. A direct flow right cannot be used to store water for use at a later time. A storage right allows water to be diverted into a reservoir or other means of storage for use at a later time. Only one filling of a reservoir is allowed each year.

Water rights are based on the "first in time, first in right" doctrine of prior appropriation. The date that water was first diverted for use, or the right legally applied for is the date of appropriation. Appropriation dates determine the priority of water useage. All water rights must be adjudicated, which is a legal court ruling on the right. The adjudication date is the date that the water court approves the right.

Return flows and consumptive use are important factors in water supply planning. Return flow is that part of water diverted for use which is not consumed and returns to the original, or to some other, water course (Foss, 1978). Consumptive use is that portion of the diverted water that is unavailable for further use. Water is consumed by evaporation from ground and water surfaces and from snow, by transpiration from plants, and by incorporation into a manufactured product.

Front Range agriculture has a consumptive use of approximately 40 per cent (Gerlek, 1977). The return flow of 60 per cent is irrigation water that seeps into the soil, eventually finding its way into an irrigation ditch, the South Platte River or one of its tributaries or the groundwater reservoir. Larger municipalities in the Front Range have been shown to have a consumptive use of approximately

20 to 35 per cent (Janonis, 1977). The return flow is via the sanitary sewer system. Municipal wastewater is collected, treated and discharged into a receiving stream where it can be reused. Consumptive use by municipalities is greater in the summer months than winter months due to the heavy lawn irrigation, which has a larger consumptive use than in-house uses of water. Return flows, with the exception of some imported waters, are subject to appropriation by downstream users.

B. Sources of Raw Water Supply

The available water resources of the study area come from three sources: native surface runoff, trans-mountain diversions and groundwater. Native surface runoff is the major source of raw water in the area.

1. Native Surface Runoff

The northern Colorado Front Range communities are located in a semi-arid region where annual precipitation averages approximately 15 inches per year. Streamflows within the watersheds or drainage basins are primarily the result of the melting snowpack that accumulates in the higher elevations along the Front Range each winter. Local precipitation at the lower elevations is not a significant contributor to streamflows. Approximately three-fourths of the total annual runoff occurs during the months of May, June and July.

The northern Colorado Front Range is a part of the South Platte River drainage basin shown in Figure 2. The South Platte has its headwaters in the front range mountains southwest of Denver, then flows east and north along the base of the foothills, through Denver, before entering the study area. The South Platte River collects the runoff from the four primary watersheds, the Cache La Poudre River, Big Thompson River, St. Vrain River and Boulder Creek, in the study area before flowing eastward through Fort Morgan into Nebraska.

The subbasins of the South Platte River Basin are shown in Figure 3. All of the native surface water supply used by northern Front Range communities originates in four watersheds: Boulder, St. Vrain, Big Thompson and Cache La Poudre. All of these basins have their headwaters above 9,000 feet elevation. The drainage area and long-term average annual runoff for each drainage basin in the study area is given in Table 10. The South Platte Transition, Crow and Plains Tributaries basins, which are not a source of municipal surface water supply, contribute relatively small amounts of runoff.

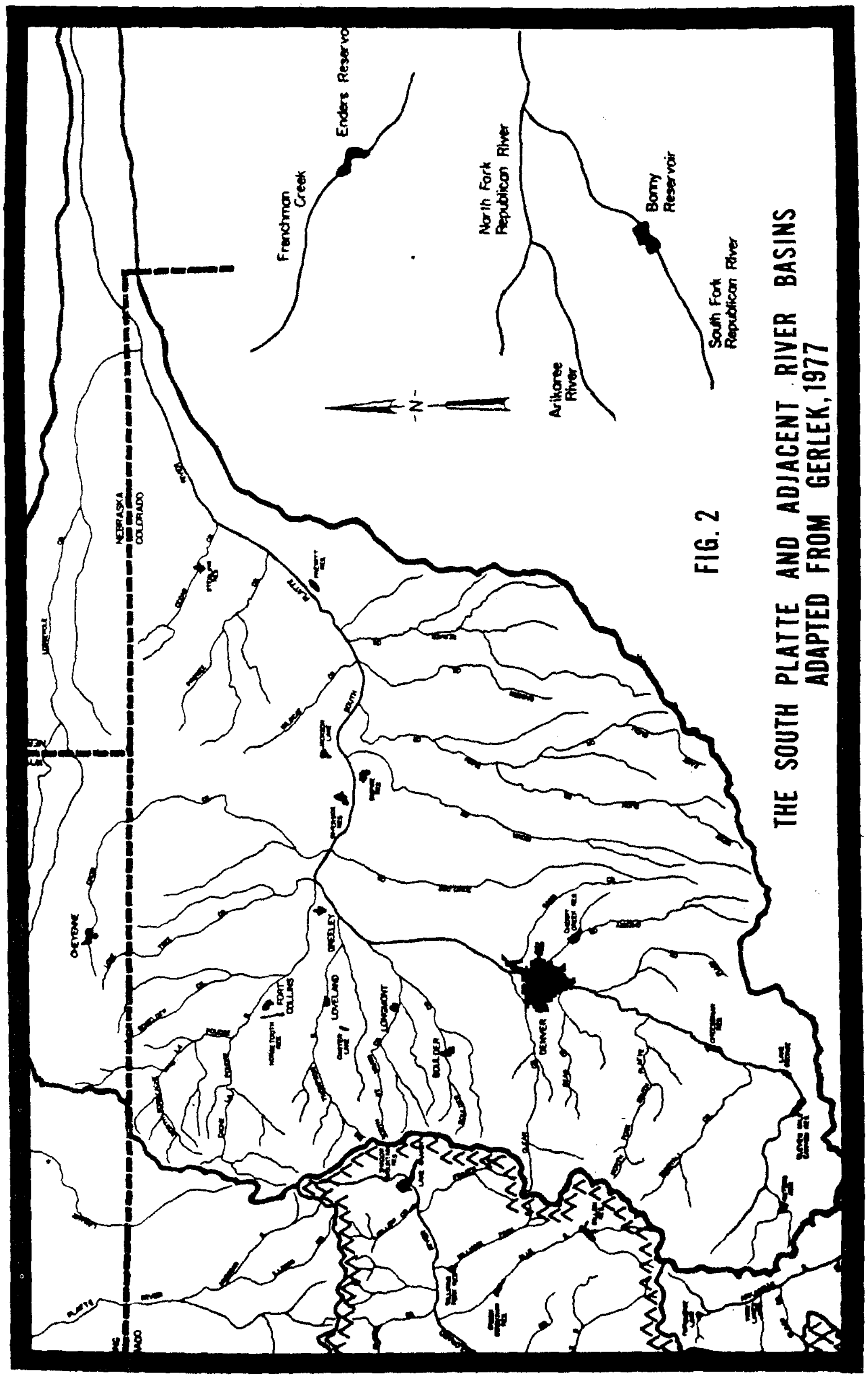

FIG. 2

THE SOUTH PLATTE AND ADJACENT RIVER BASINS
ADAPTED FROM GERLEK, 1977

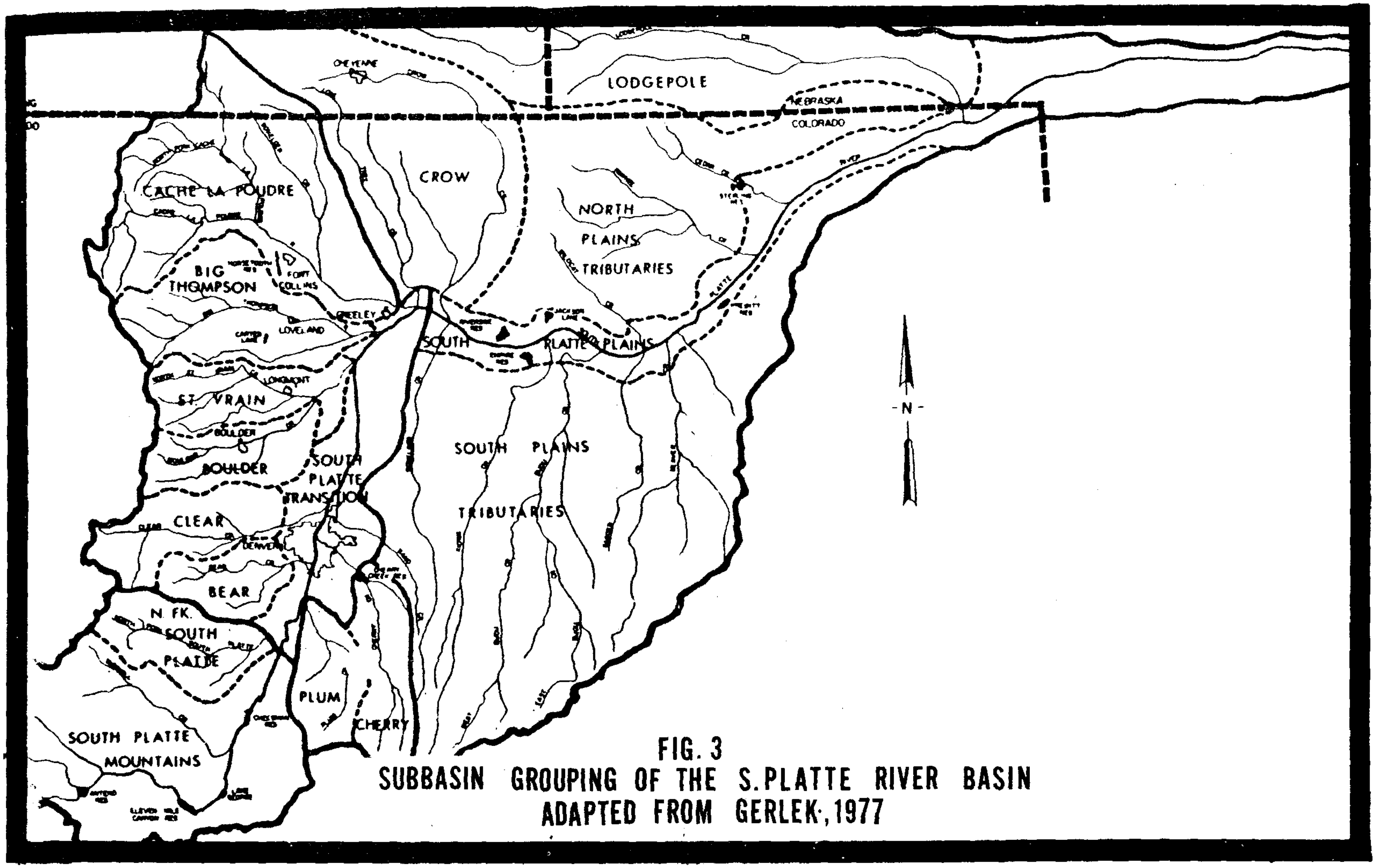

FIG. 3
SUBBASIN GROUPING OF THE S.PLATTE RIVER BASIN
ADAPTED FROM GERLEK,1977

TABLE 10

NATIVE SURFACE RUNOFF*

Drainage Basin	Drainage Area (in square miles)	Average Surface Runoff in acre-feet per year
Boulder	439	122,832
St. Vrain	537	117,600
Big Thompson	828	147,600
Cache La Poudre	1877	234,833
South Platte Transition	1477	12,341
South Platte Plains	1956	0
South Plains Tributaries	4276	50,000
Crow	1824	60,000
North Plains Tributaries	2400	1,090

*Source: Gerlek, 1977

2. Groundwater

The principal supplies of groundwater in the study area are contained in the alluvial deposits underlying the valleys of the mainstem South Platte River and its tributaries. Some municipal water systems located within the South Platte Transition and South Platte Plains basins use this aquifer as their source of municipal water supply. The aquifer typically consists of an ancient stream channel eroded in the bed rock and partly filled with unconsolidated sand, gravel and clay (Gerlek, 1977).

It is important to note that this aquifer is hydrologically connected to the surface flow of the South Platte River and tributaries. During high flows much of the adjacent floodplain is inundated resulting in groundwater recharge to the valley alluvium. As the floods subside and during periods of low streamflow, much of the water stored in the alluvium slowly seeps back into the stream (Gerlek, 1977). Irrigation is the greatest source of recharge of this aquifer, as over 50 per cent of the surface water applied percolates downward into the aquifer. This irrigation recharge water may eventually seep back into the stream. Since the aquifer and the stream are hydrologically connected, groundwater pumpage out of this aquifer can affect streamflows.

3. Imported Water

Imported waters, which are not native to the study area, are an important water resource. Trans-mountain diversions from the West Slope of the Rockies average approximately 280,000 acre-feet/year (Gerlek, 1977). There are also a number of trans-basin diversions which import East Slope waters of the Laramie and North Platte Rivers into the Cache La Poudre basin. A summary of imported water projects is shown in Table 11. The major source of imported water in the study area is the Colorado-Big Thompson Project which diverts West Slope waters into the Big Thompson basin. There is a major trans-mountain diversion through the Moffat Water Tunnel into the Boulder basin, but this project is owned by the City of Denver and its waters are not available to northern Front Range communities.

The Colorado-Big Thompson Project is operated by the Northern Colorado Water Conservancy District (NCWCD). Construction was started in 1938 at the end of the "Dust Bowl" drought. The Project was intended to supplement Front Range native surface water supplies with Western Slope water, primarily for use by irrigators. The District consists of 1,500,000 acres embracing portions of Boulder, Larimer, Weld, Morgan, Logan, Washington and Sedgwick Counties (Barkley, 1974). Of the 25

TABLE 11

SOURCES OF IMPORTED WATER*

Trans-Basin Diversion Structure	Source	Destination	Years of Operation	Average Annual Imports (acre-feet)
Alva B. Adams Tunnel (Colorado-Big Thompson)	Colorado Basin	Big Thompson Basin	1947-present	240,000[1]
Eureka Ditch	Colorado	Big Thompson	1940-present	80
Grand River Ditch	Colorado	Cache La Poudre	1892-present	21,513
Wilson Supply Ditch	Laramie	Cache La Poudre	1902-present	2,383
Laramie-Poudre Tunnel	Laramie	Cache La Poudre	1914-present	15,630
Skyline Ditch	Laramie	Cache La Poudre	1893-present	1,707
Cameron Pass Ditch	North Platte	Cache La Poudre	1913-present	107
Michigan Ditch	North Platte	Cache La Poudre	1905-present	1,190
			TOTAL	282,610

*Adapted from Gerlek, 1977

[1]NCWCD estimate

municipalities included in this study all but Brighton, Erie, Fort Lupton, Jamestown, Lafayette, Louisville and Nederland are located within the District boundaries.

The planned yield of the Colorado-Big Thompson (CBT) Project was 310,000 acre-feet per year. The Project has the physical capabilities to deliver 310,000 acre-feet per year but historically has only yielded approximately 240,000 acre-feet/year. Waters of the upper Colorado River, on the Western Slope, are stored in Granby Reservoir, accumulating largely during the snow-melt season. These waters are pumped into interconnected Shadow Mountain and Grand Lakes. They reach the Eastern Slope through the 13.1 mile-long Alva B. Adams Tunnel. The primary East Slope storage facilities are Carter Lake and Horsetooth Reservoir. The southern part of the District is served from Carter Lake by the St. Vrain, Boulder Creek and South Platte Supply Canals. The northern section is served by the Hansen Supply Canal which releases into the Poudre River. The project includes 10 major reservoirs having a total capacity of nearly 1 million acre-feet. The Green Mountain Reservoir on the West Slope serves as storage for replacement water to downstream West Slope users.

The NCWCD determines the amount of water to be allotted per CBT unit before the growing season each year. The allotment is based on estimated supplemental irrigation needs. If native surface runoff is projected to be below average, the allotment is normally above the average of 0.7 acre-foot per unit. Similarly, if above average runoff is predicted, the allotment may be only 0.6 acre-foot per unit. Allotments for the years 1975-1978 are shown in Table 12. Note that a full allotment was made in 1977.

TABLE 12

ALLOTMENT OF WATER PER UNIT OF CBT WATER

Year	Acre-Foot/CBT Unit
1975	0.80
1976	0.76
1977	1.00
1978	0.60

C. Water Rights and Municipal Water Supply

The development of the water resources of the northern Colorado Front Range began in 1859 when the Lower Boulder Ditch Company diverted 25 cubic feet per second (cfs) for the purpose of irrigation (Gerlek, 1977). This water right was adjudicated in 1882 and became the number one priority not only on Boulder Creek but the entire South Platte River basin (Wilkinson, 1974). By 1973 there were 5,734 decreed water rights held in the South Platte River basin (Wilkinson, 1974). An examination of water rights held in the four major sub-basins in the study area reveals that the streamflows in all the basins are over-appropriated. The absolutely and conditionally decreed water rights, as of 1973, are given in Table 13. Even accounting for return flows and imported water, it is evident that it would take an unusually wet year to satisfy all of the water rights.

The continued population growth in the northern Front Range communities will require the municipalities to expand their existing water supplies. A municipality seeking to increase its raw water supply has four options: 1) file for direct flow rights; 2) develop new storage rights; 3) import water; or 4) acquire existing water rights. These four options will be briefly discussed and evaluated.

1. Filing For Direct Flow Rights

The filing for new direct flow rights is no longer a viable option due to the fact that the four primary water basins are already overappropriated. An analysis of water rights in the South

TABLE 13

ABSOLUTELY AND CONDITIONALLY DECREED WATER RIGHTS*

Sub-Basin	Direct Flow Number	Direct Flow Total CFS	Acre-Feet Equivalent[1]	Storage # Reservoirs	Total AF	Total Rights in Ac-Ft
Boulder	90	5,500	1,742,400	31	49,300	1,791,700
St. Vrain	90	3,040	963.072	55	42,200	1,005,272
Big Thompson	75	2,730	864,864	14	101,000	965,864
Poudre	188	6,440	2,040,192	76	200,000	2,240,192

*Adapted from Gerlek (1977).

[1]Assumed diversion for 160-day period only (corresponding to growing season)

Platte River basin showed that between the years 1952 and 1972 a water right with an appropriation date of 1875 would be called out, that is, not be allowed to divert 34 percent of the time in May and 25.5 percent of the time in June (Beck, 1974). A water right with an appropriation date of 1980 may only yield water during periods of excessive runoff.

2. Development of Storage Rights

The development of storage rights by filing for the right and construction of a reservoir might yield enough water by capturing heavy spring runoff. The costs of engineering, land acquisition and reservoir construction must be carefully weighed against the benefits from the projected water yield from the storage project. Delays caused by environmental considerations can also significantly increase the costs of the project. Several municipalities are currently planning new storage projects and these will be discussed later.

3. Importation of Water

The importation of water not native to the study area is also a feasible means of increasing supplies. Trans-basin diversions from other East Slope basins are not likely as these basins are also over-appropriated. Trans-mountain diversions from the

West Slope, however, may be economically justifiable as there are some undeveloped waters on the West Slope. A trans-mountain diversion project is a very expensive undertaking and it is highly unlikely that any single municipality in the study area could afford the expense.

At present, the Windy Gap or Six Cities Project is the only trans-mountain diversion project planned. This project is under the administration of the Municipal Subdistrict of the Northern Colorado Water Conservancy District, consisting of the cities of Boulder, Estes Park, Fort Collins, Greeley, Longmont and Loveland. The project is designed to utilize the unused capacity of the existing Colorado-Big Thompson Project to transport water to the East Slope. Water would be diverted from the Colorado River below the confluence of the Fraser and Colorado Rivers and pumped to Lake Granby. From Lake Granby the water would be transferred via the existing CBT facilities.

The Windy Gap Project has experienced legal difficulties since it was first announced. Legal objections to the project by West Slope and environmental interests have prevented the start of construction. It now appears that the West Slope interests have been satisfied and a ruling on the environmental objections is expected in 1980.

Deliveries could start by 1984. The yield of the project, once estimated to be 60,000 acre-feet/year is now estimated to be approximately 48,000 af/yr or 8,000 acre-feet to each of the six municipalities. Several of the municipalities have transferred part, or all, of their share to the Platte River Power Authority (PRPA). The PRPA will supply part of the electrical power needs of these towns.

4. Acquisition of Existing Water Rights

The acquisition of existing water rights remains the most viable option to a municipality seeking to increase its raw water supply. Under Colorado water law, water rights may be bought and sold independent of the land. Senior water rights that have good water yields even in dry years are mostly held by irrigation ditch companies. Municipalities have acquired part or total shares in irrigation ditches through purchase on the open market. However, a lengthy, complicated legal process is involved before the municipality can legally utilize irrigation rights for municipal use.

Colorado water law requires that any change in use of a water right cannot injure any appropriator, even if the right is junior. Utilization of irrigation rights for municipal use often requires a change in the point of water diversion as well as a water court approved change of use from irrigation to municipal. This change of use can result in a significant reduction in the amount of water transferred with the water right. In the past, a change of use usually resulted in only the consumptive use of the irrigation right being transferred for municipal use. This was due to the fact that, historically, other appropriators had relied on the return flows. A plan for augmentation, filed with the request for change of use, may result in amounts greater than the consumptive use being transferred for municipal use. Augmentation involves placing water into the stream or body of water at locations where return flows from irrigation historically returned. This can be accomplished through the use of sewage flows, the purchase of water rights to be left in the stream, or the placing of water into a stream at the points of historic return flows. A plan for augmentation may not always be practical as significant administrative, legal and operation and maintenance costs may outweigh the benefits of the additional water acquired.

Water rights are carefully evaluated before purchase by a foresighted municipality. Average and dependable yields from the right and water quality are evaluated. Purchase price and annual assessments, of ditch company stock, also are compared among the available rights. Expected legal opposition to a change of use can also make one purchase more attractive than another.

In Colorado, municipalities may use the power of eminent domain to condemn irrigation water rights or storage facilities. This is usually regarded as a last resort by municipalities as negative publicity and strained relations with agricultural interests can result. The effects of municipal condemnation of irrigation water rights on agriculture is unknown. It may have the effect of undermining farmers' committment to maintain their agricultural pursuits and could increase their willingness to sell their water rights and ditch company shares to municipalities on the open market (Peak, 1977).

Municipalities in the study area that are within the Northern Colorado Water Conservancy District have the option of purchasing units of Colorado-Big Thompson water on the open market. CBT water is attractive to many municipalities because complicated legal transfers are not required for a change of use. In addition, the yield of CBT units increases in dry years when other municipal water holdings are normally yielding less water.

D. Impacts of the 1976-1977 Drought

In terms of native surface runoff, water year 1977 was one of the lowest years on record along the northern Colorado Front Range. This had been preceded in 1976 by a dry year. Total streamflows entering the NCWCD from the Poudre, Big Thompson, St. Vrain and Boulder Creek sub-basins averaged 538,000 af/yr for the period 1957-77. Streamflows for 1976 and 1977 were approximately 450,000 and 320,000 a.f. or 77 and 55 per cent of the 1957-77 average (NCWCD, 1978 Annual Report). The years 1975 and 1978 were both above normal years with runoff of 105 and 124 per cent of the 1957-77 average.

Though the 1976-77 drought included one of the driest years on record, the 1953-56 drought is the longest drought of record along the northern Front Range. Comparison of streamflows at selected gaging stations, shown in Table 14, indicate that the period 1954-55 averaged slightly less runoff than 1976-77. The 1954-55 drought, however, was preceded and followed by below-normal years of runoff while the 1976-77 drought was preceded and followed by above-average years.

During the same study period precipitation was averaged for six reporting stations within the NCWCD.

TABLE 14

AVERAGE AND DROUGHT STREAMFLOWS FOR SELECTED GAGING STATIONS

Gaging Station	Long-Term Average	1954-55 Average	1976-77 Average
Boulder Creek at Orodell	64,190	38,190	33,925
St. Vrain River at Lyons	92,740	41,205	47,405
Big Thompson River near mouth of canyon	*	63,235**	77,150**
Cache La Poudre at mouth of canyon	277,159	122,300	124,705
South Platte River near Kersey	562,900	160,150	379,450

*Long-term average not determined

**Adjusted for Colorado-Big Thompson diversions

Precipitation was approximately 12 and 25 per cent below the long-term average for 1976 and 1977, respectively. 1975 and 1978 precipitation was 5 and 10 per cent above the average.

Streamflows during the 1976-77 drought were typified by steadily decreasing flows. Streamflows dropped quickly and significantly in late summer 1977, especially on the Cache La Poudre River. Even though 1977 was the driest year on record, the total water used within the NCWCD was approximately 88 per cent of the 1957-77 average as shown in Figure 4.

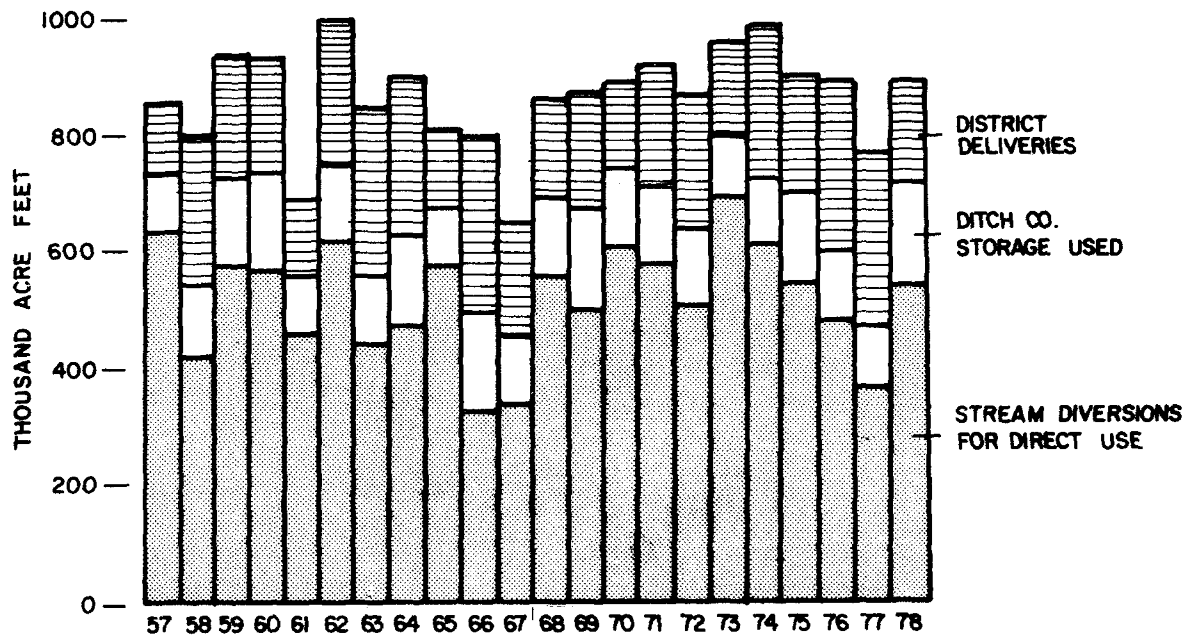

FIG. 4 *

TOTAL WATER USED IN THE NCWCD TRIBUTARY AREA, 1957-1978

* NCWCD, 1978 ANNUAL REPORT

This was largely a result of the full allotment per unit of CBT project water that was granted in 1977. The full impact of this extremely dry year was greatly mitigated by the availability of CBT water. As an indication, gross crop values and harvested irrigated acreage varied by less than 2 per cent between 1977 and 1978 (NCWCD, 1978).

If 1978 had been a dry year on both the East and West slopes it is very likely the drought effects would have been severe. On April 16, 1978, a record low active storage of only 13,069 acre-feet was reached in Granby Reservoir, the major storage reservoir of the CBT Project. If the winter of 77-78 had been dry the CBT allotment may only have been 0.5 af/unit or possibly less due to insufficient water in storage (Simpson, 1980). Native East Slope streamflows would also have been below average, with soil moisture and aquifer depletions from 1977 also reducing streamflow. Front Range ditch company reservoirs had some carryover from 1977, primarily due to the full CBT allotment. Total carryover storage from ditch company and CBT Project reservoirs was the lowest on record, approximately 50 per cent of the 1957-77 average as shown in Figure 5.

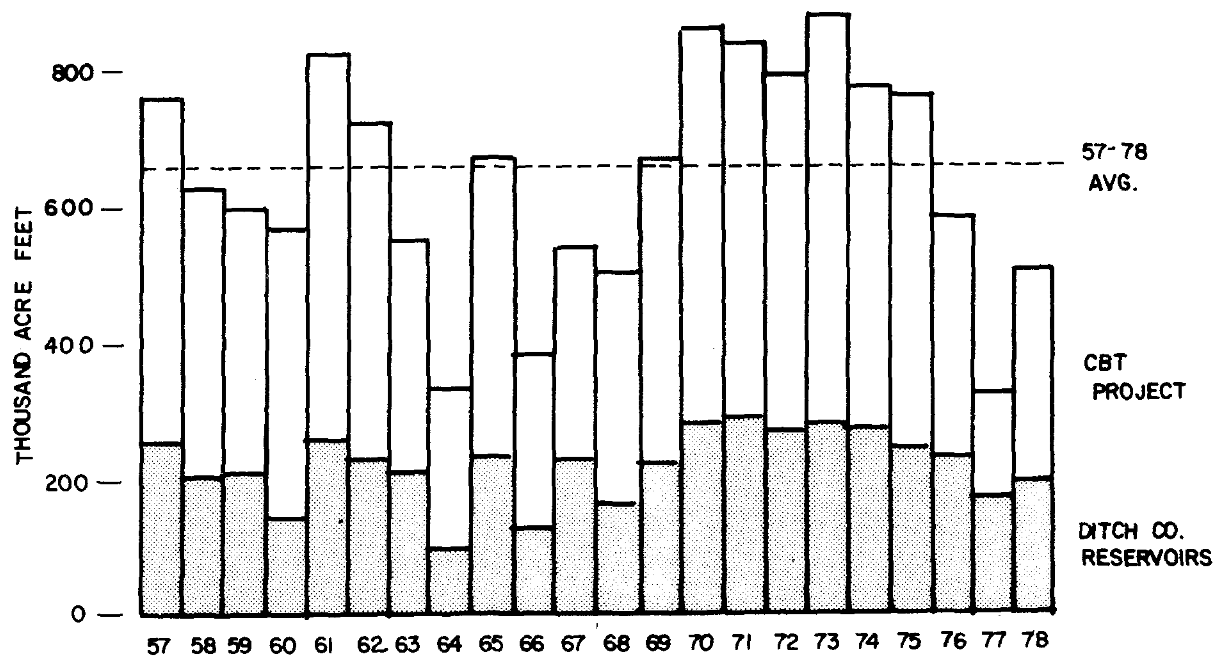

FIG. 5 *

CARROVER STORAGE IN RESERVOIRS WITHIN THE NCWCD, 1957-1978

* NCWCD, 1978 ANNUAL REPORT

CHAPTER VI

MUNICIPAL WATER MANAGEMENT POLICIES

Management practices and policies differ greatly among the numerous municipal water utilities along the Northern Front Range. The major difference in management practices involves the issue of metering. Rate structures, tap on and plant investment fees and water rights donation policies are management practices that greatly affect the financial status and the operations of the water utilities. Management practices and policies in the above areas were investigated and compared. The overall status of municipal water resource planning and the effects of the 1976-1977 drought were also evaluated.

A. Water Rates and Pricing Policies

All of the unmetered communities studied charged flat rates to their inside-city single family residential customers. Practices differed among the unmetered communities on the method used to determine the flat rate, as shown in Table 15. Few unmetered communities charged the same fixed rate for all residential users within the town. Most communities

TABLE 15

MONTHLY WATER CHARGES IN UNMETERED TOWNS

Town	Minimum Charge	Additional Charges
Berthoud	$ 7.00	Based on lot area
Brighton	4.00	Based on # of rooms
Ft. Collins	4.65	Based on lot area
Ft. Lupton	4.33	Based on lot frontage
Ft. Morgan	4.00	
Greeley	3.15	Based on rooms, sprinkling charge
Jamestown	7.50	Based on # of baths
Johnstown*	10.00	
LaSalle	7.25	Based on lot frontage
Longmont	7.75	Based on # of rooms
Loveland	12.33	Sprinkling charge
Lyons	9.00	
Nederland	8.67	
Platteville	5.50	Summer sprinkling charge
Wellington	4.80	

*Flat rate is charged for the winter months only have additional charges added to the base rate on the basis of lot size or extra rooms or baths in the house. Several communities have summer sprinkling surcharges. The minimum bill in the unmetered communities ranged from $3.15 to $12.33 per month.

Water rates in the metered communities, shown in Table 16, differed significantly with respect to minimum charges. A wide range of minimum prices and marginal costs for use over the minimum amount can also be seen. Minimum charges ranged from a low of $2.50/month in Boulder to a high of $10.50/month in Milliken. The minimum amount associated with this base charge also differed greatly. Boulder had the lowest minimum amount of 2,000 gallons/month, while Johnstown had the greatest with 20,000 gallons/month.

Marginal prices, the cost per 1,000 gallons over the minimum amount, also showed a great deal of variation. All but one utility has a decreasing block rate structure where the cost per 1,000 gallons over the minimum is less than the cost per 1,000 gallons within the minimum. Lafayette is the only town which employs an average price structure in which the marginal unit cost is the same as the minimum unit cost. Marginal costs ranged from a low of $0.25/1,000 gallons in Johnstown to a high of $1.06/1,000 gallons in Estes Park.

TABLE 16

MONTHLY WATER RATES IN METERED TOWNS

Town	Minimum Charge and Minimum Amount	Marginal Price for Exceeding Minimum	Cost/10,000 gal
Ault	$ 7.75/3,000 gal	$0.60/1,000 gal	$11.95
Boulder	2.50/2,000 gal	0.43/1,000 gal	5.94
Brush	8.00/5,000 gal	0.30/1,000 gal	9.50
Erie	11.00/3,000 gal	1.00/1,000 gal	18.00
Estes Park	6.75/2,500 gal	1.06/1,000 gal	14.70
Greeley	3.90/10,000 gal	0.31/1,000 gal	3.90
Johnstown	10.00/20,000 gal	0.25/1,000 gal	10.00
Lafayette	10.00/10,000 gal	1.00/1,000 gal	10.00
Louisville	5.50/10,000 gal	0.45/1,000 gal	5.50
Milliken	10.50/6,000 gal	1.00/1,000 for next 3,000 gal then $0.70/1,000	14.20
Windsor	6.90/3,750		14.45

Using a monthly use of 10,000 gallons, which is equivalent to 95 gpcd in an average household consisting of 3.5 persons, a comparison of average winter prices per household is also shown in Table 15. Greeley had the lowest rate of $3.90/month while the same use would cost over $14/month in Milliken, Windsor and Estes Park. The winter rates in Greeley, Boulder and Louisville are lower than many of the monthly rates in several unmetered towns.

B. Revenues From Water Sales

Income from the sale of treated water in 1978 ranged from less than $40,000 in Lyons to over $2 million in Boulder, Fort Collins and Greeley. Revenues per acre-foot delivered is a common way to compare revenues derived from the sale of treated water. Income derived solely from the sale of treated water is divided by the total acre-feet produced by the municipal water treatment plant. Income derived from tap-on, plant investment and water rights donation fees is not included.

Revenues per acre-foot for thirteen communities are shown in Table 17. Revenues among the metered towns ranged from $176 per acre-foot for Boulder to $370 per acre-foot for Windsor. Ault and Windsor, which both collected revenues greater than $270 per acre-foot, were supplied treated water by other

TABLE 17

REVENUES AND OPERATION AND MAINTENANCE COSTS, 1978

Town	Acre-feet/ Delivered	Revenue/ acre-foot	O & M Costs/ acre-foot
	Unmetered Towns		
Berthoud	688	$148	$123
Brighton	3,353	102	34
Ft. Collins	17,064	156	49
Ft. Morgan	4,216	65	58
Greeley	20,087	105	52
LaSalle	730	87	63
Longmont	10,865	153	120
Loveland	7,906	115	90
	Metered Towns		
Ault	209	$280	$247
Boulder	17,494	176	98
Brush	1,216	184	195
Estes Park	1,188	253	207
Windsor	519	370	322

agencies. The high rates charged by these two towns are reflected in the greater revenues per acre-foot collected. Revenues among the unmetered towns ranged from $65 per acre-foot collected in Fort Morgan to $156 per acre-foot in Fort Collins. The metered towns, as expected, derived greater revenues per unit of water delivered although the average per capita delivery was less than in the unmetered towns.

A review of operation and maintenance costs shows that metered towns generally have greater O & M costs than their unmetered counterparts, as indicated by Table 17. It is likely that this difference is due to the additional administrative costs involved in meter readings and billing. As expected, the groundwater supplied towns had lower O & M costs than the surface water supplied towns due to the lower treatment costs. However, Ft. Collins and Greeley, which treat surface water, have O & M costs about the same as the groundwater supplied towns. This may be due to economies of scale since their systems are much larger than those of the groundwater towns.

C. Tap-on and Plant Investment Fees

Nearly every community in the study area has adopted the policy of making new development pay for itself. In the area of water supply, this means charging water tap and plant investment fees and requiring water rights donations that reflect the actual costs of supplying water to new developments. Tap and plant investment fees, often lumped together, vary considerably, ranging from $375 to $2,220, as shown in Table 18. Part of this wide range of fees is due to the different plant investments required to treat groundwater and surface water supplies.

Total fees for the groundwater supplied towns ranged from $375 to $1,500 with an average of $906 for the seven towns on groundwater. At present, plant investment required for goundwater supply includes well and pump facilities, chlorination equipment, treated water storage plus transmission mains. As will be discussed later, several groundwater towns are anticipating treating surface water for municipal use. Surface water treatment, typified by coagulation, sedimentation, filtration and disinfection, requires greater capital investment which may account for the upper range of total tap fees levied by certain groundwater communities. Total tap fees for the surface water towns ranged from $500 to $2,220 with an average of $1,206 for 16 communities. Several of the fees appeared to be unusually low for surface water treatment facilities

TABLE 18

WATER TAP-ON AND PLANT INVESTMENT FEES, 1979

Source Water Supply	Town	Total Tap Fee*
Groundwater	Brighton	$1,270
	Brush	375**
	Eaton	1,500
	Ft. Lupton	1,000
	Ft. Morgan	400
	Platteville	1,000
	Wellington	900
Surface Water	Ault	1,400**
	Berthoud	950
	Boulder	1,300**
	Estes Park	2,220**
	Ft. Collins	1,245
	Erie	1,800**
	Greeley	750
	Johnstown	500**
	Lafayette	1,800**
	Longmont	975
	Loveland	1,015
	Louisville	1,900**
	Lyons	1,000
	Milliken	1,200
	Nederland	1,100
	Windsor	1,000

*Includes tap-on and plant-investment fee; labor extra; for 3/4" tap

**Includes cost of meter

and probably do not reflect the full costs of supplying new customers

D. Raw Water Supply Planning in the Surface Water Supplied Towns

1. Water Rights Holdings

A detailed accounting of water rights, including appropriation and adjudication dates and estimates of available average and dependable yields from these rights were requested from each town's water manager. Approximately half of the water managers were able to provide a relatively current listing of water rights held, though only a few of these could supply appropriation and adjudication dates. A listing of the types and sources of surface water rights held by the towns is shown in Table 19. Of the 16 towns listed, 10 owned direct flow rights, 9 had storage rights and 12 owned various irrigation ditch company stock. Erie, Lafayette and Louisville, which are part of the Coal Creek basin, listed ditch company stock as the primary source of water supply. All of the water supply for these three towns is diverted by ditch companies from the South Boulder Creek basin.

Every town within the NCWCD owns units of CBT water. Ault and Milliken, which have rural-domestic water districts treat their water, are entirely

TABLE 19

SURFACE WATER RIGHTS OWNED, 1979

Town	Direct Flow	Storage	Ditch Company	CBT Units
Ault				360
Berthoud	Big Thompson River #1, 7.14 cfs		Handy Ditch - 9 shares; Loveland Ditch - 3 shares	432
Boulder	Boulder Creek 70 cfs	Barker, 8000 af other small reservoirs	# of ditch company shares	19,500
Erie			South Boulder Cannon Ditch - 120 shares Leyner-Cottonwood Ditch - 155 shares	*
Estes Park	Fall River, Black Canyon, Glacier Creek			450
Ft. Collins	Cache La Poudre 19 cfs	Joe Wright, 6700 af	# of ditch company shares	10,200
Greeley	Cache La Poudre 12.5 cfs	# small reservoirs 13,230 af	# of ditch company shares	18,200
Johnstown	Big Thompson River 4.01 cfs		Home Supply Ditch, 1.25 shares	615

TABLE 19 (continued)

SURFACE WATER RIGHTS OWNED, 1979

Town	Direct Flow	Storage	Ditch Company	CBT Units
Jamestown			Left Hand Ditch, 24 shares	*
Lafayette		Wanaka Reservoir 150 af	Howard Ditch, South Boulder & Bear Creek Ditch, Dry Creek #2 Ditch, Goodhugh Ditch, Davidson Ditch	*
Longmont	St. Vrain Creek 31.5 cfs	Buttonrock 18,000 af other small reservoirs	# of ditch company shares	7,800
Loveland	9.44 cfs Big Thompson River	600 af	# of ditch company shares	7,000
Lyons	North St. Vrain 4.9 cfs	Buttonrock, 300 af		250
Louisville		Marshall - 93 af Louisville - 290	# of ditch company shares	*
Milliken				85

TABLE 19 (continued)

SURFACE WATER RIGHTS OWNED, 1979

Town	Direct Flow	Storage	Ditch Company	CBT Units
Nederland	Middle Boulder Creek	Barker - 19 af	North Boulder Farmer's Ditch	*
Windsor		Donath Lake	Louden Ditch	500

*Not in the Northern Colorado Water Conservancy District dependent upon CBT water for their water supply. This has created problems in the past for Ault, during years of above normal runoff, when CBT allotments are less than average. Municipal holdings of CBT units as a percentage of actual use in 1978 are shown in Table 20. CBT holdings ranged from 22 to 95 per cent of 1978 use. The NCWCD has adopted a recent policy of allowing a municipality to own a maximum of 100 per cent of its use in CBT units, but not more, as a deterent against hoarding (Simpson, 1980).

The degree of sophistication and understanding in the area of raw water supply varied greatly among the towns. As noted, approximately half of the water managers did not have a working knowledge of the town's water supply yield. In many of these cases consulting engineers or water lawyers handled water supply matters. Only two towns, Fort Collins and Boulder had a designated water resources engineer on the town staff though water supply planning, to various degrees, was being undertaken by staffs of several other towns.

Estimates of available average and dependable yields from water rights were not available from the majority of the towns. Fort Collins, Greeley, Loveland and Louisville had performed some type of analysis of average and dependable yields. The

TABLE 20

MUNICIPAL OWNERSHIP OF COLORADO-BIG THOMPSON UNITS

Town	1978 Water Use (acre-feet)	CBT Units*	Yield**	CBT Units as Per Cent of Actual Use
Ault	209	330	198	95
Berthoud	688	410	246	36
Boulder	17,494	19,000	11,400	65
Estes Park	1,188	430	258	22
Ft. Collins	16,426	10,000	6,000	37
Greeley	20,092	17,880	10,728	53
Johnstown	401	600	360	90
Longmont	12,541	7,800	4,680	37
Loveland	7,906	7,500	4,500	57
Lyons	195	240	144	74
Milliken	115	85	51	44
Windsor	519	480	288	55

*1978 estimate

**1978 allotment was 0.6 af/unit

concept of "dependable" yield varied among the water managers. Estimates of dependable yield ranged from the average historic yield for the five driest years since 1950 to the yield experienced during the driest year on record. Very little analysis had been performed regarding the effects of a long-term drought on direct flow rights and carryover storage in municipal reservoirs.

2. Water Rights Acquisition Policies

Municipal policies regarding the acquisition of water rights, exclusive of donations required for new development, were not firmly defined in any municipality. The larger towns generally had annual budget allocations for the purchase of water rights offered on the open market, though there were few established guidelines regarding purhcases. Acquisition of CBT units was regarded as desirable in both the large and small towns. Many of the smaller towns reported recent increased activity in the purchase of CBT units compared with past years. Financial limitations were cited as the primary constraint on additional acquisitions of water rights, especially in the smaller towns with limited resources.

3. Water Rights Donation Policies

Nearly every surface-water supplied town has an adopted policy that new developments should provide the raw water resources needed to meet the new water demands. Many towns rely heavily on this policy to provide the majority of new water rights. For this reason, required developer donation policies for water rights are better defined than new water acquisitions. Water rights acquisition for municipal use has become a complicated process requiring some knowledge of ditch company operations, water diversion records and current developments in water law. A number of towns appear to have placed undue reliance on developer donation policies to simplify the municipal water resource planning process. There are several factors that must be examined in determining the adequacy of water rights obtained by donation to meet future municipal demands.

Water rights donation policies for the surface water supplied towns are listed in Table 21. One-half of the towns require that water rights yielding 3 acre-feet/year or 3 units of CBT be donated for every gross acre of development. Ault and Milliken require one unit of CBT/lot, which at current subdivision densities of 2.75 to 3.25 lots per gross acre, is comparable to the 3 af/acre requirement. Berthoud and Lyons require donations of 2 af and 1.5 af/acre respectively, but place additional requirements on the water to be donated.

TABLE 21

WATER RIGHTS DONATION POLICIES IN THE SURFACE-WATER SUPPLIED TOWNS

Surface Water Town	Water Rights Donation
Milliken	$3,000/lot or 1 af/lot CBT
Berthoud	2 af/acre CBT, Handy Ditch stock, negotiated
Ft. Collins	$4,800/acre or 3 af/acre selected ditch stock, CBT
Longmont	3 af/acre, negotiated
Lyons	1.5 af/acre, must be available to city 12 months/yr
Loveland	Existing rights or 3 af/acre CBT
Greeley	3 af/acre CBT or selected ditch stock
Windsor	3 af/acre CBT or Louden Ditch stock
Erie	South Boulder Cannon or Leyner-Cottonwood Ditch stock
Nederland	No new annexations allowed
Boulder	Existing rights on annexed property
Ault	1 af/lot, CBT or North Poudre Ditch stock
Johnstown	3 af/acre CBT
Lafayette	3 af/acre, negotiated
Louisville	Existing rights on land or $2,200/lot, negotiated

Assuming a gross density of 3 lots/acre and 3.5 persons/dwelling unit, a 3 af/acre donation would yield 255 gpcd, which would meet the average gpcd use in all the metered and most of the unmetered surface water supplied towns. A donation of 1.5 af/acre would provide 128 gpcd under similar conditions, which is below the average gpcd use in all but a few towns. Precise language is generally needed in the statement for donation policies as the requirement of 3 af/acre may prove to be inadequate because certain factors act to reduce the amount of water available for municipal use. Donation policies are generally worded to require that ditch company stock, CBT units, existing water rights on the land or cash or a combination of the above be provided. A description of each type of donation is provided below.

a. Existing water rights. Most towns will accept the existing water rights on the property to be developed, as it is likely that the rights can be utilized by the municipality directly for water supply or for augmentation purposes. The majority of these towns require other donations if the land to be developed has no rights or the rights are thought to be inadequate. Boulder, however, has no requirement other than that the existing rights, if any, be transferred.

An incident occurred in Longmont that illustrates the need for precise wording of donation policies. A developer sold the existing water rights on property to be annexed and provided the city with rights purchased at a lesser price, resulting in a net profit to the developer and less yield to the city.

Agriculture along the Front Range normally applies 2 to 3 af/acre of irrigated land. Thus, if the land to be developed was previously irrigated, the accompanying water rights are usually sufficient for urban use. The priority and thus the dry year yield of the existing water rights may vary significantly. If the right is relatively junior the dry year yield may be less than 1 af/acre. Existing rights are also subject to the same limitations in change of use from irrigation to municipal as ditch company stock or other purchased rights.

b. Ditch company stock. Many municipalities allow ditch company stock to be transferred to municipal ownership to meet donation requirements. The types of ditch stock that are acceptable and the shares that are required to meet the 3 af/acre requirement varies with each town, depending upon the geographic location and yield per share of stock. The majority of the towns specify which ditch stock is acceptable, though in several cases it appears that the stock has not been adequately evaluated as to yield. There is no common, accepted practice on evaluating the yield per share for donation purposes. An average yield per share, based on historic 10, 20, 25 or 50 year periods is the most common practice. Dependable, or minimum yields of the stock are not used in determining donation amounts.

Evaluation of the various donation policies revealed inconsistencies in determining the average yield per share. Average yield per share at the point of diversion, at the historic delivery point or at the municipal intake point can differ greatly. Most policies do not specifically state which delivery point will be used in determining the yield per share. In many cases the yield for municipal use, as compared with the previous agricultural use, has not been determined. A change of use petition in the appropriate water court is required for a municipality to legally use irrigation water for domestic, commercial and industrial purposes.

The average yield per share at the point of diversion can be determined by examining water commissioners' field books on microfiche at the State Engineer's office. The average yield at the historic point of delivery at the farmer's headgate will always be less than the diversion amount due to ditch losses. Examination of ditch company records or discussions with ditch superintendents will indicate the carrying charge or "shrinkage" loss that is charged each share. If the share is for a reservoir company, annual declarations of yield at the point of delivery may be available. Shrinkage assessments, which vary with each ditch, generally range from 15 to 50 per cent of the diversion amount. This historic yield at the headgate is normally the maximum that a municipality can expect to receive.

Ditch water is available only during the irrigation season, from the months April to November at best. A municipality, on the other hand, has a year round demand, though the demand is greater during the irrigation season. A change of use to year round municipal use or a change in the point of diversion may effectively limit the amount useable to the historic consumptive use. A plan for augmentation may be filed with the water court for its approval, which provides that amounts equal to the historic return flows will be released at designated return points. The cost-effectiveness of an augmentation plan is dependent upon the need for acquisition of water for augmentation purposes, the administrative and operation and maintenance costs involved in augmenting flows and the engineering and legal expenses incurred in having the plan decreed.

A number of municipalities have had change of use decrees involving ditch water and are aware of the amounts that will actually be available for municipal use. These towns usually are more specific as to the ditch stock that is acceptable as a donation. Other towns, however, have used ditch water directly and for storage without ever filing for a change of use. Some have never attempted to use their ditch stock for municipal use. These towns cannot be certain of the amounts of water that will be available after a change in use or point of diversion decree. One town manager expressed extreme disappointment in the results of a recent change of use case.

c. Colorado-Big Thompson Water. Every municipality within the NCWCD will readily accept CBT units as a water rights donation. Even though a CBT unit averages approximately 0.7 af/unit, it is unique in certain respects. In a dry year when Front Range native surface water supplies are lower than normal, a CBT unit will have a greater than normal yield. In addition, CBT water may be called for during the winter months when agricultural rights are not diverting. The town, however, must be able to transport the water to the municipal water treatment plant during the winter when the ditches are not operating or have adequate storage facilities to last through the winter months.

Another attractive feature of aquisition of CBT water is that ownership is easily transferred within the NCWCD. CBT water is not subject to complicated court action before the use is changed from agricultural to municipal purposes. The available yield for municipal purposes is the same as that for agricultural use and can be estimated without detailed analysis. Only carrying losses or charges incurred during transmission from CBT storage facilities to the water treatment plant must be accounted for.

Donation policies requiring 3 af/acre of either ditch stock water or CBT units should be examined by each individual town to determine whether new water demands will be met. After a change of use or point of diversion, ditch water that had an average yield of 3 af at the point of diversion may only net 1.5 af, or less, for municipal use. Similarly, 3 CBT units will only yield 2.1 af on the average. Actual available yields should be compared to estimated water demands in evaluating the adequacy of donation policies.

d. Cash Contributions. A cash contribution in lieu of water rights will be accepted by most municipalities. Of the towns that have dollar amount requirements, the prices ranged from $1600/af in

Fort Collins to $3000/lot in Milliken. As the price of ditch company stock varies widely and most towns and ditch companies are reluctant to state the current prices, a price summary on cost per acre-foot of ditch stock is not readily available. Fort Collins, however, has monitored the approximate average cost per acre-foot for the years 1974 to 1979. The Northern Colorado Water Conservancy District has also monitored the price of CBT water over this time period. A comparison of the selling price of CBT water and selected ditch stock in the Fort Collins area versus the Consumer Price Index is shown in Figure 6. While the Consumer Price Index has increased less than 100 per cent during the period 1974 to 1979, the average price per acre-foot of ditch water in the Ft. Collins area has increased over 400 per cent from $350 in 1974 to $1600 in 1979. The price for a unit of CBT water has shown a greater increase with a 1974 price of $350 and $2200 in 1979.

The rapid increases in the price of water rights suggests that any municipality that accepts cash donations should re-evaluate the cash amounts necessary at least semiannually to ensure that the donations reflect the true costs of water acquisition. The water rights should then be purchased within a relatively short time after the donation. Figure 6 indicates the increased competition for the available

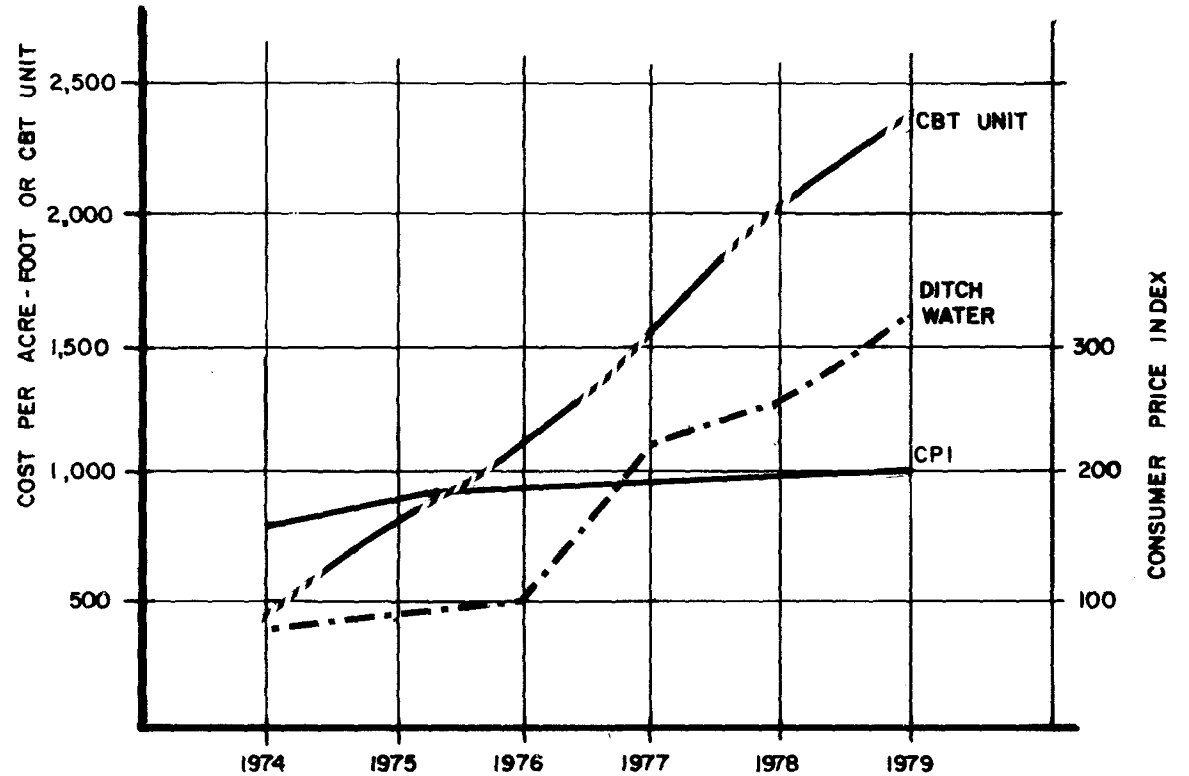

FIG-6 *

COST OF RAW WATER IN THE FT. COLLINS AREA
VS.
THE CONSUMER PRICE INDEX, 1974-1979

* SOURCE: NCWCD & CITY OF FT. COLLINS

water rights. The steady price increases are an indication of the relative scarcity of water rights for sale. It is possible that by requiring developers to donate ditch water or CBT units, municipalities are unwittingly and indirectly competing against themselves for the available water rights. Municipalities seeking to expand their water supply, developers needing to purchase rights to meet donation requirements and speculators or "water brokers" hoping to cash in on the municipalities' and developers' needs may all be competing for the same water even though the water will eventually end up for municipal use.

4. Proposed Water Storage Projects

A number of major municipal water storage projects are currently under construction or in the planning stage in the study area. The Windy Gap or Six Cities Project is the largest of these storage projects. The basic features of the Windy Gap Project were outlined in Chapter 5. The project originally consisted of six cities: Boulder, Estes Park, Fort Collins, Greeley, Longmont, and Loveland. Each city owned a one-sixth share which would yield approximately 8,000 acre-feet/yr each. Estes Park and Loveland have transferred one-half of their shares, or 4,000 af/yr each, to the Platte River Power Authority. Fort Collins has transferred its entire right to the PRPA.

The Windy Gap Project, which is operated as a subdistrict of the NCWCD, is unique in one major respect. CBT Project water cannot be reused by the municipalities owning units as per the terms of the NCWCD Project. Irrigators in Morgan, Sedgewick, Logan and Washington counties have paid for the right to the reuse of this water. Windy Gap water is not subject to these constraints and the member municipalities can reuse or sell their return flows, i.e., sewage effluent. As the return flows of the Six Cities' members are in the range of 50 to 80 per cent, this represents a significant addition to municipal water supply. Ft. Collins, though it has transferred its share to the PRPA, has reserved the right of first use. The PRPA will be supplied with effluent from Ft. Collins. The other municipalities in the project are anticipating borrowing irrigation water and replacing it with sewage effluents based on Windy Gap shares. In addition, unlike CBT water, it is possible that Windy Gap water can be transferred out of the district. Other towns, not within the NCWCD, may be able to benefit though this is dependent upon the willingness of Six Cities members and the NCWCD to cooperate.

The City of Fort Collins has 6,700 acre-foot capacity Wright Reservoir under construction, and two other mountain reservoirs have been proposed.

These are Sheep Creek Reservoir, which is in the early planning stages, and has an ultimate design capacity of 4,000 acre-feet, and Rockwell Reservoir, also in the planning stages with a design capacity of 4,900 acre-feet. The Rockwell site is within proposed Wildnerness and Wild and Scenic River Areas and environmental objections will have to be overcome if this site is to be utilized.

The City of Longmont, in conjunction with the St. Vrain and Lefthand Water Conservancy District, has proposed two major reservoirs. Coffintop Reservoir, which is proposed for the South St. Vrain River, has a design capacity of 84,000 acre-feet. Geer Canyon Reservoir, with a storage capacity of 25,000 acre-feet, is planned on Left Hand Creek. Both reservoirs are propsed as multi-purpose with agricultural, municipal and industrial water supply benefits.

The City of Greeley is involved in the planning for two storage facilities; Seamann Reservoir and Grey Mountain Reservoir. The Grey Mountain Reservoir, in which Ft. Collins and the Platte River Power Authority are also involved, has a design capacity of 300,000 to 400,000 acre-feet, though the average yield would be approximately 40,000 acre-feet. The proposed site has serious environmental constraints which may never be resolved.

The Coal Creek Basin Water and Sanitation Association, which includes the towns of Louisville, Lafayette and Erie, has proposed a 13,000 acre-foot reservoir on Coal Creek. This is the most water short area in the study. Coal Creek has an average flow of 3,000 acre-feet year, with the minimum of 396 acre-feet recorded in 1968 (Hobbs, 1980). The towns in the Coal Creek basin are not within the NCWCD boundaries and thus unable to receive CBT water.

The Narrows Reservoir, planned by the U. S. Water and Power Resources Service for the South Platte River near Ft. Morgan, has a history dating to the 1940's. It is designed for a maximum capacity of 1,609,000 acre-feet with 498,000 acre-feet of this designed for water supply. In addition to irrigation, municipal, and industrial water supply benefits, it is designed to regulate flows that must be released to Nebraska as required by interstate compact. The Narrows Project has had a history of environmental and funding problems and its status is uncertain.

E. Raw Water Supply Planning in the Groundwater Supplied Towns

1. Water Rights Holdings

Water managers in the groundwater supplied towns were generally more aware of the expected yields from their water rights than their counterparts in the surface water supplied towns. This is largely because groundwater rights are less complex than the surface water rights system. Most managers felt that the rated pumping capacity of their wells was the anticipated safe yield in terms of raw water availability. Most of the adjudication dates on municipal wells are junior, however, to surface water rights on the South Platte River. Adjudicated rights and well pumping capacities for the groundwater supply towns are listed in Table 22. This chart shows that the 1978 water demand was 60 per cent or less than the rated pumping capacity for the reporting towns. Adjudicated rights were generally much greater than pumping capacities. Several towns had adjucicated rights for wells that had not yet been drilled.

2. Water Rights Acquisition Policies

Four groundwater supplied towns have regularly been purchasing surface water rights when available. Brighton leases its surface water rights to local irrigators or leaves the water in the South Platte for augmentation purposes. Eaton, LaSalle and Platteville have begun acquisition of units of CBT water in anticipation of using this high quality surface water for municipal purposes some time in the future. As of April, 1980, Eaton owned 822 units

TABLE 22

WATER SUPPLY VS. DEMAND IN GROUNDWATER SUPPLIED TOWNS

Town	Adjudicated Rights	Pumping Capacity	1978 Demand	Demand/Pump Capacity
Brighton	14,000 gpm	12,740 gpm	2,083 gpm	16.4%
Brush	*	*	750 gpm	*
Eaton	*	3,100 gpm	390 gpm	12.6%
Ft. Lupton	16,830 gpm	2,460 gpm	833 gpm	33.9%
Ft. Morgan	17,500 gpm	6,490 gpm	2,430 gpm	37.4%
LaSalle	*	820 gpm	493 gpm	60.0%
Platteville	2,065 gpm	2,065 gpm	342 gpm	16.6%
Wellington	1,150 gpm	1,400 gpm	278 gpm	19.9%

*Not available

of CBT water, approximately 100 per cent of its present demand. LaSalle owned 38 units and Platteville owned 32 units, approximately 5 per cent of each town's present water demands.

3. Water Rights Donation Policies

Water rights donation policies differed greatly among the groundwater supplied towns, as shown in Table 23. LaSalle, Eaton and Platteville require units of CBT water and Wellington requires cash or North Poudre Ditch stock. These towns are planning for the possibility of changing from groundwater to surface water as a source of water. Brush assumes the existing rights on developed property and Fort Morgan negotiaties the type of water to be donated. Brighton was the only town to specifically state that the groundwater rights donated must have a net yield of 3 af/acre adjudicated for municipal use. Brighton will also accept selected ditch stock which is generally left in the stream for augmentation purposes or leased to irrigators.

4. Raw Water Quality Problems

Every groundwater supplied town is experiencing water quality problems. With the exception of Brush, hardness and total dissolved solids are high, often exceeding recommended drinking water limits as shown in Table 24. Town water managers reported that

TABLE 23

WATER RIGHTS DONATION POLICIES IN GROUNDWATER SUPPLIED TOWNS

Groundwater Town	Water Rights Donation
Brush	Existing rights on annexed land
Brighton	3 af/acre <u>net</u> adjudicated for municipal use, if groundwater 3 af/acre ditch stock useable in the area
LaSalle	3 af/acre CBT
Eaton	3 af/acre CBT
Ft. Lupton	3 af/acre ditch stock or groundwater, negotiated
Ft. Morgan	1 af/5 acres, negotiated
Platteville	1 af/lot CBT
Wellington	$1750/lot or North Poudre Ditch stock

TABLE 24

WATER QUALITY OF MUNICIPAL GROUNDWATER SUPPLIES

Town	Date of Sample	Total Hardness	Total Dissolved Solids**	Nitrates***	Gross Alpha Radioactivity****
Brighton	9/23/76	525 mg/l	1,050 mg/l	13.6 mg/l	40±21 pCi/l
	2/23/77	NA	NA	9.0	NA
	" "	NA	NA	15.7	NA
	" "	NA	NA	7.8	NA
	3/26/79*	NA	NA	8.0	31±14
Brush	12/9/76*	90	120	1.1	12±6
Eaton	6/22/77*	670	1,150	1.5	NA
	4/20/78	NA	NA	5.1	41±5
Ft. Lupton	1/21/77	460	1,000	17.9	NA
	6/2/77	NA	NA	8.7	47±18
Ft. Morgan	4/20/78	NA	NA	5.1	94±26
	" "	NA	NA	5.3	102±27
	" "	NA	NA	5.8	75±23
	4/21/78	NA	NA	7.4	72±24
	4/29/78	NA	NA	6.9	53±21
LaSalle	12/18/77	510	980	30.0	21±13
Platteville	6/6/77*	410	860	7.0	26±14
Wellington	7/21/78	1,300	2,090	7.1	22±21
	" "	1,300	1,890	7.0	NA
	" "	860	1,430	5.0	NA

*Denotes sample was taken from a house tap; other samples taken at well heads
**Recommended limit for TDS is 500 mg/l as $CaCO_3$
***Mandatory limit for Nitrates is 10 mg/l as NO_3
****Mandatory limit for gross alpha radioactivity is 15 pico-Curies/l
NA - not available

individual home water softeners were used extensively in every groundwater supplied town with the exception of Brush. Nitrates in the water supply are also a problem for many towns as also indicated in Table 24. The federal mandatory limit of 10 mg/l NO_3 as N has been exceeded in a few instances. The major health effect associated with the prescence of high concentrations of nitrates in drinking water is the disease, methanoglobanemia, which affects infants. Nitrates in the groundwater supplies are largely a result of percolation of fertilized irrigation water plus recharge of the aquifer from streamflows consisting of municipal sewage effluent. Brush has closed one municipal well due to high levels of nitrates. Federal limits on gross alpha radioactivity have been exceeded in several towns as indicated in Table 24. The source of this contamination is not known. The health effects of these levels of radiation are not well defined.

Preliminary investigations into solutions to the water quality problem have been undertaken by a number of the groundwater supplied towns. Treatment costs involved with reducing nitrates, total dissolved solids and gross alpha radioactivity to acceptable limits are generally regarded to be prohibitive. Brighton is currently evaluating treatment processes for nitrate removal, including the use of algae ponds.

The general consensus among these towns' water managers and their consultants is that the acquisition and treatment of surface water would be more economical than the treatment of groundwater. A loosely formed organization, the Northern Colorado Domestic Water Authority, NCDWA, has been investigating the feasibility of a regional water treatment system. Eaton, Platteville, Ault, Berthoud, Fort Lupton, Lyons, Loveland, Greeley, Brush and Fort Morgan have been included as possible members (Baker, 1980). The number of towns interested at any one time varies, as well as the economics of the project. Many of the smaller towns are investigating the possibility of receiving federal aid, especially from the Farmers' Home Administration. The project would most likely involve the treatment of CBT Project water at a water treatment plant to be constructed in the vicinity of CBT's Flatirons Reservoir and then delivery by pipeline to the towns involved.

Blending treated surface water with existing groundwater supplies to produce a better quality water than exists at present has also been widely discussed by town water managers. Treated surface water would be provided by the NCDWA or one of the rural-domestic water districts. Platteville has considered blending surface water obtained from the Central Weld County Water District with its present groundwater source.

The option also exists to have one of the rural-domestic water districts provide all the water for the municipality. Policies differ among these water districts with several requiring that ownership of municipal water rights be transferred to the water district. One rural-domestic water district stipulated that an interested town turn over the entire water distribution system to the district. In this instance the town refused, but is still negotiating with the water district.

F. Raw Water Yield Analysis--Town of Berthoud

A case study has been chosen to illustrate many of the concepts concerning water rights that have been discussed in this chapter. The Town of Berthoud has been selected as its raw water supply consists of direct flow rights, ditch company stock and CBT water. Town officials were cooperative and provided the needed information for the following analysis. The analysis ignores certain minor water rights holdings and simplifies the physical operations of the raw water system.

1. Water Rights Holdings

Berthoud holds an impressive portfolio of water rights for a community of its size. A summary of its major water holdings is listed in Table 25. Berthoud has two separate decreed direct flow rights on the Big Thompson River. Both of these direct flow rights are part of the #1 priority on the Big Thompson with an appropriation date of November 10, 1861. The June 29, 1916 adjudication provides for 3.0 cfs, decreed for domestic use. This decree has a provision that once a pipeline has been constructed to the Big Thompson, this diversion of 3.0 cfs could be made year round (Vranesh, 1979). Berthoud also received 4.14 cfs which was transferred from the #1 priority Big Thompson Ditch in the October 7, 1925 adjudication.

In addition to direct flow rights, Berthoud owns 9.85 shares of the Handy Ditch Company. The Handy Ditch holds interests in priorities #2, 4, 5, 10½, 39 and 49½ on the Big Thompson River. Berthoud also owns 3.5 shares of Loveland Lake and Ditch Co. and 630 inches of Welch Reservoir Co. water for the irrigation of specified lands. The Loveland Lake and Ditch Co. and Welch Reservoir Co. shares have not been used in the yield analysis. The town also owns 452 units of CBT water.

TABLE 25

BERTHOUD'S MAJOR WATER RIGHTS

Type of Right	Amount	Big Thompson Priority
Direct flow, Domestic use	3.00 cfs	#1
Direct flow, Transferred from Big Thompson Ditch	4.14 cfs	#1
Handy Ditch Co.	9.85 shares	#2, 4, 5, 10½ 39 and 49½
Colorado-Big Thompson	452 units	NA

NA - not applicable

2. Potential Water Yields

The potential yield from Berthoud's existing major water rights holdings has been evaluated on an average and dependable basis. Potential yield is defined as the yield from the water rights of the point of diversion on the Big Thompson River. Physical (hydrologic) limitations on diversion amounts and possible legal limitations on rates and times of diversion as a result of decrees have not been accounted for.

a. Average annual yield. Berthoud's #1 domestic priority for 3.0 cfs, if diverted for the full year, would yield 2,168 acre-feet of water annually at the point of diversion on the Big Thompson river. The additional #1 priority of 4.14 cfs was transferred from the Big Thompson Ditch. This is an irrigation right which has historically been diverted through the Handy Ditch headgate. The Handy Ditch diverts for an average of 157 days per year (Vranesh, 1979). Based on this average period of diversion, at a constant rate for 157 days, the 4.14 cfs #1 priority would provide an additional 1,287 acre-feet per year at the Handy Ditch headgate on the Big Thompson.

Berthoud owns 9.85 shares of the Handy Ditch Company. The Handy Ditch has both direct flow and storage rights on the Big Thompson. Direct flow rights total 198.4 cfs but the ditch does not divert the full decreed amount during the irrigation season. Storage rights are held in the Hertha and Welch reservoirs. Analysis of the average yield of a share of Handy Ditch is complicated by several factors. State water commissions records do not separate the times when the Handy Ditch is diverting under Berthoud's #1 priority separate from the Handy Ditch priorities. These records also do not account for the releases from storage by the Handy Ditch. Records kept by the Handy Ditch are incomplete before 1970. Based on average deliveries to shareholders along the main ditch and accounting for a 15 per cent ditch loss, the average yield of a share of Handy

Ditch stock at the point of diversion was estimated to be 12.4 acre-feet per year. Berthoud's 9.85 shares would provide 123 acre-feet per year.

Berthoud also owns 452 units of CBT water. The average annual yield of CBT water is approximately 0.7 acre-feet/unit. CBT water could provide an additional 316 acre-feet per year to Berthoud's water supply.

b. Dependable yield. The dependable yield from water rights can be evaluated by different methods. Actual diversions during the driest period on record, whether the driest single year or an extended drought, appears to be the most common method for estimating the dependable yield. Since historic records are often sketchy and conflicting and physical diversions under other priorities may have changed, evaluation of yield through the use of a basin-wide model may be more satisfactory but the complexity and cost of such a model has precluded its use in most cases.

Evaluation of dependable yield from Berthoud's direct flow rights has been performed by examining historical data on Big Thompson River streamflows. Streamflow data for the Big Thompson River was examined for the past 30 years, a period which covers two of the driest periods on record. Examination of the streamflow data was hampered by the fact that since

1953 two tunnels have diverted Big Thompson River water along with West Slope diversion water at Estes Park which is upstream of the gaging station located near the mouth of the canyon. These waters are placed into the Big Thompson River just below the gaging station. The Handy Ditch diversion structure is also located downstream of the gaging station but upstream of the tunnel outfall to the Big Thompson River. The result is that some Big Thompson River water bypasses the gage.

Gaging station streamflows and adjusted streamflows for the Big Thompson River at the mouth of the canyon are shown in Table 26. The drought periods 1953-1956 and 1976-1977 were the worst in the last 30 years, with the 1953-1956 drought the worst on record along the northern Front Range. In terms of driest single years, 1954 and 1977 rank first and second with streamflows of 52,700 and 63,590 acre-feet/year, respectively. The average streamflow for the years 1947-1978, a period of 31 years, was 115,600 af/yr (Wenzel, 1980). Based on this average, streamflow during 1954 was only 46 per cent of normal.

Average monthly streamflows for 1954 and 1977 were examined to determine if Berthoud's direct flow rights would have a yield year round. Stream gage and adjusted streamflows were examined for the minimum month in each year. The minimum adjusted the availability of return flows from irrigation and municipalities (Blewitt, 1980). Berthoud's dependable yields from its direct flow rights are, therefore, essentially the same as the average yields.

Dependable yield analysis of a share of Handy Ditch stock is complicated by the same factors as described earlier for the average yield. The driest yield on records kept by the Handy Ditch Company, as measured at the headgate and including reservoir releases, occurred in 1977 when the yield was 8.1 af/share (Yellick, 1980). Berthoud's 9.85 shares would provide 80 acre feet of water.

The 452 units of CBT water could have a yield of 1.0 af/unit as occurred in 1977. CBT allotments are greater during drought periods than average years if Western Slope water is available. The potential average and dependable or dry year yields from Berthoud's major water holdings are shown in Table 27. Based on the fact that the #1 priority right has the same average and dry year yields and that the CBT units held yield more water in dry years, Berthoud's dry-year potential yield is 93 acre-feet greater than the average yield. This is probably not the case with most other towns.

TABLE 27

POTENTIAL WATER YIELDS

Type of Right	Amount	Average Yield	Dry-year Yield
#1 Domestic	3.00 cfs	2,168 af	2,168 af
#1 Irrigation	4.14 cfs	1,287 af	1,287 af
Handy Ditch Stock	9.85 shares	123 af	80 af
CBT Units	452 units	316 af*	452 af**
Total		3,894 af	3,987 af

*Based on 0.7 af per unit delivery in average year
**Based on 1.0 af per unit delivery in dry year

3. Existing Water Yields

There is a significant difference between the potential water yields and the existing water yields that can be realized by Berthoud during an average and dry year. The potential water yields were evaluated at the point of diversion on the Big Thompson River. The potential water yields are reduced by physical and operating limitations which decrease the actual yield as measured at the Berthoud pipeline.

Berthoud diverts its entire water supply through the Handy Ditch headgate on the Big Thompson River. As the Handy Ditch only diverts an average of 157 days per year, Berthoud can only receive water during this period. Berthoud's water rights during the irrigation season are the 3.0 cfs domestic and 4.14

irrigation diversions. The 3.0 cfs domestic right for year round use has never been utilized during the non-irrigation season because it must come through the Handy Ditch. This inability to divert during the winter months results in a loss of 1,236 acre-feet per year over the potential yield.

Under a working relationship established at the turn of the century, the Handy Ditch is entitled to one-half of Berthoud's direct flow rights as a transportation charge for delivering the water to the Berthoud pipeline (Vranesh, 1979). CBT water is charged a 25 per cent transportation charge (Yellick, 1980). These two carrying charges result in a reduction of 1,268 acre-feet in the average year yield and 1,336 acre-feet in the dry-year yield.

The 1970-1979 average yield of a share of Handy Ditch stock, as measured at headgates on the main ditch similar in location to Berthoud's was 10.8 acre-feet/share. The minimum yield during this period was 7.1 af/share in 1977. The ditch losses between the headgate on the Big Thompson and the delivery to the Berthoud pipeline reduce the average annual yield by 16 acre-feet and the minimum yield by 11 acre-feet.

The transportation agreement with the Handy Ditch and the inability to fully develop year round use of the 3 cfs domestic right results in a loss of

2,520 acre-feet during an average year, which is 65 per cent of the potential yield as measured at the point of diversion on the Big Thompson. The dry-year yield is reduced by 2,583 acre-feet, which is also 65 per cent of the dry-year potential yield.

4. Evaluation of Options

Berthoud is unable at present to utilize 65 per cent of its potential water supply. The entire winter supply for Berthoud must be stored in the 450 acre-foot Berthoud Town Lake. At current winter use rates of 135 gpcd, the 450 acre-feet of storage could support a maximum population of 6,000 persons, almost double the existing town population. Evaporation and seepage losses, dead storage and unforeseen emergencies can significantly reduce the amount of water that is actually available during the winter months.

Berthoud is presently evaluating the options available that can increase the available yield from their existing water rights, especially during the winter months. This would involve the construction of a pipeline to the Big Thompson River. The decree of June 25, 1916 provides that once this pipeline has been constructed, diversions of 3 cfs could be made year round. Construction of this pipeline with a capacity of 8 cfs or greater could free Berthoud of the carrying charges currently levied by the Handy Ditch. A maximum gain of 2,520 acre-feet per average year could be realized.

Berthoud's failure to use the 3.0 cfs domestic right as provided by the 1916 decree may have resulted in abandonment of the right. Colorado courts have established that an extensive period of non-use may forfeit a water right. It is certain that an attempt to construct the pipeline would be opposed by the Handy Ditch and other ditch companies that hold winter storage rights on the Big Thompson, such as the Home Supply Ditch Co. These irrigators could argue that their winter storage would be injured by Berthoud's winter diversions and that the stream would be injured during the irrigation season due to the lack of return flows from ditch seepage.

Other judicial doctrines, such as the "great and growing cities doctrine," may be invoked by Berthoud, however (Vranesh, 1980). This doctrine lessens the hardship on a town planning ahead for future growth by allowing it to acquire and hold, without using, water rights to meet future growth.

Berthoud's most pressing water supply problem is meeting winter water demands. The 452 units of CBT water owned by Berthoud cannot be utilized, at present, during the winter months because over 30 cfs is required at the Handy Ditch headgate on the Big

Thompson River for any flow to reach the Berthoud pipeline. Seepage losses and operational difficulties thus make winter diversion of CBT water through the Handy Ditch an emergency option. Berthoud and the Handy Ditch have discussed the possibility of increasing the storage capacity at Hertha or Welch Reservoirs. Berthoud could then store its CBT water during the irrigation season and deliver it by pipeline, as needed, to its existing raw water system. The possibility of extending Berthoud's pipeline to the St. Vrain Supply Canal to take delivery of CBT water via Carter Lake has also been proposed (Vranesh, 1979). This would provide additional winter supply without the need for additional reservoir storage. Berthoud is currently evaluating these options.

The average yield from Berthoud's currently unused 9.85 shares of Handy Ditch stock is approximately 106 acre-feet per year. This water is only available during the irrigation season which at present is not a time when Berthoud needs more water. Berthoud cannot legally store this water for later use because it is a direct flow right. A change of use would be required in order for Berthoud to legally use and store the Handy Ditch stock water for municipal purposes. If Berthoud increases its storage capacity and continues to accept Handy Ditch stock as developer water contributions, it may be desirable to seek a ruling on the change of use. Berthoud would likely be limited to use of the historic consumptive use portion of the Handy Ditch yield unless the water court approves a plan by which Berthoud could ensure that historic return flows are not diminished by the change of use.

G. Impacts of the 1976-1977 Drought

The impact of the 1976-1977 drought on water supplies of the northern Front Range was described in Chapter 5. The 1.0 acre-foot per unit allotment of CBT water was instrumental in mitigating the effects of the drought. Municipal water supplies, in most cases, were adequate to meet demands during the drought period. Few municipalities needed to institute special conservation measures as a result of the drought. Many towns had sprinkling restrictions in effect before the drought that were continued during the dry period. An analysis of water use before, during and after the 1976-1977 drought and the effects of restrictions is presented in the next chapter.

Of the towns utilizing surface water for municipal supply, Lafayette and Erie were more significantly affected by the drought than other communities. Both of these towns are outside of the NCWCD boundaries and rely on ditch company diversions from South Boulder Creek for their water supply.

Sprinkling restrictions were in effect for both of these towns in 1977.

All the groundwater supplied towns reported adequate well yields with no significant declines in water levels. Nearly all municipal wells are junior to surface water rights and difficulties arose with the State Engineer as surface water calls increased as the drought period lengthened. Platteville was ordered to cease pumping from a municipal well in 1977 by the State Engineer. The dispute was eventually settled out of court. If the drought had extended into 1978, it is probable that disputes between groundwater users and the State Engineer over shutting down wells would have increased significantly.

Every groundwater supplied town in the study is now a member of the Groundwater Appropriators of the South Platte (GASP). GASP, which operates under the approval of the State Engineer, was organized in 1972 for the purpose of augmenting South Platte streamflows to replace depletions by groundwater withdrawals. The augmentation of surface water streamflows by GASP allows the junior wells to continue groundwater withdrawals even if there is a senior surface water call on the South Platte. GASP currently replaces 5 per cent of the total groundwater withdrawals through releases of storage water held in various reservoirs. In addition, GASP receives water credit for the diversion of unappropriated streamflows that are used to recharge the alluvial aquifer.

All members of GASP are assessed $40 per 100 acre-feet withdrawl. New members are assessed $240 per 100 acre-feet as back assessments (Sievers, 1980). Assessments are used for the purchase of additional storage rights plus the administration and operation and maintenance costs associated with the storage water releases and recharge program.

The future operation of GASP is uncertain. It is likely that the current 5 per cent replacement rate will be increased to correspond eventually with the consumptive use of the groundwater withdrawals. In the event of a long term drought, GASP's available replacement water may be severely limited as occurred in late 1977. The legality of the State Engineer's policy regarding the operations of GASP has also not been confirmed. A court decision could possibly prevent groundwater withdrawals unless the entire consumptive use was replaced by surface water releases. This would require larger assessments by GASP in order to acquire the additional surface water rights for stream augmentation.

CHAPTER VII

MUNICIPAL WATER USE

A. Data Collection

The municipalities within the northern Front Range include a wide range of water users that have been exposed to various demand modification strategies. Twenty-five towns, thought to be representative of the northern Front Range, were chosen for examination of their water use patterns. The primary objective was to collect data on water use for the period of 1975 to 1978 from each town and analyse the effects of various demand modification policies on water use and return flows. A secondary objective was to determine the impact, if any, of the 1976-1977 drought on municipal water use.*

Every town water manager was requested to provide monthly water treatment plant flows for the period 1975-1978. Only nine of the twenty-five towns had

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*It was originally thought that a great deal of the required data on water use and return flows via the sanitary sewer systems would be available from the State Water Use Survey being conducted by the State Engineer's Office. The State study, however, was not available at the time of data collection for this study.

complete data for this period. A number of the groundwater supplied towns did not have meters on their municipal wells. In several of these towns estimates of pumpage were made by taking the amount of electricity used and assuming a pump efficiency. A problem common to both groundwater and surface water supplied towns was that meters had broken and were not replaced for long periods or that the meters had been found to give inaccurate readings. Many of the smaller towns experience constant turnover of water management and operations personnel which makes difficult any systematic record-keeping.

The attempt to separate single-family residential use from total municipal use also proved to be a difficult task. In the unmetered towns that did not have records of total water produced, or did not meter commerical and multi-family users, it was not possible to derive an estimate of single-family residential use. In the unmetered towns that did meter commerical and multi-family users, an estimate of system leakage and public uses was required to derive single-family residential use. Surprisingly, an accurate count of the number and types of water taps serviced, was not available from a number of both metered and unmetered towns. In addition, the lack of data processing capability prevented several of the small metered towns from compiling water use data by user class.

Problems in data collection of wastewater flows were also widely encountered. Many of the smaller towns had sewage lagoon treatment with unmetered inflows or releases. Other towns were serviced by one or two independent sanitation districts. The towns that did have metered wastewater flows, in many cases, had poor record-keeping that greatly hampered the retrieval of flow data. Most of the sanitary sewer systems experience excessive infiltration and inflows which prevent reliable estimates of the effects of water-saving devices on return flows.

B. Classification of Towns

The twenty-five municipalities selected for study were segregated into a number of categories that were thought to have an impact on water use. A natural separation between the large or urban cities, all with populations greater than 30,000, and the smaller rural towns, with populations of less than 13,000, was evident. The urban cities were found to have a wide variety of water customers, including commercial/industrial and multi-family users as well as the single-family residential users which more typify the smaller towns.

In addition to the population size distinction, water management policies that may reduce water demand was used as a basis to categorize towns. Metering is the most widely used management tool for modifying water use. Another policy that was found to be common was the use of summer lawn watering restrictions. Water use in the metered and in the flat-rate municipalities, as well as those with and without restrictions, have been examined to evaluate the effects, if any, of these water management tools on water use.

A third category that was used to distinguish the study towns was the source of water supply, i.e., surfacewater or groundwater. This water source distinction identifies the general geographic location of the towns as well as the typical quality of the town's water supply. The groundwater supplied towns generally are further east and have higher hardness and dissolved solids in their water than the surface water supplied towns. The towns are listed by categories and their 1978 service populations and total water use in acre-feet identified in Table 28.

C. Water Use Patterns

1. Water Use in the Urban Cities

The five urban cities, i.e., with populations greater than 30,000, service a large number of

TABLE 28

TOTAL 1978 MUNICIPAL SERVICE POPULATION
AND WATER USE BY TOWN CATEGORY

Category	Town	Service Population	Total Water Use in Acre-feet
Groundwater, Unmetered, Rural	Brighton	12,350	3,353
	Eaton	2,300	645
	Ft. Lupton	4,300	1,359
	Ft. Morgan	9,500	4,216
	LaSalle	1,830	790
	Jamestown	240	22
	Platteville	1,700	552
	Wellington	1,250	*
Groundwater, Metered, Rural	Brush	4,300	1,216
Surfacewater, Unmetered, Rural	Berthoud	3,000	688
	Louisville	5,600	
	Lyons	1,300	195
	Nederland	850	125
Surfacewater, Unmetered, Urban	Ft. Collins	78,100	16,426
	Greeley	74,471	20,092
	Longmont	44,370	12,541
	Loveland	33,700	7,906
Surfacewater, Metered, Rural	Ault	990	209
	Erie	1,300	103
	Estes Park	*	1,188
	Johnstown	1,650	401
	Lafayette	10,250	1,398
	Milliken	1,200	*
	Windosr	3,590	519
Surfacewater, Metered, Urban	Boulder	90,000	17,494

*Data unavailable

commercial and industrial water users and would be expected to have a greater gallon per capita per day (gcd) use than the rural towns. Water use, by category of water user, for the year 1978 for the urban cities is shown in Table 29. Residential use, both inside and outside the city limits, averaged 72 per cent of the total municipal water demand in these five cities. Water use by commercial and industrial users averaged 19.7 per cent with the lowest percentage of commercial/industrial use reported by Ft. Collins at 13.7 per cent. The commercial and industrial water users in both Greeley and Loveland comprise over 26 per cent of each cities' water use.

Unaccounted for water, which includes both system leakage and public uses such as parks irrigation, was estimated by the water managers to be equal to or less than 10 per cent in every town. Since every city except Boulder has a large number of flat-rate customers, the unaccounted for water, and thus the flat-rate usage, can only be estimated. Greeley reported the lowest unaccounted for losses of only 4 per cent.

Water use in the five cities was examined on a gallon per tap per day (gtd) and gallon per capita per day (gcd) basis for various classes of users, as indicated in Figure 7. Due to the differing ways of classifying residential taps used by the cities,

TABLE 29

WATER USE, BY CATEGORIES, URBAN CITIES, 1978

Town	Total Ave. Use in MGD	Residential Use in MGD: Inside City Metered	Residential Use in MGD: Inside City Unmetered	Residential Use in MGD: Outside City Metered	Commercial/Industrial Use in MGD: Inside City	Commercial/Industrial Use in MGD: Outside City	Use by Category As Percent of Total Use: Residential	Use by Category As Percent of Total Use: Com/Ind	Use by Category As Percent of Total Use: Unacnt'd
Boulder	15.6	10.25	0	1.75	2.4**		76.9%	15.4%	7.7%
Ft. Collins	14.7	2.31	7.95	0.93	1.97	0.05	76.3	13.7	10.0*
Greeley	17.9	3.18	7.07	2.13	3.03	1.78	69.1	26.9	4.0*
Longmont	11.2	0.70	7.50	0.11	1.36	0.41	74.2	15.8	10.0
Loveland	7.1	0	3.83	0.68	1.49	0.39	63.5	26.5	10.0

*Estimated
**Includes both inside and outside city usage

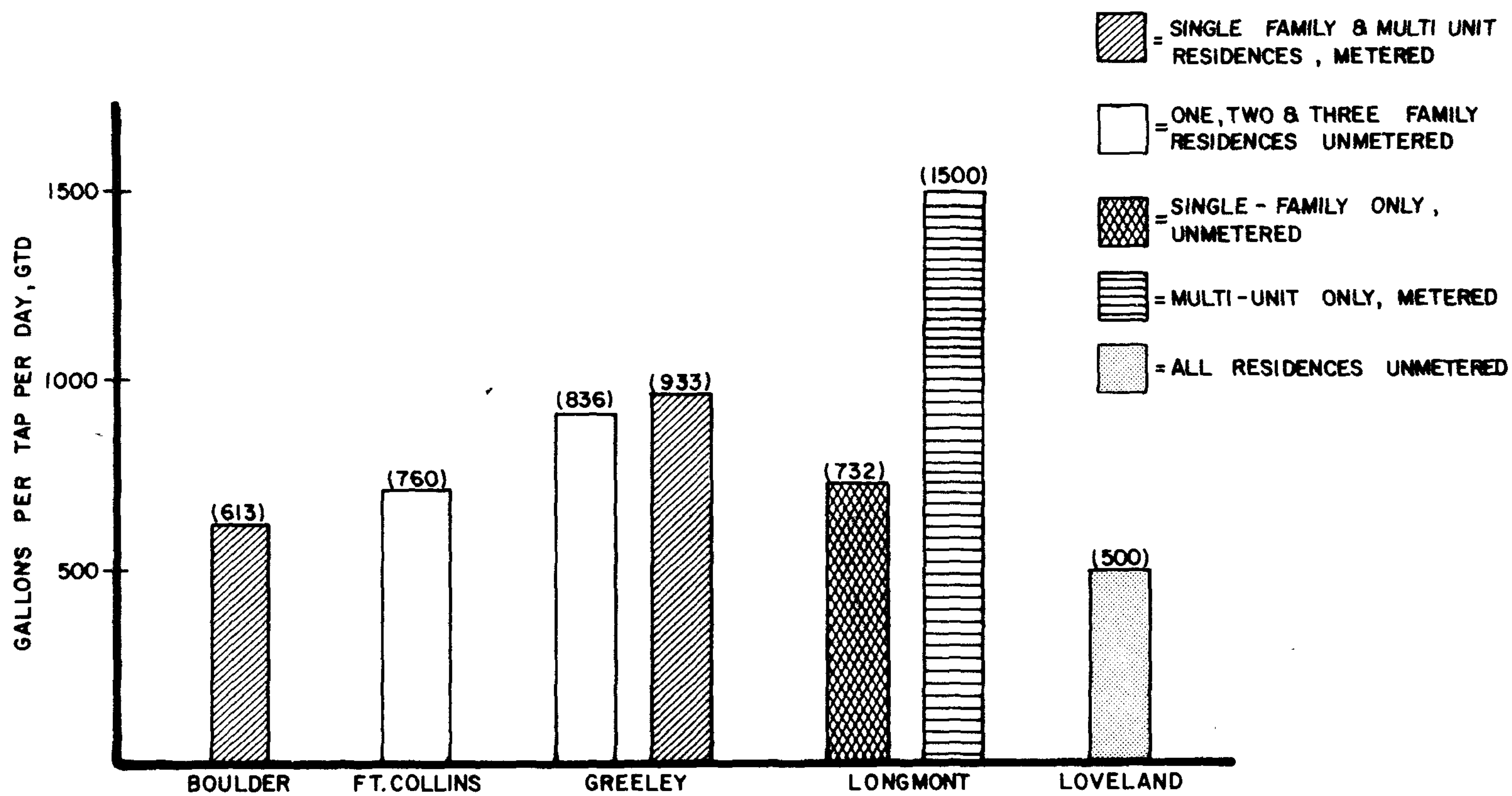

FIG. 7

INSIDECITY, PER TAP WATER USE, 1978

the gallon per tap per day estimate is of questionable value for comparison. Loveland, which does not meter its inside-the-city residential users, reported the lowest estimate of 500 gtd. Boulder, the only city which is 100 percent metered, was the next lowest at 613 gtd. Both Greeley and Longmont reported greater per tap usage by their metered than their unmetered customers. It is likely that the gallon per tap per day estimates are greatly influenced by the number and type of multi-family units in each city.

Analyzing water use on a per capita basis yields more meaningful figures, although the population and leakage have been estimated. Total residential and total municipal use (including leakage) on a per capita basis are shown in Figure 8. The effects of metering on residential water use do not appear to be significant. Loveland and Fort Collins, which are largely unmetered, reported average per capita residential water use of 134 and 143 gallons per day, respectively. Boulder, which is totally metered, reported average residential use of 133 gcd. There are several factors which may explain why Loveland's residential water use is comparable to Boulder's. Loveland was under fairly strict lawn watering restrictions in 1978 while Boulder had none. The types of restrictions imposed by the various cities

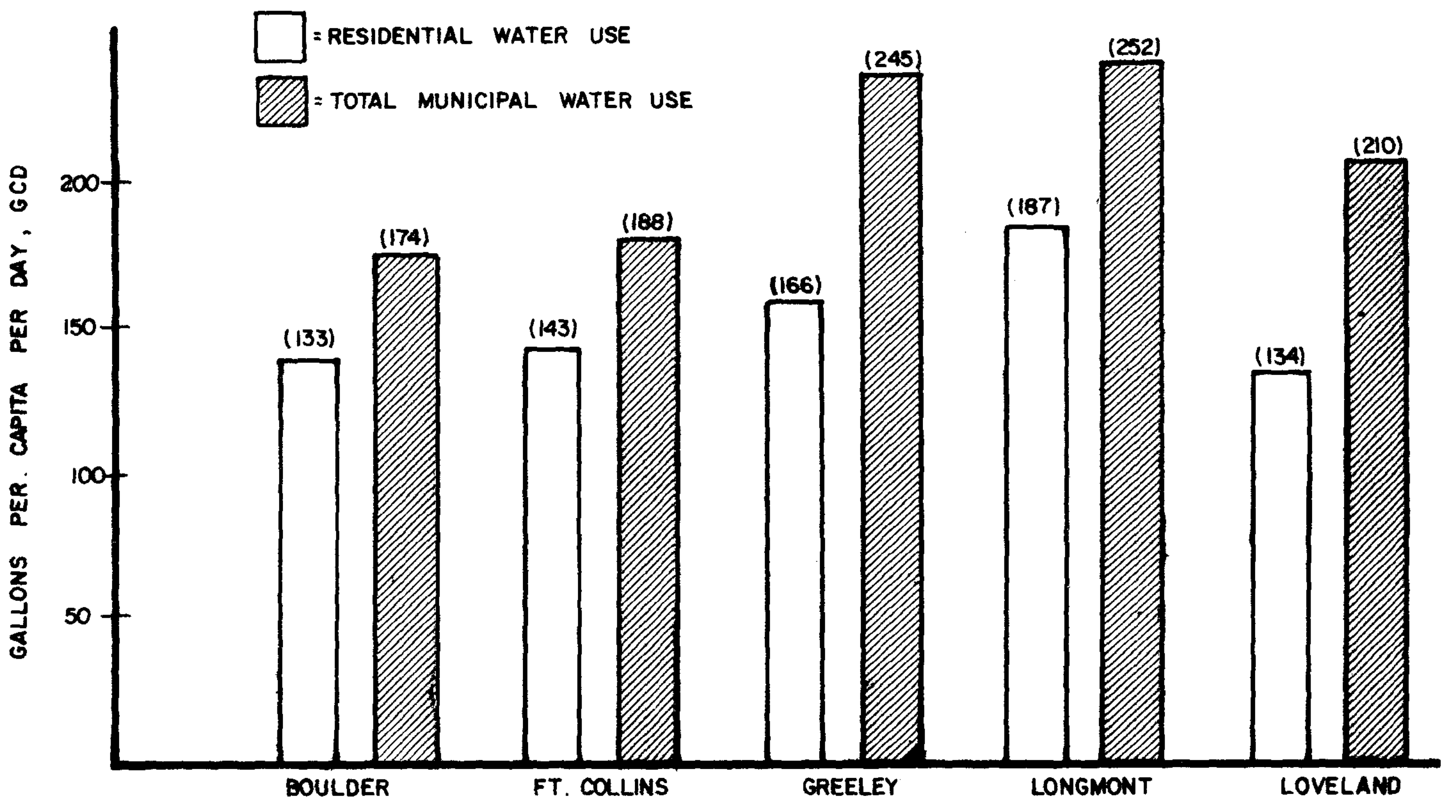

FIG. 8

RESIDENTIAL & TOTAL PER CAPITA WATER USE 1978 will be discussed later. Boulder had a fairly low water rate structure with a marginal cost of $0.43 per 1,000 gallons. A Boulder homeowner would have to use over 22,000 gallons per month to equal the $12 per month summer rate charged Loveland's flat-rate residences. Boulder's rate structure may be low enough that it doesn't induce significant water conservation relative to flat-rate users on restrictions.

Greeley and Longmont reported the largest residential per capita water use of 166 and 187 gcd, respectively. Both cities are largely unmetered although Greeley has metered all new residences since 1972. Sprinkling restrictions that limited the hours of watering each day were in effect for both cities. Greeley also had a relatively low metered water rate of $0.39 per 1,000 gallons which is patterned after the flat-rate charges to unmetered customers.

In the urban cities it appears that a sampling of individual residences would be required to determine the actual effects of metering on water use. The data collected does not indicate significantly lower water use by metered customers at the prices charged in these cities compared with flat-rate customers, all of which, except for Ft. Collins, were on restrictions.

2. Water Use in the Rural Towns

Data on water use by customer class in the smaller towns was often unavailable. Water use in these small towns was compared by dividing the total municipal use by the estimated service population to arrive at a per capita usage figure that included commercial, industrial and public rises as well as system losses. However, water use by single large industries in Brush, Johnstown, Ft. Morgan and Ft. Lupton were subtracted from their total usage. The assumption was made that, exclusive of these large water-users, the types of water users in all the small towns were similar.

Municipal water use, on a per capita basis, is shown in Figure 9. Water use in the metered towns ranged from 71 gcd in Erie to 188 gcd in Ault. The low per capita use in Erie, Windsor and Lafayette can be partially explained by the fact that a number of the older homes in each town have wells which are used for lawn irrigation. In addition, all three towns have relatively high water rates compared to Boulder and Greeley. Lafayette was also under strict watering restrictions in 1978 that allowed sprinkling only 2 hours per day every other day.

The unmetered, surface water supplied towns exhibited significant variation in water use. Jamestown is a mountain community that was included

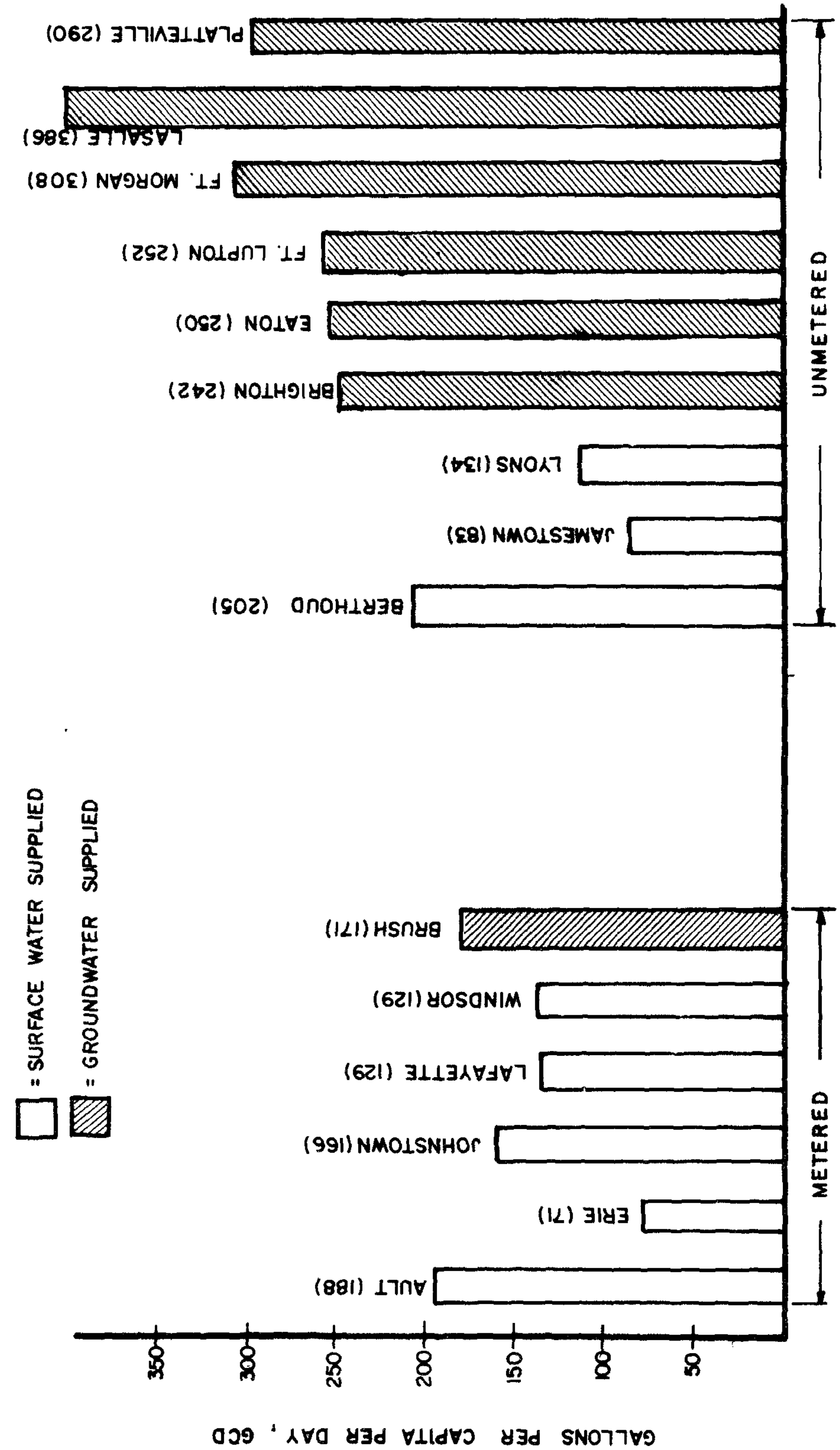

FIG. 9

PER CAPITA WATER USE, RURAL TOWNS, 1978

for comparison purposes. The cooler temperatures, greater precipitation and less lawn area than the other towns all appear to contribute to its low water use of 83 gcd. Lyons is located in the foothills and these same characteristics apply, although to a lesser degree. Berthoud, which averaged 205 gcd, is similar to the groundwater supplied unmetered and surface water supplied metered towns with respect to lot size and climatological conditions.

The groundwater supplied, unmetered towns exhibited significantly greater per capita use than the other categories of water users. Water use averaged 288 gcd with Brighton the lowest at 242 gcd and LaSalle the greatest at 386 gcd. Brush, which is similar to these towns except that it is metered and has the best water quality of any of the groundwater supplied towns, had an average use of 171 gcd, 40 per cent less than the average water use in its unmetered counterparts. Ault, which is situated in a location similar to that of many of the groundwater supplied towns but is metered and surface water supplied, had an average use of 188 gcd, 35 per cent less than the groundwater, unmetered average. Neither Brush nor Ault were under watering restrictions in 1978.

3. Winter Water Use

Per capita water use during the winter months was evaluated for those towns that had complete, reliable water records over the four-year period 1975-1978. The winter months were defined as the six-month period November through April. The winter water use estimates do not represent actual domestic water use as commercial/industrial users, system leakage losses and some outdoor water uses are included. Average winter water use for three metered towns and six unmetered towns is shown in Figure 10. The metered towns were Boulder, Ault and Brush. The water use figures for Brush have been corrected for the water used by one large meat-packing plant. The unmetered towns were Berthoud, Brighton, Ft. Collins, Loveland, Longmont and Lyons.

Winter water use in both the metered and unmetered towns was fairly constant over the four-year period. The metered towns averaged 119 gcd for the period. Ault averaged the lowest, 112 gcd and Brush the greatest, 132 gcd. The unmetered towns averaged 131 gcd, 10 per cent greater than the unmetered towns. Lyons reported the lowest winter use of 95 gcd over the four-year period, while Loveland had the greatest winter use of 152 gcd. The high winter water use in Loveland is probably a result of its large percentage of commercial and industrial water customers.

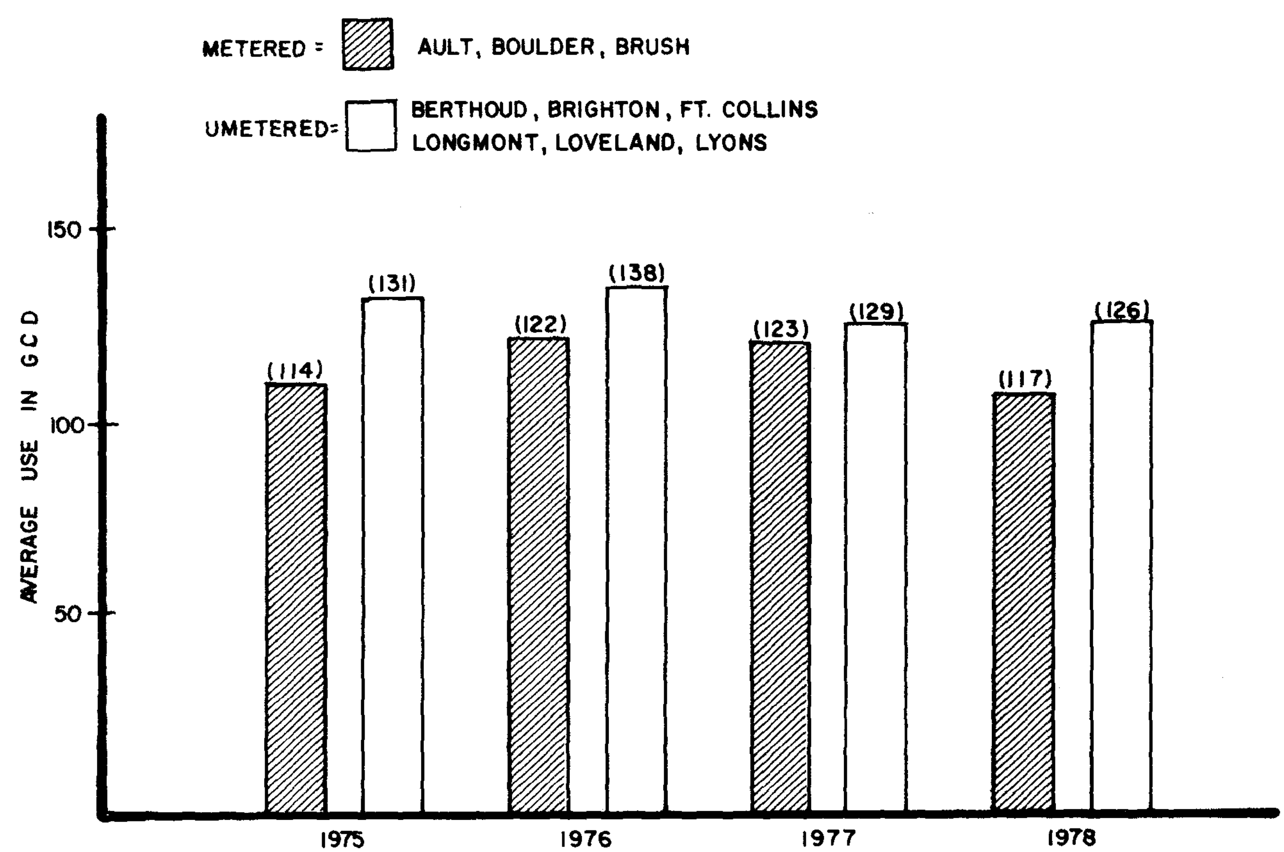

FIG. 10

METERED VS. UNMETERED WINTER WATER USE, 1975-1978

4. Summer Water Use

Water use during the summer months, May through October was evaluated in the same manner as winter water use. Summer water use, shown in Figure 11, declined in 1976 and 1977 compared to 1975 for both the metered and unmetered towns. Average summer use in the unmetered towns continued to decrease in 1978 while the metered average was similar to 1976 and 1977. The metered towns averaged 239 gcd while the unmetered towns averaged 308 gcd, 29 per cent greater than the metered towns. Boulder, a metered town, reported the lowest summer use of 231 gcd for the four-year period. Brighton, which is unmetered, had the greatest summer use of 347 gcd.

5. Sprinkling Use

Sprinkling use, the amount of water used outdoors primarily for lawn irrigation, can be estimated by a number of methods. A modification of the winter base rate method, as proposed by Haw (1978) was used to estimate sprinkling use. Indoor water use during the summer months was assumed to be 85 per cent of the winter average water use. This would account for the apparent outdoor water use found during the winter months.

Relative water needs of lawns during the four-year period were calculated using the modified

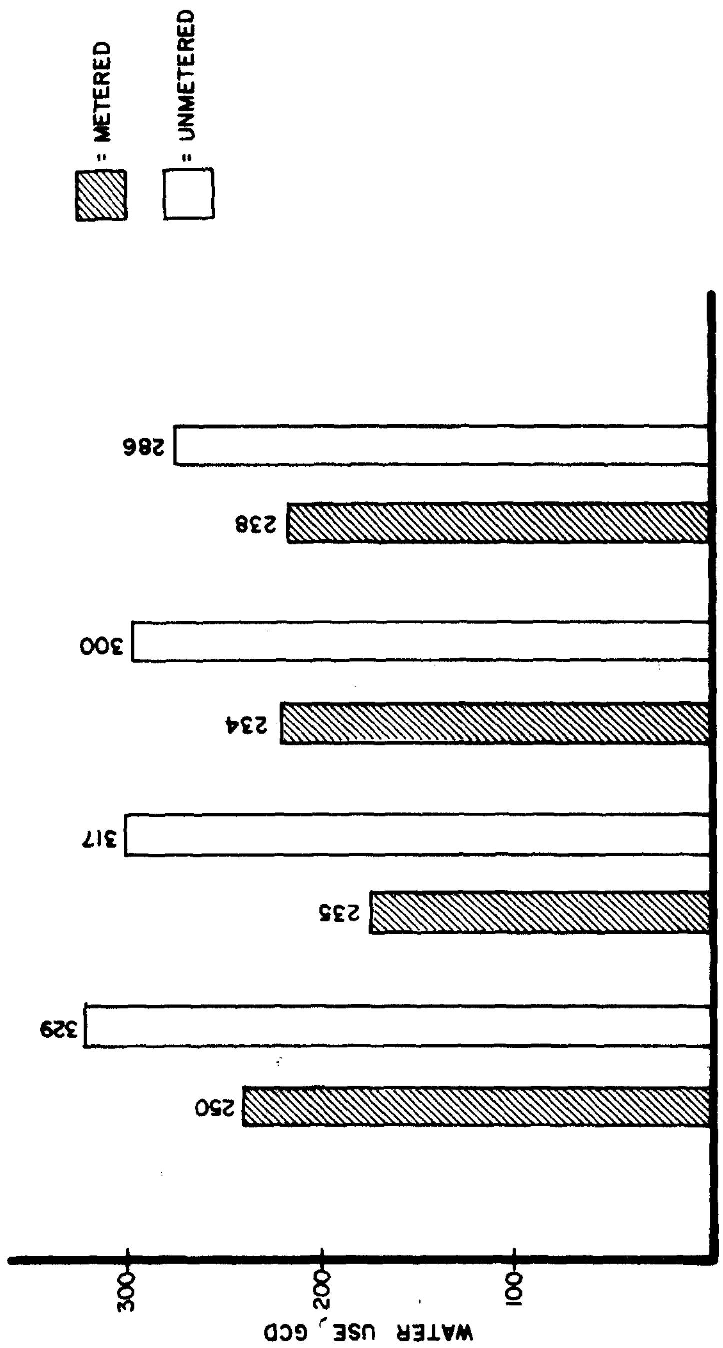

FIG. 11

METERED VS. UNMETERED SUMMER WATER USE, 1975-1978

Blaney-Criddle equation (SCS, 1967). Climatic data was used from seven reporting stations in the study area. Average lawn evapotranspiration, effective precipitation and lawn irrigation requirements are shown in Figure 12. Using 1975 as the base year, lawn irrigation requirements were 5 per cent greater in 1976, 25 per cent greater in 1977, and 5 per cent greater in 1978.

Sprinkling use in the three metered and six unmetered towns is shown in Figure 13. In the unmetered towns, sprinkling use decreased from 1975 to 1977, with a slight increase in 1978. The unmetered towns exhibited the same general trend, although sprinkling use continued to decline through 1978. Comparing the pattern of sprinkling use shown in Figure 13 with the estimated irrigation requirements in Figure 12 reveals that sprinkling use did not follow the same pattern as lawn irrigation requirements. The fact that sprinkling use was low in 1977 and irrigation requirements the highest relative to 1975 for both the metered and unmetered towns suggests that some type of water demand modification common to both types of towns occurred in 1977. None of the three metered towns were under sprinkling restrictions during the study period while four of the unmetered towns had restrictions for the entire

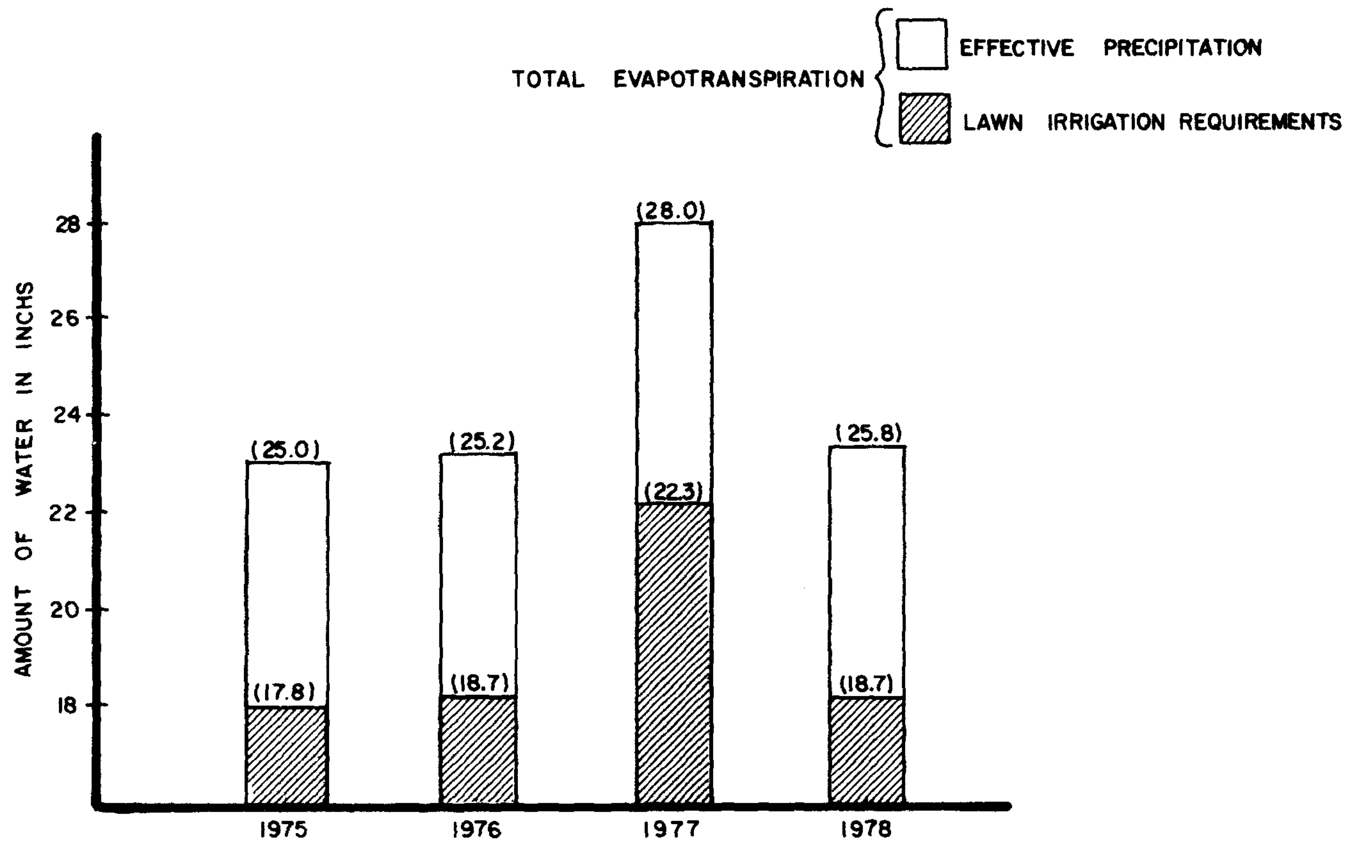

FIG. 12

ESTIMATED LAWN EVAPOTRANSPIRATION, EFFECTIVE PRECIPITATION & LAWN IRRIGATION REQUIREMENTS

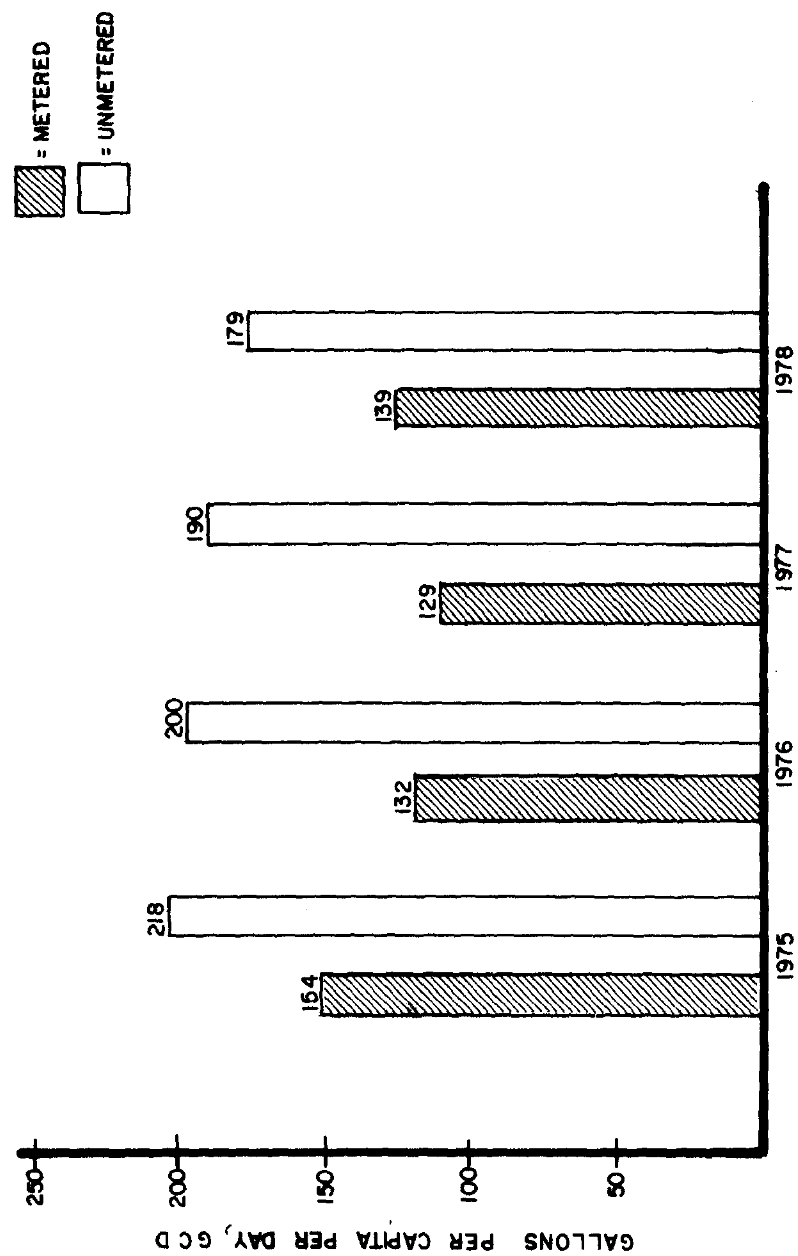

FIG. 13

METERED VS. UNMETERED SPRINKLING USE, 1975-1978 period, indicating that restrictions were not responsible for the reduced sprinkling in 1977.

The western U.S., including the Colorado Front Range, experienced a drought in 1976 and 1977. As the drought increased in severity in 1977 the local mass media highlighted coverage of this event, especially the critical water supply situation in northern California. Although the water supply situation in the study area was not critical, it appears that there was an increased public awareness of the drought as voluntary reductions in sprinkling use relative to irrigation requirements occurred in all of the sample towns.

D. Sprinkling Restrictions

1. Effects on Sprinkling Use

Fourteen of the twenty-five study communities imposed some type of sprinkling restrictions during the four-year period. Of the eleven towns that had no restrictions, several had tried them in the past but had discontinued them primarily because the restrictions were judged to be ineffective. Differing opinions regarding restrictions were noted on the part of water managers. Several thought that without restrictions, the treatment and distribution capacity of their water systems would be severely overloaded. Other managers, including several who had imposed restrictions, stated that sprinkling restrictions actually increased sprinkling demands. This increase in demand was attributed to the observation that many customers would water during their allowed time whether or not the lawn required water. Many water managers noted that sprinkling was often observed during or immediately after a summer rainfall.

The types of sprinkling restrictions used and the reasons for their imposition are outlined in Table 30. Most of the restrictions were instituted due to difficulties in meeting peak day demands or for system pressure regulation. The non-availability of raw water was cited in only two cases. Of the fourteen towns that had restrictions at some time during the study period, only five were metered. Milliken and Windsor, two of the metered communities, had the restrictions imposed by outside water supply agencies. The most common types of restrictions during the study period were every other day watering and a ban on mid-day sprinkling.

Average seasonal sprinkling use in the nine towns, over the 1975-1978 period, was evaluated on the basis of whether or not restrictions were in effect. Four of the communities, three of which were metered, did not have any type of restrictions during the study period. Three towns, all unmetered had restrictions for the entire study period. Ft. Collins and

TABLE 30

WATERING RESTRICTIONS, 1975-1978

Town	Years in Effect	Type of Restriction	Reason for Restriction
Berthoud	1/75-6/78	Odd-even days; no sprinkling 12-5 PM. No sprinkling during winter	Peak Reduction
Brighton	1975-1978	Odd-Even; sprinkling 4-10 AM, 4-10 PM only	Peak/Pressure Control
Erie*	1977-1978	Odd-even	Peak Reduction, Raw Water Insufficient
Ft. Collins	7/77-8/78	2 days/week watering; 4-10 AM 6-12 PM only	Raw Water Insufficient to Meet Demand
Ft. Morgan	1975-1978	Odd-even	Peak/Pressure Control
Greeley	1975-1978	No sprinkling 12-5 PM	Peak/Pressure Control
Jamestown	1976-1977	No sprinkling when notified	Raw Water Insufficient
Lafayette*	1975-1978	Odd-even; sprinkling 2 hours/day	Treatment Plant Capacity Insufficient
Longmont	1975-1978	Odd-even; no sprinkling 8-6 PM in 1978	Peak/Pressure Control
Loveland	1975-1978	4 step plan, increasing in severity	Peak/Pressure Control
Lyons	1975-1977	Odd-even	Treatment Plant Capacity and Peak Problems
Milliken*	1975-1978	No sprinkling 11-5 daily	Imposed by Central Weld County Water District
Platteville	1978	No sprinkling 12-5 PM daily	Peak/Pressure Control
Windsor*	1975-1978	No sprinkling 12-5 PM daily	Imposed by Greeley

*Denotes metered town; all others are unmetered

Berthoud, also unmetered, had restrictions for a portion of the period. Per cent changes in sprinkling use and lawn water needs for the restricted and unrestricted towns are listed in Table 31. All the changes are listed relative to sprinkling use and lawn water needs in 1975. Significant reductions in sprinkling use and increases in lawn irrigation requirements occurred for the unrestricted as well as restricted communities. Only LaSalle and Ft. Collins, which were unrestricted, and Longmont which was restricted, showed increases in sprinkling use relative to 1975. As a group, the changes in sprinkling use and lawn water needs were not significantly different for the restricted than the unrestricted towns. It is difficult to compare the two groups, however, because the unrestricted towns were largely metered, while the restricted towns were primarily unmetered. In addition, many of the towns with restrictions had instituted the restrictions prior to 1975.

Fort Collins and Berthoud were the only communities to impose or lift restrictions during the study period. Fort Collins imposed restrictions on July 15, 1977, when the flow in the Cache La Poudre River dropped significantly. Due to previous commitments of a portion of their direct flow rights to agriculture, the unexpected low flow and existing storage

TABLE 31

RESTRICTED VERSUS UNRESTRICTED SPRINKLING USE

Towns with Sprinkling Restrictions				
Town	Year	Sprinkling Use	Percent Change in Sprinkling*	Percent Change in Lawn Irrigation Requirements*
Brighton	75	255 gcd		
	76	232	-10%	+ 5%
	77	210	-21	+ 9
	78	231	-10	+ 9
Loveland	75	233		
	76	190	-23	- 3
	77	209	-10	+17
	78	155	-50	- 2
Longmont	75	191		
	76	161	-19	- 7
	77	218	+14	+27
	78	224	+17	- 1
Berthoud	75	285		
	76	215	-33	- 3
	77	184	-55	+17
Ft. Collins	77	155	- 8	+40

*Percent changes are relative to 1975

TABLE 31 (continued)

RESTRICTED VERSUS UNRESTRICTED SPRINKLING USE

Town	Year	Towns without Sprinkling Restrictions: Sprinkling Use	Percent Change in Sprinkling*	Percent Change in Lawn Irrigation Requirements*
Ault	75	160 gcd		
	76	149	- 7%	+ 7%
	77	118	-36	+16
	78	155	- 3	+ 8
Boulder	75	152		
	76	177	-30	+ 2
	77	131	-16	+16
	78	139	- 9	+ 5
Brush	75	150		
	76	129	-16	+ 8
	77	137	- 9	+27
	78	122	-23	+ 1
LaSalle	75	358		
	76	373	+ 4	+ 7
	77	366	+ 2	+35
	78	418	+17	+ 8
Ft. Collins	75	167		
	76	162	- 3	+28
	78	176	+ 5	+21
Berthoud	78	180	-58	- 2

*Percent changes are relative to 1975

could not supply sufficient water to meet demands. The initial restrictions allowed one-fourth of the city to water on each of four weekdays and half of the city to water on Saturday and half on Sunday. No watering was allowed on Friday. This system was revised on July 27 due to water pressure problems caused by an entire geographical portion of the city watering on a particular day. The altered restrictions allowed twice a week watering on the basis of house address number (Anderson, Miller and Washborn, 1980).

In a report to the City of Fort Collins, Anderson et al., analysed the effect of the 1977 restrictions. It was difficult to judge the effect of the restrictions because late July and early August were unusally wet and cool. Water use declined 41 per cent compared to the same period in 1976, but slightly less than half of this decline was attributed to the restrictions. Lower evapo-transpiration rates and increased precipitation were responsible for the rest of the reduction. Anderson et al. concluded that during a period of normal evapo-transpiration rates the restrictions imposed would be expected to reduce Ft. Collins' municipal water use by 19.7 per cent.

The town of Berthoud had every other day sprinkling with a mid-day ban on watering for the years 1975-77. On June 1, 1978, these restrictions were lifted. Actual sprinkling use and estimated lawn water requirements, on a per capita basis, have been computed for the peak irrigation period June-September of each year. The lawn requirements were converted from inches per month to gcd by assuming 2300 square feet of irrigated area for each person within the service district. A ratio of actual sprinkling to estimated lawn needs has also been computed and listed in Table 32. The actual-to-required sprinkling use ratio in 1978, the year without restrictions, was actually lower than the years 1975 and 1976, when restrictions were in effect. This suggests that, for the town of Berthoud, sprinkling use with every other day restrictions did not differ greatly than sprinkling use when there were no restrictions. The ratio of actual-to-required sprinkling use is significantly lower in 1977, relative to the other three years. This low ratio seems to indicate that water users in Berthoud were responding to outside conservation appeals. The actual-to-required ratio is greater than 1.0 for each year, indicating, as expected, that water users over-irrigate to a certain extent. Either that, or the estimated lawn watering needs are underestimated by the Blaney-Criddle method used here.

TABLE 32

ACTUAL AND REQUIRED SPRINKLING USE
BERTHOUD (JUNE-SEPTEMBER)

Year	Actual Sprinkling Use in gcd	Estimated Lawn Needs in gcd*	Actual Use/ Estimated Requirement
1975	346	178	1.94
1976	329	153	2.15
1977	220	175	1.26
1978	337	188	1.79

*Based on 2,300 ft^2 of irrigated land/capita; derived from interview with town official

2. Peak Demand Reduction and Pressure Regulation

In most of the towns studied, sprinkling restrictions were instituted to regulate water pressure or to reduce peak demand. High peak usage requires that water treatment and distribution facilities be made larger to accomodate this demand. Peak day demand in the unrestricted towns was significantly lower than in the towns that had restrictions. This may be due to the fact that the unrestricted towns were largely metered while most of the towns that had restrictions were unmetered, see Table 33. The ratio of peak day to average day was essentially the same value for the unrestricted towns (2.44) as for the restricted towns (2.49). Average use was

TABLE 33

PEAK DAY WATER USE IN RESTRICTED AND UNRESTRICTED TOWNS

Unrestricted	1975		1976		1977		1978	
Town	Peak Day	Peak/ Average	Peak Day	Peak/ Average	Peak Day	Peak/ Average	Peak Day	Peak/ Average
Boulder	483 gcd	2.67	446 gcd	2.59	387 gcd	2.36	402 gcd	2.31
LaSalle	670	2.09	748	2.16	683	1.98	808	2.08
Ft. Collins	533	2.64	504	2.64			470	2.50
Berthoud							467	2.30
Restricted								
Ft. Collins					440	2.41		
Berthoud	732	2.59	655	2.70	441	2.13		
Greeley	568	2.39	568	2.44	484	2.18	550	2.28
Loveland	632	2.73	562	2.65	491	2.41	531	2.52
Longmont	591	2.64	537	2.51	560	2.35	620	2.46
Brighton	759	3.04	669	2.85	536	2.29	559	2.30

much greater in the restricted towns. Peak day use followed the same general pattern as sprinkling use, with peaks less in 1977 than in the other years. Peak day use did not show a noticeable increase in Berthoud in 1978 when the restrictions were lifted.

A review of historical peak day usage for Loveland reveals that their restrictions have been effective in reducing peak demands. Peak day demand averaged 743 gcd for the period 1960-69 when no restrictions were in effect. Watering restrictions have been in effect since 1970 and peak day usage averaged 610 gcd for the period 1970-78. Loveland's restrictions are more severe than most, allowing every third day watering on the average for the period.

E. Other Demand Modification Policies

Metering and lawn watering restrictions are the two most common demand-reduction strategies employed by municipal water utilities in the study area. Innovative pricing policies associated with metering, such as increasing block rates or peak demand pricing, have not been implemented by any of the towns. Every metered town had either a declining block rate or average price structure, described in earlier chapters. Elasticity of demand, the effect of price on the amount of water used, was not computed for the metered towns due to the lack of individual household use data. Winter water use appears to be relatively inelastic as indicated in Table 34. The average cost per 1,000 gallons ranged from $0.53 to $1.53, a factor of almost 3 while winter water use ranged from 99 to 119 gcd, a difference of only 20 per cent. Sprinkling use, shown in Table 35, did not change greatly with price. This is probably because the marginal cost per 1,000 gallons of sprinkling water is at a low enough level that it does not significantly impact water use. Windsor and Lafayette were not included in the sprinkling use analysis because a number of residents have irrigation wells.

TABLE 34

WINTER USE IN METERED TOWNS, 1978

Town	gcd	Average Cost Per 1,000 Gal.	Average Monthly Bill Per Dwelling Unit
Windsor	99	$1.53	$12.10
Lafayette	104	1.00	14.07
Ault	119	1.26	10.67
Brush	119	0.80	9.80
Boulder	112	0.53	6.89

TABLE 35

SPRINKLING USE IN METERED TOWNS, 1978

Town	gcd	Marginal Cost/1,000 Gal.
Ault	155	$0.60
Boulder	139	0.43
Brush	167	0.30

The use of water saving devices, which has received a great deal of attention in recent literature, is another demand modification strategy which has not been aggressively implemented by town water managers of this study. Only three of the twenty-five study towns require water saving devices in new construction. Several of the town water managers stated that the devices save so little water that it was a waste of time to discuss them (White et al., 1980). Other towns have made water-saving devices available to customers at little or no cost. Results of a survey performed by Greenberg indicate that approximately 60 per cent of residents randomly sampled in seven towns selected from the study area claimed the usage of at least one water saving device (Greenberg, 1980). The actual effects of the devices on individual water use were not analysed.

Horticultural changes, such as the use of native plant species and reductions in lawn size, were discussed in Chapter 3. White et al. (1980) in a survey of the town managers, found that 18 per cent strongly approved of restrictions on lawn size while 26 per cent slightly approved. Eighteen per cent of the managers strongly disapproved of lawn size restrictions while another 37 per cent slightly disapproved. Greenberg's customer survey results indicate that only a slight majority of water customers surveyed either strongly or slightly approved of restrictions on lawn size. At present, no town has a restriction on lawn size or requires that native plant species be used in landscaping.

The effect of public education of water users regarding water conservation issues could not be positively determined. As discussed earlier in this chapter, public awareness of the drought was probably responsible for the reduction in water use throughout the study area in 1977. Only one town, Fort Collins, has a paid employee that promotes water conservation. It is too early to conclusively evaluate the effectiveness of this public education policy but indications are that per capita water use is declining.

CHAPTER VIII

EFFICIENCY OF USE: A DESIRED OBJECTIVE?

A great deal has been written about the need for urban water conservation. Most methods for achieving urban water conservation concern increased efficiency of water use both inside the house and outside for lawn watering. Metering, price increases and water-saving devices are the most common in-house methods proposed to increase efficiency of use. Better lawn-watering techniques and more drought-tolerant shrubs and grasses, in addition to metering and restructuring water rates, have been proposed to increase outdoor water use efficiency. A reduction in lawn size, while a conservation measure, would not be a increased efficiency of use.

Colorado water law is such that there are legal barriers that prevent increased efficiency of use. Agricultural use of water for farm irrigation has historically resulted in an efficiency of approximately 45 per cent. That is, 55 per cent of the water diverted is not consumed by crops or evaporated but seeps into the soil, eventually reaching streams or shallow aquifers where it is available for reuse by downstream appropriators. The value of many existing senior water rights are based on the continuance of historic return flows. Any increased efficiency of use of water that results in less than historic return flows or a disruption in the timing and location of returns can and probably will be legally challenged by downstream appropriators.

The transfer of agricultural water to municipal use results in a change in the timing, location and amount of return flows. The majority of the returns are via the sanitary sewer system which usually discharges into a stream. Discharge of municipal wastewater occurs year round at nearly constant flow rates although spring and summer returns are slightly higher. Since no irrigation system is 100 per cent efficient, returns are also realized from urban lawn irrigation. These returns from lawn irrigation inefficiency closely mimic historic returns from agricultural irrigation. Another source of municipal return flow is stormwater runoff, but in the semi-arid Front Range this runoff can be discounted as a major source of return flows.

A. Existing Municipal Return Flows

1. Wastewater Return Flows

The percentages of treated waters that were returned via wastewater treatment plant discharges for the period 1975-78 are shown in Figures 14-16 for five municipalities. Average return flows, shown in Figure 14, ranged from 79 per cent in Berthoud to 29 per cent in LaSalle. These estimates have been corrected for differences between water and sewer service areas. Average returns during the winter months are shown in Figure 15.

Berthoud and Fort Collins reported significant amounts of infiltration/inflow (I/I). The effects of I/I can be seen in Figure 15. Berthoud's winter returns were greater than treated water produced for the study period. LaSalle's low percentage of return appears to be a result of inaccurate well pump meters or extremely high water distribution leakage.

Average summer month returns are shown in Figure 16. Boulder, which is metered, had an average summer water use of 231 gcd and returned 63 per cent or 145 gcd via wastewater discharges. Berthoud, which is not metered, has an average summer water use of 331 gcd and returned 64 per cent or 212 gcd via wastewater discharges. Despite

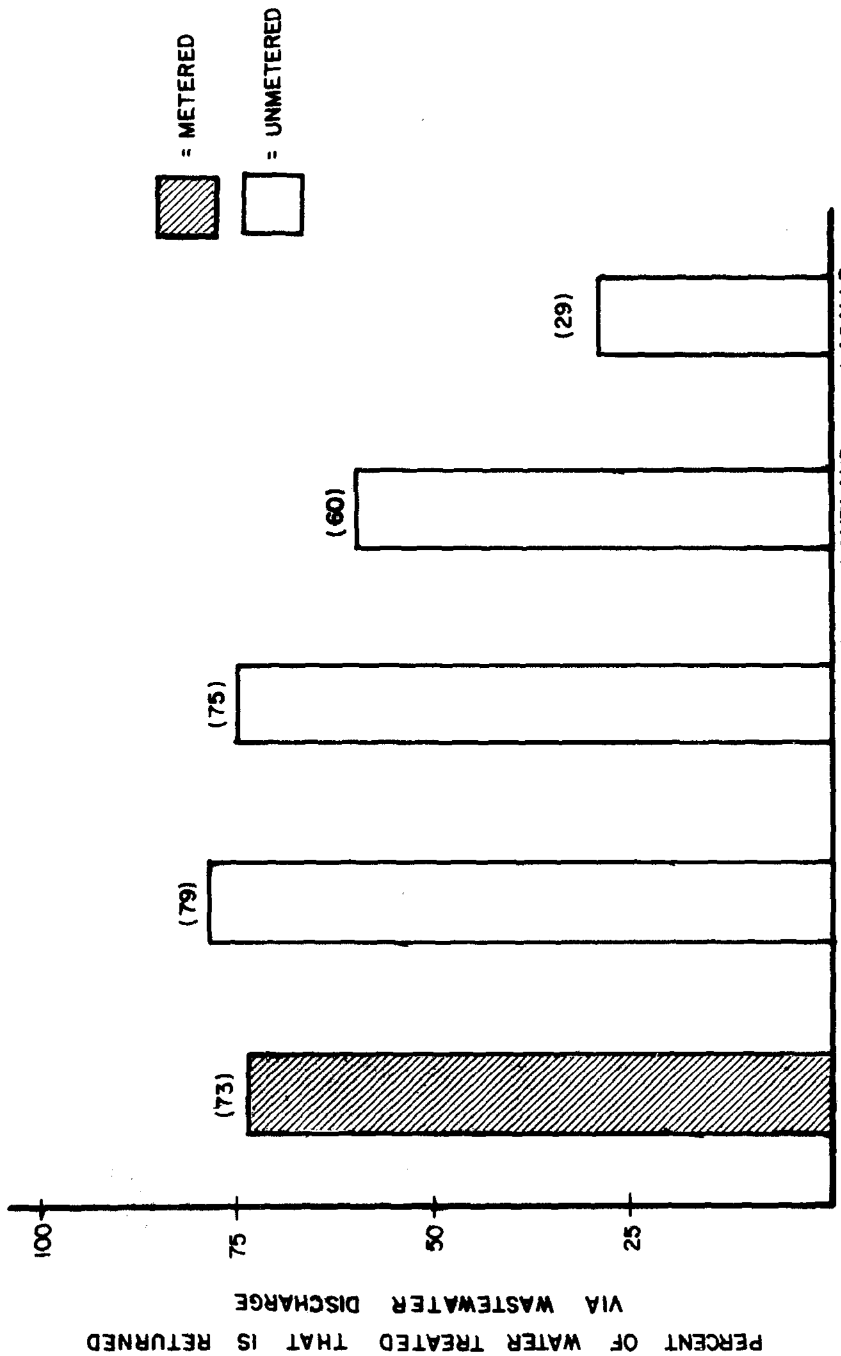

FIG. 14

AVERAGE RETURN FLOWS, 1975 - 1978
(FROM SANITARY SEWER)

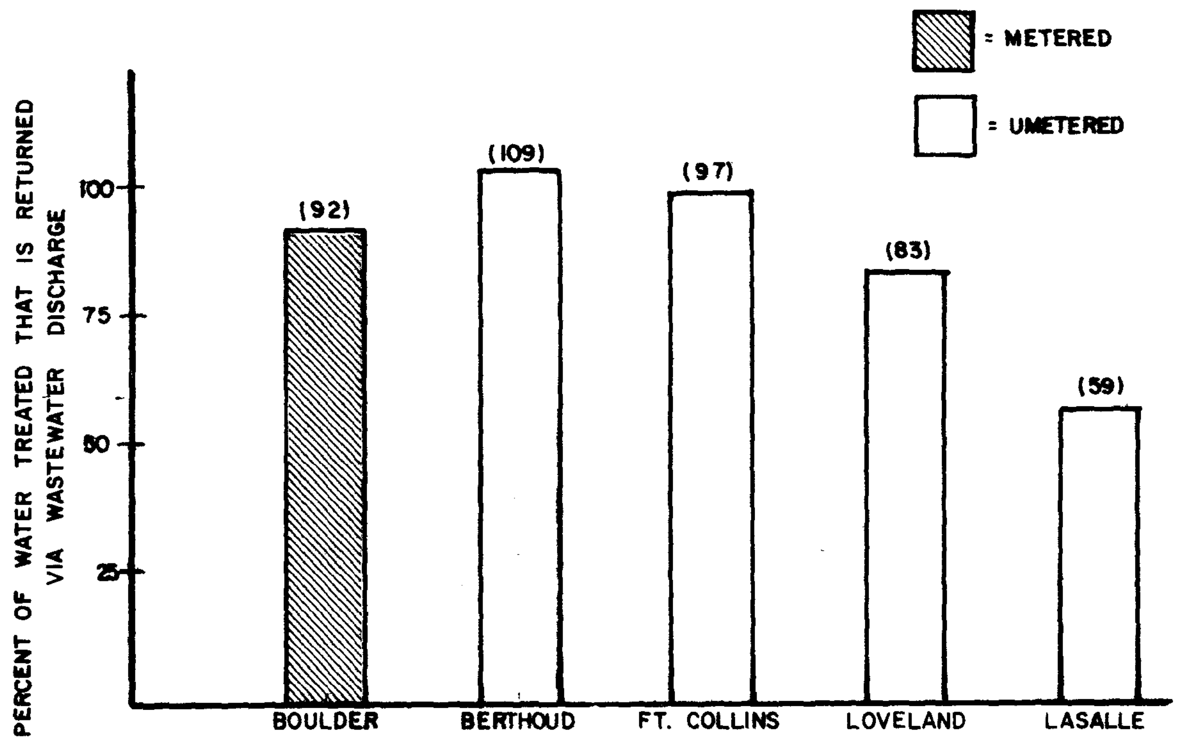

FIG.15

AVERAGE WINTER RETURN FLOWS, 1975-1978
(FROM SANITARY SEWERS)

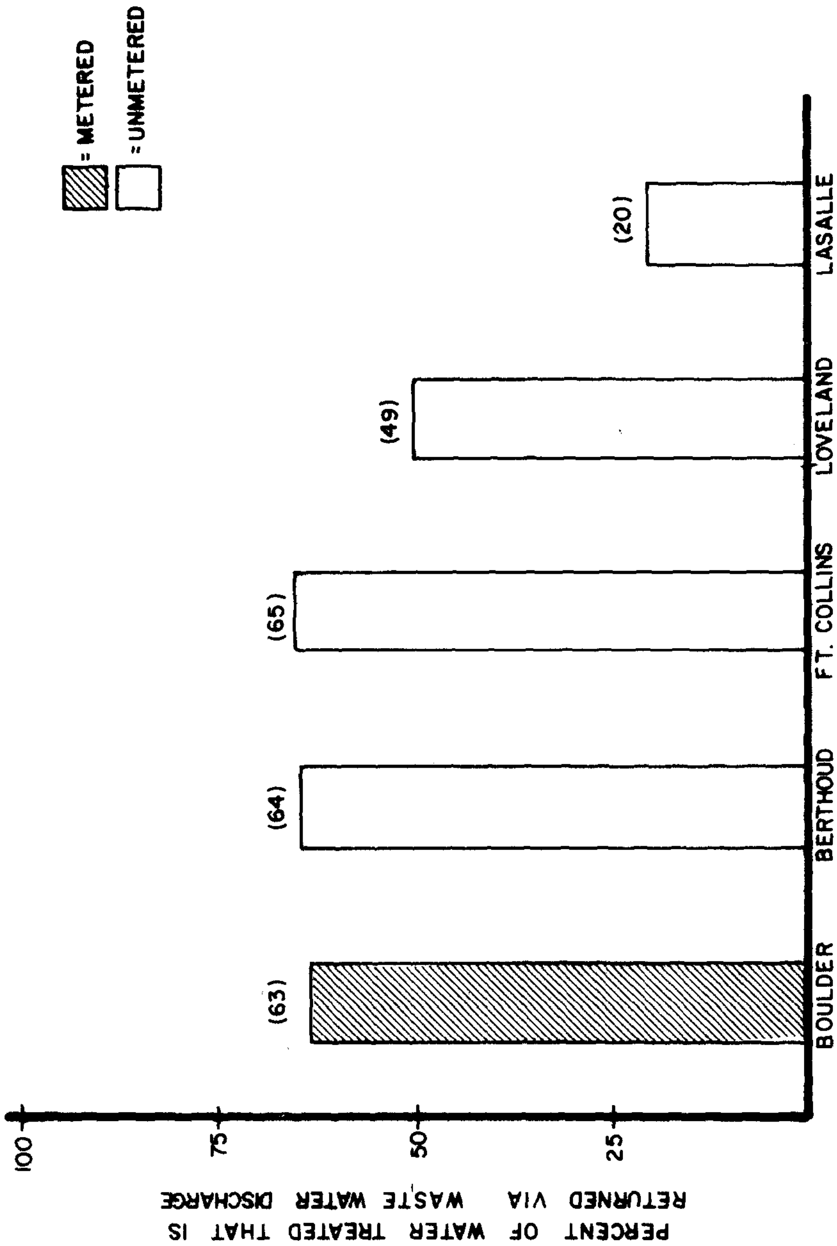

FIG. 16

AVERAGE SUMMER RETURN FLOWS, 1975-1978
(FROM SANITARY SEWER)

this apparent explanation of higher per capita returns in unmetered towns, infiltration appears to be more significant in determining the amount of municipal returns than metering.

2. Returns from Lawn Irrigation

The actual lawn watering efficiency in each of the study communities can only be correctly evaluated through on-site studies of actual evapo-transpiration and sprinkling practices. An examination of the data for the Town of Berthoud indicates that lawn watering efficiency over the May to October season was 69 per cent in 1978. An on-site study conducted in Ft. Collins and Northglen, Colorado, found that irrigation efficiency in Fort Collins was 79 per cent for the same period using measured evapo-transpiration (Danielson et al., 1979). Haw (1978) compared the modified Blaney-Criddle estimates of evapo-transpiration with measured evapo-transpiration. Using his results, the irrigation efficiency in Ft. Collins was 67 per cent in 1978, if the modified Blaney-Criddle formula is used.

An analysis of the irrigation efficiency in the metered communities has not been performed but Danielson et al. (1979) found that lawn application rates in Northglen, a metered suburb of Denver, were slightly below measured evapo-transpiration.

Northglen's water rates are similar to the highest rates found in the study area, with marginal costs exceeding $1.00 per thousand gallons. Danielson found an increase in lawn quality as water application rates approached measured evapo-transpiration, reflecting the fact that application and distribution efficiency cannot be 100 per cent and some over-irrigation is justified for maintenance of green lawns.

The amounts of return flow from lawn irrigation is dependent upon the amount of irrigated area, precipitation, evapo-transpiration, and irrigation efficiency. The irrigation efficiency in the unmetered communities appears to be in the range of 50 to 80 per cent. The metered communities are probably in the range of 75 to 90 per cent. It is doubtful if efficiency exceeds 90 per cent given current lawn watering practices.

Of the amount that is not consumed, a small percentage returns as surface runoff down streat gutters and via the storm drainage system. This percentage is probably greater in the unmetered communities as application rates are greater than in the metered communities.

B. Effects of Increased Water Use Efficiency on Historic Return Flows

A hypothetical water conservation program, designed to increase both indoor and outdoor water use efficiency, has been applied, using the town of Berthoud's 1978 water use data, to examine the probable effects of increased water use efficiency on municipal return flows. The conservation program consists of metering and retroactive fitting of water-saving devices in all houses. It has been assumed that this program has resulted in a 15 gcd reduction in indoor water use, reducing winter sewage flows by 13 per cent from 118 to 103 gcd.

The assumption regarding outdoor water use is that the metering program would increase lawn watering efficiency from 69 to 85 per cent, reducing sprinkling use from 180 gcd to 149 gcd. The total reduction in average annual water use from the total conservation program would be from 205 gcd to 174 gcd, a reduction of 31 gcd or 15 per cent. The reduction in return flows from wastewater discharge would be from 153 to 138 gcd or 11 per cent. The increased lawn watering efficiency would further reduce the returns from lawn irrigation by 41 per cent from 27 gcd to 16 gcd annually.

A summary of the impacts of the conservation program, in acre-feet, is shown in Table 36. The

TABLE 36

EFFECTS OF A CONSERVATION PROGRAM ON BERTHOUD*
(BASED ON 1978 DATA)

	Existing	Conservation Program	Reduction in Water Use	Existing		Conservation Program		Reduction in Return Flows	
				Sewage	Irrigation	Sewage	Irrigation	Sewage	Irrigation
Summer	483.7	405.0	78.7	316.9	58.4	291.5	34.1	25.4	24.3
Winter	204.6	180.0	24.6	196.7	31.4**	171.7	18.4**	25.0	13.0**
Total Year	688.3	585.0	103.3	513.6	89.8	463.2	52.5	50.4	37.3
				603.4		515.7		87.7	

*All values in acre-feet
**It has been assumed that 35 per cent of the return flows from lawn irrigation occur during the winter months.

increased efficiency of use would result in an additional 103 acre-feet per year available for use in the town. At reduced water use rates of 174 gcd this would be sufficient supply for an additional 530 new residents, an 18 per cent increase over the 1978 population of 3,000. The total effect on return flows from the increased efficiency would be an apparent loss of 88 acre-feet per year or 15 per cent of the present level of return. However, if the additional 103 acre-feet per year made available from reduced water use were used to service new customers, additional returns would be generated. Based on existing data, Berthoud returns 78 per cent of its water use. This figure is misleading because a great deal of the wastewater returns are excessive infiltration/inflow into the sanitary sewers. The increased efficiency in lawn irrigation would result in less groundwater available for infiltration into the sewers. The actual returns would be the 103 acre-feet used less the consumptive use from new domestic and lawn irrigation uses of approximately 45 acre-feet and the reduced amount of excess lawn irrigation water that might infiltrate into the sewers of approximately 37 acre-feet. The total effect would be a loss of approximately 67 acre-feet or 11 per cent in returns although 530 additional residents could be served without developing or purchasing new supplies.

C. Legal, Environmental and Other Implications of Increased Water Use Efficiency

The benefits and costs of a municipal water conservation program extend beyond the obvious benefits of increasing the available water supply for municipal use and the costs of instituting metering, installing water-saving devices or other conservation methods. Depending upon the type of water right, the increased use efficiency may or may not prove to be beneficial to the municipality's interests. The costs of acquiring or developing new rights, treating this water and also treating the wastewater are considerations which should be evaluated.

A municipality which owns waters which can be fully consumed should maximize the efficient use of these waters. The wastewater effluent attributable to this source can be leased to downstream users or possibly exchanged with a ditch company for better quality water that can be diverted upstream. Since it would be very difficult to lease return flows resulting from lawn irrigation inefficiency, minimizing excess sprinkling use would be desirable. Many municipalities use Colorado-Big Thompson water. Credit cannot be claimed for return flows from use of this water. However, historic returns are not owed on this water and it would be beneficial to maximize the efficient use of this water.

A municipality which is applying for a change of use from irrigation to municipal use or wishes to store direct flow waters may be limited to historic consumptive use unless claims of return flows from municipal use can be quantified. Return flows resulting from lawn watering inefficiency most closely mimic historical returns from agricultural use. However, if the resulting court decree requires that actual returns be monitored and quantified, this is most easily accomplished by reporting returns from sewage treatment plant discharges. Increased efficiency of use of lawn irrigation will result in a greater percentage of total return flows being made at the sewage treatment plant discharge.

Excessive infiltration/inflows are a common problem for many municipal wastewater systems. The costs of acquiring and developing new water supplies should be compared against the flow related cost of treating municipal wastewater. If the cost of raw water exceeds the flow-related wastewater treatment cost and credit or exchange can be made for municipal effluent, it may be beneficial to allow excessive infiltration inflows to continue.

The environmental impacts of developing new water supplies have proven to be major problem for most new municipal storage projects. Efficient use of existing municipal supplies allows additional growth to be served without developing new supplies and creating adverse environmental impacts. Most municipal water managers favor developing new supplies, expressing the feelings that if new supplies are not developed now, they will not be available at a later date when the excess water made available from conservation has been fully utilized. The same logic also holds true regarding the purchase of existing water rights. With the cost of water rights increasing faster than inflation and competition for existing water rights also increasing it may be more cost effective to acquire new supplies now and increase efficient water use at a later date when all sources of supply have been exhausted.

Opponents of metering have claimed that it would result in reduced lawn watering and thus less groundwater returns to streams. They suggest that most streams would be dry in the fall and winter months if not for these returns. However, returns to streams from irrigation are normally high in total dissolved solids and nitrates and the resulting water quality may not be acceptable to sustain aquatic life. The primary beneficiaries from winter returns are those downstream appropriators who own winter storage rights.

One possible problem that has not yet arisen in the northern Front Range communities is the effect of a long-term drought on municipalities that have already maximized efficient use of their water supplies. A long-term drought or other water supply emergency may create the need for all communities to achieve significant reductions in water use. A water user that is already maximizing efficient use of water will more likely experience hardships than the inefficient user if major reductions in water use are required. For example, if a 30 per cent reduction in existing water use is required, this cutback may result in damage to landscaping of the efficient user while the inefficient user can achieve the required use reduction and still apply sufficient water to maintain the landscaping in acceptable condition.

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

Municipal water management policies in a number of northern Front Range towns have been examined. Of the twenty-five towns, eleven were metered with several other towns discussing the possibility of metering in the near future. Metered towns derived greater revenues per unit of treated water produced but also had greater operation and maintenance costs. As expected, per capita water use in the metered towns was less than in the unmetered towns. Metering is particularly effective in reducing average sprinkling use. A comparison of sprinkling use in three metered and six unmetered towns over a four-year period showed that the unmetered towns averaged 42 per cent greater sprinkling use than the metered towns on a per capita basis.

Total per capita water use in the large urban cities, including commercial and industrial users, was less than in many of the small, more rural towns. This reflects the fact that the urban cities have higher densities in residential areas with more multi-unit development and less lawn area per capita than in the rural towns that are predominantly single family residences. The towns using groundwater for water supply had higher per capita water use than the towns using surface water. The groundwater towns were all small and rural in addition to being unmetered (except for Brush).

Sprinkling restrictions were not found to be particularly effective in reducing average summer water use. The towns that did not have restrictions generally had lower average sprinkling use and peak day water use than the restricted towns, but the unrestricted towns were mostly metered while the towns under restrictions were primarily unmetered. Metering was more significant than sprinkling restrictions in reducing average sprinkling use and peak day demands.

The 1976-1977 drought did not have a serious impact on municipal water supplies. The availability of Colorado-Big Thompson Project water was an important factor in lessening the drought impact. As the drought progressed into 1977, sprinkling use decreased even though lawn irrigation requirements increased. This was observed for nearly every town regardless of metering or sprinkling restrictions. There was an apparent voluntary public response to the extensive media coverage of the drought.

The 1976-1977 drought did not prove to be a critical test of the adequacy of municipal water supplies and their drought responses. The degree of sophistication of municipal water utilities regarding water supply planning varied greatly. Most town water managers did not have estimates of the impact of a record drought on their water supply. Howe et al. (1980) in a statewide study of the 1976-1977 drought effects on rural entities found that some of the towns experienced serious supply and financial problems. The state eventually provided some drought aid with the primary beneficiaries being those entities which had not adequately planned for a severe drought.

The majority of the study towns are relying heavily on water rights donation policies to provide the water needed to service new growth. Water rights acquisitions and transfers to municipal use are becoming an increasingly complicated and costly process. Many towns should evaluate their water rights acquisition policies to determine if they will actually provide for their long-range needs. An inadequate water rights policy may result in costly legal and engineering fees and insufficient dependable yield during an extended dry period. The smaller towns generally do not have the financial resources to hire the needed legal and technical expertise.

The groundwater supply towns are experiencing serious water quality problems. Several are considering a change to surface water as the municipal water source. This change would be very expensive and probably result in the metering of residents to recover costs. CBT water would probably be the primary water source as a change to municipal use would not be required.

The northern Front Range has a very extensive and healthy agricultural economy. The water supply, with the inclusion of Colorado-Big Thompson Project water, is sufficient to meet both municipal and agricultural needs for many years. The costs of acquiring raw water supplies, construction of storage and treatment facilities and raw water quality will be greater problems to the municipalities than the actual physical availability of the raw water resources. Agriculture will continue to be adversely affected as municipal growth occurs on irrigated lands. Water acquisition policies may act to dry up irrigated acreage in order to provide water for municipal growth that occurs on unirrigated lands. Municipal-agricultural water exchanges are one way to provide needed water for municipal growth while minimizing the adverse impacts on agriculture.

The results of the analysis of municipal water management policies suggest that town water managers should evaluate the following recommendations to determine if they may be applicable or of benefit to the town's water management system:

a) Water rights donation policies should be evaluated to determine if the water rights will provide the desired yield at the town's point of intake into its water treatment system.

b) Water rights donation policies that allow cash in lieu of water rights should be evaluated regularly to ensure that the cash price remains current with the actual cost of acquiring the water rights.

c) Tap on and plant investment fees should be examined and readjusted, if needed, if a town policy is to have growth pay for itself.

d) An estimate of the dependable yield of the town's raw water supply system should be prepared and drought contingency plans made.

e) Water rights not decreed for municipal use or requiring a change in point of diversion should be evaluated to determine if it is advantageous to file with the water court for a proper decree.

f) Municipal water and wastewater utilities should institute systematic record-keeping procedures to ensure the continuity of records and allow analysis of water production data.

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APPENDIX

TABLE A-1

MONTHLY WATER TREATED
(million gallons)

AULT

	1975	1976	1977	1978
January	1.84	2.66	3.41	3.75
February	2.67	2.71	3.78	4.12
March	2.72	2.55	3.80	2.97
April	2.84	4.03	4.69	4.50
May	5.93	5.07	5.66	5.73
June	4.59	7.16	7.85	6.62
July	8.00	10.16	9.21	10.84
August	10.03	8.08	5.20	9.17
September	8.15	8.46	7.75	8.36
October	5.51	4.07	5.59	5.91
November	3.17	3.38	3.55	2.89
December	2.64	3.42	3.76	3.11
Total	58.08	61.72	64.25	67.92
Number of Taps				
Population	968	975	983	990
Average use in mgd	0.17	0.17	0.18	0.19
Average use in gcd	164	174	179	188
Ave. winter use in mgd	0.09	0.10	0.13	0.12
Ave. winter use in gcd	91	107	129	119
Ave. summer use in mgd	0.23	0.23	0.22	0.25
Ave. summer use in gcd	237	240	228	256
Ave. sprinkling use in gcd	160	149	118	155

TABLE A-2

MONTHLY WATER TREATED
(million gallons)

BERTHOUD

	1975	1976	1977	1978
January	9.9	10.9	9.2	9.9
February	9.4	10.2	8.3	8.8
March	9.6	10.3	10.2	10.0
April	10.6	10.7	11.5	16.5
May	22.2	21.8	21.8	14.3
June	26.7	30.0	31.0	26.2
July	37.3	28.8	24.2	33.6
August	31.8	23.8	22.0	32.7
September	22.7	20.4	27.7	30.9
October	14.7	10.2	14.4	20.0
November	8.1	9.5	10.9	10.1
December	7.6	9.2	9.1	11.4
Total	210.6	196.2	200.2	
Number of Taps				
Population	2050	2350	2650	3000
Average use in mgd	0.58	0.54	0.55	0.61
Average use in gcd	282	229	206	205
Ave. winter use in mgd	0.31	0.34	0.33	0.37
Ave. winter use in gcd	149	143	123	123
Ave. summer use in mgd	0.84	0.74	0.77	0.86
Ave. summer use in gcd	412	313	289	286
Ave. sprinkling use in gcd	285	215	184	180

TABLE A-3

MONTHLY WATER TREATED
(million gallons)

BOULDER

	1975	1976	1977	1978
January	278.1	263.7	220.7	267.4
February	252.7	270.1	268.2	242.7
March	279.0	286.9	276.7	289.9
April	322.9	383.0	299.0	414.6
May	468.7	434.9	555.1	387.0
June	581.3	778.7	738.6	690.1
July	876.6	779.0	693.4	868.2
August	785.0	671.8	517.2	730.8
September	578.4	461.5	645.0	694.0
October	435.4	299.3	402.9	508.1
November	273.1	354.9	285.4	306.3
December	258.4	294.9	262.1	299.2
Total	5,389.6	5,278.7	5,224.1	5,698.4
Number of Taps	16,800	17,350	17.980	18,550
Population	81,500	84,150	87,200	90,000
Average use in mgd	14.8	14.5	14.3	15.6
Average use in gcd	181	172	164	174
Ave. winter use in mgd	9.2	10.2	9.2	10.1
Ave. winter use in gcd	113	122	106	112
Ave. summer use in mgd	20.2	18.6	19.3	21.1
Ave. summer use in gcd	248	221	211	234
Ave. sprinkling use in gcd	152	117	131	139

TABLE A-4

MONTHLY WATER TREATED
(million gallons)

BRIGHTON

	1975	1976	1977	1978
January	40.2	42.7	48.2	44.6
February	37.4	40.3	46.0	38.9
March	44.4	46.5	50.7	52.5
April	64.9	45.0	68.3	77.1
May	106.9	106.3	134.6	85.7
June	135.6	147.3	139.4	139.4
July	160.7	169.5	140.4	173.2
August	157.2	143.0	118.3	159.2
September	121.2	93.7	118.6	141.9
October	83.2	65.3	74.7	33.4
November	44.7	44.5	45.6	44.4
December	43.1	48.2	45.5	46.6
Total	1.039.5	992.8	1,030.3	1,092.0
Number of Taps	2,930	3,030	3,130	3,230
Population	11,200	11,580	11,940	12,350
Average use in mgd	2.8	2.7	2.8	3.0
Average use in gcd	254	235	236	242
Ave. winter use in mgd	1.5	1.5	1.7	1.7
Ave. winter use in gcd	136	123	141	136
Ave. summer use in mgd	4.2	3.9	3.9	4.3
Ave. summer use in gcd	371	341	330	347
Ave. sprinkling use in gcd	255	232	210	231

TABLE A-5

MONTHLY WATER TREATED
(million gallons)

BRUSH

	1975	1976	1977	1978
January	23.5	23.3	31.8	19.1
February	18.3	20.1	19.1	16.4
March	21.9	22.4	23.1	22.7
April	25.5	32.0	26.5	33.5
May	37.2	37.4	40.3	36.8
June	43.0	49.5	50.4	51.7
July	60.2	46.1	60.2	63.4
August	50.5	51.7	47.8	44.3
September	43.5	37.8	46.5	35.4
October	32.0	26.8	33.8	32.9
November	22.8	21.7	24.0	25.0
December	22.6	22.4	22.0	20.1
Total	400.8	401.2	425.7	396.0
Number of Taps				
Population	3,700	3,900	4,100	4,300
Average use in mgd	1.10	1.10	1.16	1.08
Average use in gcd	297	282	284	252
Ave. winter use in mgd	0.74	0.78	0.81	0.76
Ave. winter use in gcd	201	201	198	175
Ave. summer use in mgd	1.45	1.41	1.52	1.41
Ave. summer use in gcd	391	361	370	328
Ave. sprinkling use in gcd	150	129	137	122

TABLE A-6

MONTHLY WATER TREATED
(million gallons)

ERIE

	1975	1976	1977	1978
January				3.04
February				2.57
March				3.18
April				2.50
May				2.53
June				2.70
July				3.31
August				3.12
September				2.54
October				2.58
November				3.04
December				2.58
Total				33.69
Number of Taps				390
Population				1,300
Average use in mgd				0.09
Average use in gcd				71
Ave. winter use in mgd				0.09
Ave. winter use in gcd				72
Ave. summer use in mgd				0.09
Ave. summer use in gcd				70
Ave. sprinkling use in gcd				

TABLE A-7

MONTHLY WATER TREATED
(million gallons)

ESTES PARK

	1975	1976	1977	1978
January	47.2	28.9	35.4	23.3
February	21.3	27.5	33.4	22.9
March	47.5	29.6	34.3	26.7
April	47.2	32.5	34.1	16.0
May	53.9	44.2	42.5	31.5
June	50.9	65.1	53.9	42.3
July	74.3	80.0	57.8	50.3
August	74.6	56.0	48.6	60.3
September	52.6	43.9	40.8	36.7
October	32.1	33.7	32.8	25.5
November	31.6	29.4	25.1	24.9
December	22.3	33.4	25.4	26.1
Total	575.5	504.2	464.1	387.0
Number of Taps	1,894	1,950	2,010	2,070
Population				
Average use in mgd	1.6	1.4	1.3	1.1
Average use in gcd				
Ave. winter use in mgd	1.3	1.0	1.0	0.8
Ave. winter use in gcd				
Ave. summer use in mgd	1.8	1.8	1.5	1.3
Ave. summer use in gcd				
Ave. sprinkling use in gcd				

TABLE A-8

MONTHLY WATER TREATED

(million gallons)

FORT COLLINS

	1975	1976	1977	1978
January	267.0	227.5	237.0	237.5
February	248.5	227.2	245.6	217.5
March	250.5	255.5	284.4	278.3
April	285.2	384.9	321.9	450.4
May	490.2	418.2	526.2	398.9
June	500.0	705.4	765.1	647.5
July	773.4	828.3	621.3	810.6
August	671.5	597.1	485.3	703.8
September	556.4	444.1	605.5	658.7
October	409.1	323.1	383.1	464.7
November	226.8	229.8	255.6	227.3
December	229.8	262.6	251.1	234.9
Total	4,948.4	4,940.0	4,958.3	5,352.9
Number of Taps				
Population	67,300	70,800	74,500	78,100
Average use in mgd	13.6	13.5	13.7	14.7
Average use in gcd	202	191	183	188
Ave. winter use in mgd	8.6	8.8	8.8	9.1
Ave. winter use in gcd	128	124	118	117
Ave. summer use in mgd	18.5	18.2	18.3	20.2
Ave. summer use in gcd	275	247	246	259
Ave. sprinkling use in gcd	167	162	155	176

TABLE A-9

MONTHLY WATER TREATED
(million gallons)

FORT LUPTON

	1975	1976	1977	1978
January			14	16.5
February			18	15
March			19	25
April			22	31
May			49	30
June			70	71
July			70	74.7
August			52	62.5
September			53	62
October			27	32
November			14	17
December			15	18
Total			403	444.7
Number of Taps			1,350	1,415
Population			4,100	4,300
Average use in mgd			1.1	1.2
Average use in gcd			269	282
Ave. winter use in mgd			0.6	0.7
Ave. winter use in gcd			137	157
Ave. summer use in mgd			1.6	1.8
Ave. summer use in gcd			399	407
Ave. sprinkling use in gcd			283	274

TABLE A-10

MONTHLY WATER TREATED
(million gallons)

JOHNSTOWN

	1975	1976	1977	1978
January	21.3	20.8	20.1	5.3
February	18.9	18.7	16.1	7.5
March	22.2	20.4	14.9	8.0
April	21.3	25.1	15.7	9.3
May	28.2	27.8	27.0	10.2
June	29.6	36.3	32.8	17.2
July	40.4	37.8	28.9	19.1
August	27.8	27.2	22.0	15.6
September	29.0	24.9	26.4	14.5
October	25.1	23.7	16.6	9.9
November	20.7	21.1	6.2	6.4
December	20.7	21.8	3.8	7.7
Total	305.2	305.6	230.5	130.7
Number of Taps				
Population	15i0	1550	1600	1650
Average use in mgd	0.8	0.8	0.6	0.4
Average use in gcd	557	540	395	217
Ave. winter use in mgd	0.7	0.7	0.4	0.2
Ave. winter use in gcd	461	457	265	148
Ave. summer use in mgd	1.0	1.0	0.8	0.5
Ave. summer use in gcd	653	623	522	285
Ave. sprinkling use in gcd				

TABLE A-11

MONTHLY WATER TREATED
(million gallons)

LAFAYETTE

	1975	1976	1977	1978
January			25.3	30.8
February			22.4	27.4
March			25.2	32.6
April			24.1	41.5
May			39.2	37.3
June			19.1	46.1
July				56.7
August			↑	53.1
September			Broken	45.2
October			flow	34.7
November			meter	25.0
December			↓	25.3
Total				
Number of Taps				2150
Population				9700
Average use in mgd				1.3
Average use in gcd				129
Ave. winter use in mgd				1.0
Ave. winter use in gcd				104
Ave. summer use in mgd				1.5
Ave. summer use in gcd				153
Ave. sprinkling use in gcd				65

TABLE A-12

MONTHLY WATER TREATED
(million gallons)

LASALLE

	1975	1976	1977	1978
January	7.1	6.2	7.2	8.1
February	6.1	4.8	8.7	7.7
March	10.1	9.6	13.8	11.7
April	11.5	17.3	14.6	21.6
May	21.7	21.3	27.2	19.9
June	26.9	39.8	37.5	36.1
July	36.3	41.5	34.2	45.9
August	29.2	33.0	29.8	40.0
September	28.2	20.2	30.8	37.2
October	13.9	14.9	14.0	15.8
November	7.1	7.8	8.8	7.1
December	5.5	9.1	7.4	6.4
Total	203.6	225.3	231.0	257.5
Number of Taps	700	718	721	732
Population	1750	1790	1800	1830
Average use in mgd	0.6	0.6	0.6	0.7
Average use in gcd	319	344	352	386
Ave. winter use in mgd	0.3	0.3	0.3	0.4
Ave. winter use in gcd	150	168	185	189
Ave. summer use in mgd	0.9	0.9	0.9	1.1
Ave. summer use in gcd	485	516	523	579
Ave. sprinkling use in gcd	358	373	366	418

TABLE A-13

MONTHLY WATER TREATED
(million gallons)

LONGMONT

	1975	1976	1977	1978
January	139	158	190	169
February	130	131	172	142
March	154	141	166	204
April	166	173	159	318
May	303	276	374	293
June	356	420	509	559
July	471	442	499	699
August	411	384	377	514
September	283	241	479	489
October	221	216	296	324
November	159	189	176	160
December	152	196	167	125
Total	2,950	2,967	3,565	4,085
Number of Taps		9,740	10,440	11,360
Population	36,130	38,056	41,120	44,370
Average use in mgd	8.1	8.1	9.8	11.2
Average use in gcd	224	214	238	252
Ave. winter use in mgd	5.0	5.5	5.7	6.7
Ave. winter use in gcd	138	143	138	151
Ave. summer use in mgd	11.1	10.8	13.8	15.6
Ave. summer use in gcd	308	283	335	352
Ave. sprinkling use in gcd	191	161	218	224

TABLE A-14

MONTHLY WATER TREATED
(million gallons)

LOUISVILLE

	1975	1976	1977	1978
January	13.6	12.0	12.0	↓
February	8.8	13.7	10.9	
March	9.5	13.9	12.7	
April	12.4	22.6	14.4	
May	37.8	24.2		
June	47.5	47.5		
July	53.8	61.4	↑	57.5
August	46.0	52.2	Broken	46.1
September	24.9	39.3	flow	38.3
October	19.2	40.1	meter	23.9
November	28.2	46.9	↓	13.5
December	8.3	42.1		12.7
Total	335.1	415.8		
Number of Taps				
Population	4,200	4,800	5,200	5,600
Average use in mgd	0.9	1.1		
Average use in gcd	218	237		
Ave. winter use in mgd	0.5	0.8		
Ave. winter use in gcd	106	175		
Ave. summer use in mgd	1.4	1.4		
Ave. summer use in gcd	329	300		
Ave. sprinkling use in gcd	239	151		

TABLE A-15

MONTHLY WATER TREATED
(million gallons)

LOVELAND

	1975	1976	1977	1978
January	118.5	120.2	105.9	123.4
February	88.2	113.1	105.2	101.3
March	95.8	109.1	110.4	136.5
April	115.4	171.7	118.1	208.8
May	214.0	228.1	251.8	155.4
June	248.1	333.9	314.4	268.1
July	371.0	345.0	293.4	372.9
August	321.7	260.0	222.2	350.9
September	261.9	183.4	318.9	325.1
October	213.8	154.1	228.0	232.7
November	118.3	135.5	146.7	154.0
December	119.2	120.5	136.8	136.4
Total	2,295.1	2,274.3	2,351.1	2,575.2
Number of Taps	7.684	8,074	8,757	9,342
Population	27,200	29,200	31,350	33,700
Average use in mdg	6.3	6.2	6.4	7.1
Average use in gcd	232	212	204	211
Ave. winter use in mgd	4.0	4.2	3.9	4.8
Ave. winter use in gcd	147	144	124	142
Ave. summer use in mgd	8.9	8.2	8.9	9.3
Ave. summer use in gcd	327	281	284	276
Ave. sprinkling use in gcd	233	190	209	155

TABLE A-16

MONTHLY WATER TREATED
(million gallons)

LYONS

	1975	1976	1977	1978
January	1.6	1.8	1.7	3.1
February	3.4	3.1	2.4	2.5
March	3.3	4.9	3.8	4.3
April	4.8	7.8	4.9	5.0
May	9.9	9.3	8.6	3.6
June	10.0	14.9	11.7	7.1
July	14.3	24.9	14.3	10.6
August	9.9	14.8	8.4	8.0
September	6.3	7.0	9.2	11.5
October	1.2	4.6	5.0	2.7
November	1.1	3.6	5.8	1.4
December	2.9	4.1	3.7	3.3
Total	68.7	100.8	79.5	63.6
Number of Taps	430	450	470	484
Population	1150	1215	1250	1300
Average use in mgd	0.19	0.28	0.22	0.17
Average use in gcd	164	227	174	134
Ave. winter use in mgd	0.10	0.14	0.12	0.11
Ave. winter use in gcd	82	115	98	85
Ave. summer use in mgd	0.28	0.41	0.31	0.24
Ave. summer use in gcd	244	337	249	182
Ave. sprinkling use in gcd	174	239	166	110

TABLE A-17

MONTHLY WATER TREATED
(million gallons)

NEDERLAND

	1975	1976	1977	1978
January			6.6	8.4
February			4.2	7.8
March			2.7	8.6
April			5.0	8.5
May			5.7	7.9
June			7.2	9.2
July			5.9	11.0
August			4.4	9.1
September			4.8	10.0
October			8.0	9.1
November			9.2	8.7
December			9.7	8.6
Total			73.4	106.9
Number of Taps			335	350
Population			815	850
Average use in mgd			0.20	0.29
Average use in gcd			247	345
Ave. winter use in mgd			0.21	0.28
Ave. winter use in gcd			254	329
Ave. summer use in mgd			0.20	0.31
Ave. summer use in gcd			241	360
Ave. sprinkling use in gcd				

TABLE A-18

MONTHLY WATER TREATED
(million gallons)

WINDSOR (Quarterly Data)

	1975	1976	1977	1978
January				
February				
March	18.3	20.9	25.3	26.2
April				
May				
June	23.6	26.3	36.0	40.0
July				
August				
September	37.7	41.3	43.2	64.7
October				
November				
December	25.8	24.9	33.2	38.4
Total	105.4	113.4	137.7	169.3
Number of Taps				
Population	2830	3080	3315	3590
Average use in mgd	0.29	0.31	0.38	0.46
Average use in gcd	102	101	114	129
Ave. winter use in mgd	0.24	0.25	0.32	0.36
Ave. winter use in gcd	86	82	97	99
Ave. summer use in mgd	0.33	0.37	0.43	0.57
Ave. summer use in gcd	118	119	130	158
Ave. sprinkling use in gcd				

TABLE B-1

MONTHLY WASTEWATER TREATED
(million gallons)

BERTHOUD

	1975	1976	1977	1978
January	12.5	14.7	13.6	12.2
February	11.4	12.9	9.6	10.9
March	12.8	14.8	11.6	12.1
April	14.0	15.4	13.6	12.6
May	17.0	16.5	14.1	23.4
June	21.4	22.1	18.8	19.7
July	25.0	22.8	22.6	22.3
August	25.7	22.6	22.3	21.6
September	20.1	21.7	20.8	19.0
October	17.1	18.4	18.4	21.2
November	14.6	16.0	15.9	16.2
December	14.4	14.7	13.1	15.7
Total				
Number of Taps				
Population	2750	3075	3350	3700
Average use in mgd	0.56	0.38	0.57	0.56
Average use in gcd				
Ave. winter use in mgd	0.44	0.49	0.50	0.44
Ave. winter use in gcd				
Ave. summer use in mgd	0.69	0.67	0.64	0.69
Ave. summer use in gcd				

TABLE B-2

MONTHLY WASTEWATER TREATED
(million gallons)

BOULDER

	1975	1976	1977	1978
January	288.3	269.4	268.2	223.2
February	226.0	266.6	252.0	246.4
March	277.8	289.5	258.2	291.4
April	353.7	301.2	294.0	279.0
May	492.0	304.7	300.7	573.5
June	534.0	360.3	321.0	399.0
July	503.8	372.0	359.6	412.3
August	473.4	352.5	328.6	372.0
September	444.6	322.8	291.0	328.1
October	329.2	318.1	319.3	316.3
November	309.6	277.2	249.0	283.0
December	300.7	267.2	226.3	279.0
Total	4,533.2	3,703.8	3,479.7	4,002.0
Number of Taps				
Population	81,500	84,150	87,200	90,000
Average use in mgd	12.4	10.1	9.5	11.0
Average use in gcd	152	121	109	122
Ave. winter use in mgd	9.7	9.2	8.6	8.9
Ave. winter use in gcd	119	110	98	99
Ave. summer use in mgd	15.1	11.0	10.4	13.0
Ave. summer use in gcd	185	131	120	145

TABLE B-3

MONTHLY WASTEWATER TREATED
(million gallons)

FORT COLLINS

	1975	1976	1977	1978
January	285.7	242.1	295.1	222.0
February	225.4	237.2	263.6	224.4
March	235.2	244.3	210.3	254.5
April	255.7	242.5	248.1	237.6
May	285.6	274.2	298.8	358.1
June	347.8	344.2	305.7	358.2
July	427.3	403.8	454.4	456.7
August	434.3	452.5	390.1	446.9
September	383.4	408.0	306.4	366.8
October	310.3	343.3	291.4	347.6
November	271.1	293.5	260.0	299.1
December	252.3	307.0	234.6	282.5
Total	3,714.1	3,787.6	3,805.8	3,854.1
Number of Taps				
Population	67,300	70,800	74,500	78,100
Average use in mgd	10.2	10.4	10.4	10.6
Average use in gcd	151	145	140	135
Ave. winter use in mgd	8.4	8.7	8.7	8.4
Ave. winter use in gcd	125	122	117	108
Ave. summer use in mgd	11.9	12.1	12.1	12.7
Ave. summer use in gcd	177	171	163	162

TABLE B-4

MONTHLY WASTEWATER TREATED
(million gallons)

LASALLE

	1975	1976	1977	1978
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				
Total				
Number of Taps				
Population	1700	1790	1800	1830
Average use in mgd	0.19	0.18	0.18	0.18
Average use in gcd	113	100	101	98
Ave. winter use in mgd	0.19	0.18	0.19	0.17
Ave. winter use in gcd	109	101	103	93
Ave. summer use in mgd	0.20	0.18	0.18	0.19
Ave. summer use in gcd	116	99	99	108

TABLE B-5

MONTHLY WASTEWATER TREATED
(million gallons)

LOVELAND

	1975	1976	1977	1978
January	78	111	80	95
February	63	96	85	89
March	68	93	99	93
April	72	93	89	91
May	86	93	94	145
June	114	120	99	130
July	139	149	114	144
August	140	124	125	151
September	132	90	114	130
October	114	90	103	133
November	129	84	96	135
December	115	84	102	135
Total	1,250	1,226	1,216	1,472
Number of Taps				
Population	24,280	26,200	28,250	30,440
Average use in mgd	3.4	3.4	3.3	4.0
Average use in gcd	141	128	118	133
Ave. winter use in mgd	2.9	3.1	3.0	3.5
Ave. winter use in gcd	119	118	108	116
Ave. summer use in mgd	3.9	3.6	3.6	4.5
Ave. summer use in gcd	162	138	128	149

APPENDIX C

ESTIMATED LAWN EVAPOTRANSPIRATION*

Weather Station	1975	1976	1977	1978
	Inches of Water			
Boulder	25.33	25.31	27.75	26.36
Brighton	24.67	24.91	27.51	25.84
Ft. Collins	24.06	24.58	27.37	25.07
Ft. Morgan	27.28	27.13	29.93	27.64
Greeley	26.06	25.85	29.50	26.14
Longmont	24.59	25.14	27.81	26.07
Waterdale (Loveland)	23.16	23.61	25.84	23.09
Average	25.02	25.22	27.96	25.75

ESTIMATED IRRIGATION REQUIREMENTS*

Weather Station	1975	1976	1977	1978
	Inches of Water			
Boulder	17.50	17.92	20.26	18.35
Brighton	18.26	19.10	21.14	19.99
Ft. Collins	15.07	19.26	21.08	18.22
Greeley	18.13	19.45	24.50	19.63
Longmont	19.05	17.80	24.16	19.16
Waterdale	16.60	16.14	19.47	16.29
Average	17.80	18.73	22.27	18.67

*Based on Blaney-Criddle Formula