ACHIEVING URBAN WATER CONSERVATION, A HANDBOOK

by

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A HANDBOOK

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To all of the researchers, utility personnel, consultants, agency personnel and others whose findings and experience form the basis for this handbook, we sincerely offer our appreciation. The data is theirs but the conclusions are ours and we accept full responsibility for the opinions, findings, and recommendations.

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PREFACE

Competition for urban water has resulted in an increasing interest in conservation. As water becomes more scarce and increasing demand drives up the price, ways of reducing demand become more attractive. Two phenomenon, when brought into play at the same time, reinforce and aggravate each other. These are the increasing costs of development, treatment and delivery and the physical scarcity of water that occurs during a drought.

Costs of water delivery, even in normal years of precipitation, are increasing because of the need to ever-widen the sources of supply. Likewise on the delivery side, increased population, the amenities of water-using appliances, higher standards of living, and urban sprawl result in increases in the costs of delivering water. In addition, inflation increases the costs of manpower and goods to deliver treated water to the user. Last but not least, are the increasingly stringent water quality requirements for delivered potable water and the consequent increased costs for treatment. The result of all of these are sharply increased prices and real scarcity.

It is not likely that urban water conservation will come about because of some technological breakthrough. Rather, it will be through the application of known technology and adoption of a conservation ethic by urban water utilities and their customers. With the realization that new water supplies are extremely costly to develop and in the face of predicted low water years ahead, increasing numbers of water utility managers are coming to the realization that a concerted program of water conservation is needed. Otherwise, the risks of disruptive outages, low pressures in the distribution system and restrictions on use and on system expansion can increase to intolerable levels.

Implementation of a program of water conservation by a utility can result in the following banefits;

(1) reduced demands for water - peak hour, peak day and average use,

(2) reduced costs of operation and maintenance of the system because less water is treated,

(3) postponement in system expansion (treatment plants, pumping stations, etc.,) and

(4) increases in the time horizon for new raw water supply acquisition and development.

In this treatise the focus is on conservation of water by residential customers, however, many of the recommendations and suggestions are applicable to commercial and industrial users.

National trends in water use reflect both population increases and increased intensity of use as measured in gallons per capita per day (gpcd). Water withdrawals in the United States, as reported by the National Water Commission, increased more than 3 times from 1900 to 1940 and tripled again by 1970. Consumptive use of public water supplies increased 70 percent in the decade 1960 to 1970. Projected withdrawals and consumptive use are given below. (National Water Commission, 1973, p. 11).

Projected Water Use For Public Supplies

(billions of gallons per day)

	Withdrawals			Consumpive Use		
Year	1980	2000	2020	1980	2000	2020
	33.6	50.7	74.3	10.6	16.5	24.6

The National Water Commission made the following recommendations regarding reducing water losses in urban use: (National Water Commission, 1973, pp. 305-306).

"7-60. Effective leak control programs should be instituted and meters to measure individual water use should be installed by water supply agencies in urban areas.

7-61. Water prices and sewer charges for individual service should be set at levels which fully cover the costs of amortizing and operating the facilities necessary to provide these services, and a municipal water supply rate structure should be adopted which encourages intelligent, rather than excessive, water use.

7.62. Amendments to plumbing codes should be adopted, requiring the installation of water-saving fixtures and appliances in all new construction, and whenever existing water-using appliances or fixtures are replaced.

7.63. The water supply should be managed to accommodate sequential uses of water, such as using effluent from treatment plants for irrigating parks and golf courses and for industrial use within the area; and irrigation uses should be timed to coincide with low water demand periods to conserve reservoir and pipeline capacity.

7.64. A public relations program should be conducted to encourage wise water use, pointing out to customers the benefits to the city and its inhabitants to be realized through conserving the water supply."

In this treatise the components of residential water use will be delineated and analyzed. The means of reducing water use within each of these components singly or in combination are evaluated. Lastly, the total net effect of a concerted plan for urban residential water conservation is presented in a case study.

Policy alternatives which are considered feasible by traditional methods for estimating their worth and viability frequently lack sufficient public or social acceptability. This means that water conservation alternatives which are technologically possible to accomplish (technological feasibility) and are demonstrated to be worth doing (economic feasibility) may never be adopted because of low public acceptance (political feasibility).

In a separate chapter of this handbook a crucial question is addressed for it asks whether the technologically and economically feasible alternatives can actually be accomplished politically. Will the public accept specific conservation alternatives or will they reject them? As applied to two case study towns, the question asked was; how politically feasible are certain water conservation policies? The results of that study, as presented in Chapter V, indicate how survey research through doorstep interviews can aid water utility managers and decision makers in determining the acceptability by the concerned community of proposed water conservation programs.

It should be emphasized that public acceptance of and response to a program of water conservation is the ultimate goal. While not mutually exclusive it should be observed that combinations of various means of conserving water are not strictly additive. The real trick is to combine the various means in such a way as to attain the maximum of conservation at least cost with the least inconvenience to the water customer.

ABSTRACT

Water supply and wastewater flow problems have resulted in an increasing concern with urban water demand. This treatise is a study of the feasibility of using various water conservation measures to reduce residential water usage. It was first necessary to examine the demand reduction alternatives and identify those applicable to residential areas. Many different conservation techniques were found to be relevant. Structural means such as water meters, recycle systems, water saving devices and flow reduction devices were examined. System and household leakage reduction as well as water use restrictions were among the operational methods investigated. Social and economic methods of public education, building code modifications, horticultural changes and pricing policy were also studied.

A review of the literature was made to determine the water savings that each conservation method could accomplish. Baseline water use conditions representative of a typical western American city were established against which each alternative was evaluated as to its technological, economic and social-political feasibility. The amount of water savings and the return flow implication for each method were also investigated. Estimates of the combined impact of several methods used together in a common program were postulated.

As a case study, alternative conservation methods were examined for a small community - Lyons, Colorado. A preliminary assessment, made on the basis of available data, found that water demand reductions of 35 to 40 percent were possible through implementation of a combination of water conservations methods. It was concluded that demand reduction techniques could successfully be incorporated in a water utility's management program.

CHAPTER I

INTRODUCTION

In the past the ubiquitous nature of water has led the average urban water consumer to regard water availability as unconstrained. Water utilities have historically provided this water, usually at very low cost. However, in many areas the demand for water is surpassing the supply. The growth and urbanization of much of the United States accentuates these demand-supply problems for the urban water utility. It has been estimated that seventy-five percent of the nation's population presently reside in urban areas and that by the year 2000, the percentage will have grown to eighty-five percent (Rivkin/Carson, Inc., 1971, p. 1; Pickard, 1967).

The past twenty-five years have seen increased size in urban centers and the current trend is toward expanding metropolitan areas. Many of these areas have developed readily available "low cost" water supply sources and in the future will rely increasingly upon supply outside their immediate area. Efforts to obtain more water have involved increased transport distances and their attendant costs. Other categories of utility costs have also risen, primarily due to inflation. In the face of these growing operating costs some utility managers are modifying their concept of water provision to that of supplying, "only the water needed at the least possible cost" (Flack, 1976, p. 1). Additionally, in recent years the general public has become concerned with water supply projects and their possible environmental effects. This concern has reinforced the notion that the demand side of supply-demand situations should be examined more thoroughly.

The purpose of this study is to investigate demand modification techniques in the light of such concern.

First, a brief examination of water use is made. The following discussion includes both technological and economic analysis of a number of water conservation alternatives. In addition, social and political considerations involved are discussed along with design and implementation of integrated conservation programs.

A. MUNICIPAL WATER USE

Municipal water use is at an all-time high. In 1970, it was estimated that municipal water use in the United States averaged 27 billion gallons per day (Murray, 1973, p. 306). This water was distributed for four primary types of uses, residential, commercial, industrial and public uses including system losses. The proportion of the total use as well as the level of use per customer in each water use class varies widely among utilities. Table 1 illustrates several system distribution percentages by use category. It is apparent that residential use is the largest single category. Because residential use determines much of the design of water and wastewater systems, this user class will be the focus of this study.

TABLE 1

MUNICIPAL WATER USE, 1970

USE CATEGORY	% BOULDER,CO	% CALIFORNIA	% U.S.
RESIDENTIAL	72	68*	35
COMMERCIAL	9	10	23
INDUSTRIAL	9	18	14
PUBLIC USES/SYSTEM LOSSES	10	4	--

* Includes system losses

Sources: Douglas, 1977; State of California, 1976, p.14; AWWA Journal, 1973, p. 299.

B. RESIDENTIAL WATER USE

The importance of residential water use in the planning and management activities of a municipality has increased as both urban population and its demand for water have risen. Per capita usage in the residential sector has increased as a result of changes in the economic, physical and environmental characteristics of communities. Some of the principal factors affecting residential water use include population and its distribution, income, consumer habits and lifestyles, water pricing policies, status of the economy and the extent to which lawn irrigation is practiced (National Water Commission, 1973, p. 3; AWWA, 1973, pp. 286-287).

Population levels are expected to increase markedly in major urban centers. More important may be the regional distribution of population. Westward movement of the nation's population began in the pioneer days and continues today. Population growth in many of the arid western areas had been at a much higher rate than in the rest of the nation (Westside Study, 1975, p. 5). The energy production potential of the West due to its abundant natural resources will play a major role in future water trends. In much of the West water is already in short supply. The increased demand for water by energy industries and by the additional populations associated with them will increase the value of water.

Increasing income has an important effect on residential water use levels. Since the 1940's the introduction of water-using appliances into homes has increased the average residential usage (AWWA, 1973, p. 286). It is now thought that the uses of water-using appliances has reached its ultimate level in most communities.

Rising income levels have also influenced increased water usage through ownership of larger home lots and the consequent larger amounts of residential area being allocated to lawns. Consumer habits and lifestyles have been closely associated with income levels. In the past, the trend toward single-family housing has been influenced both by income determinants and lifestyle preferences. In more recent years apartment and condominium living has been increasing in popularity. These higher-density developments are generally accompanied by lower per capita water usage mainly due to decreased irrigable area. Another noticable shift in lifestyle patterns has also been gaining momentum, i.e., that of working wives and, consequently, less residential water use during the business day. The degree to which these patterns affect water use is highly dependent on the particular community involved.

Historically the price of water has been so low as to have a minimal affect upon residential water user's budgets. Due to steadily increasing rates and the growing awareness that water is a scarce resource, the water consumer is beginning to become more aware of the role water plays in his life. Changes in the method of billing for water have been shown to bring about significant decreases in usage. Studies have documented that municipalities with flat rate pricing are more wasteful in their water usage than are metered users (Linaweaver, et al., 1967). Pricing levels have also been correlated to usage reductions (AWWA, 1973, pp. 287-288). The current trend of increasing utility costs indicates that pricing policies in the future will function as a much larger determinant of water usage than in the past.

The overall economy of an area determines water use to varying degrees. Changes in economic conditions can result in water usage changes. The addition or demise of a major industry in a community can affect residential water-use as well as industrial use. Overall economic levels related to such changes affect the purchasing power of a community's residents and, consequently, their pattern of water use. Other activities such as land use planning and growth policies can similarly affect water usage.

The extent of supplemental lawn watering is one of the most influential factors in determining a community's residential water usage. Climatic conditions relating to the level and timing of precipitation and the amount of evapotranspiration are important in establishing lawn watering needs. Regional and national studies have indicated that geographical location is a primary determinant of these needs (Linaweaver et al., 1967). Changes in climate can dramatically affect watering requirements. Drought situations can create large lawn sprinkling deficits at a time when competing uses for water are most severe. Lawn sprinkling has been shown to increase with income level but decrease with increases in water prices. Based upon the interaction of these variables in a community, the amount of water used for lawn irrigation can vary over a wide range.

C. FORECASTING FUTURE DEMANDS

In the past, most water demand projections have estimated future requirements by extending present conditions. In many cases these have grossly overestimated future water demands. One such projection of residential water use, made in 1968 by the U.S. Water Resources Council, is shown in Table 2.

TABLE 2

PROJECTED AVERAGE PER CAPITA WATER USE IN THE U.S. (gpcd)

YEAR	RESIDENTIAL	TOTAL MUNICIPAL
1965	73	157
1980	77	163
2000	81	168
2020	83	170

Source : U.S. Water Resources Council, 1968, p. 8.

The table shows a gradually increasing per capita usage. These projections, however, did not take into account changes in demand conditions created by pricing policy changes and other alterations.

Another kind of projection has been to utilize drought conditions in estimating the worst possible demand situation for some future population of an area. These projections, while advocating a very conservative approach to water requirements, distort future water supply needs.

The basis for projection of future water demands is changing. Factors relating to trends in sociological factors and changes in utility management direction are being introduced into demand forecasting. The National Water Commission in its final report to the President expressed the judgement that:

> "It is impractical, and in fact undesirable to attempt to forecast precise levels of future water use on the basis of past water use. How much water will be used, where and for what purpose will depend on the policies that are adopted."
> (National Water Commission, 1973, p. 3).

The Commission advocated looking at a range of future demands. The alternative to supplying more water when confronted with increasing costs is that of reducing demand. The adoption of water-conserving techniques affects the demand side of the supply-demand relationships, makes better use of existing water, and reduces the need for developing new supplies.

D. BENEFITS FROM REDUCING DEMAND

A water conservation program directly or indirectly benefits the utility and homeowners of a municipality. The municipal utility benefits through reduced pumping costs, deferment of system expansion, increased life of present supplies and reduced loading of sanitary sewer facilities. Both water and wastewater treatment facilities experience additional benefits in reduced energy and chemical costs and reduced disposal costs due to lower residual sludge volume (decreased chemical additions). In addition, the attenuation of peak demands allows scaled-down designs and lower system investment costs for water treatment facilities, pumping plants, and storage and piping in the distribution system (Flack, 1976, p. 3). The homeowner benefits directly via reduced energy bills and slightly reduced water costs (due to decreased utility operating costs) and indirectly through lower present and future plant investment expenditures.

E. RESIDENTIAL WATER CONSERVATION

Water conservation can be defined as making more efficient use of existing supplies through structural, operational, economic and socio-political means. The need for residential water conservation has been recognized by organizations of national repute. The National Water Commission has declared, "In planning to meet future demands for municipal and industrial water, full consideration should be given to the possibilities for reducing water withdrawals by metering, by imposition of pricing systems that encourage more efficient use of water, by changes in building codes, by reducing leakage, and by other measures, as an alternative to increasing supply, or as a means for minimizing the necessary increase" (National Water Commission, 1973, pp. 168-169). Public law 92-500 establishes a legal mandate for water conservation by requiring reductions in the total flow of wastewater to treatment facilities (92nd Congress, 1972, Section 104 (0) (1)).

1. Structural Methods

The municipal utility may implement structural means of reducing the demand for residential water. Through metering, flow control devices and recycling systems various levels of demand reduction can be achieved. The metering of customers is a structural method of causing customers to be sensitive to price, i.e., customers are charged for water on the basis of use. The use of hydraulic flow controllers physically restricts the amount of water available to consumers. By reducing the system pressure less water is delivered in a given time period and thus the volume of usage is reduced. Recycling treated wastewater in the public use or residential use sectors represents an important future supply alternative. Reuse for irrigation and recreation purposes as well as other selected uses will become more feasible as utility costs escalate.

The consumer can implement structural alternatives by the installation of water-saving devices, flow controllers and recycle systems. Water-saving devices are plumbing fixtures and appliances that accomplish the same function as standard equipment but utilize less water. These devices primarily relate to household water-using activities. Flow controlling devices accomplish the same objective of pressure reduction in an individual residence as in a system. Home recycle systems are based upon segregation of wastewater flows in the home using water quality as the criteria. Recycle involves treatment and successive reuse of the wastewater effluent.

2. Operational Methods

Operational methods of demand reduction are chiefly under the control of the utility. Leakage detection and repair and the implementation of use restrictions are the major operational means of water conservation. System leakage is responsible for large quantities of unaccounted for water in some communities. Leakage detection and repair improves system efficiency and increases water availability.

The implementation of restrictions for different categories of use is also a conservation technique. Residential water use restrictions may be specifically addressed exterior water uses such as lawn irrigation and the filling of swimming pools or, in more severe instances, the total usage per customer.

The consumer has essentially only one operational technique of demand reduction, that of leakage repair. The detection and repair of fixture leakage is principally the homeowner's responsibility.

3. Economic Methods

Economic means of demand reduction can be accomplished solely through utility actions. The economic modes of water conservation includes pricing policy, incentives and penalties and demand metering. The adoption of an increasing block rate structure or other system of pricing places increased value on the use of water. The potential benefits of pricing may serve to maximize other conservation techniques. Incentives relate to rebates, tax breaks or other rewards for conserving water. The imposition of penalties or fines pertains to the wasteful use of water. Demand metering is essentially a pricing mechanism based upon measurement of incremental volumes in relation to time of use. It represents a structural means for implementing daily peak demand pricing.

4. Social Methods

Public education regarding conservation techniques is necessary in any demand reduction program. Instruction in how water is used and home conservation alternatives provides a basis for the adoption of these techniques. Development of a conservation ethic is essential to successful water conservation campaigns. Building code modifications are a means of legally mandating the use of low water-consuming plumbing fixtures. By requiring water-saving equipment in all new homes and all remodeling plans, significant water use reductions are possible in growth areas.

The individual consumer can affect lawn water usage through alternative horticultural practices. These alternatives can be of a physical or operational nature. The use of native species of plants and of landscaping techniques can reduce lawn sprinkling requirements. Installation of more efficient sprinkling equipment, such as drip irrigation systems, and more effective irrigation help to utilize the available water more efficiently.

5. Water Conservation Programs

Combinations of various water conservation alternatives will determine the programs most suitable for specific situations. All of the previously discussed conservation methods have affects upon one another, but are not strictly additive, therefore, absolute savings cannot be predicted by examining each method individually. In chapter IV these combined affects and their design implications are examined.

CHAPTER II

REVIEW OF PREVIOUS WORK

Only recently has research been directed at many of the water conservation alternatives. Before the early 1970's little consideration was given to demand modification. Even then most of the research conducted was instigated by problems concerning overloading of wastewater treatment facilities instead of a concern for water supply resources. Gradually, but in some cases swiftly, the realization of impending water shortages has created great interest in demand modification techniques.

The literature contains many references to the need for implementation of water conservation. Much of the work done in the past stated qualitatively the effects of water conservation alternatives, with little reference given to specific amounts. Some conservation alternatives have been investigated in greater depth than others. In the following sections the work done on each alternative is discussed.

A. WATER USE

1. Domestic Use

A noteworthy study of domestic water use was performed at the Johns Hopkins University (Linaweaver et al, 1967). The study showed that per capita domestic water use was relatively constant regardless of differences in climate and methods of water rate billing. Since the Johns Hopkins study a number of investigators have estimated the specific water usages of a variety of household fixtures and appliances. Table 3 is a summary of the results of some of these studies. The studies cited give a range

TABLE 3

PER CAPITA DOMESTIC WATER USE
(gpcd)

WATER USE FUNCTION	REFERENCES: Linaweaver, et al, 1963	Bailey, et al., 1969	Kreissl, 1971	Reid, 1965	Felton, 1974	Metcalf & Eddy, 1976	Nelson, 1975	Sharpe, 1975	RANGE	MEAN	% OF USE
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	8.7-20.0	18.4	30
LAVATORY SINK	3.0	2.0	----	----	4.9	----	3.0	3.0	2.0- 4.0	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

of values for each household water use component. The differences arise from the different methods of measurement and the varying size of sample populations. Of significance is the fact that 75 percent of water use in-house takes place in the bathroom. The largest components of use are the toilet and shower. Thus, these categories have the greatest potential for in-house water savings. The flow and quality characteristics of domestic wastewater have been shown to vary considerably with the time of day (Ligman et al, 1974; Felton, 1974). Since majority of residential wastewater flows are domestic in origin these determinations are significant for wastewater flow reduction.

2. Exterior Use

Exterior uses of water are predominantly the amounts of water used for lawn irrigation. The Johns Hopkins study found that a wide range of quantities were used for this purpose (Linaweaver et al., 1967). A number of studies have attributed this variation to climatic factors (Grima, 1972; National Water Commission, 1973). 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).

Actual sprinkling usage amounts have been reported to constitute from as low as 3 percent to over 70 percent of residential demand (Bailey et al, 1969; Cotter and Croft, 1974). Linaweaver and others derived an equation correlating effective precipitation and potential evapotranspiration to sprinkling requirements (Linaweaver et al, 1967); however, the effect of price was not taken into account. Due to the cross-sectional nature of the Johns Hopkins study a coefficient was necessary to adjust the forecast usage to the actual usage. For these two reasons the derived equation lacks some validity for specific cases (Whitford, 1970). Howe and Linaweaver derived equations based on the Johns Hopkins study data that did take price into account (Howe and Linaweaver, 1967).

Peak water demand rates are primarily the result of sprinkling demands. The peak hourly and maximum daily demands from sprinkling are used to determine the design capacities for water supply systems. The extra capacity provided for these peak demands are idle much of the time and possible mitigation of these demands is highly desirable.

B. WATER SAVING DEVICES

Standard plumbing fixtures and appliances have in the past been designed with little or no regard for water consumption. Because of the low-cost and seemingly endless supply of water very few plumbing manufacturers thought it necessary to develop low water use models. This attitude has changed in the last ten years as equipment makers have realized the market potential of low volume plumbing devices. As a result many new water saving models that perform the same desired functions as their predecessors have been developed.

Practically every type of household water use fixture can and has been redesigned to use less water. Many devices have been developed in an effort to cut down on toilet flushing volumes. Reduced flow shower heads and faucet controls have also been introduced. Low volume washing machines have been made available. The manufacturers of these fixtures and other types of systems have made claims as to the quantity of water they save and their overall performance. At the present time there is no impartial testing facility for these devices, however, a few studies have been made on specific devices and a number of studies have postulated possible water savings based upon the manufacturers' claims. These studies are discussed in the following sections.

1. Water Closet Devices

The four main types of devices on the market for reducing toilet flushing are (a) reduced volume water closets, (b) volume displacement devices, (c) variable flush modifications, and (d) special systems. These devices can effect a relatively large reduction in total domestic water usage (Baker et al, 1975, p. 71).

There are several types of reduced volume water closets. The most common is termed the shallow trap toilet which is a modification of the conventional toilet. Changes in the bowl design and the tank volume allow the shallow trap toilet to save about 1.5 gallons per flush over conventional models (Milne, 1976, p. 179). One of the first studies to evaluate the water use reduction of the shallow trap toilet was conducted by General Dynamics Corporation in 1969 (Bailey et al., 1969). A per capita savings of 7.5 gallons per day was reported based on a use of 3.5 gallons per flush for the shallow trap and 5.0 gallons per flush for conventional models (Bailey et al., 1969, p. 62). A follow-up study tested the shallow trap toilet in actual households with savings amounting to approximately 4.0 gpcd (Cohen and Wallman, 1974, p. 4). The difference in savings between the two studies was due to an estimation of nearly 8.0 gpcd more for toilet flushing in the Bailey study.

An investigation of the costs for the shallow trap toilet showed that it would be considerably more cost effective in new installations as opposed to retrofitting situations (Cohen and Wallman, 1974, p. 2). One of the alleged problems with the shallow trap toilet is inadequate solids removal. Several investigators have found that, with adequate pipe grades, clogging of the sewer lines should not be encountered with reductions of two gallons per flush or less (Konen and DeYoung, 1975, p. 155; Cole, 1975, p. 47). Table 4 is an economic analysis of the theortical savings of the shallow trap and other water closet devices using 1973 costs (Metcalf and Eddy, 1976). From Table 4 it can be seen that the shallow trap toilet becomes cost effective at low ($0.20/1000 gal) water and wastewater costs in new installations and at reasonable ($0.90/1000 gal) cost levels for retrofit conditions.

Volume displacement devices are generally fixtures designed to fit inside the water closet. They function much as their name implies by taking up some of the space flush water would occupy or by preventing escape of some of the tank water into the bowl. Examples of volume displacers include bricks, plastic bottles and damming devices. Bottles and bricks generally save about one-half gallon per flush or approximately 2.5 gpcd (North Marin County, 1976, p. 31). The most extensive experience using these devices was through the municipal water conservation campaign instituted by the Washington Suburban Sanitary Commission in the early 1970's (WSSC, 1974). This program distributed plastic bottles and other items to their customers in hopes of obtaining a 5 percent reduction in water usage. Their goal was obtained but it is difficult to say how much of the reduction was specifically due to the water bottles (WSSC, 1974, p. 10). Damming devices are currently marketed by a number of manufacturers (Milne, 1976, North Marin County, 1976). Figure 1 illustrates how damming devices work.

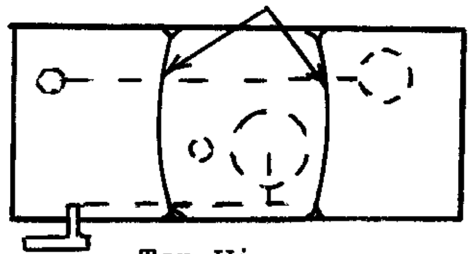
About 1.0 gallon per flush or 5.0 gpcd can theoretically be saved through the use of damming devices (North Marin, 1976, p. 30). The only full scale testing of these types of devices was done in the Cabin John Study during 1972 (WSSC, 1973). The usage reduction for single family dwellings in this study ranged from 16 to 26 percent. One of the notable facets of that study is that in some instances actual increases in usage occurred, especially in the case of apartment areas. The reasons for these increases were attributed to the need for double-flushing of the toilets due to improper admustment of the devices (WSSC, 1973), and the inability of some of the models and some units within otherwise good

TABLE 4

ECONOMIC ANALYSIS OF WATER SAVING TOILET DEVICES AND SYSTEMS*

TYPE	WATER USE	REDUCTION IN USE		ANNUAL SAVINGS		BREAKEVEN COST ($/1000 gal)	
	gpcd	gpcd	% Total	gpc	gal/house	NEW	REPLACEMENT
Conventional Toilet	25.0	----	----	----	----	---	----
Single-Batch Flush Valve	17.5	7.5	12	2,738	9,309	1.83	2.58
Dual-Batch Flush Valve	9.5	15.5	24	5,658	19,236	1.04	1.40
Shallow Trap Toilet	17.5	7.5	12	2,738	9,309	0.11	0.86
Dual Cycle Toilet	7.5	17.5	27	6,388	21,719	0.14	0.46
Dual Cycle Tank Inserts	15.0	10.0	16	3,650	12,410	0.08	----
Reduced-Flush Devices	15.0	10.0	16	3,650	12,410	0.40	----
Brick in Tank	24.0	1.0	2	350	1,190	0.004	----
Vacuum Flush Toilets Single Home	2.5	22.5	35	8,212	27,921	4.23	4.58
150 Homes	2.5	22.5	35	8,212	27,921	0.75	1.11
Recirculating Oil System	0.0	25.0	39	9,125	31,025	9.19	9.51

*Based Upon: 3.4 persons/household; 64.0 gpcd total usage; 5 toilet usages/capita/day; June, 1973 Costs; 20 Year Service Life. Source: Metcalf & Eddy, 1976, p. A-14.



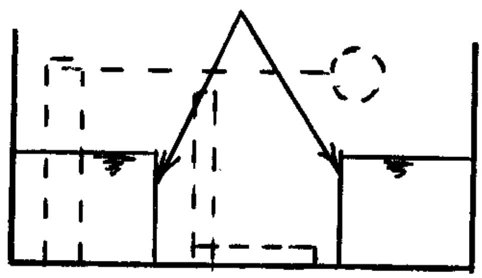


FIGURE 1. VOLUME DISPLACEMENT DAMS

performance models to flush away all solids. The performance of the devices was found to decrease with age and condition of the toilet and required sufficient grade on the sewer line to carry the waste away (WSSC, 1973, p. 21). In Table 4 slightly higher savings are estimated for the displacement devices than were found in the Cabin John Study, but even at the lower savings levels the devices are cost effective.

Variable flush attachments are devices that let the operator choose when the flush cycle should end. Through the use of weights or flapper types of tank balls the amount of water flushed can be varied by the length of time the toilet lever is depressed. In Great Britain the dual cycle water closet has been widely accepted (Bailey et al, 1969, p. 55). One cycle of this toilet is for liquid wastes and uses approximately 1¼ gallons per flush and the other cycle is for solid waste and uses 2.5 gallons (Crisp and Sobolev, 1959, pp. 513-525). The dual cycle toilet was found to save 3.3 gpcd in a 1974 study (Cohen and Wallman, 1974, p. 4). In the same study a weighted tank ball device was found to save approximately 5.4 gpcd. Table 4 shows a considerably higher water savings for the dual cycle toilet than was found during the 1974 testing. The discrepancy is due to a difference in models. The Cohen and Wallman study used an American brand of toilet while the figures in Table 4 are based upon the English version of the dual cycle toilet. The dual cycle toilet is shown to be cost effective in Table 4.

Batch-type flush valves are currently used in many commercial establishments. These valves provide for a forceful flushing action due to an oversized feed line and a quick release valve (North Marin County, 1976, p. 29). These devices can be set to deliver from 0.5 to 4 gallons per flush, with three to four gallons being the usual setting (Crisp and Sobolev, 1959, pp. 513-525). Bailey and others estimated a water savings of 7.5 gpcd with these devices (Bailey et al., 1969). The main disadvange of these flush valves is the cost of installing a larger feed line (Bailey et al., 1969). Values given in Table 4 confirm that because of the cost of the new feed line the batch flush valves are cost effective only at high water and wastewater prices.

The fourth category of water saving toilet devices is termed special systems. These systems range from variations in the design of conventional toilet models to self contained treatment units. Milne presented an excellent description of the wide range of systems that are available (Milne, 1976, pp. 347-358). Generally the systems cost more than conventional toilets and thus may be most applicable in areas where traditional means of wastewater disposal cannot be utilized. The water use of these systems ranges from zero to 2½ gallons per use. The substitution of other modes of disposal of wastes has been designed into several of these systems.

The vacuum system was first used in Sweden and has since been marketed in the United States (Bailey et al, 1969, p. 57). Several types of systems utilizing compressed air or pressurized flush tanks have been designed (Milne, 1976, pp. 165-218; North Marin County, 1976, p. 110). Other systems utilizing mineral oil as a recirculating medium have been tested and are in use in some areas (Matthew and Nesheim, 1973; Hoxie and Toppan, 1975, p. 152). The main problem with these systems is the need for ultimate disposal of the wastes. Table 4 shows that for single units the vacuum transport system and the oil recycle system are not cost effective. Multiple installations in groups of homes or subdivisions would decrease the cost of these systems.

2. Shower Head Devices

Flow limiting shower heads are designed to deliver less water per unit time than conventional models. These shower heads restrict the passage of water by decreasing the shower head opening. Most shower heads operating under a supply pressure of 40-50 psig have a flow of 5 to

10 gpm when fully opened (Moses, 1975, p. 118). Flow limiting shower heads reduce the flow rate to about 2.5 to 3.0 gpm (Bailey et al, 1969, p. 54). Both fixed and variable orifice shower heads are available; the latter allow the user to control the flow rate (Milne, 1976). The actual amount of water savings that these devices will save is difficult to estimate since shower duration and intensity differ greatly among individuals. It has been estimated that for a shower of five minutes duration, a savings of 7.5 gpcd is possible (Metcalf and Eddy, 1976, p. 1-14; North Marin County, 1976, p. 23). Actual documentation of this theoretical water savings was attempted by the WSSC through their water conservation program. An initial study showed a 12 percent decrease in usage but later studies indicated increases in usage (WSSC, 1974). Thus, precise water savings amounts were shown to be dependent on more than just technologic capability.

Estimates as to the quantity of hot water saved and the energy savings vary considerably with the assumptions made in such a calculation. North Marin County estimated a household energy savings of $4.30 a year using a flow limiting shower head (North Marin County, 1976, p. 24). In contrast, Sharpe estimated an annual savings of over twenty-one dollars in power costs through the use of the flow limiting shower head (Sharpe, 1975, p. 6). The problem with these estimates lies in how the energy is supplied and what the consumer's habits are. Considerable difference exists in the cost of energy from different sources and in the means of heating and conducting water to the point of use.

3. Faucet Control Devices

Faucet control devices operate in the same manner as shower flow controls. By installing a fixed orifice in the supply line the delivery rate can be reduced to between 0.5 to 4.0 gpm (North Marin County, 1976, p. 20). Depending on the use estimates made, a water saving of from 0.5 to 1.0 gpcd has been calculated (Bailey et al., 1969; Metcalf and Eddy, 1976). The use of aerators and spray taps are two means of structurally reducing the amount of water used. Aerators introduce air and concentrate the flow, thus reducing the amount of water needed for rinsing. Aerators, of course, do not decrease the amount used for filling fixed volumes such as glasses or bottles (Flack , 1976). Bailey and others estimated a 25 percent savings or a decrease of 0.5 gpcd in water used in sinks by installation of aerators (Bailey et al, 1969, p. 55). Others have reported greater savings through aerators capable of reducing flow to 0.75 gpm (Milne, 1976, p. 242). A savings in hot water usage is also accomplished by this device.

The spray tap is used extensively in Europe. The spray tap is simply a minature shower head designed to deliver small droplets of water and thus reduce usage by increasing rinsing power. A number of studies have shown decreases of over 50 percent in water used for sinks in commercial buildings using spray taps (Crisp and Sobolev, 1956; Field, 1973). The cost effectiveness at current water prices is considered marginal for both the aerator and the spray tap primarily due to the small amount of water savings (Metcalf and Eddy, 1976; Bailey et al., 1969).

Another means of reduction of both sink and shower water usage is through the use of thermostatically controlled mixing valves. These valves control the temperatures of the delivered water and, therefore, reduce wasting of water while the water temperature is manually adjusted. The savings of these devices lies principally in hot water conservation, however, their high cost does not make them cost effective (Metcalf and Eddy, 1976; Milne, 1976).

4. Low Water Using Appliances

The clothes washer and the dishwasher are the chief domestic water using appliances. Clothes washer water requirements have been reported to vary from 38 to

69 gallons per cycle (Consumer Reports, 1975, pp. 611-615). Front loading machines use one-third less water than top loaders but also wash about one-third less clothes per load (Milne, 1976, p. 282). Some machines are equipped with a suds saver option. This alternative allows for reuse of the washwater for additional loads. Savings of 20 to 26 percent of the wash water has been estimated utilizing the suds saver option (Milne, 1976, p. 282). However, the necessity of a utility storage sink may preclude the use of the suds saver in many homes (Flack, 1976). Machines having water level controls enable the consumer to use water according to the load. A savings of 1.2 gpcd has been estimated using water level controls (Bailey et al., 1975, p. 57).

Dishwashers use between 12 and 18 gallons per cycle. Adjustment of the cycle has been estimated to result in savings of from 7.5 to 12.5 gallons in some models in a survey done by the Washington Suburban Sanitary Commission.

C. RECYCLING

Historically water utilities have sought to alleviate supply problems by developing new sources of water. Traditionally, water has been supplied to municipal residents, used, treated and then discharged as wastewater. The reuse of water has been overlooked in most cases. Through the recycling of water more efficient use of the resource is obtained. Recycling of water can be categorized as planned and unplanned.

1. Unplanned Water Recycling

Recycling of water has been practiced since the beginnings of civilization. The unplanned reuse, or more correctly successive use, of the wastewater of one settlement by downstream communities has increased with rising populations. The Environmental Protection Agency has estimated that during low flow periods the proportion of wastewater in many surface water supplies ranges between zero and eighteen percent, with an average of three and one-half percent (Graeser, 1974, p. 577). This trend of increasing proportions of the water supply being wastewater is expected to continue in the future. One can view many rivers as successive use systems where water and wastewater are the recycle components. The advantage of planned reuse of wastewater in a community becomes much more apparent by recognizing such a cyclic pattern.

2. Planned Water Recycling

The planned reuse of water has been recognized by many as a viable alternative to new water supplies (Milliken et al., 1977, Chapter VXII; Culp and Culp, 1971). The advantages are obvious; the water supply and the wastewater discharge components are reduced in magnitude. A new level of interest in water recycling has been generated as the result of increasing costs of importing new water supplies and capabilities of advanced wastewater treatment. The costs of advanced treatment have also been reduced and approach more closely the cost ranges for raw water supply treatment than in the past.

3. Indirect Recycling

Recycle systems can be divided into two general categories according to use: indirect reuse and direct reuse. Indirect reuse involves the discharge of a wastewater into a surface or underground water supply and then subsequent reuse of the water in a diluted form. The previously discussed unplanned reuse of surface waters is an indirect reuse. Similarly, the percolation or injection of wastewater into ground water aquifers is also a form of indirect reuse. Ground water recharge using sewage effluents is presently practiced in many locations in the United States (Schmidt et al., 1975, p. 2229). The primary reuse of such water is for irrigation with a small percentage being allocated for recreation and fire protection and for municipal purposes (State of California, 1973).

4. Direct Recycling

Wastewater can be used directly in irrigation, industry and for some residential applications. A survey by Schmidt and others indicated that 358 municipalities, located primarily in the Southwest, reuse wastewater for such purposes (Schmidt et al., 1975, p. 2229). In the same study it was found that approximately 20 percent of the reuse sites supplying wastewater for irrigation received income from its sale. Of primary concern to the residential use sector is the recycle quantity and quality supplied for domestic use and lawn irrigation.

Institutional Attitudes: Endorsement of wastewater reuse has been fragmented with some authorities viewing it as a major solution to water supply, while others have voiced considerable concern (Phillips, 1974, pp. 231-326). The American Water Works Association and the Water Pollution Control Federation have issued a joint resolution recognizing the potential of wastewater recycling but cautioning that further research needs to be done on some of the possible health hazards involved (WPCF, 1973, p. 2404). Surveys of health officials have expressed similar concerns (Dworkin and Baumann, 1974).

Health Aspects: The possible health effects of ingestion of low levels of viruses, organics and heavy metals that may be present in treated wastewater have not been determined for prolonged periods. Questions relate to the frequency and the amount of recycled water ingested. Most authorities agree that there is much more to be learned before recycled water can be used as a drinking water supply (Phillips, 1974, p. 231). A distinction between potable and nonpotable residential reuse has been advocated by many researchers due to these health uncertainties (Okin, 1969, p. 213; Reinhardt, 1975, p. 477).

Public Attitudes: The acceptance of recycled water is of considerable importance in planning for wastewater reuse. Several surveys have been conducted to assess the public's attitudes towards water reuse. Pagorski found that 81 percent of a sample survey population were willing to use recycled water if it was guaranteed to be safe (Pagorski, 1974, p. 108). Bruvold and Ongerth found that the degree of acceptance decreases with higher body contact uses (Bruvold and Ongerth, 1974, p. 295). A survey of the Denver area showed that half of the sample population would accept purified wastewater for drinking (Carley, 1972). Gallup reported that 54 percent of those surveyed opposed drinking recycled sewage (Gallup, 1973, p. 519). A study by Sims and Baumann correlated higher reuse acceptance with higher levels of education (Sims and Baumann, 1974, p. 659). Regardless of the specific figures involved it appears that public attitudes currently oppose using recycled water for drinking, cooking, bathing, laundry and swimming but do not oppose its use for waste disposal and irrigation purposes. A recent symposium concluded that, "Attempts to institute potable reuse have not been sufficiently numerous to develop a clear picture of what the social reaction might be to this practice," (English, Linstedt and Bennett, 1977, p. 136).

5. Methods of Direct Recycling

Methods of direct recycle range from those instituted on an individual home basis to system-wide operations. The most cost effective means of recycling water is to reduce or minimize the treatment required. To better comprehend how recycling of water can be accomplished and the treatment needed several authors have looked at the qualities of each type of home use effluent (Bailey et al, 1969; Ligman et al, 1974; Felton, 1974). A number of recommendations have resulted from these findings. Table 5 gives the potential of possible residential recycle components (Milne, 1976, p. 382).

Individual Home Recycle: The waste stream from the various domestic water uses can be categorized as grey water or black water. Those flows containing high concentrations of organic matter are termed black water while

TABLE 5

POTENTIAL FOR RESIDENTIAL WATER REUSE

ORIGINAL USE	REUSE										
	Toilet	Irrigation	Sprinkler	Kitchen sink w/grinder	Carwash	Laundry	Pool	Shower/tub	Sinks	Dishwasher	Cooking
1. Toilet	2	-	-	-	-	-	-	-	-	-	-
2. Irrigation*[a]	1	1	1	-	1	-	-	-	-	-	-
3. Sprinkler*[b]	1	1	1	-	1	-	-	-	-	-	-
4. Kitchen sink with grinder	1	1	1	-	-	-	-	-	-	-	-
5. Carwash*	1	0	1	-	1	-	-	-	-	-	-
6. Laundry[c]	1	0	1	-	1	1	-	-	-	-	-
7. Pool	1	3	3	-	1	1	2	-	-	-	-
8. Shower/tub	1	0	1	-	1	1	-	-	-	-	-
9. Sinks	1	0	1	-	1	-	-	-	-	-	-
10. Dishwasher	1	0[o]	1[o]	1	1	-	-	-	-	1	-
11. Cooking	1	0	1	0	1	-	-	-	-	0	0

Adapted From: Milne, 1976, p. 382.

LEGEND

- 0 Reusable directly without treatment
- 1 Reusable with settling and/or filtering (primary treatment)
- 2 Reusable with settling, filtering, and chemical treatment usually chlorination (secondary treatment)
- \- Not reusable or impractical

NOTES

- * Difficult to collect
- o Special soaps required
- a Large orifice: unpressurized open hose or channel
- b Small orifice: pressurized
- c Assumes no fecal matter

flows polluted primarily with soap-related wastes are termed grey water (Withee, 1975, p. 8). Currently these two wastewater flow components are combined and discharged into the sewer system. The concept of onsite recycle is still a relatively new idea with very few systems in actual operation, but a few studies have been conducted. McLaughlin found that a system separating the two wastewater streams and reusing the wash water, or grey water, from laundry and shower uses for toilet flushing saved approximately 23 percent of normal water usage (McLaughlin, 1975, pp. 133-141). Figure 2 is a schematic of a typical grey water toilet reuse system. In 1969 Bailey and others performed cost estimates on a number of types of individual home treatment systems for in-home water recycle (Bailey et al, 1969). Their general findings indicated that treatment costs were too high in most cases to make recycling cost effective. A follow-up study by Cohen and Wallman indicated that average savings of between 23 and 26 percent of total water use could be obtained by wash water recycle for toilet flushing (Cohen and Wallman, 1974). The same study noted that recycle systems could achieve marginal cost savings in areas having high water and sewer rates. Reuse of black water flows is extremely unlikely because of the possible health hazards that could be caused by mechanical failure (Milne, 1976).

System Recycle: The literature contains much discussion on system-wide reuse possibilities. The classic case of direct reuse of wastewater took place in Chanute, Kansas when a severe drought brought about a water shortage and the recycle of wastewater was necessary to supply the town's water needs (Metzler, 1958, p. 1021). Windhoek, South Africa has in the past recycled 15 percent of its total supply for domestic uses (Seeger, 1976, p. 50). Schmidt and others reported that the only planned non-potable domestic reuse of wastewater in the United States is practiced at the Grand Canyon (Schmidt et al, 1975, pp. 2229-2245). Recycled grey water is used for toilet

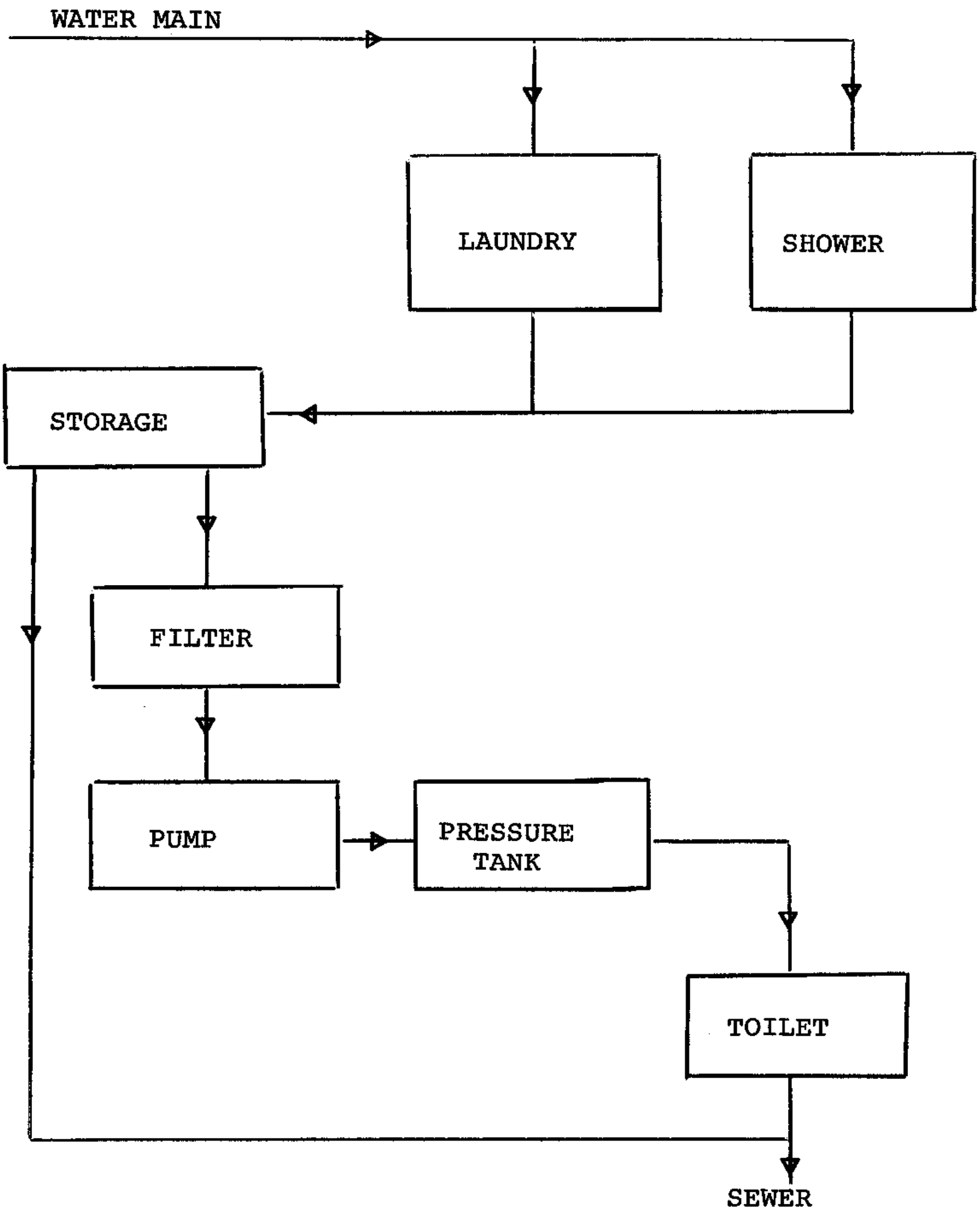


FIGURE 2.

TYPICAL HOUSEHOLD GREY WATER RECYCLE SYSTEM
(Source: McLaughlin, 1975, p. 137)

flushing and lawn irrigation in the Grand Canyon Village. The cost of the reuse there was calculated as $25.08 per thousand gallons, but the high cost was stated as a reflection of the low volume used. Other areas such as Tucson, Arizona and St. Petersburg, Florida currently reuse water for similar purposes or plan to reuse water for non-potable use in the near future (Metzler and Russleman, 1968, p. 95; Roll, 1974, p. 60; Dove, 1974, p. 58).

The implementation of dual systems to accomplish domestic reuse has been examined by a number of authors (Haney and Hamann, 1965, pp. 1073-1098; Haney and Beatty, 1976). The provision of two qualities of water each suited for different purposes promotes efficiency. Haney and Hamann based their calculations for a dual system on a need of 40 gpcd of high quality water (Haney and Hamann, 1965, p. 1973). High quality water in a dual system would be furnished for drinking, cooking, dishwashing, bathing and cleaning purposes. Recycled water would be furnished via a non potable system for toilet flushing, lawn irrigation, air conditioning and clothes washer uses. Deb and Ives estimated that 85 percent of total supply could be provided by the nonpotable system (Deb and Ives, 1975). DeLapp found that by using reclaimed water to provide lawn irrigation, toilet flushing and fire protection the quantity of water currently supplied would be decreased by 73 percent (DeLapp, 1973). The same study found that in new subdivisions the incremental cost of utilizing a dual system was $0.60 per 1000 gallons while installation and operation of dual lines using the existing system would cost $0.80 per 1000 gallons. Presently dual systems are used in several small communities across the United States (Okun, 1970, p. 2174; Haney and Hamann, 1965, p. 1073). Dual systems in Coalinga, California and Cataline Island, California are two examples of operating recycle systems.

D. PRESSURE REDUCTION

The use of pressure reducers to regulate the flow of water for both distributional zones and individual services has been recognized as a conservation technique (Moses, 1976). System pressure reducers function in much the same way as the household flow reducers discussed previously. The amount of water savings possible with hydraulic flow restrictors is a function of the normal operating pressure and the desired pressure of the system (Moses, 1976). The WSSC has mandated reduction of all line pressures over 60 psi to pressures in the range of 50-60 psi (WSSC, 1974). The WSSC has predicted a 33 percnet reduction in water flow in their system using pressure reducers. The minimum advisable water pressure is 20 psi based upon the needs of various household water using appliances. Thus a range of system pressures and their concommitant savings is possible.

E. METERING

Metering the use of water assigns a positive value to the water. Under conventional flat-rate billing methods the consumer has no economic incentive to conserve water because he pays the same fee no matter how much water he uses. Metering provides the structural means of charging a customer on the basis of the quantity he uses. According to one source over 90 percent of the water services in the United States are metered (Fleming, 1964). However, several large cities such as Denver and New York City and a number of smaller municipalities still have large percentages of their systems unmetered.

1. Effects

The effects of metering on residential water usage has been a subject of much discussion. This is due to the difficulty of quantification of the usage reductions of universal metering. The Johns Hopkins Study claimed that the domestic use component was essentially the same in flat-rate and metered areas (Linaweaver et al., 1967).

The same study demonstrated large differences in sprinkling use between unmetered and metered areas. In order to measure the effect of metering, Hanke examined water use records for the city of Boulder, Colorado, before and after universal metering was instituted (Hanke, 1969). He concluded that metering produced a substantial reduction in residential water use. The domestic component decreased by 36 percent and a reduction of 230 gpd per dwelling unit in the sprinkling demand was reported. While the reduction in domestic use was attributed primarily to the repair of plumbing leaks, the reduction in sprinkling irrigation of lawns and gardens under flat rate pricing was shown to decrease to levels approximating the consumptive use requirements of the vegetated areas not met by precipitation (Hanke, 1967; Flack, 1973).

In another study, Bryson estimated the difference in sprinkling use between metered and unmetered areas in Denver (Bryson, 1973). Table 6 from his study shows that the average annual application of water in metered areas was substantially less than that for flat rate areas. He calculated that lawn watering requirements amounted to about 2.2 feet per year. It is obvious that differences in the physical, social, and economic conditions of neighborhoods and communities give rise to different levels of water savings after metering. Green calculated savings levels ranging from 70 to 210 gpd per dwelling unit through meter installation within the same city (Green, 1972). Brauer and others found in a survey of 28 cities in northern Colorado that metered communities used about 30 percent less water than largely unmetered communities (Brauer et al, 1976). Similarly, maximum day and peak hourly usages have been found to be much higher in unmetered areas than in metered areas (Green, 1972; Linaweaver et al., 1967).

TABLE 6

COMPARISON OF METERED AND FLAT-RATE RESIDENTIAL WATER USAGE FOR THE YEARS 1969 to 1972
Denver, Colorado

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 (ft)	1.9	3.9	3.6

Source: Bryson, 1973, p. 37.

Grima has suggested that the variable prices accompanying metering is the mechanism causing usage reduction (Grima, 1972, pp. 50-53). Flack has stated that initially the psychological effect is the primary cause of usage reductions but afterward the effect is chiefly due to price (Flack, 1976, p. 6).

2. Benefits and Costs

The benefits derived from metering are both short and long-term in nature. On a short term basis, equity in customer charges, increased efficiency in water usage and savings in the cost of water aquisition, treatment and pumping are achieved (Flack, 1970, p. 645). Long term benefits include cost savings in design capacities and deferment of investment in facilities. Improved resource allocation, pricing policy modifications and accounting for water are also benefits obtained through metering.

The costs of metering are substantial. Installation, maintenance and reading of meters can account for significant portions of a utility's revenues. For example, Bryson estimated in 1973 that it would cost over 27 million dollars for Denver to meter its nearly 90,000 flat rate customers (Bryson, 1973, p. 2). With such costs in mind a utility must weigh the potential benefits of metering carefully.

F. LEAKAGE REDUCTION

Leakage occurs in most water distribution systems and in many individual homes. The primary causes of system leakage relate to the age of the system, the quality of materials used, the physical and chemical soil properties, the chemical properties and pressure of the water and the degree of system maintenance (Howe, et al., 1971). It is difficult to determine the amount of leakage present in a system. This is partially due to the fact that most systems have uses that are not accounted for, such as street cleaning, fire-fighting and hydrant flushing. These unaccounted-for uses are quantified by taking the amount of metered use from the total production amount. In flat rate systems there is no way to determine accurately unaccounted-for water amounts, and this makes it difficult to estimate the exact savings of water conservation programs (McPherson, 1976, p. 4). Similarly the amount of leakage in individual homes is difficult to estimate. The type and condition of plumbing fixtures varies widely.

1. System Leakage

Unaccounted-for-Water. Surveys of water utilities conducted in 1965 and 1970 showed that unaccounted-for water amounted to 9.5 and 10.9 percent of the total water distributed (Keller, 1976, p. 160). The range of percentage loss was from less than 2 percent to over 27 percent. A system with unaccounted-for water of 10 to 15 percent of total distributed water was considered to be quite tight. It has been suggested that the amount of unaccounted water that is system leakage could be accurately determined through proper accounting procedures.

Leakage. Leakage amounts from as low as two percent for tight systems to sixteen percent or more for leaky systems have been estimated (Temporary State Commission Southeastern New York, 1973). All of a system's leakage may not come from leaky pipes, but may also be attributable to inaccurate meters. One survey showed that at least 20 percent of meters with more than 9 years service would not register flows below 0.75 gpm. This flow rate accounted for approximately 25 percent of a household's usage flows (Hudson, 1964, p. 145). A survey of 91 cities found mean loss rates due to leakage of 12 percent (Howe, 1971, p. 285). Howe estimated, in the same study, that at least 9 percent of this amount could be saved by cost effective leakage detection and repair.

The East Bay Municipal Utility District of Oakland, California has instituted a leak detection and repair program. In two years, it has been reported that losses of four mgd have been eliminated (Laverty, 1976). The utility expects to double this figure and thus decrease its unaccounted-for water from 8.3 percent to 5.4 percent of total use (Metcalf and Eddy, 1976, p. 4-3). Other utilities that have made water loss surveys have discovered that a large percentage of the cost of leakage reduction is economically justifiable (Temporary State Commission Southeastern New York, 1973).

2. Household Leakage

The most common types of household leaks are from toilets and faucets. Worn supply valves, improper tank ball seating or leaky tank floats have been listed as the primary sources of toilet leakage (State of California, 1976, p. 30). Leak detection kits using dye tablets have been developed to aid the consumer in finding leaks (WSSC, 1974). Leaky faucets are generally the result of worn washers. A solution to this occurrence has been the replacement of the faucet with a washerless faucet (State of California, 1976).

G. WATER USE RESTRICTIONS

Restrictions on water usage may be very effective in reducing demand. Generally, restrictions are short term methods of reducing demand usually practiced during drought periods. As a management alternative restrictions are usually imposed when system capacity is exceeded or raw water supply is inadequate. Restrictions may be voluntary or mandatory and are usually based upon restricting certain types of uses.

1. Types

Restrictions are generally applied to outside-the-house uses such as lawn sprinkling, car washing and the filling of swimming pools. Table 7 shows the restrictive decisions made in 34 communities in Massachusetts during the drought of the 1960's (Russell et al., 1970, p. 75). Restrictions on lawn sprinkling were imposed in every system that adopted restrictions on the domestic water uses. Hudson and Roberts noted that cities used restrictions quite readily when faced with potential water shortages (Hudson and Roberts, 1955).

The enforcement of restrictions can be by police regulation or peer pressure. The restrictions can be aimed at reducing peak usage or to affect average daily usage or both.

2. Effectiveness

The effectiveness of restrictions depends upon whether the public perceives the situation as being a crisis or not (Baumann et al., 1976). Whitford noted that restrictions during dry periods can effectively decrease peak demands (Whitford, 1970). For example, when the city of

TABLE 7

NATURE OF RESTRICTIONS ADOPTED BY 34 COMMUNITIES

Sector applied to and description	Number of towns adopting	Percentage of all towns imposing any restrictions	Percentage of those towns imposing restrictions on particular sector
Domestic sector:	34	100	100
Lawn-sprinkling	34	100	100
Car-washing	26	76	76
Swimming pool(re)fill	17	50	50
All outside use	10	29	29
Industrial sector:	13	38	100
Cooling water recirculation	9	26	69
Air Conditioning	9	26	69
General cooling	2	6	15
Process water recirculation	1	3	8
Restrictions on air-conditioning use (hours, temperature)	2	6	15
Car and truck washing (including commercial establishments)	5	15	38
Public sector:	19	56	100
Ponds, fountains	13	38	68
Hydrant flushing	12	25	63
Swimming pool(re)filling	6	18	32

Source: Russell, Arey and Kates 1970, p. 75.

Denver imposed lawn restrictions during the mid-1950's a decrease of 15 percent in total annual usage occurred. (Denver Water Department, 1975, p. 43). A 20 percent reduction in a voluntary save-water program in March, 1977 was achieved by the same utility (The Denver Post, 1977). Similarily, a 12 percent decrease in average daily water usage was reported during the 1965 drought in New York City (Metcalf and Eddy, 1976, p. 4-4). 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 percent (Century Research Corporation, 1972). By contrast, other municipalities have indicated that water use after the imposition of restrictions stayed the same or actually increased (Brauer et al, 1976).

3. Costs

The costs of restrictions cannot usually be quantified in dollars. Although there are some costs involved in the administration and the enforcing of restrictions, the primary costs are social and political (Milliken et al., 1977, p. VIII-15). Lifestyle changes with regard to water use are the primary social consequences. Politically the imposition of restrictions can be unfavorable due to the public's attitude toward regulation. Restrictions were imposed in San Francisco in spring 1977 to reduce water use by 25 percent. The actual reduction was nearly 43 percent and resulted in encouragement by the utility for customers to use more water because of the sharp drop in revenues.

H. BUILDING CODE MODIFICATION

Through regulations requiring the installation of water saving devices in new construction and as replacements for old fixtures, a substantial reduction in water and sewage flows can be accomplished (Milliken, et al., 1977). No studies have been conducted specifically to evaluate the effectiveness of building code modifications on water usage but a number of municipal utilities have incorporated water saving device specifications into their codes.

The WSSC modified its plumbing code in 1972 to require pressure-reducing valves, low water use toilets, water saving shower heads and faucet aerators (WSSC, 1974). Fairfax County in Virginia and Goleta County in California have similar requirements in their codes (Metcalf and Eddy, 1976). The State of California has enacted into law a provision requiring the installation of low volume toilets for all new construction after January 1, 1978 (State of California, 1976). Also adopted in California is a regulation authorizing municipal water districts to require as a condition of service the installation of water saving devices. Although there is currently no national authority calling for the specification of water saving devices, the potential of changes in the Uniform Plumbing Code has been recognized (State of California, 1976).

One of the consequences of implementing these kinds of code requirements is that some caution or outright provision should be made to ensure adequate grade on sewer lines so that they will drain under the lower flow conditions resulting from the flushing and draining of low water using devices.

I. HORTICULTURAL CHANGES

Since residential lawn sprinkling makes up a large portion of water demand, techniques which will lower that demand can play a significant role in the reduction of overall water use. The use of natural means for controlling vegetative coverings and its water requirements is highly desirable. Horticultural changes in residential lawns and gardens can drastically affect a municipal utility system's peak water usages. The Johns Hopkins Study found that peak hour sprinkling demands can be as much as 2,251 gpd per dwelling unit (Linaweaver et al,. 1967). The storage capacity needed to meet such demands could be alleviated through horticultural changes.

The water demand of grass can be thought of in much the same way as the raising of an agricultural crop. Optimally the amount of water to apply to the lawn area should be just enough to meet the evaporation-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 speed and soil conditions (Cotter and Croft, 1974). Thus, climatic conditions of an area determine the amount of necessary lawn water application. Physical parameters which will affect the amount of evapotranspiration from a lot include the types of grasses and plants used, the landscape of the irrigated area and the size of the lawn. The literature contains essentially three modes of affecting lawn watering usage: changes in plant types, changes in landscaping and changes in lawn watering methods.

1. Plant Types

Native species of grasses and plants need much less water than imported species. The planting of such species as Buffalo Grass, Blue Grama, Sideoutes Grama and Yellow Bluestem sharply reduces watering requirements (Uno, 1974). Several lists of native plant species have been compiled, each confined to specific geographic areas (Youngman, 1975; Guneo, 1975; Elmore, 1976; Stiteo, 1975). The use of xerophytes in desert landscapes can reduce watering of these areas to near zero. 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, p. 13). The high costs of seed and low germination rates for natural grasses compared with bluegrass can be a deterrent to wide acceptance. In addition, the availability as sod is an important consideration.

2. Landscaping

The slope of the lawn and the shading are two physical landscaping considerations which can affect the watering requirements of a lawn area. The use of gentler slopes and contouring provides greater water contact time and less runoff (North Marin County, 1976, p. 165). The presence of broad leaf trees can provide shade for grass. Adjustment of the pH, adequate grading, proper density and provision of nutrients to the soil can lead to more efficient water usage (North Marin County, 1976). The use of gravel and rock areas in place of lawn area directly reduces watering needs.

3. Watering Methods

The amount of water needed for residential landscapes has been estimated by several methods including metering and calculations based upon climatic parameters (Cotter and Croft, 1974). No completely satisfactory method has been found to account for all the variables involved. Watering requirements for different types of soils and grass species have been reported (Tovey et al., 1969), pp. 863-866). Estimates of minimum amounts of supplemental watering necessary for grasses are highly dependent on the frequency and intensity of precipitation (Cundel, 1977). Technological means for measuring soil moisture are commercially available (Milne, 1976). Soil tensiometers measure soil moisture and tell when the amount of soil moisture declines to the point that sprinkling is needed. Sprinkling only when the lawn requires water rather than on a regular basis promotes water use efficiency.

The State of California estimates that as much as 20 percent of applied lawn water may represent overwatering (Stage of California, 1976). A New Mexico study found that through efficient watering techniques, water requirements could be reduced by as much as 47 percent (Cotter and Croft, 1974, p. 59). Tips on how to water efficiently have been published by many agricultural extension agencies. In addition, advanced techniques of lawn irrigation have been devised. Among these are the use of drip or trickle irrigation.

Most of the work done on drip irrigation pertains to its use in agriculture. Basically, drip irrigation provides water at relatively low pressure directly to the plant at the discharge point (Chesness, 1975). By supplying water in small amounts the water application approachs the actual consumptive needs of the plants. A more extensive root system develops with a much healthier plant. Conventional losses such as runoff, deep percolation and soil water evaporation are avoided (Howell and Hiler, 1974), although salt build-up because of lack of leaching may create problems in arid regions.

4. Acceptance

Very few attempts have been made to gain widespread acceptance of horticultural changes. Marin County Municipal Water District has constructed a model lawn and garden as a public education method of gaining acceptance of water conserving horticultural techniques (Metcalf and Eddy, 1976). Probably the most innovative approach has been taken in Northern Marin County. A subdivision there has developed lawn and landscaping techniques in cooperation with the local water utility. A water savings of 19 gpcd has been estimated from the implementation of these techniques (North Marin County, 1976, p. 169). The costs of the program were evaluated and the "irrigation plan" was found to be cost effective.

The range of water savings is highly variable with this conservation technique. Reductions of from 0 to 100 percent could result depending on the combination of strategies used. Social and psychological factors have been stated as the overriding determinants of the success of horticultural change methods (Flack, 1976).

J. PRICING

In the past, water prices have been set to generate sufficient revenue to cover costs of adequate service to a utility's customers. Declining block rates have been used extensively, by supplying water at lower unit prices for large water users than for smaller water users. The concept of using price as a means of modifying consumer demand has evolved. The National Water Commission recognized water as a scarce resource and called for the shifting of water to its most productive uses through the application of water pricing policies (National Water Commission, 1973, p. 247). Price elasticity is an important concept in water pricing policy. The price elasticity is defined as the change in demand resulting from a change in price. Numerous articles and reports have been written about the pricing of water. A brief examination of some of the basic concepts of pricing are presented here.

1. Economics

Water, as a commodity, follows the laws of economics. The basic mechanism of pricing is that the more units consumed of a commodity, the less valuable is the last unit consumed (Clark and Goddard, 1974, p. 1). Simply stated, the greater the amount of water used the less the last unit is valued. As price is increased, consumption should decrease.

The cost to supply water varies with time and space. Summer demands are usually greater than winter demands and the short term marginal costs involved are usually, but not always, higher. Increased distribution distance also increases both the capital and operating costs of water supply. These factors combine to give the municipal utility peak load problems. Typically the utility has set prices uniformly throughout the year when in actuality the costs of production vary. This practice is a type of price discrimination against those winter users that don't use the same service percentages in the summer as others do (Clark and Goddard, 1974, p. 6).

2. Effects of Pricing

Studies by Grima and Howe and Linaweaver reported that price increases resulted in more savings in lawn sprinkling use than in household use (Grima, 1972; Howe and Linaweaver, 1967). The price elasticity has been found to be greater for sprinkling usage than for in-house usage by several authors, although there is some disagreement over the specific values (Burns et al, 1975; Howe and Linaweaver, 1977). Thus, it appears that residential water price increases will reduce exterior uses more than interior uses.

A study of 14 Mississippi cities indicated that water price increases had little effect on water use (Primeaux and Hollman, 1974, p. 12-138). In that study it was concluded that with the current range of prices, price is a good revenue raising device but is ineffective in curbing consumption. A study done in the Washington, D.C. area showed that price increases have a temporary effect on water use (Chiogioji and Chiogioju, 1973). The authors recommended the use of an increasing block schedule in winter and a peak load surcharge during summer as a means of reducing demand.

3. Peak Demand Pricing

Peak demand pricing is a pricing scheme addressed at alleviating inequities in pricing. Through peak demand pricing a higher charge per volume of water during peak demands periods is imposed (Flack, 1976, p. 4). The basis of this type of structure is the use of water in the winter months as the basic allotment and the charging of higher rates for water use above this amount in the summer. In this way the peak demand rates concentrate on the irrigation component of use, which is the component most sensitive to price changes.

A case study of Victoria, British Columbia found that an 18 percent increase in off-peak demand and a 6 percent decrease in peak demand would result from seasonal pricing (Sewell and Roueche, 1974). Hanke and Davis reported similar results with an 8.3 percent decrease in peak demand and a 2.6 percent decrease in total demand (Hanke and Davis, 1974). Roussos calculated a 10 percent reduction in overall consumption for the Denver water utility through peak demand pricing (Roussos, 1976). A summer surcharge allows for more efficient use and cost allocation and it distributes the costs equitably (Boland et al., 1975, p. 5).

4. Inclining Block Rates

Another type of alternative pricing scheme is the inclining block rate. This type of pricing structure is the reverse of the declining block rate in that unit water prices increase with consumption. It holds great potential as a water conservation method. However, this structure has some problems such as excess revenue generation and the fact that it is politically unfavorable. Roussos found that reductions in consumption could approach 10 percent for residential customers in Denver using this type of pricing schedule (Roussos, 1976). The inclining rate structure has been employed in only a few instances and usually only where water shortages exist (North Marin County, 1976).

5. Examples

Many utilities are examining the use of these and other types of rate structures but currently there are only a few that have been instituted. Fairfax County in Virginia has implemented a summer peak demand charge on its water users. A surcharge of $2.00 per 1000 gallons for all usage in excess of 1.3 times the customer's winter use has been set. This rate has been devised to reduce the peak usage during the summer months and thus delay system capacity expansions.

Masonville, Colorado has adopted an inclining block rate structure (Brauer et al., 1976). A billing rate charging increasing amounts for volume above 15,000 gallons per month is in effect. This pricing scheme in conjunction with a restriction of no outside lawn watering has kept per capita water consumptions below 70 gallons per day for the last two years.

K. PUBLIC EDUCATION

Public education is a necessary part of any conservation program. The consumer must first be made aware of water waste and then of the means to reduce this waste. Most consumers give little thought to their water use habits. Only in times of shortage do they examine the ways in which they utilize water. This attitude has, in part, been fostered by the water utility managers. Their perceived function has been to supply water and leave consumption alone. As a result many utility managers have resisted the idea of conservation measures (McLeod, 1976). There have been a number of approaches toward public information programs by various water utilities. Probably the best known of these has been conducted by the Washington Sanitary Suburban Commission (WSSC, 1974).

1. The WSSC Program

Since 1971, WSSC has instituted a public education program in an effort to reduce sewage flows (WSSC, 1974). Through the program, handbooks on water conserving techniques for the household and for the lawn and garden have been developed. Water-saving workshops directed at apartment managers have been conducted. Film and slide programs, as well as television announcements, have been instituted (Brigham, 1976). Possibly the most encompassing facet of WSSC's education program has been the mass distribution of "Bottle Kits" containing water saving devices and educational material to over 215,000 of its customers. In addition, school education programs have been established.

2. The EBMUD Program

Another noteworthy public education program has been instituted by the East Bay Municipal Utility District (EBMUD, 1972). Public information booklets on water conservation have been prepared and are distributed upon request. Public relations material has been issued in the form of buttons, stickers and posters in an effort to gain public attention and acceptance of water conservation. An extensive program to educate children in the means of conserving water has been adopted. Visual and printed material has been developed for just this purpose.

The costs and effectiveness of these programs are difficult to measure and probably are in long-term future benefits through development of a conservation ethic.

3. Other Education Programs

Education programs have been adopted in other major cities and couties such as Denver, Colorado and Marin County, California. The programs established in these locales generally have the same elements as the two mentioned above. One important note should be added. Very few of the smaller utilities, which in many cases have the most severe water supply problems, have developed and adopted consumer education programs in water conservation.

CHAPTER III

ASSESSMENT OF CONSERVATION METHODS

In this chapter, the potential of water conservation alternatives and some of their possible implementation problems will be discussed. Each alternative is assessed with regard to its technological capabilities, economic consequences and socio-political impacts. In addition, the effects on return flows are estimated. A brief discussion of the benefits of water conservation alternatives on the design and operation of water and wastewater utility systems follows the analysis of these methods.

To facilitate discussion of the alternatives it was necessary to assume a set of baseline water use conditions. As mentioned in Chapter I and II, there is a wide range of water use in residential areas. The baseline of water uses was established by examining the most generally accepted estimates of water usage. This baseline was used as the starting point for the calculation of water savings by the various conservation alternatives. The values derived represent the savings that would be obtained for average water use. Actual water savings and related benefits and costs would vary from this average.

A. BASELINE CONDITIONS

It is necessary to establish certain household characteristics, water use and the amount of return flow in order to estimate the effectiveness of each water conservation alternative. A discussion of these factors follows.

1. <u>Household Characteristics</u>

A family size of four per dwelling unit was assumed in the calculations. The number of bathrooms per household was taken as two. Because the effects of metering were to be assessed, an assumption of mixed unmetered and metered residential water customers, similar to Denver, Colorado, was made. The unmetered users were assumed to be located on smaller and older lots compared with metered residential users. The average lawn area was assumed to be 5400 square feet for unmetered residences and 8700 square feet for metered residences, based on estimates made for the city of Denver in 1973 (Bryson, 1973). All other occupant characteristics such as length of residency, age and education were taken as constant or not influential on water use.

2. <u>Water Use Characteristics</u>

Residential usage was categorized on the basis of whether an area was metered or flat-rate. Metered usage was designated according to the combined price of water and wastewater service to the consumer. Representative metered use, based on the Denver area, was taken as 128 gpcd for areas with moderate prices ($0.50/1000 gal) for water and wastewater; and 149 gpcd for areas with low prices ($0.20/1000 gal) for water and wastewater. Unmetered area use was taken to be approximately 35 percent greater than the moderately priced metered water use or 172 gpcd. The ratio of maximum day to average day water use was 3.4 for unmetered areas and 2.1 for metered areas. The ratio of peak hour to average day water use was assumed to be 6.7 for unmetered areas and 5.3 for metered areas (Green, 1972). Inside-the-home and outside-the-home average day water usages were assumed to be about equal for metered areas with moderately priced water and wastewater. Unmetered areas were estimated to use approximately 63 percent of their water for lawn watering.

Domestic Water Use. Each household water use function was assigned a daily per capita usage based on the mean values presented in Table 3. Table 8 shows these amounts. Domestic use was considered to be the same in both metered and unmetered areas.

Sprinkling Water Use. Sprinkling use was taken as a variable component in metered areas based on water price. For moderately priced areas it was assumed to be one-half of the total water use or 64 gpcd. The average annual applied depth was calculated to be 1.43 feet for these areas. For metered areas with low water and wastewater prices the assumed lawn sprinkling component was taken to be equal to the potential evapotranspiration rate. This rate was found to be 2.2 feet of applied lawn water or 85 gpcd, based on lot sizes for the city of Denver for the years 1969 to 1972 (Bryson, 1973). The applied depth of water in unmetered areas was taken as 3.9 feet or 108 gpcd (Bryson, 1973).

TABLE 8

BASELINE DOMESTIC WATER USE (Metered and Flat Rate)

WATER USE FUNCTION	AVERAGE USE (gpcd)	BASELINE USE (gpcd)	TOTAL USE %
Water Closet	24.7	25.0	40
Bath/Shower	18.4	20.0	30
Lavatory Sink	3.2	3.0	5
Laundry	9.6	10.0	15
Dishwashing	3.2	3.0	5
Drinking/Cooking	3.0	3.0	5
Total	62.0	64.0	100

Validity of these Estimates. These estimates are average figures designed to give an indication of the relative magnitude of residential water use in the West. As noted earlier the specific use figures vary widely. Estimates of family size in a community range from two to six. The average residential irrigable acreage is largely unknown with a possible range in size from none to over an acre. Per capita usage amounts vary with family size and thus the average household figures assumed are not applicable to all situations. Variations of from 60 to 300 gpcd were encountered in one study and these figures reflect the tremendous effect of community differences on possible water savings (Brauer et al., 1976). Ranges in domestic use were pointed out in Table 3. Even larger ranges in use exist in the sprinkling component. Each estimate of water use used here attempts to typify an average residential condition in the western United States.

3. Return Flows

The amount of return flow was assumed to be sum of the lawn sprinkling use not consumptively used and the domestic use less the amount used for drinking and cooking. Only rough estimates of the amount of decreased return flow due to water savings were attempted.

B. ASSESSMENT OF THE ALTERNATIVES

Each conservation method is examined in this section. The technologic feasibility as well as the economic feasibility of implementing that alternative were analyzed. The mechanical methods of water conservation allowed economic comparison on the basis of cost effectiveness. Economic evaluation of the other methods was hampered by insufficient knowledge of the specific costs involved or a lack of verification concerning the amount of water savings. Social attitudes and political considerations regarding the acceptance of conservation measures are also discussed.

1. Water Saving Devices

Many business concerns currently market water saving devices. A postal survey of over 100 of these manufacturers was made in order to ascertain the costs and capabilities of their products. Appendix A presents a portion of the survey results. The devices are categorized by the method of water use reduction that they employ and representative costs are listed. It was evident from the survey that wide differences in costs and water saving amounts are reported by the manufacturers. In addition, many of the devices surveyed had not been tested independently to determine their actual performance. As a result manufacturers' claims had to be used where no tests or studies had been made.

Technological Feasibility. Water saving devices attempt to decrease the amounts of water used in household functions without inconveniencing the user. The devices currently available represent different stages of technological advancement. The two critical factors in evaluating the technological feasibility of a device are whether the water saving ability of the device is consistent and whether the water use function is adequately performed. In addition, any possible affect on the drainage system of the household and the community must be taken into account.

Toilets. The types of water-saving toilets on the market range from simple volume displacement devices to sophisticated complete treatment systems. The easiest way to reduce the flushing volume of an in-place toilet is through the placement of objects that occupy space within the toilet tank. The brick-in-the-tank is the embodiment of this practice. Technologically the brick will accomplish its purpose of flush reduction, but may decompose in time. The use of plastic bottles filled with water and a weighting material is proposed as a solution to the problem of brick decomposition. Both of these volume reducers adequately reduce toilet flush volume and can be utilized where enough space in the toilet tank is present to prevent interference with the moving parts of the toilet.

Table A-2 lists several manufacturers of slightly more sophisticated volume reduction devices. The toilet dam devices save greater amounts of water than the simple displacement devices and are fully developed technologically. These devices require proper installation with attention to the placement of the dams. The WSSC program, mentioned in Chapter II, found that follow-up adjustments were necessary in many cases to ensure satisfactory performance and avoid double-flushing. When properly installed the damming devices save water and adequately clear solids.

Dual flush devices modify toilet use by reducing the volume of water used for flushing liquid wastes as compared with solids. More moving mechanical parts are involved in the dual flush mechanism and thus increased chance for failure is introduced. The dual flush devices appear to be fully developed and technologically sound. The dual flush device and the other volume reduction devices discussed here are primarily applicable to a retrofitting situation where the existing toilet is modified.

Other toilet systems on the market are designed to replace the existing conventional toilet. These systems range from modifications in the design of conventional toilets to entirely new concepts for waste transport. The shallow trap toilet and the air pressure toilet are two water saving adaptations of conventional toilets. The shallow trap toilet is fully developed and technologically fulfills its purpose of waste disposal. The air pressure toilet utilizes the pressure of the water supply line to compress air in the toilet tank. It uses less water than the shallow trap toilet by employing the increased tank pressure for rinsing action. Solids carry away has been shown to be adequate for water closet flush volumes of 3.5 gallons or more (Cole, 1975). Table A-1 shows that the shallow trap toilets generally are of a size allowing for the 3.5 gallon limit, but the air pressure toilet uses approximately 2.5 gallons per flush (depending on the supply line pressure). A critical consideration in the installation of these toilets would, thus, seem to be the location of the toilet in relation to the rest of the household water using fixtures. A location where the toilet is to be placed on the end of a sewer line having a small slope might preclude the installation of an air pressure toilet or at least require some provision for periodically flushing the line.

The location of households with low volume toilets may pose drainage problems in the sewer system. Sewer lines in relatively flat areas and especially at the upper ends of the collection system may experience solids deposition due to inadequate flushing flows.

Most of the special toilet systems that are currently available are applicable to specific situations where either water is in short supply or wastewater disposal is a problem. Table A-3 lists some of the commercially available systems and the quantities of water they save over regular toilets. The systems generally appear to be technologically feasible as far as the water they save, but other operating problems have not been satisfactorily solved. Many of the systems need auxillary means for ultimate disposal causing a concern for possible health problems. Provision of a separate grey-water system is necessary for all of the special toilet systems. A number of the systems are quite complex and require greater-than-normal maintenance and repair. Most of the systems require special approval by regulatory agencies before installation.

There are essentially three types of special toilet systems on the market. The chemical or oil recycling toilet is one of these systems. This type of system uses mineral oil as the transport medium for waste disposal.

A quiescent holding tank allows for separation of waste materials from the oil. The oil recycle system is technologically feasible in design. Ultimate disposal, high maintenance costs and its reliance on a power source makes the system inadvisable except under special circumstances. Another type of special system, the vacuum transport system, utilizes small amounts of water in conjunction with a vacuum pump to transport wastes. Hookup with a conventional gravity flow sewer solves the problem of ultimate disposal, but the problem of mechanical parts failure and failure due to power interruptions remains unsolved. Possibly the least complicated of the special systems is the composter toilet. The composter toilet operates with no additional input other than the waste itself. Organic stabilization of the waste products by using them as a soil conditioner in land disposal makes this type of toilet system technically feasible. Venting of the anaerobically produced gases allows the composter toilet to function without unfavorable odors. Composter toilet systems have been used with success in Europe and Canada (Lindstrom, 1974). Special authorization is currently needed for installation of the composter system in the United States. This type of system seems to be technologically feasible with the only possible problem being assurance that the end product is biologically safe.

Showers and Faucets. Flow limiting shower heads and valves operate by restricting the flow of water through the shower head. The flow restricting orifices that operate in these devices are fully developed. The water savings vary in accordance with supply line pressures. Flow limiting shower heads are designed for replacement installation, whereas valves are suited to insertion within existing shower heads.

Faucet flow controls restrict the passage of water in the same manner as the shower control devices. Aerators and spray taps save water in rinsing activities in the sink. Both the aerator and spray tap are fully developed and completely adaptable to most conventional plumbing. The temperature mixing valve cuts down on water wastage. These mixing valves have been developed to operate within a wide range of supply line pressures and have been demonstrated to be consistent in their temperature control (Milne, 1976).

Washers. The suds saver option and the water level control on automatic clothes washers have been demonstrated to save water. The technological feasibility of both of these devices is positive. Provision of a holding tank for the wash water of the suds saver option is necessary for most of the available models. The water level control is designed to give the user a range of water use in accordance with the amount of clothes to be washed. Little work has been done on water-saving dishwasher models. A recent development for this appliance has been the introduction of low energy use models which utilize less hot water than conventional models.

The technological feasibility of water-saving devices is positive. Many water saving alternatives have been conceived and put into practice. The number of available water saving devices is increasing each year. New innovations and improvements in old designs are appearing with increasing frequency. Further perfection of some existing water fixtures and appliances appears to be imminent, thus improving the technological capability of these devices to save water.

Effectiveness. The cost effectiveness of water saving toilet systems, faucet aerators and shower control devices is presented in this section. A lack of available cost data on the other plumbing fixtures and appliances prevented a similar analysis for them. A wide range of water saving capabilities and equipment costs was found to exist among different models of water saving devices. The cost of the equipment used for the determination of a device's cost effectiveness was obtained from the manufacturers' literature. The cost of installation of the devices was determined through a poll of several plumbers' hourly fees and the time they estimated for installation. The life of each device was estimated on the basis of a 25 year economic life. These costs and other assumed variables are tabulated in Appendix B. Tables 9 and 10 show the water saving and cost characteristics of each water saving device. Each household savings calculation is based upon the baseline data presented in earlier sections. The actual water savings for each type of device is highly dependent on water user habits and the condition of the plumbing system.

Each device listed in Tables 9 and 10 was evaluated as to its cost effectiveness to the consumer. An example of the type of analysis made is presented in Appendix B. Three discount rates - five, eight and ten percent - were used to determine the effect, if any, on cost effectiveness. Table 11 shows the breakeven price for water and wastewater service for the installation of water-saving toilets in new residences. The air pressure toilet has a breakeven price of less than 10 cents per thousand gallons and is the best toilet alternative on an economic basis. The shallow trap toilet costs a little more than the conventional toilet, but saves almost 11,000 gallons a year. The breakeven price at even the highest interest rate was at the low total service charge of $0.12/1000 gallons. The price of the shallow trap is decreasing, and in the near future will probably become cost effective at all water service charges. The air pressure toilet initially costs the same as the regular toilet. The only increase in annual costs of this type of toilet is due to higher annual maintenance costs. The oil recycle toilet is not cost effective except at extremely high prices of water and wastewater treatment because of its high initial costs, short life and high annual operation and maintenance costs.

TABLE 9

WATER USE CHARACTERISTICS OF DEVICES

Type of Device	Water Use Per Unit	Daily Per Capita Water Use	Water Savings Per Household Per Year
Regular Toilet	5.0 gal/flush	25.0	-
Shallow Trap Toilet	3.5 gal/flush	17.5	10,950 gallons
Air Pressure Toilet	2.5 gal/flush	12.5	18,250 gallons
Oil Recycle Toilet	0.0 gal/flush	0.0	36,500 gallons
Dual Flush Device	2.5-5.0 gal/flush	18.75	9,125 gallons
Water Closet Dams	4.0 gal/flush	20.0	7,300 gallons
Plastic Bottles	4.5 gal/flush	22.5	3.650 gallons
Regular Faucet	5.0 g.p.m.	6.0	-
Faucet Aerator	2.5 g.p.m.	2.5	3,650 gallons
Regular Shower Head	5.0 g.p.m.	20.0	-
Reduced Flow Shower Head	3.0 g.p.m.	12.0	11,680 gallons
Flow Reducing Shower Valve	3.0 g.p.m.	12.0	11,680 gallons

TABLE 10

ECONOMIC CHARACTERISTICS OF DEVICES

Type of Device	Installed Cost	Operation-Maintenance Costs	Salvage Value	Life (Years)
Regular Toilet	$ 91.50	$5.00 every 5 yrs	$30	25
Shallow Trap Toilet	97.58	5.00 every 5 yrs	30	25
Air Pressure Toilet	91.50	10.00 every 5 yrs	30	25
Oil Recycle Toilet	3,051.50	40.00 per year	150	15
Dual Flush Device	4.50	2.00 per 15 yrs	0	15
Water Closet Dams	4.39	0	0	25
Plastic Bottles	.15	0	0	25
Regular Faucet	20.15	0	0	15
Faucet Aerator	2.00	0	0	15
Regular Shower Head	20.15	0	0	15
Reduced Flow Shower Head	25.15	0	0	15
Flow Reducing Shower Value	1.50	0	0	15

TABLE 11

NEW INSTALLATION BREAKEVEN WATER SERVICE PRICES FOR WATER-SAVING TOILETS AT VARIOUS DISCOUNT RATES

Type of Toilet	Annual Costs Per Toilet			Increased Annual Costs (Over 15 Yrs)			Breakeven Water and Wastewater Price[a] ($/1000 g.)		
	i=5%	i=8%	i=10%	i=5%	i=8%	i=10%	i=5%	i=8%	i=10%
Regular Toilet	$6.66	$8.94	$10.54	-	-	-	-	-	-
Shallow Trap	7.08	9.51	11.21	$0.42	$0.57	$0.67	0.07	0.10	0.12
Air Pressure	7.46	9.65	11.31	0.80	0.71	0.77	0.08	0.07	0.08
Oil Recycle	265.13	323.76	374.13	258.47	314.82	363.59	7.09	8.62	9.96

[a]Breakeven price based on two toilets per household except for oil recycle which is only one per household.

Table 12 gives the necessary price of water and wastewater service to just offset the increased annual costs of the shallow trap and air pressure toilets in a retrofit situation. For this calculation it was assumed that the existing toilets had fifteen years life left. Thus, the calculations made are conservative for retrofitting older toilets and somewhat understated for retrofitting newer toilets. As is evident, both types of toilets have breakeven water costs much higher than in new installations. It appears that retrofitting 10 year old toilets becomes cost effective at moderately high (∿$1.00/1000 gal) water and wastewater service costs and is dependent on the discount rate. The oil recycle toilet in retrofit circumstances would have a breakeven price well above the possible range of water service charges. The flow reducing shower head was found to be cost effective in retrofit situations at a water and wastewater price of 28 cents per 1000 gallons at a discount rate of 10 percent.

Table 13 depicts the breakeven prices of water and wastewater service for new toilet, faucet and shower devices. The breakeven price for all of the devices was found to be less than 15 cents a thousand gallons. These breakeven prices consider only the dollar savings due to decreased water use. Additional savings due to the decreased energy consumption caused by some of these devices is discussed in a later section.

Table 14 shows the necessary amount of time for the devices to pay for themselves at various water and wastewater prices. All the devices except the oil recycle toilet pay for themselves within four years of their installation date.

Tables 15, 16, 17, 18, and 19 illustrate the possible annual savings in expenditures for water and wastewater service by water-saving devices for various prices of water services in new installations. At 40 cents per 1000 gallons the maximum savings is approximately $6.00.

TABLE 12

RETROFIT COSTS AND BREAKEVEN PRICES FOR WATER-SAVING TOILETS AT VARIOUS DISCOUNT RATES*

Type of Toilet	Annual Costs Per Toilet			Increased Annual Costs (Over 15 Yrs)			Breakeven Water and Wastewater Price[a] ($/1000 g.)		
	i=5%	i=8%	i=10%	i=5%	i=8%	i=10%	i=5%	i=8%	i=10%
Regular Toilet	$6.66	$8.94	$10.54	-	-	-	-	-	-
Shallow Trap	9.08	11.46	13.05	$5.35	$6.79	$7.77	0.98	1.24	1.42
Air Pressure	9.39	11.96	13.35	6.04	7.59	8.70	0.66	0.83	0.95

[a]Breakeven price based on two toilets per household.

*Retrofit to take place when existing toilet age = 10 years.

TABLE 13

NEW INSTALLATION BREAKEVEN PRICES FOR TOILET, FAUCET AND SHOWER DEVICES AT VARIOUS DISCOUNT RATES

Type of Device	Annual Costs Per Toilet			Increased Annual Costs (Over 15 Yrs)			Breakeven Water and Wastewater Price[a] ($/1000 g.)		
	i=5%	i=8%	i=10%	i=5%	i=8%	i=10%	i=5%	i=8%	i=10%
Regular Toilet	$6.66	$8.94	$10.54	-	-	-	-	-	-
Dual Flush Device	6.99	9.37	11.04	$0.33	$0.43	$0.50	.07	.09	.10
Water Dams	6.97	9.35	11.02	0.31	0.41	0.48	.08	.11	.13
Plastic Bottles	6.67	8.95	10.56	0.01	0.01	0.02	.005	.005	.01
Regular Faucet	1.46	1.93	2.27	-	-	-	-	-	-
Faucet Aerator	1.60	2.12	2.49	0.14	0.19	0.22	.07	.10	.12
Regular Shower Head	1.46	1.93	2.27	-	-	-	-	-	-
Reducing Shower Head	1.82	2.29	2.83	0.36	0.47	0.56	.06	.08	.09
Reducing Shower Valve	1.57	2.06	2.41	0.11	0.13	0.14	.01	.02	.02

[a]Breakeven price based on two units per household.

TABLE 14

TIME FOR DEVICES TO BECOME EFFECTIVE AT i=10% FOR
VARIOUS WATER AND WASTEWATER PRICES

Type of Device	Average Water and Wastewater Price ($/1000 gal)			
	$0.40	$0.60	$0.80	$1.20
Shallow Trap Toilet	3.5 years	2.2 years	1.75 years	1.1 years
Air Pressure Toilet	Immediately	Immediately	Immediately	Immediately
Oil Recycle Toilet	>100 years	>100 years	>100 years	>100 years
Dual Flush Device	2.9 years	1.9 years	1.5 years	1 year
Water Dams	2.8 years	2.4 years	1.8 years	1.2 years
Plastic Bottles	<1 year	<1 year	<1 year	<1 year
Faucet Aerators	2.8 years	1.8 years	1.4 years	<1 year
Reduced Flow Shower Head	2.6 years	1.8 years	1.3 years	<1 year
Shower Reducing Valve	2.0 years	1.4 years	<1 year	<1 year

TABLE 15

NET ANNUAL SAVINGS FOR DEVICES IN NEW INSTALLATION AT WATER PRICE OF $0.40/1000 GAL.

Type of Device	Annual Savings in Water and Wastewater Costs ($)	Increased Annual Costs For Two Devices ($)		Net Annual Savings ($)	
		i=5%	i=10%	i=5%	i=10%
Shallow Trap Toilet	4.38	0.86	1.34	3.52	3.04
Air Pressure Toilet	7.30	1.00	1.00	6.30	6.30
Dual Flush Device	3.65	0.66	1.01	2.99	2.64
Water Dams	2.92	0.62	0.97	2.30	1.95
Plastic Bottles	1.46	0.02	0.03	1.44	1.43
Faucet Aerator	1.46	0.29	0.45	1.17	1.01
Reducing Shower Head	4.67	0.72	1.12	3.95	3.55
Reducing Shower Valve	4.67	0.22	0.35	4.45	4.33

TABLE 16

NET ANNUAL SAVINGS FOR DEVICES IN NEW INSTALLATIONS
AT WATER PRICE OF $0.60/1000 GAL.

Type of Device	Annual Savings in Water and Wastewater Costs ($)	Increased Annual Costs For Two Devices ($)		Net Annual Savings ($)	
		i=5%	i=10%	i=5%	i=10%
Shallow Trap Toilet	6.57	0.86	1.34	5.71	5.23
Air Pressure Toilet	10.95	1.00	1.00	9.95	9.95
Dual Flush Device	5.47	0.66	1.01	4.82	4.47
Water Dams	4.38	0.62	0.97	3.76	3.41
Plastic Bottles	2.19	0.02	0.03	2.17	2.16
Faucet Aerator	2.19	0.29	0.45	1.90	1.74
Reducing Shower Head	7.01	0.72	1.12	6.28	5.88
Reducing Shower Valve	7.01	0.22	0.35	6.78	6.66

TABLE 17

NET ANNUAL SAVINGS FOR DEVICES IN NEW INSTALLATIONS
AT WATER PRICE OF $0.80/1000 GAL.

Type of Device	Annual Savings in Water and Wastewater Costs ($)	Increased Annual Costs For Two Devices ($)		Net Annual Savings ($)	
		i=5%	i=10%	i=5%	i=10%
Shallow Trap Toilet	8.76	0.86	1.34	7.90	7.42
Air Pressure Toilet	14.60	1.00	1.00	13.60	13.60
Dual Flush Device	7.30	0.66	1.01	6.64	6.29
Water Dams	5.84	0.62	0.97	5.22	4.87
Plastic Bottles	2.92	0.02	0.03	2.90	2.89
Faucet Aerator	2.92	0.29	0.45	2.63	2.47
Reducing Shower Head	9.34	0.72	1.12	8.62	8.22
Reducing Shower Valve	9.34	0.22	0.35	9.12	9.69

TABLE 18

NET ANNUAL SAVINGS FOR DEVICES IN NEW INSTALLATIONS
AT WATER PRICE OF $1.20/1000 GAL.

Type of Device	Annual Savings in Water and Wastewater Costs ($)	Increased Annual Costs For Two Devices ($)		Net Annual Savings ($)	
		i=5%	i=10%	i=5%	i=10%
Shallow Trap Toilet	13.14	0.86	1.34	12.28	11.80
Air Pressure Toilet	21.90	1.00	1.00	20.90	20.90
Dual Flush Device	10.95	0.66	1.01	10.29	9.94
Water Dams	8.76	0.62	0.97	8.14	7.79
Plastic Bottles	4.38	0.02	0.03	4.36	4.35
Faucet Aerator	4.38	0.29	0.45	4.09	3.93
Reducing Shower Head	14.02	0.72	1.12	13.30	12.90
Reducing Shower Valve	14.02	0.22	0.35	13.80	13.67

TABLE 19

NET ANNUAL SAVINGS FOR DEVICES IN NEW INSTALLATIONS
AT WATER PRICE OF $2.00/1000 GAL.

Type of Device	Annual Savings in Water and Wastewater Costs ($)	Increased Annual Costs For Two Devices ($)		Net Annual Savings ($)	
		i=5%	i=10%	i=5%	i=10%
Shallow Trap Toilet	21.90	0.86	1.34	21.04	20.56
Air Pressure Toilet	36.50	1.00	1.00	35.50	35.50
Dual Flush Device	18.25	0.66	1.01	17.59	17.24
Water Dams	14.60	0.62	0.97	13.98	13.63
Plastic Bottles	7.30	0.02	0.03	7.28	7.27
Faucet Aerator	7.30	0.29	0.45	7.01	6.85
Reducing Shower Head	23.36	0.72	1.12	22.64	22.24
Reducing Shower Valve	23.36	0.22	0.35	23.14	23.01

As the price of water services is increased the net annual savings gradually increase. At a service cost of $2.00 per 1000 gallons, annual savings of over $35.00 are possible because of reduced water demand.

Tables 20 and 21 show that retrofitting toilets do not save much money unless high water and wastewater prices are charged. Table 22 shows that the flow limiting shower head saves money in a retrofit situation at nearly all water service prices.

In absolute terms these savings are significant, but realistically the financial incentive to the average homeowner appears low because the cost of water services is low. Thus, the overriding incentive for each device must be socially induced. The combination of the net annual savings of several of these devices can bring about a total savings from about $11.00 per year to over $65.00 per year. To the average homeowner this level of annual savings, accompanied by knowledge that a natural resource is being conserved, may be sufficient inducement for adoption of the devices.

Low water using clothes washers and dishwashers for new installations are cost effective. However, the primary influence on the selection of these appliances appears to be related to customer convenience and preference. The water saving models are generally only slightly higher in price than conventional models.

Household Energy Savings. Energy for hot water heating would be reduced with some of the water saving devices. Difficulty in determining the dollar amount of energy savings stems from the fact that temperature control, system heat losses and the price of energy varies greatly. The amount of hot water used is contingent on the personal preferences of the water user. The age and general condition of the plumbing system and, especially, the hot water heater affects the amount of heat losses in transporting the water to plumbing fixtures. The cost of energy varies, whether it is electricity, gas or

TABLE 20

NET ANNUAL SAVINGS FOR RETROFITTING WITH SHALLOW TRAP TOILET
AT VARIOUS PRICES AND DISCOUNT RATES*

Price of Water ($/1000 gal)	Annual Savings in Water and Wastewater Costs ($)	Increased Annual Costs (Over 15 Yrs)		Net Annual Savings ($)	
		i=5%	i=10%	i=5%	i=10%
0.40	4.38	10.70	15.54	-6.32	-11.16
0.60	6.57	10.70	15.54	-4.13	- 8.97
0.80	8.76	10.70	15.54	-1.94	- 6.78
1.20	13.14	10.70	15.54	2.44	- 2.40
2.00	21.90	10.70	15.54	11.20	6.36

*Retrofit: Age of existing toilet = 10 years

TABLE 21

NET ANNUAL SAVINGS FOR RETROFITTING WITH AIR PRESSURE TOILET AT VARIOUS PRICES*

Price of Water ($/1000 gal)	Annual Savings in Water and Wastewater Costs ($)	Increased Annual Costs ($)		Net Annual Savings ($)	
		i=5%	i=10%	i=5%	i=10%
0.40	7.30	12.08	17.40	-4.78	-11.30
0.60	10.95	12.08	17.40	-1.13	- 6.45
0.80	14.60	12.08	17.40	2.52	- 2.80
1.20	21.90	12.08	17.40	9.82	4.50
2.00	36.50	12.08	17.40	24.42	19.10

*Retrofit: Age of existing toilet = 10 years

TABLE 22

NET ANNUAL SAVINGS FOR RETROFITTING WITH REDUCED FLOW SHOWER HEAD AT VARIOUS PRICES*

Price of Water ($/1000 gal)	Annual Savings in Water and Wastewater Costs ($)	Increased Annual Costs ($)		Net Annual Savings ($)	
		i=5%	i=10%	i=5%	i=10%
0.40	4.67	1.88	3.32	2.79	1.35
0.60	7.01	1.88	3.32	5.13	3.69
0.80	9.34	1.88	3.32	7.46	6.02
1.20	14.02	1.88	3.32	12.14	10.70
2.00	23.36	1.88	3.32	21.48	20.04

*Retrofit: Age of existing shower head = 10 years.

heating oil, from community to community. Baker and others made estimates of energy savings from using water saving shower heads, faucets and washing machines (Baker et al., 1975, pp. 71-87). Their theoretical savings showed these devices to be very cost effective. On the other hand, North Marin County estimated a savings of somewhat over $4.00 a year in power costs to each household due to installation of flow restricting shower valves (North Marin County, 1976). Reid reported on possible energy savings from reductions in water usage, hot water usage, wastewater treatment and water supply treatment for a wide variety of water savings devices and systems (Reid, 1976, pp. 92-101).

Energy savings are possible with the use of these devices, however, the variables affecting the energy consumption of water using fixtures and appliances deserves site specific and detailed study to predict accurately the amount of dollars saved due to decreased energy consumption. It is sufficient to say that energy savings are possible through the use of water saving devices and programs; and that the savings are of sufficient magnitude that energy savings should be included in the economic feasibility analysis of installing these devices or programs.

System Water Savings. The amount of water saved with low water use devices becomes significant on a community wide basis. Table 23 shows the total effects of each type of device compared to normal usage for that fixture on an per capita, individual household and for two communities - one with 2000 customers and the other with 10,000 customers. Several utilities have adopted building code amendments requiring the installation of water saving devices in new homes and in remodeling efforts. The specific code requirements are discussed in a later section. The utility may also institute a retrofitting program aimed at converting existing plumbing fixtures to lower water use. Table 24 shows

TABLE 23

WATER USE BY VARIOUS HOUSEHOLD DEVICES

Device	Per Capita gpcd	Per Household* gpd/du	Per Household* gal/yr	Utility Size, Number of Households: 2000 (million gal./yr.)	Utility Size, Number of Households: 10,000 (million gal./yr.)
Regular Toilet	25.0	100.0	36,500	73	365
Plastic Bottles	22.5	90.0	32,850	65.7	328.5
Water Dams	20.0	80.0	29,200	58.4	292
Dual Flush	18.75	75.0	27,375	54.8	273
Shallow Trap Toilet	17.5	70.0	25,550	51.1	255
Air Pressure Toilet	12.5	50.0	18,250	36.5	182
Regular Faucet	6.0	24.0	8,760	17.5	87.6
Aerated Faucet	3.5	14.0	5,110	10.2	51.1
Regular Shower Head	20.0	80.0	29,200	58.4	292
Reduced Flow Shower	12.0	48.0	17,520	35.0	175

* Assumes 4 persons per household

TABLE 24

WATER SAVINGS BY HOUSEHOLD CONSERVATION PROGRAMS - IN HOUSE

Program	Gallons per Year per Household	Water Used Or Saved Number of Households 2000	 10,000 millions of gals per yr
Baseline			
Regular Toilet	36,500	73	365
Regular Faucet	8,760	17.5	87.6
Regular Shower	29,200	58.4	292
Total	74,460	148.9	744.6
Bldg. Code Plan 1			
Shallow Trap Toilet	25,500	51.1	255
Reduced Flow Shower	17,520	35.0	175
Faucet Aerators	5,110	10.2	51.1
Total	48,180	96.3	481.1
Savings Over Baseline	26,280	52.6	263.5
Bldg. Code Plan 2			
Air Pressure Toilet	18,250	36.5	182
Reduced Flow Shower	17,520	35.0	175
Faucet Aerators	5,110	10.2	51.1
Total	40,880	81.7	408.1
Savings Over Baseline	33,580	67.2	336.5
Retrofit Plan 1			
Plastic Bottles	32,850	65.7	328.5
Shower Reducing Flow	17,520	35.0	175
Faucet Aerators	5,110	10.2	51.1
Total	55,480	110.9	554.6
Savings Over Baseline	18,980	38.0	190.0
Retrofit Plan 2			
Water Dams	29,200	58.4	292
Reduced Flow Shower	17,520	35.0	175
Faucet Aerators	5,110	10.2	51.1
Total	51,830	103.6	518.1
Savings Over Baseline	22,630	45.3	226.5

Bldg. Code Plan 1	35% savings over Baseline
Bldg. Code Plan 2	45%
Retrofit Plan 1	25%
Retrofit Plan 2	30%

the relationship among two water system retrofitting plans and two building codes modifications and the expected water conserved per household and for utilities with 2000 and 10,000 customers.

Retrofitting Plan 1 incorporates the distribution of plastic water bottles and shower flow reducing valves to a utility's customers. The cost of the materials and the distribution of this material by either volunteer groups or on a request basis can be accomplished for under $2.00 per customer (North Marin County, 1976; WSSC, 1974). A utility with 2000 customers could save over 100,000 gallons per day or nearly 40 million gallons per year.

A survey of Denver area municipalities found that the utility costs of water production ranged from approximately five cents per 1000 gallons to well over 20 cents per 1000 gallons. Using this cost range for the same customer size, annual total water production costs could be reduced by $1,400 to $5,600. The cost of installation in 2000 residences would be about $4,000. Depending on the cost of the utility's water production, the devices would pay for themselves over a period of less than a year to slightly over 3 years. Decreased revenue, however, could necessitate raising the price of water. The increase in charges would be dependent on what portion of current revenues were being allocated for future resource development and system expansion (which would be deferred into the future with the water saving plan implementation).

Retrofitting Plan 2 calls for the installation of toilet dams, plastic flow limiting shower heads and faucet aerators. The materials could be purchased on a bulk basis for less than $5.00 per customer. The water savings under Plan 2 for 2000 customers would amount to 124,000 gallons a day. The initial cost of such a program would be $10,000 and would pay off within four years.

Building Code Plan 1 calls for shallow trap toilets, flow limiting shower heads and faucet aerators in new installations and as replacements for worn out equipment by legal mandate. The cost for these items to the individual homeowner would be approximately $20.00. The rate of implementation of this type of plan would be dependent on the rate of growth of the municipality. Water saved using this plan could total over 52 million gallons per year for a customer population of 2000. Similarly, Building Code Plan 2 calls for the same fixtures except a substitution of the air pressure toilet for the shallow trap toilet. This modification assumes that the air pressure toilet discharges enough flushing water to prevent solids deposits in receiving sewer lines. With the institution of these code requirements a utility servicing 2000 residences could save at least $3,300 a year in water production costs.

The overall water savings to the utility using these devices will vary directly with the number of customers that actually install and use the devices. Public education programs can markedly affect the percentage of water customers that utilize the devices. A survey of one utility that made Retrofitting Plan 1 available to its customers showed that over 40 percent of those polled were using the flow limiting shower heads and over 60 percent were using the toilet tank displacement bottles (Rogers, 1977). It must be remembered that the estimated savings are for a specific household water use rate. Variations in the amount of domestic water use per household will yield different water savings. Changes in a customer's attitude may also change the amount of savings for a water use function. For instance, a consumer may lengthen his daily shower after installation of a flow reducing shower head thinking that the flow decrease more than compensates for his lengthened usage. Public education programs are necessary to bring about the proper awareness.

Social and Political Acceptability. The social acceptance of water saving devices is generally positive. Those devices which do not inconvenience the user and do not offend his senses are readily accepted. The faucet aerator, spray tap and mixing valve are considered a convenience. Water saving toilets do not cause customer inconvenience if properly maintained. Other toilet devices such as the dual flush and the plastic tank dams may cause some inconvenience either through their design or in their performance. The water saving dishwashers and clothes washers have a neutral sort of acceptability to most water users. The inconvenience of resetting controls seems to be weighed against the saving of water in these machines. Personal bathing habits may dictate whether the flow limiting shower head delivers enough water.

The least socially acceptable water saving devices are the special toilet systems. The vacuum transport system appears to be quite acceptable, but oil recycle systems, composter toilets and other variations such as the incinerator and freeze toilets are not acceptable to much of the public. The incinerator, freeze and packaging toilets are inconvenient to the consumer and have a low acceptability. The special toilet systems are most acceptable in those situations where either or both water supply and wastewater disposal are a problem and the residents opt for these systems to maintain their living location.

The political feasibility of implementing these devices appears to be favorable. The political costs of changing building codes to require the devices are minimal and short term. The political costs of implementing a device distribution program appear to be somewhat higher in that some positive proof of actual water savings must be shown to the customers both before and after a program is put into effect.

Return Flow Implications. Return flows originating from wastewater treatment facilities will decrease in proportion to the amount of water use decrease accomplished by in-home water saving devices. Decreases in return flows of from 17 to 36 percent could occur. The negative effects on downstream water users could be mitigated by augmenting surface flows with raw water storage during low flow periods.

Methods of Implementation-Assessment. The most probable means of gaining widespread use of water saving devices is through the use of building code modifications and utility distribution programs. The use of building codes places the burden of cost on the customers, while in utility programs the utility initially bears the cost. In either case water prices to the consumer may have to be raised to compensate for reduced revenues. Price increases caused by such action or instituted due to other reasons, could in turn make the homeowner install more water saving devices as they become more cost effective.

Water saving devices appear to be one of the best methods of reducing domestic water use. The devices make more efficient use of water than conventional fixtures. Essentially the devices cut down on nonessential water use. The devices have been technologically perfected to save significant amounts of water. They are, for the most part, socially and politically acceptable.

2. Recycling

Recycled water can be used for several purposes. Irrigation, industry, recreation and domestic water demands can be met with renovated wastewater. Presently the primary reuse of water is for irrigation. Some municipalities reuse water in certain industries and a few reuse water for recreational purposes. Only Grand Canyon Village currently reuses water for residential needs. The reuse of water for residential uses on a system-wide basis can be accomplished through a dual system. One water line of such a system is designated for potable uses such as drinking, cooking, bathing, dishwashing and laundry. The other water line is for nonpotable uses such as toilet flushing and lawn sprinkling. The recycle of once used water for an individual home can be achieved by separation of grey water and black water with partial treatment of grey water before reuse. Both the dual system and the home recycle system are means of providing consumers with water of a quality suitable for a specific need.

Technological Feasibility. Although wastewater treatment technologies for system reuse have been developed that will provide water of acceptable quality for each category of water use, much controversy still exists. Advanced wastewater treatment methods have been shown to produce high water quality in pilot plant studies and in actual treatment plants. The major concern is related to providing renovated wastewater for potable domestic use. Possible health hazards resulting from exposure to low levels of contaminants for prolonged periods of time is an issue that is unresolved. Other concerns relate to the health dangers of treatment plant failure and operator inefficiency. While the treatment technology is available, no fail-safe control has been devised to ensure constant water quality. However, the reuse of water for nonpotable residential uses has excellent merit and could probably be accomplished with little or no opposition. Reuse of treated wastewater for toilet flushing and lawn irrigation where body contact is minimal would have little or no effect on the health of water users. The quality of the potable water would meet drinking water standards but the required quality of water in the non-potable water line could be slightly inferior in terms of contaminant levels. The possibility of ground water contamination from lawn irrigation is a concern in evaluating reuse plans. The quality of water in the nonpotable supply line should approach drinking water standards if at all possible to allow for any accidental consumption. Table 25 shows the drinking water standards of several health organizations and the suggested water quality limits for lawn watering and toilet flushing. It is apparent that higher water quality is necessary for irrigation water than water used for toilet flushing. This is primarily due to the much greater possibility of ingesting lawn sprinkling water than ingesting toilet flush water. Also, some of the standards such as that for boron relate to the tolerance limits of plants. The toilet flushing water quality limits are based on aesthetics and staining limits rather than on health criteria.

As the table indicates water quality requirements for non-potable uses are below that for drinking water. Several reclamation treatment schemes are capable of achieving these water quality levels. The precise constituents in the wastewater influent and the general make-up of the municipality's sewage will determine the types of treatment that are necessary. The possibility of cross connections is a primary concern. Toilet water reuse has been precluded in many studies because of this possibility. One solution to this problem is the maintenance of higher pressure in potable water lines than in nonpotable lines. The water supply savings of dual systems in terms of average day water demand and peak day water demand would be most significant in flat rate areas having high summer sprinkling demand.

Home recycle systems reuse grey water for nonpotable water uses. Black water reuse systems are currently available from several manufacturers, but considerable owner maintenance and understanding of how the system operates is necessary for proper performance of these systems. These factors plus state health department restrictions make these systems generally infeasible.

By providing the necessary plumbing alternations and installing pumps and treatment equipment grey water

TABLE 25

SUMMARY OF RECOMMENDED WATER QUALITY STANDARDS
(Limits in mg/l)

Constituent	World Health Organization (1971)	EPA Interim Primary Regulation (1975)	U.S. Public Health Service (1962)	Irrigation Water Standards (Bailey et al., 1969)	Toilet Flushing Water Standards (Bailey et al., 1969)
Turbidity	25.0	5.0	5.0	10.0	20.0
Color	50.0	-	15.0	15.0	30.0
Odor	-	-	3.0	3.0	6.0
TDS	-	-	500.0	1000.0	-
pH	-	-	-	6.5-8.3	-
NO_3	45.0	45.0	45.0	180.0	-
SO_4	400.0	-	250.0	500.0	-
Fe	1.0	-	0.3	1.0	1.0
Mn	0.5	-	0.5	0.5	0.5
ABS	1.0	-	0.5	1.0	-
CCE	0.5	-	0.2	0.4	-
Cl	600.0	-	250.0	500.0	-
Cu	1.5	-	1.0	1.0	1.0
Phenols	0.02	-	0.001	0.05	-
CN	0.2	-	0.01	0.2	-
Cr^{+6}	0.05	-	0.05	0.05	-
Bo	-	-	-	1.0	-
Se	0.01	0.01	0.01	0.01	-

Sources: Bailey et al., 1969, pp. 27-28; WHO, 1971; EPA, 1975.

reuse is feasible. A range of water qualities are associated with the discharge from various water use functions and Table 26 gives the wastewater quality characteristics of several household water use devices. It is apparent that the relatively low contamination of the bathroom sink, bathing, clothes and dishwashing flows makes them usable for toilet flushing. The treatment systems proposed for reusing grey water range from nothing more than pumping to a storage tank for establishing the necessary pressure head to advanced wastewater treatment systems. In Chapter II McLaughlin's home recycle system was presented. Figures 3, 4, and 5 represent several other, somewhat more elaborate, treatment schemes (McLaughlin, 1975; Withee, 1975). These yield effluents of qualities sufficient for reuse in toilets or on lawns. Table 28 attests to their performance capabilities in pollutant removals for the wastewater characteristics listed in Table 27. Owner operation and maintenance is required, but they are very easy to maintain and should require little attention. The performance of the systems is generally good and the amount of water savings with these and other types of systems has been determined (Cohen and Wallman, 1974).

The technical feasibility of adopting a community wide dual supply system or installing a home recycle system has been shown to be possible. Improvement in treatment technologies for both these systems will improve their overall capabilities in the future.

Costs of Dual Water Supply. The cost effectiveness of a dual water supply system is site specific. The price and availability of fresh water supplies is very important in any consideration of a dual system. Projections of an area's growth, its land use plans and physical parameters such as the topography and climatology will determine if dual systems are warranted (Schmidt and Ross, 1975). The size of the facilities that are necessary for a dual system in a municipality is of

TABLE 26

CHEMICAL CHARACTERIZATION OF HOUSEHOLD DEVICE WASTEWATER DISCHARGES

Source	COD (mg/l)	BOD (mg/l)	Total PO_4-P (mg/l)	NH_3-N (mg/l)	TS (mg/l)	TFS (mg/l)	TVS (mg/l)	TSS (mg/l)	VSS (mg/l)	pH	Temp °C
Kitchen sink	1,657	1,082	0.80	114	1,328	386	943	209	209	6.6	20
Bathroom sink	493	261	0.26	1.1	480	372	108	228	228	7.9	43
Toilet	1,300	124	24.0	300	1,723	196	1,527	650	650	5.6	21
Garbage-disposal	11,780	4,065	24.0	285	10,748	3,440	7,308	6,672	6,672	6.4	30
Bath & shower	218	100	0.22	0	339	319	20	128	128	8.2	38
Washing machine*	628	202	14.3	4.0	813	672	141	78	78	7.8	53
Dishwasher*	228	123	3.84	0.028	944	790	161	25	25	8.3	66

* Average for both wash and rinse cycles. One value was established by weighing in cycle characteristic in accordance with the relative volumes generated during the normal wash cycle.

(After Felton, 1974).

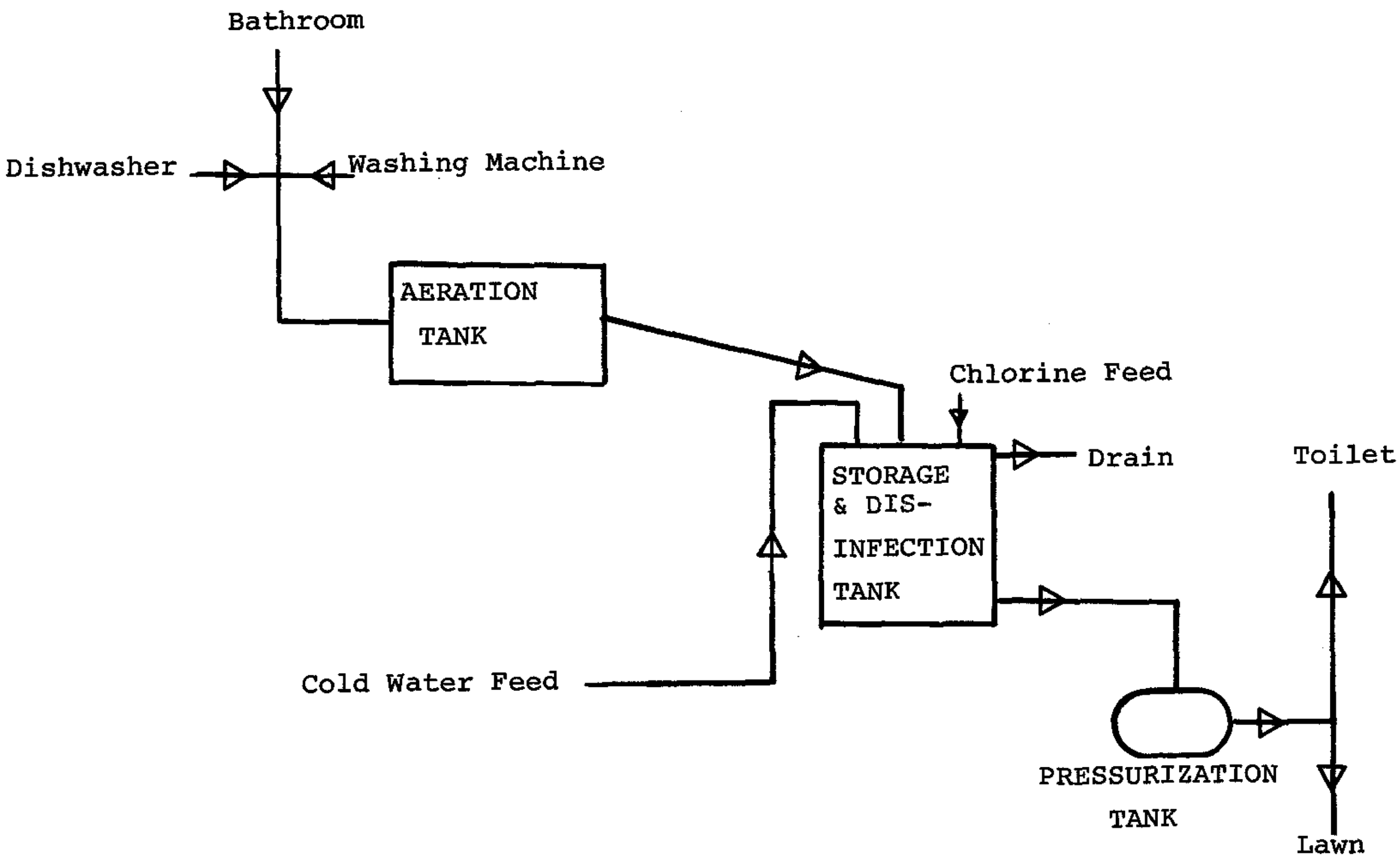


FIGURE 3. HOME RECYCLE AERATION TREATMENT SYSTEM
(Source: Withee, 1975)

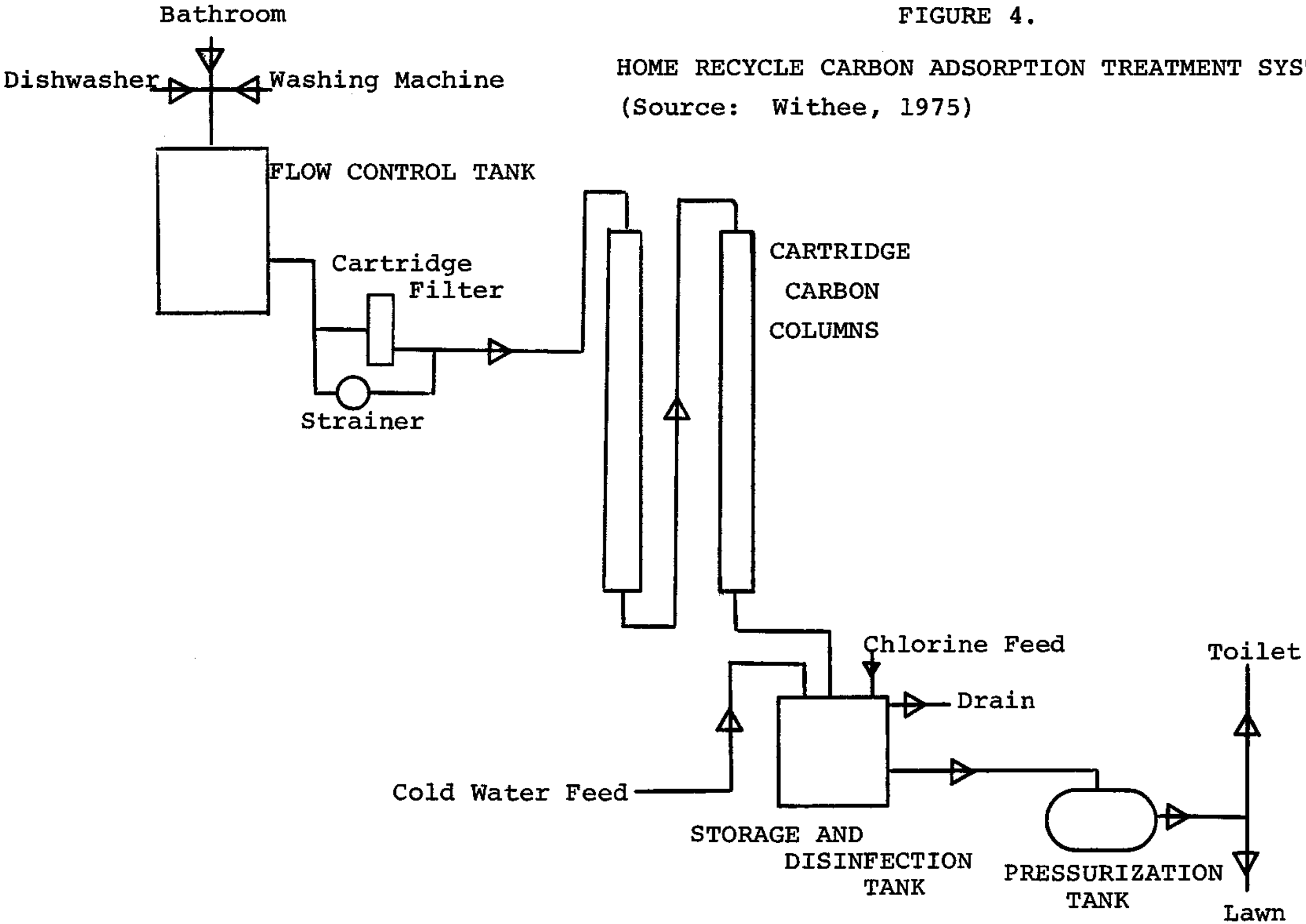


FIGURE 4.

HOME RECYCLE CARBON ADSORPTION TREATMENT SYSTEM
(Source: Withee, 1975)

FIGURE 5.

HOME RECYCLE AERATION-CARBON ADSORPTION TREATMENT SYSTEM

(Source: Withee, 1975)

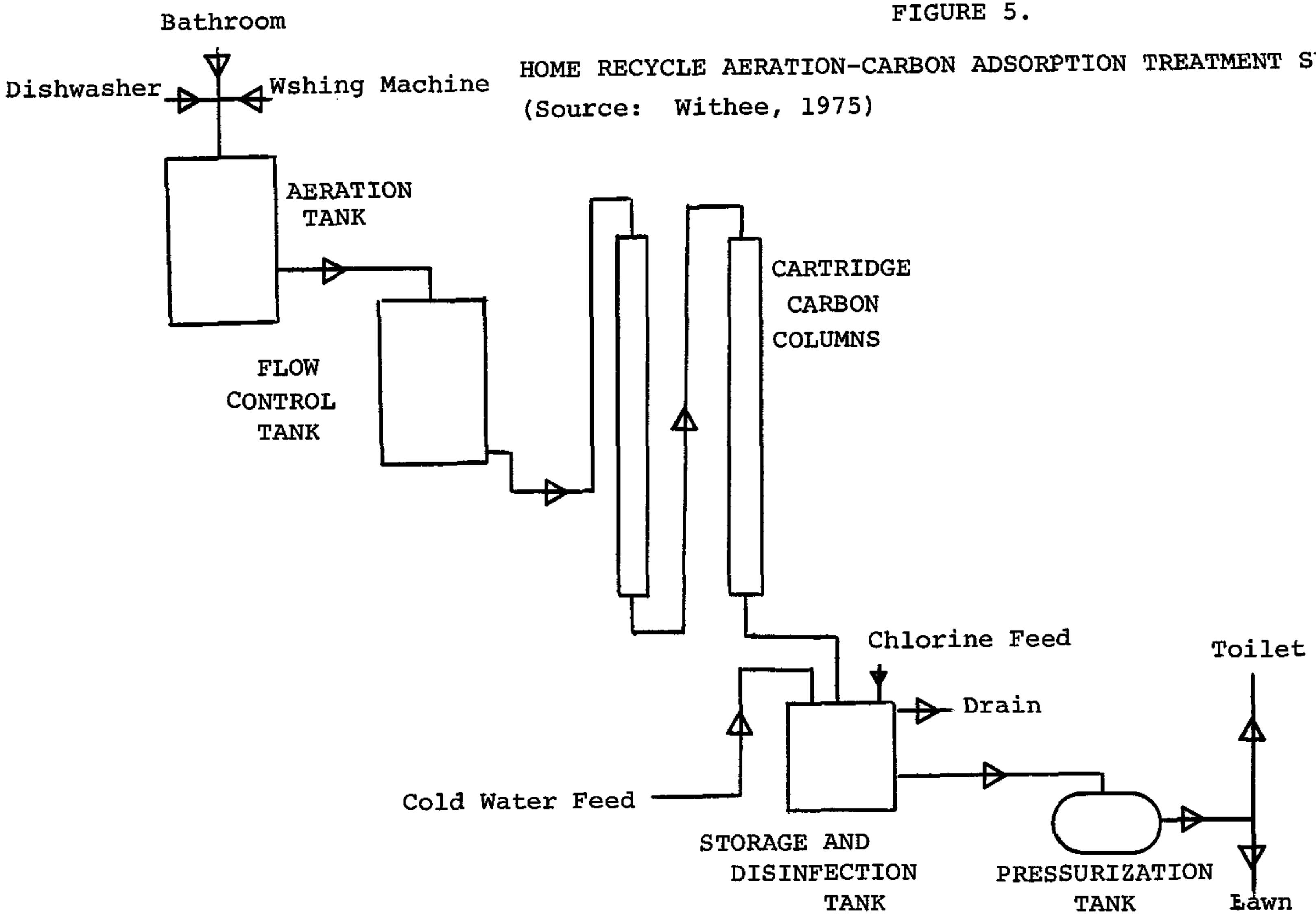


TABLE 27

POLLUTANT CHARACTERISTICS OF SOAP-RELATED WASTEWATER

Pollutant Parameter	Concentrations
COD	186 mg/l
BOD	63 mg/l
Total Solids	311 mg/l
Dissolved Solids	255 mg/l
Turbidity	44 JTU

TABLE 28

HOME RECYCLE TREATMENT EFFICIENCY SUMMARY

Type of Treatment	Percentage Removals*				
	COD	BOD	Total Solids	Dissolved Solids	Turbidity
(1) Aeration	55.4	77.3	5.4	3.8	73.5
(2) Carbon Adsorption	76.9	65.7	17.5	10.7	45.9
(3) Aeration-Carbon Adsorption	88.7	94.7	24.7	16.7	91.6

* Removals are indicative of 40 minutes carbon contact time.

Source: Withee, 1975, p. 237.

primary importance. The effect of scale on total costs varies widely. In Appendix D costs are given for both water and wastewater treatment plants as a function of size. These differences are compounded by local variations in system characteristics and needs. The amount of head against which the treated flow must be pumped back has a very significant effect on power costs. The differences in wastewater plant influents alone can account for significant treatment cost differences. The costs for advanced treatment methods also varies considerably. Unfortunately, the only operating reclamation facility for nonpotable domestic use is a small facility in the Grand Canyon of Arizona. The facility supplies only 30,000 gallons per day and the costs are high. Other dual systems supplying recycled water for other purposes are in use. These facilities operate at much lower costs than the Grand Canyon Facility. Installation costs for some of these systems has been shown to vary from $252 to $624 per capita (Haney and Beatty; 1976). In the same analysis the comparable conventional system costs ranged from $342 to $939 per capita. The analysis showed the least cost approach is to make the existing line the nonpotable line and add a new smaller line for potable water. These findings are confirmed by DeLapp's study previously cited.

Water Savings From Dual Water Supply. The amount of water savings that can be expected from a dual supply system is difficult to predict accurately. The water could be reused several times depending on the volumes involved in recycle and the total volumes entering the wastewater reclamation plant. If it is assumed that the water is reused only once and that commercial flows, infiltration and industrial flows are large enough to yield the volumes necessary for toilet flushing and lawn watering then the savings in total water use could approach 532 gallons per day per dwelling. The differences among the three values are accounted for by substitution of lower quality for water for sprinkling. The assumption is that no make-up water is necessary, that is, there is sufficient sewer flow to meet sprinkling demands. This assumption may not be true in which case the savings will decrease by the amount of make-up water necessary.

The greatest potential of dual systems is realized in the mitigation of peak demands for high quality water. Lawn irrigation reuse would significantly lower production costs for potable water by lowering peak demands. The economic savings involved would be a function of a system's water sprinkling demand. Dual systems could affect large design savings in systems with large sprinkling demands.

Cost-Effectiveness of Home Recycle Systems. The amount of water savings with home-recycle systems is the total of the grey water flows (assuming that any storage overflow is routed to the landscape areas). These quantities approach 36 gpcd or 144 gpd per dewlling unit. Utilizing the recycle system of Figure 2 an estimate was made of the water savings costs. Table 29 gives the breakeven water and wastewater prices. Appendix B lists the assumptions made for these calculations. Withee reported cost estimates for recycle systems (Withee, 1975) with breakeven prices between $6.45 and $10.25 per 1000 gallons based on an economic life of 30 years at 7 percent interest. It is evident that these systems are expensive and would be applicable only to areas having severe water supply or wastewater disposal problems.

Social and Political Acceptability. The social acceptance of reusing wastewater for toilet flushing is positive according to most surveys (Bailey, 1969; Bruvold and Ongerth, 1974). Reuse of water for lawn watering is less favored because of the increased chance of body contact and ingestion. Both reuses appear to be acceptable to the public as long as assurances are made that the recycled water is not grossly polluted.

The political acceptability of reuse is uncertain. Administrative divisions between water and wastewater

TABLE 29

NEW INSTALLATION BREAKEVEN PRICES FOR GREY WATER RECYCLE SYSTEM

Interest Rate	Annual Costs Per System ($)	Increased Annual Costs Over Regular Toilet (Over 25 yrs.)	Breakeven Water And Wastewater Price[a] ($/1000 gd)
5%	77.04	$77.04	$3.58
8%	90.08	90.08	4.19
10%	99.34	99.34	4.62

[a]Based on one recycle system - toilet per household

departments exist in many municipalities. Overcoming these divisions in trying to coordinate reuse plans could involve political costs. Elected officials and public health authorities also view reuse with less enthusiasm than the general public (Bailey, et al, 1969). Their attitudes arise from their responsibilities for protecting the public health.

Return Flow Implications. Return flows to the receiving stream from wastewater treatments plants would be dramatically reduced if a dual system were installed. Seasonal variations in stream flows downstream from a municipality practicing reuse would be accentuated. Compensation to senior downstream water appropriators would possibly be necessary either in money or in water. In addition to sewage plant effluent some of the water applied to lawn irrigation not consumptively used may find its way to the stream either through storm drain systems or as ground water. The complexity of the hydrology makes prediction of absolute amounts of return flow difficult. Those users of stream flow downstream from an originally flat billed area that converts to a dual system would be most severly affected by reduced returns flows both with regard to sewage effluent and lawn irrigation return flow.

Methods of Implementation-Assessment. Detailed studies of water use, wastewater flows, wastewater qualities, topographic parameters and return flows are necessary to investigate dual system reuse. Cost estimates on each reuse alternative are also needed. Home recycle systems would generally be implemented only in areas with high water costs or wastewater disposal problems.

Dual systems appear to be feasible for areas with increasing water production costs and scarce future supplies. Areas with large sprinkling demands also appear to be likely candidates for dual supply systems. Health guarantees and downstream flow considerations are the main concerns with dual systems. The home recycle systems that are presently available are generally not feasible except under special circumstances because of their cost and customer inconvenience. Development of less costly systems that require low owner maintenance would mitigate these problems and may make these systems cost effective.

3. Pressure Reduction

Pressure reducers are a means of reducing the amount of water wasted through faucets and shower heads. System pressure regulation is used in some cities to cut down the amounts of leakage in distribution lines. Pressure reduction of flows to the house or in house lines to plumbing fixtures is recommended in many areas having high line pressures.

Technological Feasibility. A large number of manufacturers make system and household pressure reduction valves. The performance of these devices is consistent over a wide range of line pressures. The installation and maintenance of pressure reducers is minimal.

Cost-Effectiveness. Pressure reduction valves for in-house use can be purchased and installed for about

$22.00 (Milne, 1976). The reducers will save varying amounts of water dependent on the magnitude of the pressure reduction. An estimate of 10 percent water use reduction for faucets and shower heads was used in this analysis. Tables 30, 31 and 32 show that in-house pressure reducers are cost-effective at moderate to high water service prices. The energy savings due to decreased hot water requirements is in addition to the water and wastewater monetary savings. The 10 percent water savings estimation is considered to be conservative for systems that currently operate under high line pressures. System pressure reducers accomplish greater savings through leakage reduction and can significantly cut down on water production costs.

Social and Political Acceptability. Pressure reducers are very acceptable to water consumers as long as sufficient pressure is maintained for proper operation of household fixtures and appliances. No inconvenience results from installation of these valves. Politically the pressure reducing valves are quite acceptable.

Return Flow Implications. The return flows from wastewater treatment facilities would be diminished by the amount of the in-house water savings but the most significant decrease in return flows would probably result from a decrease in system leakage amounts reaching a stream.

Methods of Implementation-Assessment. System pressure reducing valves should be used in all systems where high pressures exist. Utility action is the only method to accomplish this. Household pressure reducers should be encouraged by the water utility for installation by individual water customers. While the water savings are not large the extension of the life of household appliances, especially hot water heaters, when they are able to operate at lower inlet pressures is an added incentive for their installation.

TABLE 30

BREAKEVEN PRICE AT VARIOUS DISCOUNT RATES FOR INSTALLATION OF IN-HOUSE PRESSURE REDUCER VALVE (PRV)

Discount Rate	Increased Annual Costs (Over 25 yrs.)	Breakeven Water and Wastewater Price ($/1000 gal)
5	$1.63	0.43
8	2.14	0.56
10	2.50	0.66

TABLE 31

TIME FOR PRV TO BECOME COST EFFECTIVE

Price of Water & Wastewater ($/1000 gal)	Discount Rates	
	5%	10%
0.60	13.5 yr.	5.7 yr.
0.80	9.2 yr.	14.6 yr.
1.20	5.7 yr.	6.9 yr.

TABLE 32

NET ANNUAL SAVINGS WITH PRV FOR VARIOUS PRICES

Price of Water and Wastewater ($/1000 gal)	Annual Savings in Water and Wastewater ($)	Increased Annual Costs ($)		Net Annual Savings ($)	
		i=5%	i=10%	i=5%	i=10%
0.40	1.52	1.63	2.50	-0.11	-0.98
0.60	2.28	1.63	2.50	0.65	-0.22
0.80	3.04	1.63	2.50	1.41	0.54
1.20	4.56	1.63	2.50	2.93	2.06
2.00	7.59	1.63	2.50	5.09	5.09

System pressure reduction is an effective means of cutting down on leakage and waste if the system operates under high pressures.

4. Metering

Metering residential water use is a method of accomplishing water conservation. Metering places an economic incentive on a consumer to save water. The price charged has a direct effect on the amount of water demanded. Metering links price to the amount of water used. Through this mechanism wastage of water is curtailed because the customer pays for what he uses.

Technological Feasibility. Metering is technologically feasible. Meters perform their function of flow measurement with good accuracy for many years after their installation. Only periodic maintenance is necessary once the meter is in place. Several technological improvements in meters are taking place. Remote-reading meters have been developed and are being used and tested in some areas. These meters aim at cutting down on the reading and billing costs associated with conventional meters. Demand meters are also being researched. Although still in the development stage, the demand meter can achieve equitable charges based on water use with time (Feldman, 1975). The demand meter would allow the utility great flexibility in its rate structures. Innovations such as these will make demand metering possible for those areas replacing meters or previously without meters.

Cost Effectiveness. Table A-6 in Appendix A presents an updated estimate of the cost to install a meter for the city of Denver (Bryson, 1972). The average cost of installation of a large number of meters will vary with the number of household service lines that need to be replaced. The amount of water saved by metering from the baseline of 172 gpcd was 25 percent of flat rate usage or 43 gpcd. This savings amount is considered to be conservative. Table 33 shows the breakeven price of water services for metering using the cost criteria from Appendix B.

Based on an installation cost of $379 it is evident that metering becomes cost effective at moderate water service prices.

Table 34 shows that it takes at least 3.5 years for meters to pay off in value of water saved when water is valued at $2/1000 gallons. Other pay off periods are shown for two interest rates and various water prices. All pay off times less than 25 years can be considered as cost effective.

Table 35 shows that for a given water savings amount and set price level the installation cost of metering can go above $500 (i=5%) and still be justifiable, if the price of water service is more than 60 cents/1000 gallons.

TABLE 33

BREAKEVEN PRICE OF WATER AND WASTEWATER FOR METERING

Discount Rate	Increased Annual Costs (Over 25 yrs.)	Breakeven Water And Wastewater Price ($/1000 gal.)
5%	$28.60	0.45
8%	37.21	0.59
10%	43.46	0.69

Installation Cost = $379 per meter

TABLE 34

NECESSARY TIME FOR METERS TO BECOME COST EFFECTIVE AT VARIOUS WATER & WASTEWATER PRICES

Price of Water & Wastewater ($/1000 gal.)	Interest Rates 5%	Interest Rates 10%
0.40	34 yr	∞
0.60	15.4 yr	∞
0.80	10.2 yr	16 yr
1.20	6.1 yr	7.6 yr
2.00	3.5 yr	3.9 yr

Installation Cost = $379 per meter

TABLE 35

METER INSTALLATION COSTS WHICH JUST EQUAL THE AMOUNT SAVED FOR VARIOUS PRICES AND DISCOUNT RATES*

Price of Water & Wastewater ($/1000 gal.)	Discount Rates 5%	8%	10%
0.40	$329.83	$249.81	$212.42
0.60	506.81	383.84	326.39
0.80	683.77	517.87	440.36
1.20	1037.00	785.93	668.29

* Over 25 years

The analysis shows that metering is economically justified, but that it takes time for meters to save enough water to compensate for their high initial cost.

System Water Savings. The amount of water saved annually for a community converting from flat rate billing to metering can be large. The major part of the water saved is that normally wasted in over-irrigation. The water savings could easily be a 25 percent reduction in demand from flat rate usage levels after metering. For a municipality the size of Denver, Colorado with an unmetered customer size of over 87,000 households, the annual water savings would approach 15.3 million gallons per day. If incremental water costs were 5 cents per 1000 gallons the Denver utility could save over $270,000 dollars a year in treatment costs. The water saved would serve 30,000 new metered customers if no allowance is made for return flow reductions.

The greatest water savings from metering would occur during peak summer demand periods. Through reduction of the irrigation component of water use, summer water demands are significantly diminished with metering. Postponement of facility expansion is also possible.

Social and Political Acceptability. Generally the public dislikes metering. Since metering usually means a higher water bill this has a negative effect even though the consumers may realize that it is an equitable way of apportioning costs. Because of the negative social attitudes and the high costs involved in metering, political motivation for metering is lowered. Elected officials often view metering as too costly because no new water is made available and favor plans increasing total supply or focus on other more socially favorable methods (Green, 1972).

Return Flow Implications. The amount of return flow can be affected by metering. Total return flows may decrease by an amount approaching the water use decrease. The return flows from sanitary systems will be less affected, but, return flows from storm sewers and alluvial ground water will be greatly decreased. Hydrologic conditions dictate the exact amount of decreased return flows.

Since the 64 gpcd estimate for lawn watering is actually less than the consumptive use requirement as determined by Bryson, the return flow from lawn irrigation is reduced to zero. The difference or 44 gpcd may have to be released from storage to meet downstream water appropriators who formerly used the return flow. In this case there would be no net savings of water on a system wide basis if return flow is taken into account.

Method of Implementation-Assessment. Requiring meters on all new residential construction is generally the first step in metering a municipality. Then metering of the existing dwellings in a city is undertaken section by section. Metering should be an integral part of any successful conservation program. By assigning a positive value to water, metering promotes interest in water use. Metering is also the best means of total water accounting. Metering is possibly the most necessary component of a long-term conservation program, but pricing policy will also determine its effect in reducing water use.

In areas with severe water restrictions the limiting of water taps in new construction is often imposed.

An alternative which could lessen the impact on the new housing construction industry would be to issue water permits for domestic use only, perhaps limiting the average usage to 64 gpcd with severe penalties for violators. A less stringent requirement would be to allow 64 gpcd for domestic use plus sufficient water for a small lawn, say 1000 sq. ft., regardless of the lot size. Similar permit restrictions could be imposed on multi-family housing. Using the 64 gpcd domestic use value would allow a doubling of the number of permits issued without such restrictions.

5. Leakage Reduction

Leakage in water distribution systems is a significant "water use" category for many municipalities. As pointed out earlier the actual amount of system leakage is difficult to determine even in metered communities because of other unaccounted-for water. Leak detection and repair is a method of reducing the total amount of water delivered. Household leakage from plumbing fixtures presents a similar problem in that the precise amount of water use due to leakage is unknown and can account for a relatively large percentage of total household use. The types of leaks avoidable in a sample survey (Howe, 1971) were:

1. broken main and joint leaks,
2. leaks between main and customer's meter,
3. leakage from hydrants,
4. inactive-service leaks, and
5. sewer-flusher leaks.

Technological Feasibility. Several means have been developed for detecting distribution system leakage. Sound equipment, called aquaphones or geophones, can detect and pinpoint leaks. More sophisticated electronic equipment has also been devised that can detect leaks in household service lines and even in the house itself (East Bay MUD, 1972). While these units cost more than the sound equipment, they are very accurate in locating the exact position of a system leak. Repair of system leaks takes place once the pipe position of the leak is located. The technological feasibility of using these types of detection equipment is positive. Household leak detection is generally visual in nature. Detection of toilet ball-cock leakage is accomplished using a dye and visually observing whether the dye leaks into the toilet bowl from the storage tank. Other household leaks are generally detected by observation. Toilet repair kits and nonleak toilet ball-cocks as well as washerless faucets are commercially available.

Costs of Leak Reduction. Utilities may purchase electronic leak detection equipment for about $1200 per unit or may hire a firm to conduct a leak detection survey (Metcalf and Eddy, 1976). Manpower costs for leak detection are a major cost in leak detection performed by the utility. The costs of leakage repair vary with the type and location of the leak. Household leak detection is inexpensive. North Marin County Water utility provided a set of two dye tablets for toilet leak detection at costs less than 8 cents. Howe found that leak detection and repair was cost effective for even relatively small leaks at low to moderate prices of water (Howe, 1971).

System Water Savings. The amount of water savings as a result of leak detection and repair for a utility system is difficult to determine. It is conceivable that system leakage reduction could be one to nine percent of total production depending on how tight the system is. Larger savings could be affected in very leaky systems.

Howe reported, on the basis of a survey of 91 larger systems, that it pays to repair most leaks above 3,000 gpd per mile of main. The total savings could approach 9 percent of total water production if all economically feasible leaks were repaired (Howe, 1971).

Social and Political Acceptability - Return Flow Implications. Leak detection and repair is highly acceptable both socially and politically. The return flows would diminish in direct proportion to the amount of leakage reduction that formerly discharged to alluvial ground water or storm sewers.

Method of Implementation. No problems in implementation are apparent, especially for household detection and repair. Some utility resources are necessary for a system detection and repair program.

6. Pricing

The use of pricing policy is an effective tool for achieving water conservation. The economic incentive for using a smaller amount of water is dependent upon consumer attitudes and needs, as reflected in the elasticity of demand. Two kinds of elasticity, or the measure of change in demand with change in price, are significant. One is related to income of the consumer and, in general, indicates that for non-essential commodities a lower-income consumer will modify his demand more than a higher-income consumer. Lack of information and reliable data precludes the inclusion of income elasticities in this discussion. The second kind of elasticity relates demand with price and is expressed as ${}^{\Delta Q}/Q \div {}^{\Delta P}/P$ and reflects the change in demand that occurs for every change in price given a price-demand relationship. In terms of residential use domestic use is more price inelastic than lawn sprinkling, i.e. with a given price increase the relative change in household use will change (decrease) less than sprinkling usage. Similarly, industrial usage is usually considered to be even less elastic than residential usage. Table 36 gives some typical price elasticities for various categories of demand.

The value of water to the consumer can be categorized as essential or less than essential to his well-being. In-house water use is considered essential and is not very responsive to price change. Exterior lawn watering use is somewhat less essential and is, therefore, more responsive to price changes. The elasticity for both these categories is less than unity, but its magnitude varies geographically and with specific use. The variance

TABLE 36

PRICE ELASTICITIES

Demand Section	Elasticity	Source
Residential	-0.225	1
Domestic	-0.26	2
Sprinkling (West)	-0.703	1
Average Day	-0.3953	2
Maximum Day	-0.388	1
Commercial-Industrial	-0.10	3
Government	-0.25	4

Source: 1. Howe and Linaweaver, 1967.

2. Burns et al, 1975.

3. Hanke and Davis, 1974.

4. Roussos and Flack, 1977.

in consumer response to price change makes the prediction of demand after a price change difficult.

Technological Feasibility. Pricing theory and response have been investigated by many authorities. The idea that increasing the price of water will decrease use is accepted. However, the amount of decrease for a given price increase is a subject of some debate. Without knowing the price elasticity by use for a community, only rough estimates can be made as to the affect of price on the quantity demanded. Those areas that have a large sprinkling demand are the most affected by a price increase. Flat rate areas will exhibit either no response to price increases or increased usage. Therefore, the presence of meters in a system is required to attain conservation through price adjustments. Several pricing methods have been devised in an effort to cut back on the quantity of water demanded, and to proportion the costs equitably among consumers. In Chapter II some of the pricing schemes aimed at conservation were briefly discussed. Peak demand rates and increasing block rates are two pricing structures that can promote water conservation. The peak demand rate appears to be feasible by placing a surcharge on sprinkling use. By charging an extra fee for water used above some base allotment the marginal price can be set equal to the marginal cost for meeting peak demands. However, it has been observed that in systems designed to meet large summer sprinkling peaks the marginal cost of meeting these demands may be less than the average cost of production. Increasing block rates charge large water users higher rates for their higher usages. Depending on price elasticity increasing block rates can be effective in reducing the demand of large users of water. Some selected price elasticities are given in Table 36.

System Water Savings. The amount of water that can be conserved using pricing policy is site specific. If the price elasticity for the sprinkling demand is known, then a decrease in consumption can be calculated for any price increase. If the price elasticity is unknown, then a conservative reduction may be assumed of about 10 percent of total demand or a minimum of 13 gpcd (Roussos, 1976). It is expected that with each price change the elasticity will change and so will the percentage of demand reduction. One of the primary affects of these rate structures will be a flattening of the peak water demands. The structure of the rates discourages large peak demands. Deferring of facility and distribution expansion can be a major result of pricing changes.

As an example of the water savings that can result from a price increase, assuming the elasticities of Table 36 are applicable, the following are the water demands by categories by a totally metered community at water prices of $0.43/1000 gallons and at $0.86/1000 gallons.

TABLE 37

AN EXAMPLE OF THE CHANGE IN WATER DEMAND WITH PRICE
(millions of gallons per year)

Demand Sector	Demand @ $.43/ 1000 gal.	Elasticity Q/Q ÷ P/P	Demand @$0.86/ 1000 gal.	Difference (decrease)
Industrial/ Commercial	65.0	-0.1	58.5	6.5
Residential				
Household	50.0	-0.225	38.75	11.25
Sprinkling	100.0	-0.395	60.5	39.5
Governmental	20.0	-0.25	15.0	5.0
System Loss	18.0	-	18.0	-0-
TOTALS	253.0		190.25	62.25 (25%)

The net result of the doubling of water prices from $0.43 to $0.86 per 1000 gallons is a 25 percent reduction in demand.

Social and Political Acceptability. Pricing policy changes may be viewed with suspicion by the public. Changes in the methods of allocating charges to the customer should be kept simple and easy to understand so that the affect of making the public price-sensitive is achieved. Inclining block rates can be explained with relative ease to the public. The acceptance of such rates will be mixed, with large water users against them and small water users in favor of them. Peak demand rates will most likely raise opposition in those areas having large lawn sprinkling needs. Peak demand rates are more difficult for the public to understand and, therefore, adequate communication with the public is necessary.

Politically, changes in pricing policy and price increases are negative. Announcement of increases in water prices will invoke suspicions as to the need for such rate hikes. Peak demand rates could be costly politically unless the public is made aware of the problems that summer sprinkling loads create for the utility. Inclining block rates also appear to have some political cost in that excess revenues may be produced because some large users have small price elasticities.

Return Flow Implications. The return flows from wastewater treatment plants following price increases and changes in the type of rate structure would be minimal since primarily the sprinkling use component is affected. Decreases in recharge of ground water basins and return flow to streams could result depending on specific hydrologic conditions.

Method of Implementation-Assessment. Detailed rate studies and simulation of the utility's response to price changes should be done before any change in rate structure is implemented. Affects on revenue and on customer bills should be investigated for each type of pricing change. Elasticities of demand both by price and income should be determined as closely as possible based on past changes in usage when prices changed or from generalized data developed by other utilities.

Pricing is an effective means of conserving water, but not without costs. The costs are primarily social and political in nature and are, therefore, difficult to quantify. The amount of water savings is equally difficult to specify because it is quite variable.

7. Building Code Modifications

Modification of building codes to specify the installation of water conserving devices in all new construction of dwellings and buildings may be the most effective means of gaining acceptance of such devices. By legally putting a limit on the water using capacity of plumbing fixtures, municipal codes can result in water use and sewage flow reductions. The codes would make water saving devices more cost effective through a lowering of their price by mass manufacturing techniques.

Technological Feasibility. Several municipalities have instituted code modifications specifying low water using toilets, shower heads, faucet aerators and pressure reducing valves. These code changes are legal and appear to be effective in gaining widespread use of water-saving devices. The code modifications for new installations are technically feasible and enforceable. Several examples of adopted code modifications are reprinted in Appendix C. The possibility of using code modifications to retrofit existing residential units is remote due to enforcement problems.

System Water Savings. Building Code Modification Plans 1 and 2 were shown earlier to effect significant system water savings as the number of households under these plans grew. However, the rate of growth of the municipality is the prime determinant of when, in the future, large populations will be covered by the codes. The cost to the municipality is low while the homeowner would bear slight cost increases for the fixtures.

Social and Political Acceptability. Some opposition can be expected from building contractors and plumbers claiming that the code modifications cost them money. Some homeowners who have the increased costs passed on to them could complain, but generally the use of building code modifications would be favorably met. On the other hand, codes requiring retrofitting of low water using fixtures would probably be met with stiff social and political opposition.

Method Assessment. Building code modifications calling for the installation of water saving devices is an excellent conservation method. Adoption of code changes is applicable to all municipalities and should be universally approved.

8. Water Use Restrictions.

The imposition of water use restrictions is essentially a short-term method of conserving water. When water supplies reach a level where officials feel that there might not be enough water to meet the demand, first voluntary then mandatory restrictions are usually instituted. The primary difference between this conservation method and the others discussed in this chapter is that restrictions actually inconvenience the water consumer whereas the other methods are designed to inconvenience the customer as little as possible.

Technological Feasibility. Water use restrictions save water if they are not left on too long. The City of Greeley, Colorado has had voluntary restrictions on lawn watering for decades (Alleman, 1977). They have had little effect on water use except when the danger of shortages was conveyed to the public. Voluntary restrictions in this case are on an odd house - odd day scheme. Restrictions allowing lawn sprinkling only for pre-specified hours has resulted in increases in usage because the public watered during that time whether they felt it was necessary or not (Brauer et al., 1976).

In these instances restrictions were not accompanied by intense public education programs alerting and informing the public about water supply problems and the means of alleviating them. It is apparent that information on the need and means for water conservation is necessary for use restrictions to be effective.

The "best" scheme of water restrictions is debatable. This is partly due to the fact that water savings from restrictions vary with different community water use characteristics. The main reasons that precise savings figures cannot be stated are that the degree to which people are motivated to save water will differ according to their perception of the severity of the problem. The affect of restrictions cannot be separated from other conservation methods that are implemented at the same time. Probably the most effective type of restriction places an upper limit on the amount of water that a household can use per month.

Marin County in California imposed such a limit recently on its customers as a result of a severe water shortage (Rogers, 1977). The utility first attempted to attain a 25 percent reduction in usage by increasing the price of water from $0.43 to $0.61 per hundred cubic feet and banning lawn irrigation. Later as the water shortage worsened a 57 percent decrease in water use was mandated by raising the price to $1.22 per hundred cubic feet and placing a limit on household usage in accordance with the number of people residing in the dwelling. A decreasing per capita amount was allocated as family size increased. Severe penalties were imposed for those households that exceeded their limit. The resulting savings has been phenomenal. It was hoped that water usage would be decreased to 12 mgd, in fact, a reduction to 9 mgd has occurred. This has created a large revenue deficit which, as yet, has not been solved. In addition, social costs have been encountered, water theft and water meter vandalism have occurred. Thus the technological means for saving water through restrictions has been shown, but the costs of restrictions can be great.

System Water Savings. The amount of water savings that can result from restricting water use is not precisely known. The percent decreases as reported in Chapter II vary from 10 to 60 percent of total use. The amount of water savings depends on previous use levels, the public's response and whether or not the restrictions are enforced. Figure 6 illustrates a situation where a large amount of reduction was accomplished. A 10 to 20 percent water reduction in total usage is generally thought to occur with restrictions if accompanied by a public information and conservation program. The reduction in usage will be short-term unless the public perceives the situation as of crisis magnitude. Water reduction amounts also depend on the attitudes of the water utility professionals and the elected officials in convincing the public of the necessity to decrease use.

Through mid-summer 1977 the Denver Water Department reported water savings of 25% based on an every-third-day lawn water program plus avoidance of wastage.

Social and Political Acceptability. Water use restrictions may be the most costly conservation method socially and politically. The inconvenience and lifestyle changes that restrictions cause are often viewed as socially undesirable on a long term basis. Restrictions create problems for water utility public relations programs. The longer the restrictions are left on, the less the reduction in water usage is likely to be. The political costs of water use restrictions may be large. The imposition of restrictions may foster distrust for elected officials. Prolonged implementation could conceivable give rise to recall elections if the restrictions are severe enough and the water customers perceive that management is at fault. From the utility's viewpoint one of the hazards of restrictions is that they will be too successful. The drop in revenue when water use is reduced can place

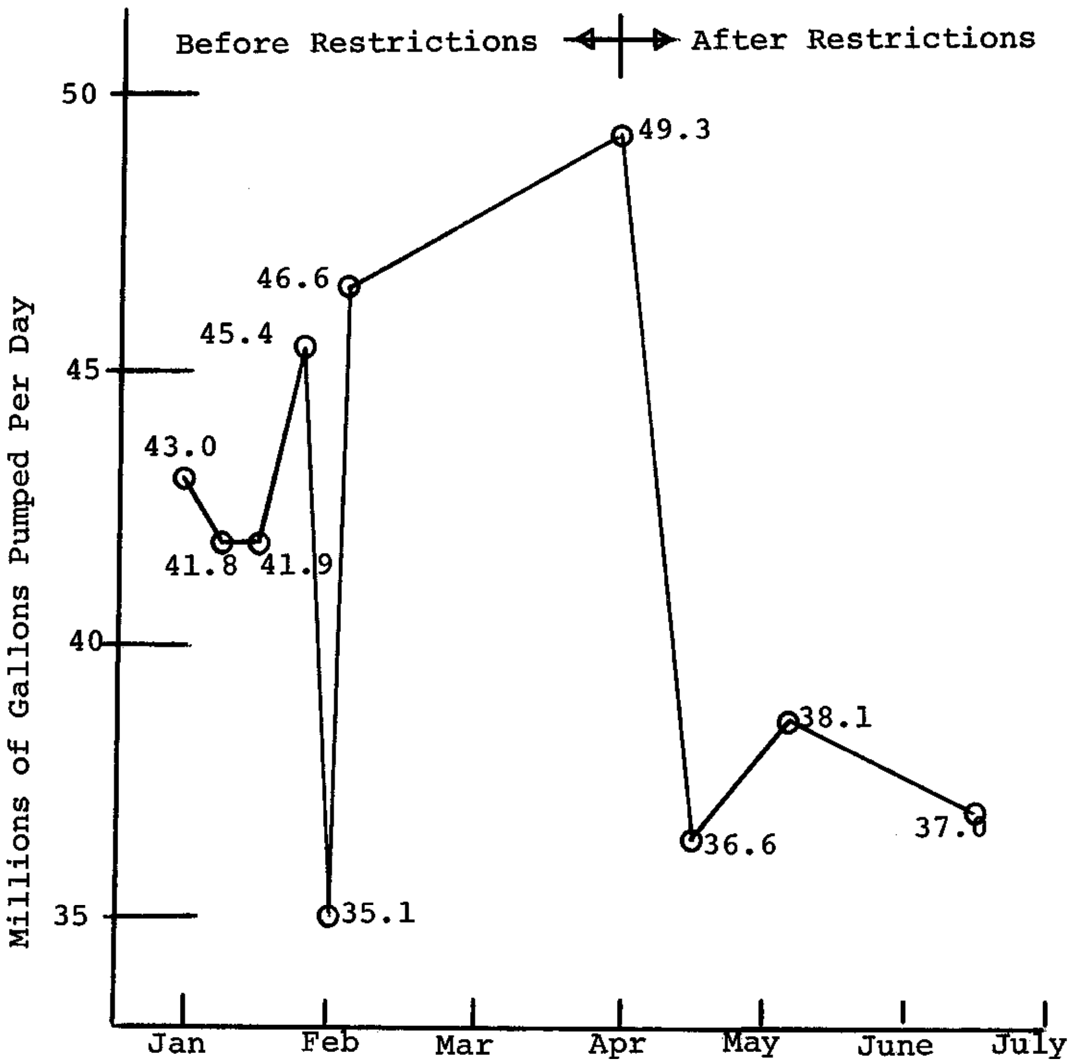


FIGURE 6.

EFFECT OF WATER USE RESTRICTIONS
Ft. Lauderdale, Florida
(Source: Century..., 1972)

the utility in the position of either raising water rates to make up for the loss of revenue or to encourage some additional water usage. Both of the courses of action are very likely to generate an adverse reaction from water customers and community leaders.

Method of Implementation-Assessment. Restrictions on lawn watering and other exterior water uses are the easiest to implement and enforce. Enforcement of restrictions on an hourly basis can entail significient enforcement costs, but may achieve slightly greater reductions than an odd day - odd numbered house restrictive watering scheme. Restrictions on total usage are by far the most effective, but also the most costly in terms of social and political considerations. Implementation of restrictions requires that the restrictions be simple in nature and easily understood. The use of economic penalties is the most effective method to enforce restrictions.

9. Horticultural Changes

Horticultural changes are methods designed to decrease sprinkling use. Since peak demand rates and much of a system's capacity is based upon this component of use it is highly desirable to mitigate sprinkling usage. Horticultural changes are aimed at using less water but still maintaining the aesthetic appeal that homeowners wish of their lawn areas.

Technological Feasibility. Horticultural changes are primarily of two types: changes in the planning of a landscape and changes in the maintenance of a landscape. Landscape can be designed to use less water more efficiently than traditional landscaping patterns. Native plants and xerophytes use less water. Lists of native species and their water requirements facilitate in choosing plant combinations. Landscaping to provide gentler slopes and provision of areas covered by rock or wood chips can be efficient in cutting down on lawn sprinkling needs. These methods are technically feasible, fully developed and can be instituted in almost any area.

Maintenance of lawn areas and shrubbery is overlooked in many water conservation programs. Aeration of the soil, maintenance of the proper pH and utilizing moisture sensors and sprinkling systems benefit the lawn and reduce the water bill. Over-irrigation and watering during the heat of the day are areas where public education could significantly lower lawn water use.

Costs of Horticultural Changes. The costs of implementing horticultural changes vary with the type of plan adopted. Relative figures on the costs of horticultural changes are difficult to obtain unless a specific site is used. Soil moisture tensiometers, sprinkler or drip irrigation systems and other mechanical devices are generally costly. Horticultural changes of plant species are moderate in price. The provision of rock areas and gentle landscaping slopes vary with the locale.

The water savings that can be achieved with horticultural changes range from zero to 100 percent of current lawn water usage. This range is due to the degree of change that can be made.

Social and Political Acceptability. Horticultural changes are socially acceptable depending on personal preferences and social attitudes toward lawn areas. Some people seem to prefer desert landscapes while others prefer traditional lawn areas. For each type of preference horticultural methods of alleviating some of the water demand are available. Gaining acceptance of these techniques is the primary difficulty. Horticultural changes should have no political costs.

Return Flow Implications. The amount of return flow may be reduced by this conservation method. The magnitude of decrease would not be significant unless very large numbers of homeowners convert to low water using plants.

Method of Implementation-Assessment. To implement horticultural changes as a conservation method the utility must inform the people on how much water is currently used for irrigation and how water consumption can be changed through use of these changes. The best idea seems to be the establishment of a model lawn and garden showing the methods and how they can actually be applied. This visual means conveys the idea much better than written material.

The horticultural changes could result in significant water savings. Conversion to desert landscapes or native scenes as well as adoption of water efficient sprinkling methods by an entire neighborhood could drastically reduce average and peak day use. Deferrment of system expansion and decreases in operating costs would be tangible if these methods were implemented.

10. Public Education

Public education is the linking component of a water conservation program. The consumers of water must know the water situation before they are asked to conserve water. Dispersal of hard data and information is the most efficient method to acquaint the public with a water problem and the possibilities of inadequate supplies in the future. Because water has traditionally been an inexpensive commodity, a change in value judgement is often necessary. Many people do not understand how water is provided for them. An understanding of water systems is essential for conservation methods to take root. At the same time an understanding of how customers' actions affect total usage is necessary.

Technological Feasibility. Presentation of a clear picture of the water supply situation is needed to get people motivated to conserve water. Trends in water use and population growth as well as information regarding water supplies available need to be incorporated into a public education program. The municipality should stress horticultural methods first since the sprinkling use component is where the greatest water savings can be accomplished.

A public education campaign on domestic uses should focus on toilet flushing and bathing. Once the general means of conservation is developed a goal for each water user should be set. This allows the individual to set his sights toward an achievable end. A number of methods to accomplish public education have been developed.

The use of bill inserts such as leaflets and handbooks is one method of gaining exposure. Television and radio announcements, newspapers and contests can also be used to develop a conservation ethic (Flack, 1976). Public school education on water use and conservation is a good means of conveying the idea of wise water use.

Costs of Public Education. The costs involved in a public education program will vary from one location to another and with the type of program that is implemented. Generally, larger municipalities can afford more inclusive information programs. Smaller utilities may be limited to those means that transmit the basic information. Thus, the costs to each utility should be viewed in terms of the need and the resources available.

System Water Savings. The long term success of an education program depends on continuing those methods that seem to work the best. Short term water savings can be expected to be significant and these levels of savings can be maintained if the program is gradually changed with time to feature a variety of methods of conservation. An estimate of 5 percent water savings due to education programs alone can be expected, however, it is not possible to document these as the sole result of an education program. Any usage reduction from conservation is at least partially due to consumer education.

Social and Political Acceptability. Public education programs promote goodwill toward a water utility and are excellent public relations. Development of enthusiasm and interest in water conservation achieves better social acceptance of conservation methods. Political interests are also served by a public education program in that the public becomes more involved in how the utility operates.

Method Assessment. Public education is vital to water conservation programs. Involvement of the public can result in total water use reductions. The type of program and method of implementation is dependent on a community's water use habits and characteristics.

C. WATER AND WASTEWATER UTILITY BENEFITS

Each of the previously discussed water saving methods affects the water and wastewater systems of a municipality. The general results are presented here. Because of the diversity in systems, supply, and costs among communities, reductions in water use will have varying effects on their water and wastewater systems. To determine accurately these affects would necessitate an examination of each municipality's water use characteristics. Some general statements can be made, however. Appendix D shows the affects of scale on treatment costs. The values presented there can be used to calculate savings given the system's size.

Water System Benefits. The most apparent benefit of decreased water use is a decrease in the amount of water production. Most utilities are encountering increasing costs associated with supplying water. The capital costs of acquiring new supplies and the costs of expanding treatment plants and distribution systems are increasing rapidly. The benefits of decreased demand include reduced costs of new water supply and deferred system expansion. These cost savings alone may encourage many utilities to adopt demand reduction measures. Reduced peak demands as a result of conservation methods extend the design life of existing facilities, and this could be a major reason for the implementation of such methods. Increasing costs of operation are also occurring in many utilities. Energy and chemical sludge handling costs would be reduced because of decreased sludge volume.

Wastewater System Benefits. The benefits of water conservation to a utility's wastewater system are more difficult to predict. Those conservation methods which affect only the sprinkling use will have no affect on the wastewater system. Those methods which reduce the domestic component of water use will decrease the sewage flow, but will not decrease the pollutant load. Thus, those wastewater system units which are hydraulically determined will need to handle smaller volumes, but those which are process controlled will need to handle higher pollutant concentrations. To determine the affect of reduced flows and greater concentrations on wastewater treatment facility design, a hypothetical situation was analyzed. It is presented in Appendix E. The results of the analysis give a general idea as to the affects on some of the design and operating requirements of a sewage treatment plant. Actual testing and operation is necessary to confirm these results. The results of flow reduction on wastewater treatment can be summarized as follows:

1. Decreased capital costs due to decreased design volumes for clarifiers.
2. Decreased influent pumping costs (unless the system is gravity feed).
3. Decreased chlorine costs due to smaller amounts necessary for disinfection.
4. Decreased chemical costs for teritiary treatment stages.
5. Increased sludge handling costs due to increased solids production.
6. Increased capital costs caused by additional aeration tank volume requirements.
7. Increased operating costs associated with greater oxygen requirements.
8. Decreased design requirements for sewers.

9. Increased efficiency of pollutant removal in existing plants and lower pollutant discharges entering the stream in both new and existing facilities.

The degree to which the above costs offset one another and the final cost effectiveness would be specific for any one location and could be affected by other operating characteristics in actual plant control. The best judgement of the affects of a water conservation program or wastewater treatment would appear to be decreased capital expenditure and slightly increased operating costs.

CHAPTER IV

PROGRAM DESIGN

In Chapter III each water conservation method was individually evaluated. In this chapter the alternatives have been ranked in relation to one another, and the resultant effects of using combinations of the methods in a coordinated program have been estimated. In addition a brief review of existing conservation programs and a preliminary analysis for a given municipality is presented.

A. METHOD RANKING

Each of the previously discussed conservation methods have both attributes and faults. Table 38 is a synopsis of the methods. The methods tabulated in Table 38 were discussed in Chapters II and III. The first entry of Water Saving Devices (Retro., Plan 1) refers to a utility action plan for providing plastic bottles for toilet tank water displacement and a flow limiting shower valve for existing housing. The next entry refers to a building code plan calling for the specification of shallow trap toilets, flow limiting shower heads and faucet aerators in all new residential construction. The last entry, "Building Code Changes", refers to the specification of air pressure toilets, flow limiting shower heads and faucet aerators in all new residential construction.

Technological Feasibility. The methods were ranked as to whether their desired water-saving functions were performed consistently and whether or not the method was fully developed technologically. Water saving devices for retrofit situations, water use restrictions and leakage reduction were conservation methods considered to be consistent in their performance and essentially

TABLE 38

COMPARISON OF CONSERVATIVE METHODS

Conservation Method	Technological Feasibility Stage of Development	Amount of Water Saved* gpcd	gpd/du	Breakeven Water and Wastewater Price $/1000 Gallons	Relative Rank	Social and Political Acceptance **	Return Flow Implications Relative Effect
Water Saving Devices (Retro.) (Plan 1)	Fully Developed	10.5	42.0	0.03	1	Favorable	Medium
Water Saving Devices (Building Code Plant)	Developed with More to Come	18.0	72.0	0.34	2	Favorable	Medium
Metering	Developed	43.0	172.0	0.69	4	Unfavorable	Great
Water Use Restrictions	Fully Developed	19.2	76.8	-	-	Very Unfavorable	Small
Pricing	Developed	-	-	-	-	Unfavorable	Medium
Horticultural Changes	Developed	6.4	25.6	-	-	Favorable	Small
Dual System Reuse	Developed	89.0	356.0	0.80	5	Neutral	Very Great
Household Recycle	Not Fully Developed	36.0	144.0	4.62	6	Neutral	Very Great
Leakage Reduction	Fully Developed	7.5	30.0	-	-	Favorable	Small

TABLE 38 (continued)

Conservation Method	Technological Feasibility: Stage of Development	Amount of Water Saved*: gpcd	Amount of Water Saved*: gpd/du	Breakeven Water and Wastewater Price: $/1000 Gallons	Breakeven Water and Wastewater Price: Relative Rank	Social and Political Acceptance **	Return Flow Implications: Relative Effect
Pressure Reduction	Developed	2.6	10.4	0.66	3	Favorable	Small
Public Education	Developed	6.4	25.6	-	-	Very Favorable	Small
Building Code Changes (Plan 2)	Not Fully Developed	23.0	92.0	-	-	Favorable	Medium

*Based on a metered use of 128 gpcd, except for metering method where a flat rate use of 172 gpcd was used; 4 persons per dwelling unit.

**See Chapter V for results of survey research on community acceptance of water conservation alternatives.

fully developed. Minor technological improvement might take place in these methods, but for the most part they are fully developed. Water saving devices for new installations is a method already developed and consistent in performance, but major technological advancements in these devices may occur. Metering was considered developed, but new innovations will make this method much more consistent in the amount of savings that is registered. Much attention has been given to alternative pricing schemes recently. The development and improvement of these pricing methods seems imminent. Major improvement in the technology available for horticultural changes, dual recycle systems, pressure-reduction and public education is probable. Building code modifications have not yet been charted by national organizations, and may yet be improved at the local scale. Thus, this method was considered not yet fully developed technologically.

In-house recycle was considered the least fully developed of all the conservation methods due to health and cost questions. Each method was ranked either as fully developed, developed (with some improvements likely) or not yet developed.

Amount of Water Saved. The amount of water saved by implementing each method in Table 38 was calculated on the basis of a metered use of 128 gpcd except for metering and horticultural changes. The water savings for metering was based on 25 percent reduction from a flat rate usage of 172 gpcd to a metered usage of 128 gpcd. The water savings from horticultural changes was based upon a 10 percent reduction in average sprinkling usage. This savings was considered to be conservative. The water savings for use restrictions was based on a 15 percent short term reduction in metered use. A leakage reduction of 5 percent of a total system usage of 150 gpcd was used in calculating the savings for that method. The water saving amounts for the other conservation methods are as justified in Chapters II and III. It can be seen that water savings amounts range from 10 to 356 gpd per dwelling unit.

Breakeven Water and Wastewater Price. The breakeven prices in Table 38 are based on discount rate of 10 percent for 25 years. The ranking of the methods is based upon cost, if known.

Social and Political Acceptance. Each method was ranked on a scale from very favorable to very unfavorable according to the expected public reaction. The ranking is judgemental and needs verification before application in any particular instance.

Return Flow Implications. Ranking of the methods with regard to their return flow implications is also judgemental. The situation visualized in such a ranking was that of low stream flow when sewage treatment plant effluent has more bearing on total stream flow than alluvial drainage. The higher the ranking, the more severe was the decrease in downstream flows.

B. COMBINATIONS OF METHODS

Each method by itself accomplishes a certain level of water savings. Combinations of several methods do not necessarily result in strictly additive savings. Double-counting of predicted water savings can occur and consideration of each water use component and its characteristics is necessary to prevent double-counting. The following sections present estimates of how each method influences the amount of water saved by other methods.

Domestic Water Use. The domestic use component can be reduced by a number of methods. Table 39 gives a synopsis of the possible effects on per capita water savings by combining several methods. The amount of savings for each method was based upon the values given in Table 38. The values in parenthesis represents the savings that would be theoretically accomplished if the methods were added without consideration of possible

TABLE 39

DOMESTIC WATER SAVINGS FROM COMBINATIONS OF TWO METHODS (gpcd)

WATER CONSERVATION METHOD	Water Saving Devices*	Building Code Changes	Household Recycle System	Dual Recycle System	Pressure Reduction	Leakage Reduction	Public Education
Water Saving Devices*	(10.5) 10.5	(28.5) 10.5	(35.5) 33.0	(35.5) 33.0	(13.1) 12.0	(18.0) 18.0	(13.7) 13.7
Building Code Changes**	(28.5) 18.0	(18.0) 18.0	(43.0) 35.5	(43.0) 35.5	(20.6) 19.0	(25.5) 25.0	(21.2) 21.2
Household Recycle Sys.	(35.5) 33.0	(43.0) 35.5	(25.0) 25.0	(25.0) 25.0	(27.6) 27.6	(32.5) 32.5	(28.2) 28.2
Dual Recycle System	(35.5) 33.0	(43.0) 35.5	(25.0) 25.0	(25.0) 25.0	(27.6) 27.6	(32.5) 32.5	(28.2) 28.2
Pressure Reduction	(35.5) 12.0	(20.6) 19.0	(27.6) 27.6	(27.6) 27.6	(2.6) 2.6	(10.1) 10.1	(5.8) 5.8
Leakage Reduction	(18.0) 18.0	(25.5) 25.5	(32.5) 32.5	(32.5) 32.5	(10.1) 10.1	(7.5) 7.5	(10.7) 10.7
Public Education	(13.7) 13.1	(21.2) 20.6	(28.2) 27.6	(28.2) 27.6	(5.8) 5.2	(10.7) 10.1	(3.2) 3.2

* Retrofitting Plan 1

* Building Code Plan 1

duplication of water savings. The values immediately below these represent the estimated total water savings accomplished by the combination of the method listed horizontally and the method listed vertically. These values are based on judgement, in that no precise relationships for calculating combinations of water savings have been developed, but consideration was given to the affect each method had on the other's water use. For example, if water saving shower heads are installed as part of building code changes (Plan 1) and pressure reducing valves are also installed then the resulting total decrease in water use is not the sum of the water saved by each method, but an amount somewhat less than the total. This is so because both methods affect the amount of water used in showers in the same manner, through reduction in the flow rate. Water savings by system leakage reduction and by public education were added directly to the savings of the other methods because the savings from these were thought to be fully additive to the other methods. Combining more than two of the conservation methods in a program would create more complex relationships. The combinations and their resultant water savings would be specific to a community. Analysis of the combined effects would need to be made through simulation of the water use in that community.

Sprinkling Water Use. Methods to reduce the amount of water used for lawn sprinkling are listed in Table 40. The use of pricing schemes and price increases is not included because of the large range of affects that could be encountered, but pricing is effective in reducing demand in conjunction with the other conservation methods. Table 40 shows that large net decreases are possible in the sprinkling component.

TABLE 40

SPRINKLING WATER SAVINGS FROM COMBINATIONS OF TWO METHODS (gpcd)

WATER CONSERVATION METHOD	Metering	Use Restrictions	Horticult. Changes	Household Recycle	Dual Recycle Sys.	Public Education
Metering	(43.0) 43.0	(62.2) 45.0	(49.4) 48.0	(54.0) 54.0	(64.0) 64.0	(46.2) 46.2
Use Restrictions	(62.2) 45.0	(19.2) 19.2	(25.6) 20.0	(30.2) 19.2	(64.0) 64.0	(22.4) 19.2
Horticultural Changes	(49.4) 48.0	(25.6) 20.0	(6.4) 6.4	(17.4) 17.4	(64.0) 64.0	(9.6) 6.4
Household Recycle	(54.0 54.0	(30.2) 19.2	(17.4) 17.4	(11.0) 11.0	(64.0) 64.0	(14.2) 14.2
Dual Recycle System	(64.0) 64.0	(64.0) 64.0	(64.0) 64.0	(64.0) 64.0	(64.0) 64.0	(64.0) 64.0
Public Education	(46.2) 46.2	(22.4) 19.2	(9.6) 6.4	(14.2) 14.2	(64.0) 64.0	(3.2) 3.2

C. DESIGN OF A CONSERVATION PROGRAM

In designing a water conservation program for a municipality several factors are of importance. The price of water to the consumer is important in gauging the response of the water customer. The customer will be much more responsive to some methods at high water prices that at low prices of water service. The amount of water use in the recent past as well as the trend in per capita consumption is important. The peak demand to average day ratios and the average monthly summer and winter usage are needed to determine the magnitudes of the domestic and sprinkling use components. Basic information on the physical and financial aspects of the utility are needed. The population growth rate and the planned land use are necessary to project possible water demands and savings. In each locale these factors and others will determine the potential of a conservation program. These conditions vary from one place to another and each municipality must examine its own situation.

A brief review of existing water conservation programs and an example of what water conservation might achieve for a specific municipality are presented in the following sections.

Washington Suburban Sanitary Commission (WSSC). The WSSC serves over 1.2 million people in Montgomery and Prince George's Counties, Maryland (WSSC, 1974). Its average daily water demand in 1974 was 129.3 million gallons. In October 1971, the WSSC established a multi-faceted conservation program in an effort to reduce wastewater flows. In terms of public education the following steps have been instituted:

1. Mail distribution of customer water-saving handbooks to all customers.
2. Organization of water-saving workshops for property managers.

3. Development and distribution of a conservation handbook for gardening and lawn care.
4. Development of a motion picture on conservation as well as a number of public relations aids.
5. Spot announcements on radio and television.
6. Sponsorship of a "Water-Saving Idea" contest.

In 1972, building code changes were instituted specifying water-saving toilets and shower heads, faucet aerators and pressure reducing valves on incoming lines having a pressure over 60 psi. The most encompassing of all WSSC's projects has been with water saving devices. Door-to-door distribution of plastic bottles for toilet tank displacement and dye pills for leak detection was made to all customers. In addition, shower head inserts for flow control were distributed on request. A special test program on retrofitting devices was also done. The total costs of the program to date are not known, however, a few of the specific costs are listed below:

Program budget - 1972	$ 16,000
Program budget - 1973	20,000
Device Testing Program	105,000
Door-to-Door Device Distribution	191,000
Shower Head Distribution	100,000
TOTAL	$431,000

The water savings from the program are not clear. Total system consumption has continued to rise, but per capita domestic use has decreased. The overall affect has been a positive reaction from the public towards the utility. The program is considered a success and is being continued.

East Bay Municipal Utility District (EBMUD). EBMUD serves over 162,000 residential customers in the San Francisco Bay area. In 1974 average daily consumption was 210 million gallons for the total system. EBMUD has instituted the following public education measures:

1. Distribution of a water conservation handbook.
2. Distribution on request of dye pills for toilet leak detection.
3. Development of conservation material for use in public schools.
4. Production of a film and slide show on water conservation.
5. Development of a demonstration landscape using low water use plants.

EBMUD has also instituted a leak detection program and has reduced the amount of water used in main flushing. Rate studies on straight unit prices and inverse pricing structures are currently being investigated. The cost of the program has been estimated at $50,000 per year (Metcalf and Eddy, 1976). Reduced per capita consumption has been found, but the level has fluctuated considerably. Thus the results are encouraging, but precise figures are quite difficult to obtain. The leak detection program is credited with having saving approximately 3 mgd with only one-third of the system covered.

Denver Water Department (DWD). The DWD serves approximately 525,000 residents within the city and 375,000 residents in the surrounding metropolitan area. The average daily consumption for 1974 was 197 mgd for the total system. The DWD has instituted a public education program designed to gain public awareness and voluntary conservation via the following approaches:

1. Development of a "tips to save water" brochure.
2. Public school presentation on water conservation.
3. Development of an animated color film on water conservation.
4. Spot announcements on radio and television.
5. Distribution of a water news publication to the customers.

A testing facility for water-saving devices is also planned. The costs of the program have been estimated at $50,000 for the years 1973-1975. The production of the color film cost an additional $35,000. The results of the program have been inconclusive, consumption seems to vary with the weather.

A voluntary, followed by a mandatory, program of water restrictions was imposed in the spring and summer of 1977. To date these restrictions on lawn watering, car washing and other outside uses have resulted in significant water savings despite a near record drought year.

Other Conservation Programs. Programs in Pinellas County, Florida; Marin County, California; San Francisco, California; Fairfax County, Virginia; and North Marin County Water District, California, have utilized similar approaches. Results of the programs in these utilities have shown decreased consumption rates proportional with the severity of the measures imposed.

Design Example. The municipality of Lyons, Colorado was chosen as a case example. A preliminary analysis of the conservation methods most appropriate are presented below.

LYONS, COLORADO - A CASE STUDY

The City of Lyons is located in northwestern Boulder County, Colorado. The City owns and operates a 0.6 mgd water treatment facility. The 1975 population totaled 1,152 persons. Average annual precipitation is 17 inches. The average water use for 1975 was 250 gpcd. Average summer and winter use was 310 and 125 gpcd respectively. Four hundred and fifty-three residential taps were served in 1975. There is one water storage facility with a capacity of 0.3 million gallons. Water is obtained through direct flow rights from North St. Vrain Creek and the Colorado-Big Thompson Project via Carter Lake. Residential use is unmetered and the distribution system is quite old with a large number of leaks. Water and wastewater utility bills are $7.00 for water and $3.00 for wastewater per month on a flat-rate basis. Some meters are installed, but billing on a metered basis was discontinued because of complaints from customers of inequitable charges.

Present Water Conservation Program

No formal water conservation program has been instituted. Lawn watering restrictions limiting sprinkling to four hours per day have been imposed for several years. In addition, due to the city's limited raw water supply, developers are required to bring into the system water rights of 1.5 acre-feet of water for every acre of land they develop. System upgrading and expansions are planned in the near future. Water is considered to be the main growth limiting feature of the city.

Preliminary Design

A. Population Growth

1. Population growth in the last few years has been at a rate over 5 percent per year.
2. The population in 1975 was 1,152 people. Table 41 shows the population growth if a rate of 3 percent per year is used.

B. Water Use

1. The 1975 average use was 250 gpcd. Table 41 shows the anticipated water use for the projected populations if this per capita rate of use persists.
2. The average daily usage in 1975 for the winter months was 125 gpcd and for summer months, 310 gpcd.

TABLE 41

POPULATION AND WATER USE PROJECTION FOR LYONS, COLORADO

YEAR	POPULATION*	AVERAGE DAILY USAGE (NO CONSERVATION) MGD	AVERAGE YEARLY USAGE (NO CONSERVATION) MG/YR
1975	1,152	0.288	105.12
1976	1,187	0.297	108.31
1977	1,223	0.306	111.60
1978	1,260	0.315	114.97
1979	1,298	0.324	118.44
1980	1,337	0.334	122.00
1985	1,549	0.387	141.35
1990	1,743	0.436	159.05
2000	2,341	0.585	213.62

* Based on 3% annual growth

3. If the baseline domestic usage figure of 64.0 gpcd is used then the amount of system leakage is:

   $125 - 64 = 61$ gpcd or $\frac{61}{250} = 24.4\%$ of average daily usage.

C. Water Savings Through Conservation Methods

1. Leakage Reduction: If a leakage detection and repair program were instituted in 1977 and the amount of leakage were reduced by approximately 50 percent to 12 percent of system demand then the water savings would be:

   (1,223 people) (61 gpcd) (.5) = 37,301.5 gpd = 13.61 million gallons per year. The cost of this reduction in leakage could be large because many of the existing lines may need to be replaced. However, the leakage must be reduced in the future due to the scarcity of water supply. Figure 7 shows the savings possible by leakage reduction.

2. Metering: Since average monthly usage is 250 gpcd and average winter usage or domestic usage is 125 gpcd, then sprinkling usage is 125 gpcd assuming leakage is the same in the winter and summer. Using Bryson's calculated evapotranspiration lawn watering requirements of 85 gpcd (Bryson, 1972), the amount of overwatering is: 125 gpcd - 85 gpcd = 40 gpcd. Through the use of metering at moderate pricing levels this amount of water could be saved. The yearly savings are plotted on Figure 7 starting in 1979, when a metering program if started in 1977 would be completed. The cost to the utility to install the meters in existing dwelling is estimated at $400 per meter for 481 dwellings or $192,400. After 1978 meters would be paid for by the owner.

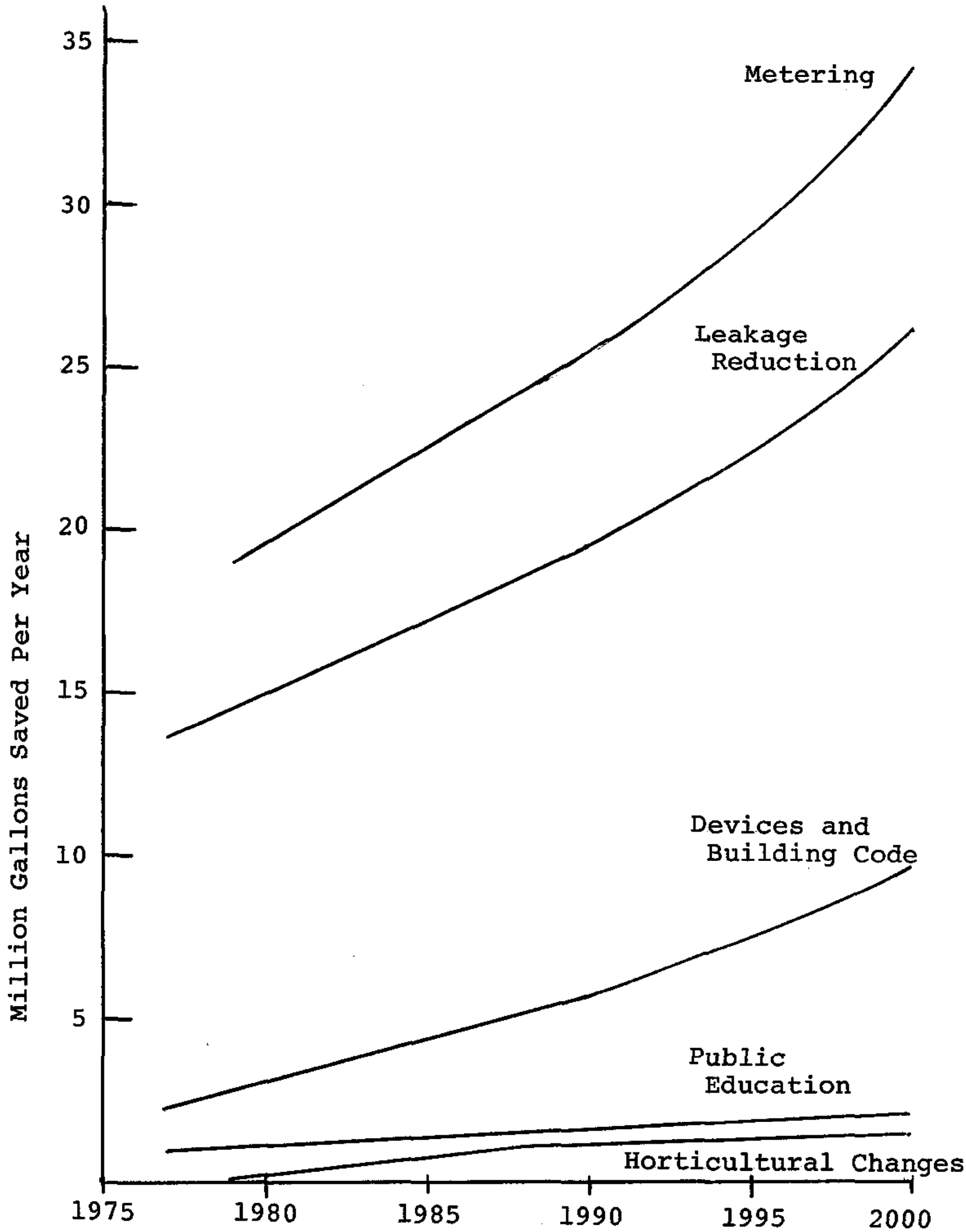


FIGURE 7.
WATER SAVINGS USING CONSERVATION METHODS, Lyons, Colorado

3. Water Saving Devices and Building Code Modifications: Through the implementing of a retrofitting plan using plastic bottles for toilet tank displacement and shower flow reducing valves, a water savings of 6,421 gpd could be accomplished based on the 1975 population and assuming that 50 percent of those obtaining the devices actually install them.

   (10.5 gpcd)(1,223 people)(.5) = 6,421 gpd.

   If at the same time building code modifications calling for the installation of shallow trap toilets, flow limiting shower heads and faucet aerators in all new construction started after January 1, 1978, then the water savings in 1978 would be:

   6421 + (18.0 gpcd)(35 people) = 7051 gpd.

   Figure 7 shows the system savings over time using this combination of methods. The cost to utility would be: $2.00 per device kit x 481 = $962, provided the utility could get the devices at bulk rates. The cost of the building code specifications would be borne by the water users.

4. Horticultural Changes: The provision of a pilot low water using landscape and garden and a public education program in horticultural techniques could possibly save 10 percent of the average sprinkling demand or (0.1) 85 gpcd = 8.5 gpcd. The acceptance of this method would be slow, therefore, a very conservative estimate of savings would show a 2 percent rise in acceptance each year starting in 1979 and leveling at a homeowner acceptance level of 20 percent in 1988. Figure 7 shows the average yearly savings that could be expected on this basis. The peak demand rates would also be greatly reduced using this method. The cost to the utility would be minimal if landscaping and water saving techniques were

developed as a promotion for contractors and manufacturers to demonstrate their services and products.

5. Public Education: In addition to the savings listed in the methods above, a one percent savings in usage, or 2.5 gpcd, might be accomplished solely through educational means.

6. Other methods not considered and the reasons they were not adopted are:

   Home recycle - too costly

   Dual System - not large enough system to be cost effective

   Restrictions - strictly short term affects

   Pressure Reductions - no system data to evaluate

   Pricing Methods - would be very effective, but not enough is known about the city's water use characteristics and price and income elasticities to determine affect on demand.

7. Overall Water Savings: Figure 8 shows the water use savings over time using the methods proposed in combination.

D. Return Flows: The return flows from lawn over-irrigation and wastewater effluent would be decreased by this program. The affects on downstream appropriations is not known.

E. Overall Assessment: A water conservation program for Lyons could include any or all of the methods described above. A more detailed analysis of costs and savings would permit effective decision making as to the program best suited for the municipality. On the basis of this preliminary study, the feasibility of implementing a conservation program in Lyons appears to be good.

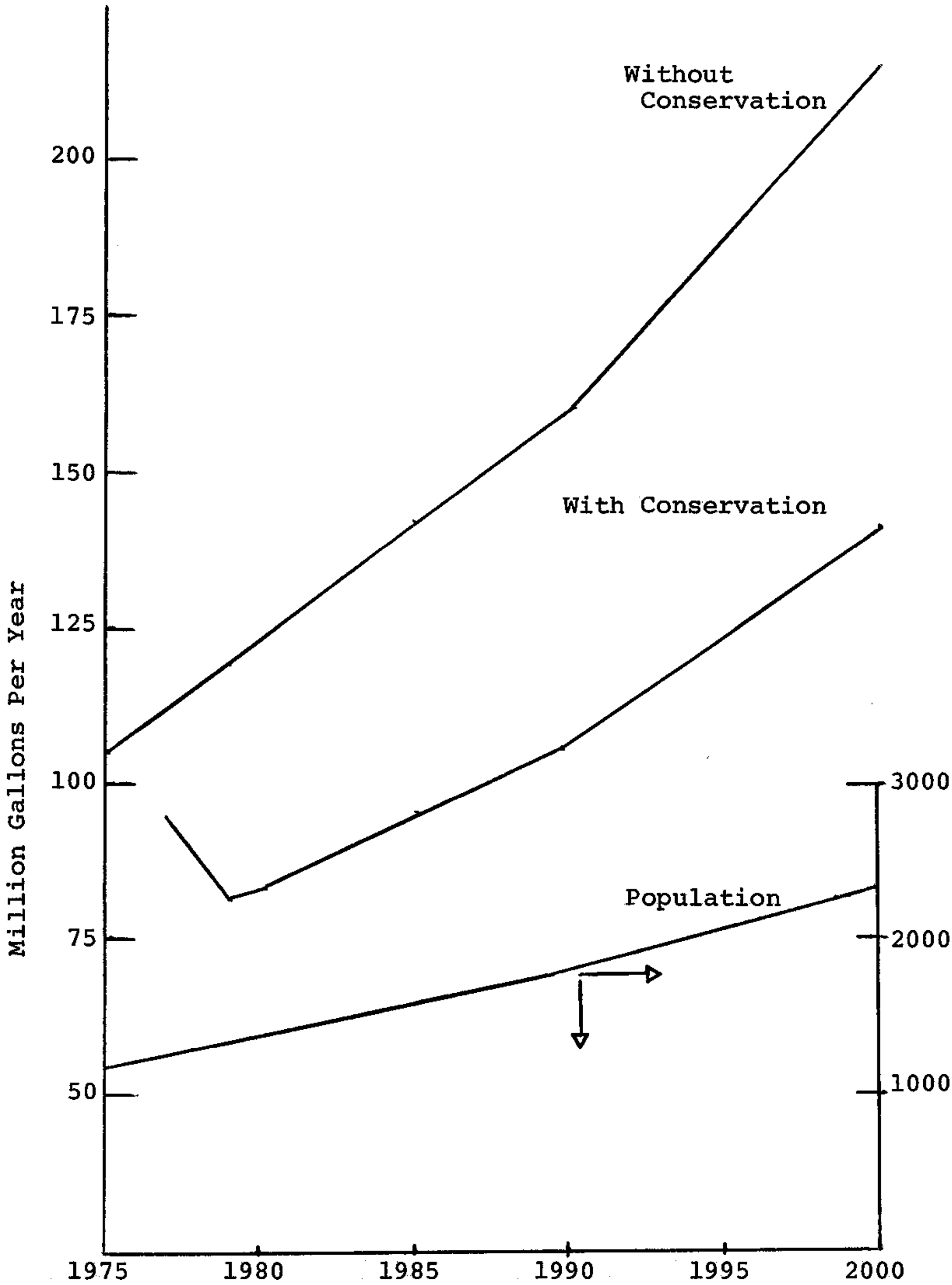


FIGURE 8.

EFFECT OF A WATER CONSERVATION PROGRAM ON WATER USE, Lyons, Colorado

CHAPTER V

DEFINING SOCIAL AND POLITICAL FEASIBILITY*

Each time a project, a proposal, or a new development is moved from the planning to the decision stage, a new or different set of criteria normally takes precedence in attempts to obtain adoption, approval or favorable action. One such criterion at the decision stage is public acceptance. Another is the political costs and benefits to the decision-makers. Such considerations often weigh far more heavily in determining the ultimate adoption or rejection of a project than does the benefit-cost ratio or technological feasibility.

In simple terms, a particular water design may be the best alternative from an engineering standpoint, and it may be shown to have the highest benefits for the least dollar costs of all designs available; yet, it may never be implemented because of low public acceptance or high political costs to the decision-maker.

It is obviously advantageous to be able to define the social feasibility of various alternatives but defining public objectives and levels of acceptance is difficult. Most members of the general public are not politically skilled and only a minority (not more than twenty to twenty-five per cent) have much political influence. The small minority which does have the necessary political skills and political impact to affect decisions varies in the interest and attention they are willing to give. Most politically skilled business and

* By Duane W. Hill, Department of Political Science, Colorado State University, Fort Collins. For full report, see Completion Report No. 81, Achieving Urban Water Conservation, Testing Community Acceptance.

professional persons, for example, devote their time to their business and professional needs. They are selective in the types of political and social issues to which they give attention and effort. This means that most decisions in the political arena have a very narrow popular base beyond the principal decision-maker. This narrow base of support frequently becomes a "built-in" premise of the principal decision-maker. Under stable social and political conditions, the average decision-maker need only satisfy, convince, cajole, or worry about a small minority. The major exception to the pattern occurs under circumstances of social or political instability. Even though such instability is the exception rather than the rule, conditions of social and political volatility can wreak havoc with the political decision-maker's world.

Estimating Public Acceptance

The traditional methods for estimating public acceptance have generally been of two types: (1) official and non-official intuitive "seat-of-the-pants" guesswork; or at best, questioning persons whom the decision-makers believe to have influenced; and (2) polling the general public. The former may work, but it is a risky venture. The latter tells the observer little beyond the preferences and opinions of the members of the general public. Little information is obtained about respondents' direction of probable action but this is vital in estimating public response to alternative programs of action.

Survey research has become the traditional means for developing estimates of probable public reaction. But, surveys usually involve bulky questionnaires and heavy personnel costs if they are competently administered to obtain valid and trustworthy results. Indeed, social surveys are far more costly in terms of money, paid interviewer time, respondent time consumption, analytical costs, and even curiosity costs than most professionals care to admit or even recognize. Further, long survey schedules result in interviewee fatigue that lowers data quality. Large schedules have been the bane of social science qua science efforts. One of the major objectives of the work completed on the project on which this chapter is based, was to test items in a multiple community cross-cultural context in order to reduce the number of items (Snodgrass, 1977). Briefly, the goal was to develop a survey instrument on water conservation of sufficiently small size to enable data collection by a doorstep interview. A second objective was to develop an analytical model which would generate reliable and valid estimates of the acceptable and non-acceptable water conservation alternatives within a reasonable margin of error.

To reach these two objectives heavy emphasis was placed upon collection of relevant attitudinal data on water conservation alternatives, and to develop the analytical model in a manner which would permit reducing the number of questionnaire items to a minimum. Because attitudes have magnitude and direction they lend themselves to vector analysis such as factor analysis. Hence, the analytic model developed for test purposes employed a Q-Factor design. Most factor programs employ a regression sort of the data (R-Sorts). An R-Sort generates independent factors, each factor being composed of closely clustered regression lines. Machine output from an R-Sort includes a matrix which gives the correlation of each variable with each of the other variables. It also includes a factor loading matrix which gives the correlation between each variable and each independent factor. Another matrix of factor scores on an R-Sort specifies the involvement of each person with each factor. The higher the score the greater the involvement.

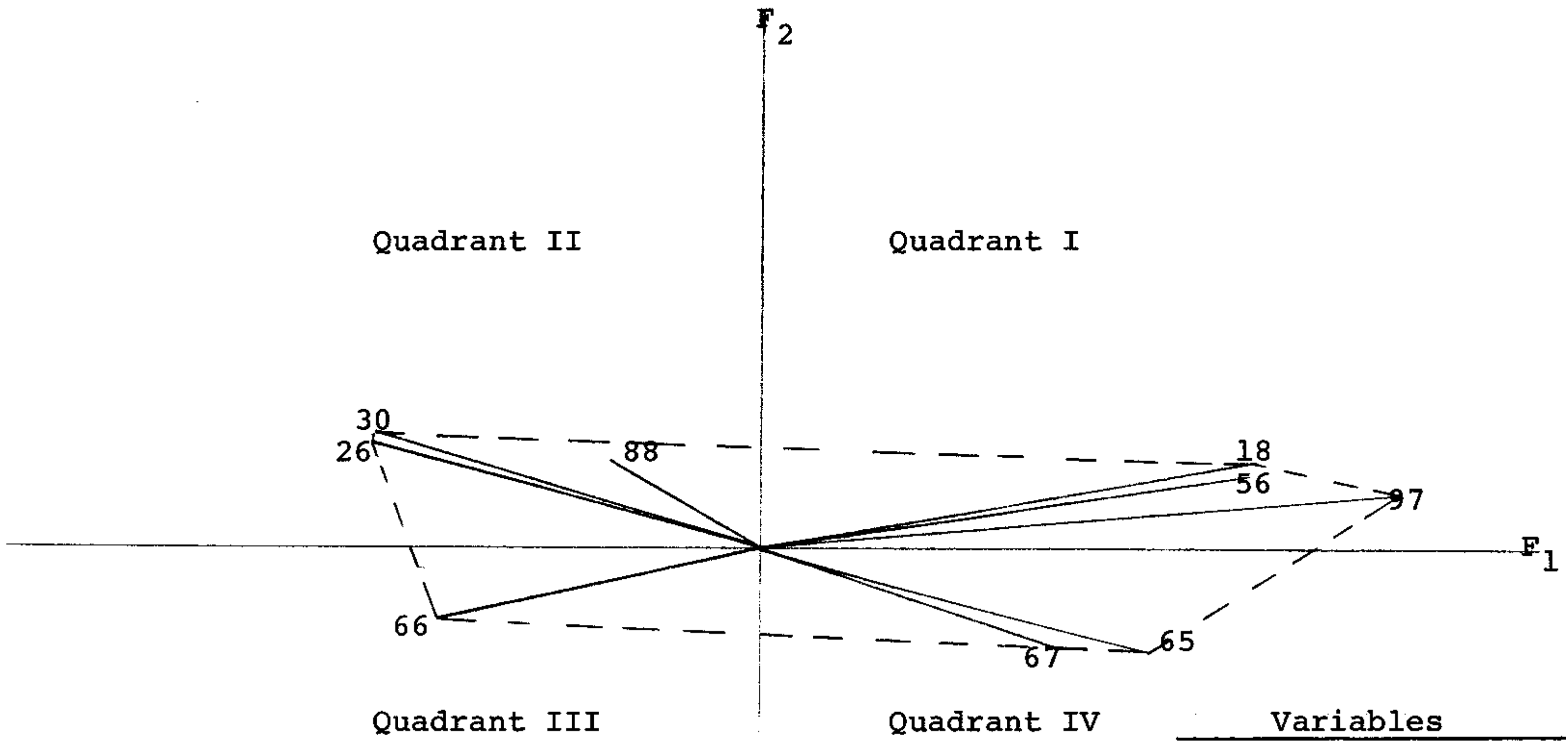
The Q-Sort Model

A Q-Sort is the same as an R-Sort except that the R-Sort data input matrix is inverted, that is, the matrix is rotated 90 degrees, turning persons (cases) into variables and variables into cases. The important feature of the programmed Q-Sort is that the involvement of the variables with each factor is measured by the factor score, thus giving an accurate reading of involvement with the factor in which it is clustered. This provides far harder data than that provided by the correlations generated in the R-Sort. Q-Sort factor scores provide quite accurate indicators of the extent of involvement of a particular variable with a distinctive set of related community characteristics that are independent of other characteristics as specified by the program.

Q-Sort also provides factor scores or distance measures among the variables themselves yielding what is called factor space (Rummel, 1966). The linear relationship between the variables and the factors depends on the total variance accounted for by a factor. The important point, however, is that factor scores can be employed to determine the independence between variables as specified by members of the community. The latter capability provides much greater power of explanation than does regression correlation.

Angular intervals between vectors and between clusters of vectors (factors) indicate correlation and degrees of independence. The degree of independence of a particular variable from another variable provides the observer with some indication of the degree to which the two variables interact with each other. The smaller the angle produced by the row vectors the greater the correlation between variables. A 45^{o} angle would indicate a correlation coefficient of 0.50 whereas a 90^{o} angle would indicate no correlation and no relationship between variables, that is complete independence. Between 90^{o} and 180^{o} an inverse relationship builds to a perfect inverse relationship at 180^{o}.

Figure 9 is a graphical display of the Q-Sort analysis using data collected from the survey of Lafayette, Colorado. The axis lines forming 90^{o} angles are the factors, in this case, Factors 1 and 2. The broken line connecting the variable points mark the factor space boundary. The lines



Variables

18. overpopulation as problem
30. poor management causes water problems
56. familiarity with legal restrictions
65. familiarity with re-use
66. familiarity with demand metering
67. familiarity with horticultural options
88. family uses more water than necessary
97. degree of affective loading

FIGURE 9: COMMUNITY FACTOR SPACE EXAMPLE

Source: Snodgrass, 1977

extending from the origin of the two factors to the variable points, called the row vectors, show the magnitude of the variables given. The longer a variable's vector the greater the magnitude of that variable. In the example given it is obvious that variable 97 has the greatest magnitude of the variables displayed. Thus, in its cluster (quadrant I) it is the more influential in relation to the other two variables, 18 and 56. The angle between any two vectors provides the correlation between the variables. Thus, in quadrant I variable 18 has an extremely high correlation to variable 56 while variable 97, although still highly correlated to 18, is less so than is variable 56.

Demonstrations of Outcomes from Procedures

To provide an adequate demonstration of the outcomes which can be obtained, sample data obtained from two Colorado communities will be used. The two neighboring Boulder County communities are Lafayette and Louisville; both have experienced severe water problems in recent years; both are established rural towns north of Denver which are experiencing severe urban growth pressures (Snodgrass, 1977).

Data was collected from 10 percent randomized household samples of each community, selection of each household's respondent was also by a process of randomization from the total number of residents within the household who were 18 years of age and over. Survey questionnaires were designed to determine familiarity with conservation alternatives, rankings of community problems, preferences and attitudes toward water conservation alternatives, perceptions of and attitudes toward community leaders and the city's water management, socio-economic characteristics of the respondents themselves and their attitudes toward water problems and possible solutions.

Public views on significant issues as determined by the surveys of the two communities are given in Table 42 with regard to; Part A. National and Local Problems, Part B. Familiarity with Water Conservation Alternatives

TABLE 42

PUBLIC VIEWS - LOUISVILLE AND LAFAYETTE, COLORADO

Percentage of Those Interviewed

Part A.	**National and Local Problems**	
a.	Rank Inflation High as Problem	58%
b.	Rank Air Pollution High As Problem	48%
c.	Rank Crime and Violence High as Problem	45%
d.	Rank Water Problem High as Local Problem	43%
e.	Rank Water Pollution High as Problem	40%
f.	Rank Water Shortage High as Community Problem	39%
g.	See Water Problem as Constraining Way of Life	37%
h.	Rank Unemployment High as Problem	36%
i.	City Administrators at Fault for Water Problem	36%
j.	Rank Over-Population High as Problem	34%
k.	Rank Drug Addiction High as Problem	26%
l.	Rank Poverty High as Problem	18%
m.	Rank Environmental Conditions High as Problem	12%
Part B.	**Familiarity With Water Conservation Alternatives**	
a.	Legal Restrictions	95%
b.	Metering	88%
c.	Waste Control	80%
d.	Pricing Mechanism	75%
e.	Growth Restrictions	70%
f.	Horticultural Techniques	67%
g.	Re-Used Water for Irrigation	46%
h.	Water Saving Technology	44%
i.	Re-Used Water for Household Use	43%
j.	Seasonal Pricing	41%
h.	Condemnation of Agricultural Water	28%
i.	Horticultural Limitations	23%

TABLE 42 (Continued)

PUBLIC VIEWS - LOUISVILLE AND LAFAYETTE, COLORADO

Percentage of Those Interviewed

Part C.	Preference for Alternatives	
a.	Waste Control	48%
b.	Growth Restrictions	29%
c.	Legal Restrictions	28%
d.	Horticultural Techniques	28%
e.	Re-Used Water for Irrigation	23%
f.	Water Saving Technology	18%
g.	Re-Used Water for Household Use	12%
h.	Horticultural Limitations	10%
i.	Pricing Mechanism	8%
j.	Seasonal Pricing	8%
k.	Demand Metering	4%
l.	Condemnation of Agricultural Water	3%

Source: Snodgrass, 1977

and Part C. Preference for Alternatives. The values show that the populations of Louisville and Lafayette had the greatest concern about inflation at the time the survey was administered. Although specific environmental problems such as air and water pollution, as well as water supply problems generally, are ranked rather high by the community populations, a low score on environmental conditions (item m) would seem to lower the probability that environmental problems have a position of importance in the general public's scale of concern. However, it should be noted that issue salience, such as these, is normally abysmally low for 70 percent of most American community populations.

Close examination of the frequency distributions of the responses leads to the conclusion that the general publics in these two communities are similar to other communities in that they simply do not have perceptions about problems which do not intrude upon their lives. However, the rankings do indicate the problems those publics would stress if such problems did intrude. In relation to this, it is significant that the values on water conservation alternatives reveal public familiarity of over 50 percent for nearly half of them and that percentages on all of them are quite high.

One can conclude that these communities are quite aware of a variety of water conservation possibilities. With few exceptions, too, it is notable that preferences for conservation alternatives tend to be low despite the generally high familiarity with such alternatives. In addition, the relatively high score given to improvement of facilities as a solution to water problems indicates that the general publics in Louisville and Lafayette are looking beyond conservation for solutions to their water problems. They may be looking to technology rather than conservation to solve their problems. Other data not displayed here supports this observation; namely, that the publics perceive their systems to be leaky and inadequate. It is important to note,however, that those general public preferences which were ranked the highest by the total population were the same as those found to fall within public acceptance in the Q-Sort vector analysis (given later). This would seem to provide additional strength to the viability of these particular alternatives in these communities.

The above demonstration illustrates how water agency management and personnel can obtain general orientations and preferences through survey research of their constituency from frequency distributions and associated, simple statistical tests. Yet, it must be remembered that this supplies few or no reliable indicators of directions communities may take or what the community policy may be. That is due to the simple fact that most people are never involved in community decisions and remain largely innocent on community issues. It is therefore essential for the water agency to identify the decision-makers and the portion of the public who have the political skills and the willingness to invest efforts to affect decisions. Q-Sort analysis provides a means for factoring out the actives and the effective influentials in the community, and thereby identifying the directions such persons will take and the policy alternatives they will support.

Evaluating Acceptable Alternatives

Table 43 gives the variables closest to vector Y, the action variable (the vector representing those who are the most active in community affairs). The lower the distance the more intermingled the variable is with the effective community action pattern. Those vectors (variables) falling close to the action variable can be considered within a community acceptance zone because those people with the clout are the ones who project the effective action.

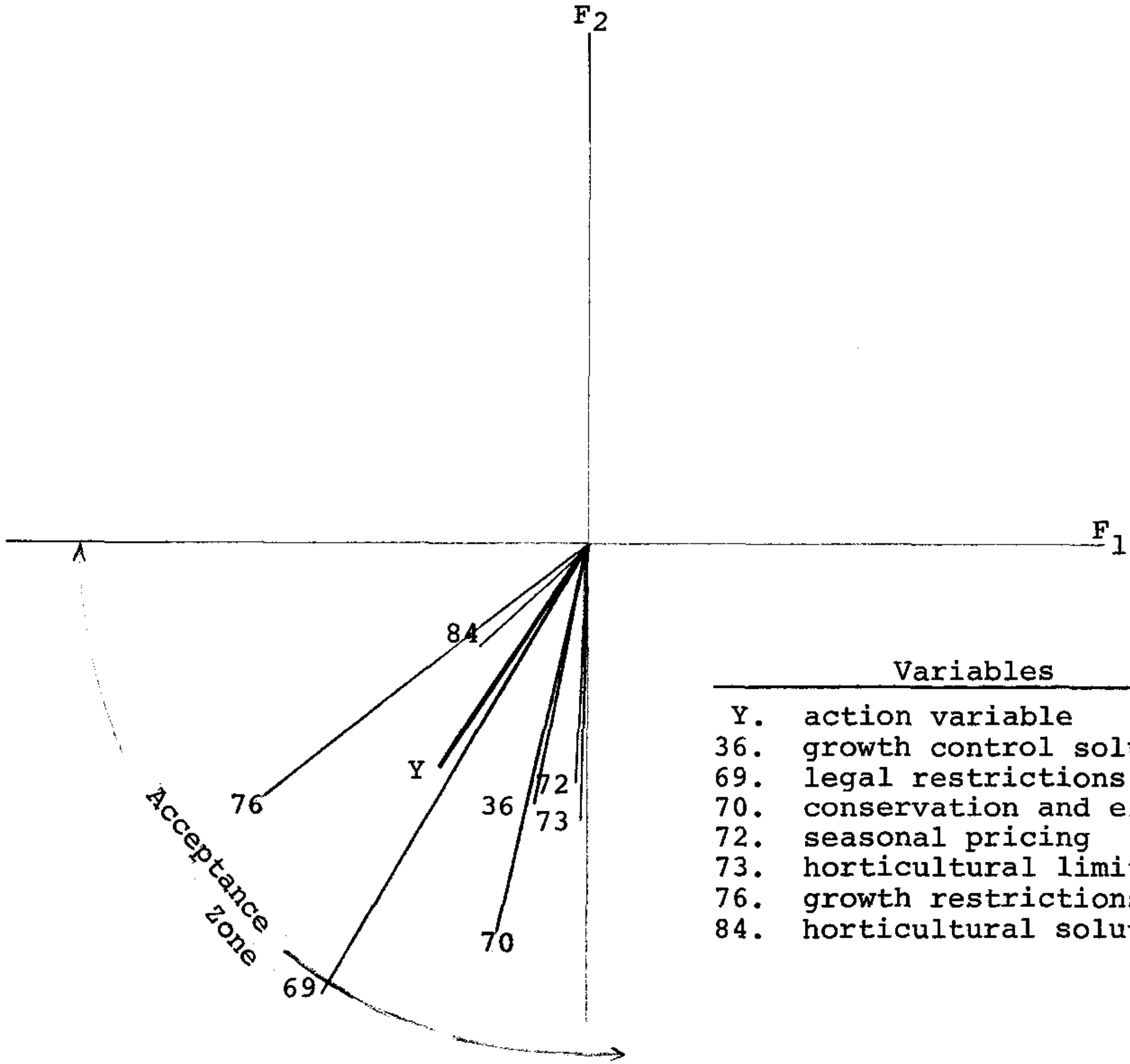
In Figure 10, the vectors representing various alternatives are shown in Quandrant III, in their magnitude and alignment with the Action Vector (Y). All of these can be considered acceptable in that they are

TABLE 43

WATER RELATED VARIABLES CLOSELY RELATED TO THE EFFECTIVE ACTION VARIABLE, Y

Variable	Distance Limits
Preference for Horticultural Limitations	1.48
Economic Solution for Water Problems	1.77
Familiarity with Metering	1.86
Issue Salience	1.87
Population Growth as Cause of Water Problem	1.87
Water Shortage as Environmental Problem	1.93
Preference for Growth Restrictions as a Solution	1.94
Familiarity with Metering	2.08
Preference for Metering as a Solution	2.20
Insufficient Water Supply as Cause of Problem	2.22
Preference for Legal Restrictions	2.27
Does Not Believe That Colorado Has Enough Water	2.28
Familiarity with Condemnation of Agriculture Water	2.28
Perceives Service Problem in the Community	2.29

Source: Snodgrass, 1977



Variables

Y. action variable
36. growth control solution
69. legal restrictions on water use
70. conservation and eliminate waste
72. seasonal pricing
73. horticultural limitations
76. growth restrictions
84. horticultural solution

FIGURE 10: WATER CONSERVATION ALTERNATIVES IN ACCEPTANCE ZONE
Source: Snodgrass, 1977

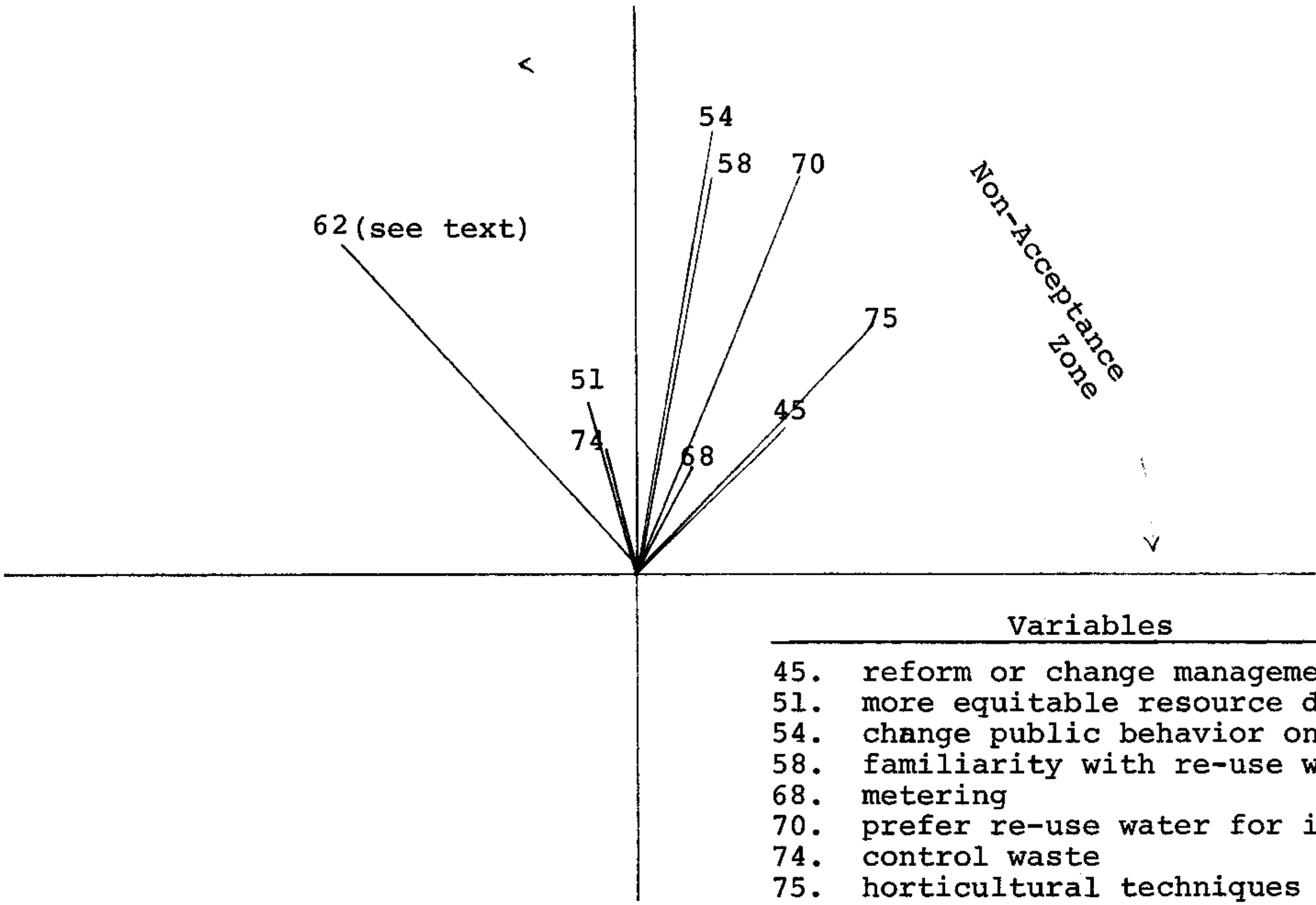
associated with the actives in the community. Their magnitude represents their strengths and their alignment with the Y vector represents the correlation with possible implementation. Growth restrictions, legal restrictions on water use, horticultural techniques and, to a lesser extent, metering and pricing mechanisms, are three alternatives that show considerable viability.

It is possible to conclude from the two analytical attempts conducted thus far that orientations, viewpoints and opinions exist in Lafayette and Louisville which support the conclusion that the communities recognize or acknowledge the existence of a water problem and perceives water conservation as a worthy solution. Obsiously the data indicates the population growth is perceived as the major cause underlying water problems and that the alternatives of growth restrictions and legal restrictions on water use are perceived as viable conservation solutions. However, there does seem to be evidence of a base for more innovative types of conservation alternatives, especially in relation to horticultural techniques, economic solutions, and to a lesser extent, re-using water. Hence, the acceptance zones in the communities appear receptive to conservation in general and the alternatives specified above.

Estimating Non-Acceptance

Conversely, those variables lying at the greatest distance from the community action vector can be projected as non-acceptable to the community under stable conditions. The most unacceptable would be inversely related. They would be at or near 180° from the action vector, Y. This, of course, involves use of strict mathematical logic which often fails to conform to human behavioral norms.

Nevertheless, based on the results of this analysis, in the non-acceptance zone water problems are defined in terms of inequitable distribution of the resource, (see Fig. 11). Within the non-acceptance zone scapegoating tendencies also seem evident; to wit, blaming the water problem on



Variables

45. reform or change management
51. more equitable resource distribution
54. change public behavior on waste
58. familiarity with re-use water
68. metering
70. prefer re-use water for irrigation
74. control waste
75. horticultural techniques

FIGURE 11: WATER CONSERVATION ALTERNATIVES IN NON-ACCEPTANCE ZONE
Source: Snodgrass, 1977

the city fathers and their governmental kin. Poor urban management lies near the non-acceptance zone. Litter, trash and solid waste are a primary environmental problem, possibly because it is sufficiently obvious and obtrusive to impinge on the human consciousness. In addition, supply is perceived as the nature of the water problem which relates to a certain segment of the American population which views shortages solely as a function of supply.

As might be expected, solutions falling within or near the non-acceptance zone include: more equitable resource distribution; demand for changes in public behavior on the ground that the public is wasteful and waste is one root of the water problem; perceiving change of management and/or reform of management as a solution to the water problem; preference for metering; preference for waste control; and to a lesser extent; preference for horticultural techniques, but not limitations, which is near the acceptance zone. Also, this non-acceptance pole is familiar with re-used water for irrigation and expresses a preference for reused water for irrigation as a solution to water problems.

Community familiarity with system waste falls outside both the acceptance and non-acceptance zones, and has considerable length. Waste is blamed on the public in general and the government officials who are perceived as somewhat negligent about upgrading a faulty and leaky system.

This pole registers dissatisfaction with the community by indicating a high preference to migrate. This pole is also critical of its community leadership and demands reform of the city administration.

All of the items falling within the non-acceptance zone are projected by the logic of the research model to be poor candidates for acceptance, even those that are the favorites of the general community but fall within the zone. Again, the reason for their non-acceptance despite their general popularity is that they do not fall within the action zone. This should be what agency leaders and lieutenants want to know. The Q-Sort analysis of survey data can thus project both acceptable (feasible) alternatives as well as unacceptable or non-feasible ones (even though generally popular).

Editors Note:

Bibliography for Chapter V is listed separately at the end of this chapter because it deals mainly with the survey research issues discussed and not with the water conservation policies and issues as listed in the general bibliography at the end of this handbook following Chapter VI.

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CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Rising water use rates and declining availability of water resources in many regions are making demand modification an important part of water and wastewater service. Increasing treatment costs and energy costs intensify interest in those methods that reduce urban water demand.

The feasibility of implementing water conservation programs appears to be good. A number of water conservation techniques have been suggested. Each utility must decide on the degree and type of conservation program to be implemented. Water saving devices were found to be technologically well developed. Devices were shown, in most cases, to be cost effective even at low water and wastewater prices, however, the amount of monetary savings to the homeowner is low in relation to the magnitude of other household costs. Increasing water service prices will make these devices more attractive. Utility provisions of retrofitted devices that modify existing plumbing fixtures and adoption of building code modifications that specify low water using fixtures in new residences appear to be feasible in many instances.

Technologically home recycle systems were generally found to be in the development stage. Most recycle systems have problems that need to be worked out and there are questions regarding health safety that need to be dispelled. Most of the home recycle systems on the market were found to be costly and would probably be feasible only in areas having severe water supply and/or wastewater disposal problems.

Dual supply systems were found to be feasible where a large number of users exist and where sprinkling demands are high. Treatment technology is sufficiently advanced to permit the recycling of renovated "grey" wastewater to residential users. Dual systems are cost effective at moderate to high water and wastewater prices.

Pressure reduction is a technique that saves water with little or no customer inconvenience as long as minimum pressures of about 40 psi are maintained. The technology for pressure reduction and the guidelines for implementing this method have been developed.

Metering is highly effective in reducing sprinkling demands and may reduce domestic usage. Peak demand reductions appear to justify the installation of meters in growing utilities due to the deferrment of facility expansions. Metering was found to be cost effective even at low water and wastewater prices if costs of installation are reasonable, i.e., less than $500 per meter.

Pricing methods were not examined in great detail, but appear to be the key for customer adoption of other conservation methods. Greater emphasis on this method as a demand modification tool appears possible. One of the great needs is knowledge of the elasticity of demand for various categories of usage.

Horticultural changes were found to be an effective means of reducing lawn sprinkling demands. Many landscaping and watering systems have been developed that are capable of using less water more efficiently than current practices. The amount of water savings depends on the degree to which the public will accept horticultural changes and suggests conservative estimates of the water savings that would result.

Water use restrictions were examined and found to be effective in those cases where the public perceived a real scarcity of water. Lawn sprinkling restrictions over prolonged time periods may lose their effect.

Public education was found to be highly developed in several utilities. Use of the media and prepared materials is effective in making people aware of the need to avoid waste of water. Multifaceted programs have been instituted by many utilities with at least partial success in each.

An example of how a water conservation program can be implemented in a small town was presented. An integrated program was examined and found to be effective, even for a small water system. Water demand reductions of 35 to 40 percent were found to be possible through implementation of a combination of water conservation methods.

Recommendations

There is a need for a testing facility for water saving devices and recycle systems. Establishment of such a facility would permit verification of manufacturers' claims of the reliability and operation of the devices.

Precise figures on the effectiveness of many of the conservation methods are not available. Research and testing in the field of the methods individually and in combination should be accomplished.

The implementation of metering, building code modifications and public education is recommended for every utility's plan of operation. These methods advocate and result in more efficient use of water and help develop a conservation ethic among water users.

The use of pricing schemes, recycle systems, horticultural changes and water-saving devices should be examined as to their applicability. Much more data is needed on price and income elasticities of demand for various categories of uses.

Water use restrictions do not appear to be effective as a long-term water conservation method, but are effective as a contingency method when supplies are short.

Survey research using a door-step interview and a computerized Q-Sort analysis can estimate a community's attitudes and perceptions relative to water conservation and other issues. The results can give a good indication of the alternatives that are generally favored by the community but more importantly, can identify those water conservation alternatives that are implementable because they are acceptable to those in the community who are active in the community or have political clout.

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APPENDIX A

1. COMMERCIALLY AVAILABLE WATER SAVING DEVICES

2. LABOR COSTS FOR INSTALLATION OF PLUMBING DEVICES AND METERS.

TABLE A-1

COMMERCIALLY AVAILABLE REDUCED VOLUME WATER CLOSETS

Manufacturer	Gallons Per Use	Gallons Saved Per Year	Cost ($)
American Standard	3.50	10,950	72.10
Borg-Warner	3.50	10,950	52.50
Briggs	3.50	10,950	N.A.
Crane	3.50	10,950	65.95
Eljer	3.50	10,950	85.66
Gerber	3.50	10,950	N.A.
Kohler	3.50	10,950	77.49
Mansfield	3.50	10,950	N.A.
Universal-Rundel	3.50	10,950	42.75
Water Control Prods.	2.50	18,250	60.00

N.A. = Cost Not Available
Average Cost Shallow Trap Toilet = $66.08
Cost Air Pressure Toilet = $60.00

TABLE A-2

COMMERCIALLY AVAILABLE WATER CLOSET VOLUME REDUCERS

Manufacturer	Gallons Per Use	Gallons Saved Per Year	Cost ($)
Ecology Plus	4.00	7,300	3.99
Energy Recovery Sys.	3.00	14,600	5.73
Harbison Industrial	2.50	18,250	5.99
HopCo	4.00	7,300	2.00
JKW 5000	4.00	7,300	N.A.
Metropolitan Co.	2.50	18,250	4.95
Ny-Del	3.50	10,950	3.68
Ramsey & Co.	2.50[a]	9,125	4.00
Sink-Bob	2.50[a]	9,125	5.00

[a]Dual flush: 2.5 for liquid flush and 5.0 for solid flush
N.A. = Cost Not Available
Average Cost Dam Devices = 4.39
Average Cost Dual Flush Devices = 4.50

TABLE A-3

COMMERCIALLY AVAILABLE SPECIAL WATER CLOSET SYSTEMS

Manufacturer	Reduction Method	Gallons Per Use	Gallons Saved Per Year	Cost ($)
Blankenship Research	Incineration	0	36,500	500.00
Clivus Multrum	Composting	0	36,500	1600-2000
Colt Industries	Vaccum	0.38	33,725	N.A.
Crysler Corp.	Oil Recycle	0	36,500	N.A.
Ecolet	Composting	0	36,500	600.00
Microphor	Compressed Air	0.5	32,850	300.00
Monogram	Oil Recycle	0	36,500	3020.00
Pureway Bioflow	Chemical	0	36,500	289.00
Safeway	Vacuum	0.5	32,850	150.00
Thiokol	Oil Recycle	0	36,500	N.A.

N.A. = Cost Not Available

TABLE A-4

COMMERCIALLY AVAILABLE REDUCED SHOWER FLOW HEADS AND VALVES

Manufacturer	Gallons Per Minute	Gallons Saved Per Year	Cost ($)
American Standard	4.0	5,840	4.00
Beacon Valve	3.0	11,680	N.A.
Crane	3.0	11,680	5.25
Dole	4.0	5,840	N.A.
Ecological Water	2.5	14,600	12.95
JKW 5000	3.5	8.760	N.A.
Kohler	3.0	11,680	22.50
Minuse System	0.5	26,280	N.A.
Moen	3.0	11,680	8.50
Noland	3.0	11,680	N.A.
Ny-Del	2.5	14,600	1.59
Richard Fife, Inc.	2.5	14,600	4.95
Sloan Valve	3.5	8,760	N.A.
Speakman	3.6	8,176	N.A.
Wrightway	2.5	14,600	N.A.

N.A. = Cost Not Available
Average Cost (Heads) = $14.65

TABLE A-5

PLUMBING LABOR COSTS (1976)

Contractor	Cost Per Hour
Bell Plumbing & Heating	$22.40
Midwest Plumbing	22.00
ABC Plumbing	18.00
Bluebird Plumbing	23.50
A-1 Plumbing	19.00
Average	$21.00

Installation Costs: Toilet = 1.5 Hours @$21.00/hour = $31.50
Faucet = 0.5 Hours @$21.00/hour = $10.50
Shower Head = 0.5 Hours @$21.00/hour = $10.50

TABLE A-6

METERING COSTS

Item	Bryson, 1972	This Study, 1976
3/4" Meter With Yoke	$66.60	$76.00
3/4" Copper Piping	12.00	17.00
External Pit	42.60	50.00
Labor	178.80*	236.00**
Total	$300.00	$379.00

*Based upon estimate for meter installation and a small amount of service line repair.

**Transformation of 1972 estimate to 1976 labor costs based upon 32% wage increase (Engineering News Record, December 1972 & 1976).

APPENDIX B

1. ASSUMPTIONS MADE FOR COST EFFECTIVE ANALYSIS
2. ANALYSIS USING SHALLOW TRAP TOILETS

ASSUMPTIONS MADE FOR COST EFFECTIVE ANALYSIS

A. Water Saving Devices (see Table, page 219)

1. Cost to repair at end of 15 year life: Oil Recycle Toilet - $800.00

2. Retrofitting: Age of toilet is 10 years: salvage value at year 25 of replacement - $45.00.

B. Wash Water Recycle

Installed Cost=$540 O&M Cost=$45.50/YR Life=15 YR

Salvage=$100 Repair at 15 YR=$250

Water Savings=23% of total in-house use

=.23(64)=15gpcd=21,491 gal/yr

C. Metering

Total Installation=$379/meter O&M Cost=$1.71/YR
Life=25 YR
See Appendix A for costs

No Salvage

Water Savings=25% of unmetered use

=0.25(172)(4)(365)=62,780 gal/yr

D. Pressure Reducer

Installed Cost=$22.00 O&M Cost=$0/YR Life=15 YR

No Salvage Value

Water Savings=10% of shower and faucet use

=0.10(26)(4)(365)=3,796 gal/use

WATER SAVING DEVICES

Devices	Materials Cost	Labor Cost	O & M Cost	Life (Yr)	Salvage Value	# Units Per House	Water Use Per Yr (Gal)
Air Pressure Toilet	$ 60.00	$31.50	$10.00*	25	$30	2	18,250
Oil Recycle Toilet	3020.00	31.50	40/yr	15	150	1	0
Dual Flush Device	4.50	0	2/15 yr	15	0	2	27,375
Water Dams	4.39	0	0	25	0	2	29,200
Plastic Bottles	0.15	0	0	25	0	2	32,850
Regular Faucet	10.00	10.50	0	15	0	2	7,300[a]
Faucet Aerator	2.00	0	0	15	0	2	3,650[a]
Regular Shower Head	10.00	10.50	0	15	0	2	29,200
Reduced Flow Shower Head	15.00	10.50	0	15	0	2	17,520
Reducing Valve Shower	1.50	0	0	15	0	2	17,520

*every 5 years

[a]assuming 10 gpcd is used volumetrically

EXAMPLE OF COST-EFFECTIVE ANALYSIS
USING SHALLOW TRAP TOILETS

A. Assumptions and Abbreviations (see Table, page 221)

2. Abbreviations Used in Analysis

I.C.R.T. = Installed Cost of Regular Toilet

C.R.F. = Capital Recovery Factor

O.M.C. = Operation and Maintenance Cost per Period

S.P.P.W.F. = Single Payment Present Worth Factor

S.V.R.T. = Salvage Value of Regular Toilet (25 yrs old)

S.F.D.F. = Sinking Fund Deposit Factor

A.C.R.T. = Annual Cost of Regular Toilet

A.C.S.T. = Annual Cost of Shallow Trap Toilet

I.A.C.N.I. = Increased Annual Cost New Installation

W.S. = Water Savings

R.T.W.U. = Regular Total Water Use

S.T.W.U. = Shallow Trap Water Use

B.P.N.I. = Breakeven Price New Installation

A.C.R. = Annual Cost for Retrofitting

I.C.S.T. = Installed Cost of Shallow Trap Toilet

S.V.S.T. = Salvage Valve of Shallow Trap Toilet (15 yrs old)

I.A.C.R. = Increased Annual Costs Retrofit (25 yrs, 15 yrs)

B.P.R. = Breakeven Price Retrofit

WATER SAVING TOILET

Type	Materials Cost	Labor Cost[a]	O & M Cost	Life (Yr)	Salvage Value	Toilets Per House	Water Use Per Yr (Gal)
Regular	$60.00	$31.50	$5.00 every 5 yr.	25	$30	2	36,500
Shallow Trap	$66.08	$31.50	$5.00 every 5 yr.	25	$30	2	25,550

[a]See Appendix B for explanation of labor cost computation.

2. Abbreviations (Continued. . .)

U.S.P.W.F. = Uniform Series Present Worth Factor

S.P.C.A.F. = Single Payment Compound Amount Factor

B. Breakeven Price of Water and Wastewater (New Installation)

1. Deriving annual costs over 25 years at various interest rates

a. Regular Toilet:

$$\text{Annual Cost} = (ICRT)(CRF_{i,\ 25y}) + (OMC)(SPPWF_{i,5y}) + (OMC)(SPPWF)_{15} + (OMC)(SPPWF_{i,\ 20y})\ (CRF_{i,\ 25y}) - (SVRT)(SFDF_{i,\ 25y})$$

i=5%, ACRT=$91.50(0.07095)+[$5.00(0.78353) +$5.00(0.61391)+$5.00(0.48102)=$5.00(0.37689)] 0.07095-$30.00(0.02095)=$6.66/YR

b. Shallow Trap Toilet

i=5%, ACST=$97.58(0.07095)+$0.80/YR -$30.00(0.02095)=$7.08/YR

2. Increased Annual Cost Per Toilet

IACNI = ACST - ACRT

i = 5%, IACNI = $7.08/YR - $6.66/YR = $0.42/YR

3. Amount Water Saved Using Shallow Trap Toilet

$WS = (RTWU) - (STWU)$

$WS = 36{,}500 \text{ GAL/YR} - 25{,}550 \text{ GAL/YR} = 10{,}950 \text{ GAL/YR}$

4. Breakeven Water and Wastewater Price

$$BPNI = \frac{IACNI}{WS}$$

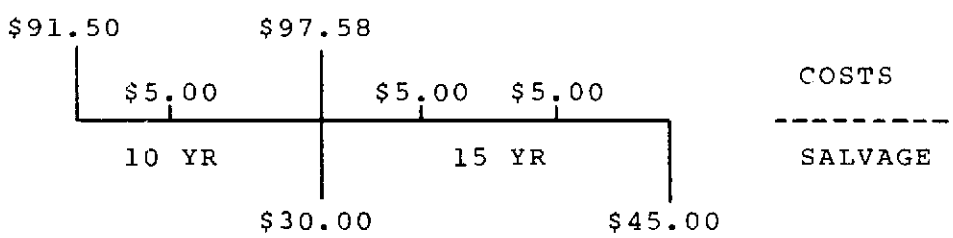
$i = 5\%$, $BPNI = \frac{\$0.42}{10.95} = \$0.0383/1000 \text{ GAL} \times 2 \text{ Toilets}$

$= \underline{\underline{\$0.0767/1000\text{GAL}}}$

C. Breakeven Price of Water and Wastewater (Retrofit)

Assume: Are retrofitting toilet that is 10 years old and has a remaining life of 15 years and a salvage value of $30.00 for the existing toilet and $45.00 for the replacement after 15 years of use.

1. Annual costs to replace 10 year old regular toilet with shallow trap model.



a) $ACR = (ICRT)(CRF_{i,25y}) + (ICST - SVRT)(SPPWF_{i,10y})$

$(CRF_{i,25y}) + CRF_{25}\Big[(OMC)(SPPWF_{i,5y})$

$+ (OMC)(SPPWF_{i,15y}) + (OMC)(SPPWF_{i,20y})$

$- (SVST)(SFDF_{i,25y})\Big]$

$i=5\%, ACR=\$91.50(0.07095)+(\$97.58$

$-\$30.00)(0.61391)(0.07095)+(0.07095)$

$[\$5.00(0.78353)+\$5.00(9.48102)$

$+\$5.00(0.37689)]-\$45.00(0.02095=\$9.08/YR$

b) $i = 5\%$, ACRT = $6.66/YR

2. Increased Annual Costs per Toilet Over 25 years.

IACR + ACR - ACRT

$i=5\%$, $IACR_{25}=\$9.08/YR-\$6.66/YR=\$2.42/YR$

3. Increased Annual Costs per Toilet Over 15 years.

$IACR_{15}=IACR_{25}(USPWF_{i,25y})(SPCAF_{i,10y})(CRF_{15})$

$i=5\%, IACR_{15}=\$2.42(14.094)(1.6289)(0.09634)$

$=\$5.35/YR$

4. Breakeven Water and Wastewater Cost (Retrofit)

$BPR = IACR_{15}/WS$

$i=5\%$, BPR=$5.35/10.95=$0.49/1000 GAL x 2 Toilets

=<u>$0.98/1000 GAL</u>

D. Necessary Time for Shallow Trap Toilet to Become Cost Effective at Various Prices

1. Increased cost over regular toilets disregarding salvage value; O & M costs are same for both.

ICORT=2(Cost Shallow Trap)-2(Cost Regular Toilet)

ICORT=2(97.58)-2(91.50)=$12.16

2. Amount of water savings

$WS = Price(WS)

i=10%, Price = $0140/1000 GAL $WS=$0.40(10.95)

=$4.38/YR

3. Time to become cost-effective

$ICORT(CRF_{i=10\%}) = \$@S$

$CRF_{i=10\%} = \frac{\$4.38}{\$12.16} = 0.3602$ TIME = <u>3.5YR</u>

E. Annual Savings for Installation in New Dwellings at Various Prices

Salvage and O & M Costs cancel out for this example

1. Increased annual costs over regular toilets

$IACNI = 2(\text{Cost Difference})(CRF_{i,25y})$

i=5%, IACNI = 2($6.08)0.07095 = $0.87/YR

2. Annual Savings

$AS = $WS - IACNI

i=5%, Price-$0.40/1000 GAL, $AS=$4.38/yr -$0.86/yr = $3.52/YR

F. Annual Savings For Retrofit

1. $\$ASR = \$WS - (IACOR_{15})2$

i = 5%, .40 $ASR = 4.38 - 10.70 = -6.32

APPENDIX C

1. SAMPLE BUILDING CODE MODIFICATIONS

2. SAMPLE WATER USE RESTRICTIONS

THE FOLLOWING REQUIREMENTS PERTAIN TO AUTHORIZATIONS AND CONNECTIONS ISSUED BY THE WASHINGTON SUBURBAN SANITARY COMMISSION WITH A "WATER-SAVING APPLIANCES REQUIRED" CONDITION

(1) Tank-type toilets for new single family homes, apartments, rental townhouses, motels, hotels, and commercial buildings will be required to be of a design that provides a maximum flush not to exceed three and a half gallons, or, if a conventional toilet is used, must be equipped with an available water closet reservoir device designed to reduce the flush to three and a half gallons or less. After July 1, 1973, the toilet designed for the maximum three and a half gallon flush will be required in the installation of all tank-type toilets.

(2) Water-saving shower heads to limit flow to a maximum of three and a half gallons a minute will be required in all units.

(3) Aerators, which result in a flow reduction to approximately four gallons a minute, will be required on all kitchen sinks and lavatories.

(4) Installation of a pressure reducing valve on the incoming service to the structure will be required for all properties where the incoming water pressure is expected to exceed 60 pounds per square inch. The Pressure Reducing Valve must provide adjustment of the pressure for the household service to within the range of 50 to 60 psi.

(5) Cellar floor drains may not be connected to the sanitary sewerage system. When floor drains are installed, they must discharge to an approved storm drain. Discharge to the surface of a lot would be permitted only when a storm drain is not available to receive drainage. All buildings erected with cellars or basements in areas known to have a water table above the basement floor will be required to have foundation drains around the outside of the building with a satisfactory point of discharge. This requirement is included as a recent revision in the WSSC Plumbing Code and is mandatory for all new structures.

SELECTED SECTIONS FROM THE FAIRFAX COUNTY PLUMBING CODE, FAIRFAX COUNTY, VIRGINIA

Section 19.26. Water Conservation (In accord with Principle #4 BOCA Basic Plumbing Code).

(a) In all new construction and in all repair and/or replacement of fixtures or trim, only fixtures and trim not exceeding the following flow rates and/or water usage shall be installed. These rates are based on a pressure at the fixture of 40 to 50 psi.

Water Closets, tank type	3.5 gal per flush
Water Closets, flushometer type	3.0 gal per flush
Urinals, tank type	3.0 gal per flush
Urinals, flushometer type	3.0 gal per flush
Shower Heads	3.0 GPM
Lavatory, sink faucets	4.0 GPM

(b) Lavatories for Public Use

Faucets of lavatories located in rest rooms intended for public use shall be of the metering, or self-closing type.

(c) Car Wash Installation

Car wash installations shall be equipped with an approved water re-cycling system. This clause shall be retroactive and all existing car wash installations shall be equipped with such re-cycling devices by not later than one year of the effective date of this Section.

(d) Coin Operated Car Washes or Similar Devices

No coin operated car wash may be permitted to be installed and used until plans have been submitted to and approved by the Administration Authority. The plans must show the method of connection to an approved sanitary sewer system, disposal or rain subsurface water and the protection of the potable water system.

(e) Continuous Flow Equipment

Any water connected device or appliance requiring a continuous flow of 5 GPM or more and not previcusly listed in this Section shall be equipped with an approved water re-cycling system.

Section 19.30. Penalties

Any person who shall violate any provision of this chapter shall be subject to the penalties as specified in the Virginia Uniform Statewide Building Code. If no penalty for the violation is specified within the Uniform Statewide Building Code for the subject violation then the penalty will be . . .

NOTICE TO ALL RESIDENTIAL CUSTOMERS

WATER RATIONING IS NOW IN EFFECT!!

WATER RATIONING IS CURRENTLY IN EFFECT FOR ALL SANTA CRUZ WATER DEPARTMENT CUSTOMERS INSIDE AND OUTSIDE OF THE CITY

1. Your Allotment

   The City Council has passed an emergency ordinance, effective March 1, placing limits on water usage for all water customers. Because you are billed every two months, the chart shows the amount of water allowed for the two month period. One month's allotment would be half the cubic feet shown.

   Your water bills are charged by cubic feet of water used in increments of 100 cubic beet.

   1 cubic ft. = 7-1/2 gallons
   100 cubic ft. = 750 gallons

   Amount of water for two months:

1 person	900	cubic ft. bi-monthly
2 persons	1500	" "
3 persons	2000	" "
4 persons	2400	" "
Over 4 persons:	400 each additional person	" "

   (approx. 112 gallons per day per household)
   (approx. 187 gallons per day per household)
   (approx. 249 gallons per day per household)
   (approx. 299 gallons per day per household)
   (approx. 50 additional gallons per person per day)

2. Allotment Procedure

   The allocation card inserted in this mailer is extremely important. Please read it carefully and list in the appropriate space the number of permanent residents living in your home. A permanent resident is one who resides 75% of the time in your home. This card will be used to establish water allocations for bi-monthly records and billing.

3. Ordinance Provisions

   A. There is no prohibition against watering your garden or washing your car: you may use your allotment however you choose provided the use is not prohibited. (See prohibitions which follow).

B. If you exceed your allotment by more than 100 cubic feet (750 gallons) bi-monthly, you will be charged $25 for every 100 cubic feet over your allotment. For flagrant abuses, it is possible that your water would be temporarily disconnected and a flow restrictor installed.

C. Due to the nature of our billing system, and administration of the Ordinance, fines will be assessed on billings billed on or after May 1st. The May 1st bills will reflect usage from March 1 to May 1. All customers uses will be monitored monthly although billings will continue to be mailed bi-monthly for most residential customers.

D. Rates for all customers will remain at the pre-rationing level for at least the next several months.

E. PROHIBITIONS

a. The washing of sidewalks, driveways, filling station aprons, porches, or other outdoor surfaces.

b. The washing of the exterior of dwellings, buildings and structures, with the exception of window washing.

c. The operation of any ornamental fountain of other such structure making a use of water from the City domestic water system.

d. The use of water from hydrants for construction purposes, flushing of water or sewer mains, or for fire drills.

e. The use of water through irrigation meters, except for domestic use, where an adequate alternate source of water is available whether such alternate source is reclaimed water, well water, spring water, or other source.

f. The initial filling of any swimming pool, public or private, that was not filled prior to the effective date of this Ordinance.

g. Any and all use of public showers, excepting public schools.

h. The external washing of trailers, trailer houses, mobile homes, and home exteriors.

i. The external washing of all commercial or recreational boat exteriors.

j. The indiscriminate running of water or washing with water not otherwise prohibited above which is wasteful and without reasonable purpose.

4. How to Read Your Meter

A. Reading a water meter is not difficult and can be a substantial aid in helping to conserve water.

By learning to read your water meter you can monitor your own water use. Residential water meters are generally located between the house and the street in a small rectangular cement box and will be one of two types.

APPENDIX D

SAMPLE COST CURVES FOR WATER AND WASTEWATER TREATMENT FACILITIES

(REPRODUCED FROM SCHMIDT AND ROSS, 1975)

SAMPLE COST CURVES FOR ESTIMATING CAPITAL AND OPERATING AND MAINTENANCE EXPENDITURES OF WATER SUPPLY AND WASTEWATER TREATMENT FACILITIES

Basic to all economic analyses is an understanding of the costs involved for each alternative course of action. Presented in this appendix are examples of cost curves which can be used to approximate the capital and operating and maintenance costs associated with various types of water supply and wastewater treatment facilities, as follows:

- Pumping stations
- Storage reservoirs
- Water treatment facilities
- Wastewater treatment facilities
- Demineralization facilities

The cost information presented herein is intended to illustrate the type of data that is available for use in estimating costs. More detailed information on water supply and wastewater treatment costs, such as found in References 1 through 5 and 7, should be used for cost-effectiveness analyses.

Capital Costs

Capital cost data provided in this appendix are summarized from the literature.[1,2,3,4,5,6,7] All costs are adjusted to an ENR Construction Cost Index of 2000, which is representative for mid-1974. Unit prices include contractor's overhead and profit, but do not include engineering, construction contingencies, rights-of-way, land acquisition, or legal costs.

Pumping Stations. Construction costs for both booster pumping stations and wastewater effluent pumping facilities are shown on Figure D-1.

Booster station costs are presented for average capacity in million gallons per day (mgd) for different total dynamic pumping heads (TDH). The costs account for enclosed stations with architectural and landscaping treatment suitable for residential areas.

Costs of wastewater effluent pumping facilities are based on units adjoined to existing chlorine contact chambers. Because additional area and enclosed structures are not required for these facilities, the costs are less than for booster stations. The costs presented are for peak capacity and should be increased by 25 percent for each additional 125 feet of pumping head greater than 125 feet.

Storage Reservoirs. Costs for storage reservoirs include expenditures for foundations, site preparation, inlet and outlet piping with appropriate controls, and overflow works.

Figure D-2 shows the construction costs used in this report for both steel ground level reservoirs and lined and covered excavated reservoirs as a function of storage capacity. Both types of reservoirs would be suitable for storing wastewater effluent prior to reuse, as well as for fresh water storage. Wastewater can also be stored in less costly unlined lagoons under suitable condition.

Water and Wastewater Treatment Facilities. Figure D-3 shows the estimated construction costs for both water and wastewater treatment facilities as a function of average daily plant capacity. These curves agglomerate costs for the various unit processes utilized in each type of treatment system, as explained below.

Total costs for surface water treatment include costs for coagulation, sedimentation, filtration, and disinfection. Costs for softening are not included. Groundwater treatment costs include facilities for the reduction of iron and manganese to drinking water standards.

Secondary wastewater facilities include conventional primary treatment and activated sludge treatment, plus disinfection. Processes involved in tertiary treatment include primary and activated sludge treatment, nitrification and denitrification, filtration, activated carbon absorption, and disinfection.

The developed costs are based on initial construction of units to accommodate a given average daily capacity with provision for enlargement up to three times the initial capacity. Initial construction includes inlet structures and channels, major pipelines, operation

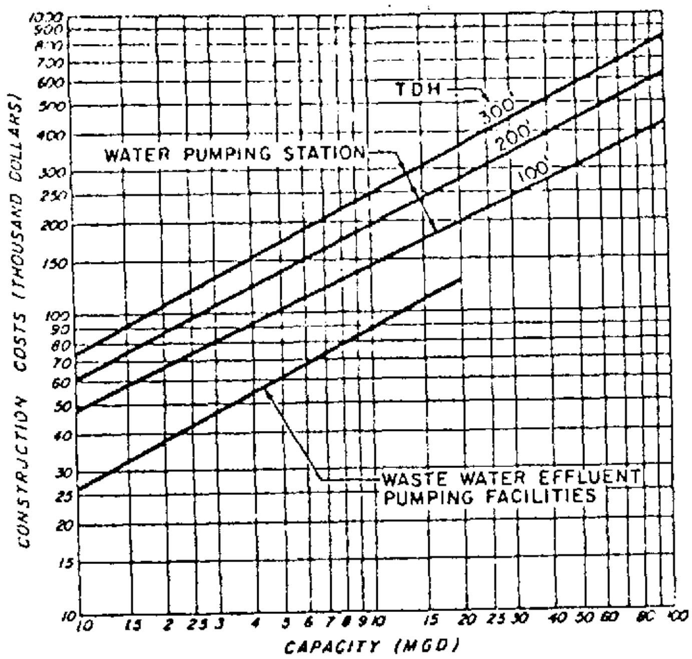


Figure D-1. Construction Cost of Pumping Facilities (ENR=2000)[6]

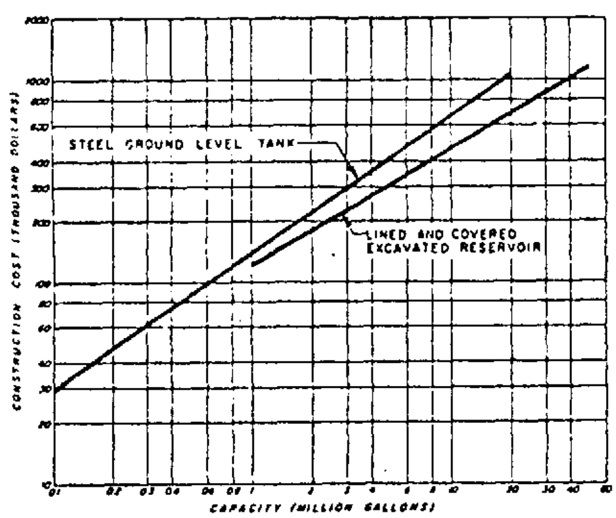


Figure D-2. Construction Cost of Reservoirs (ENR=2000)[6]

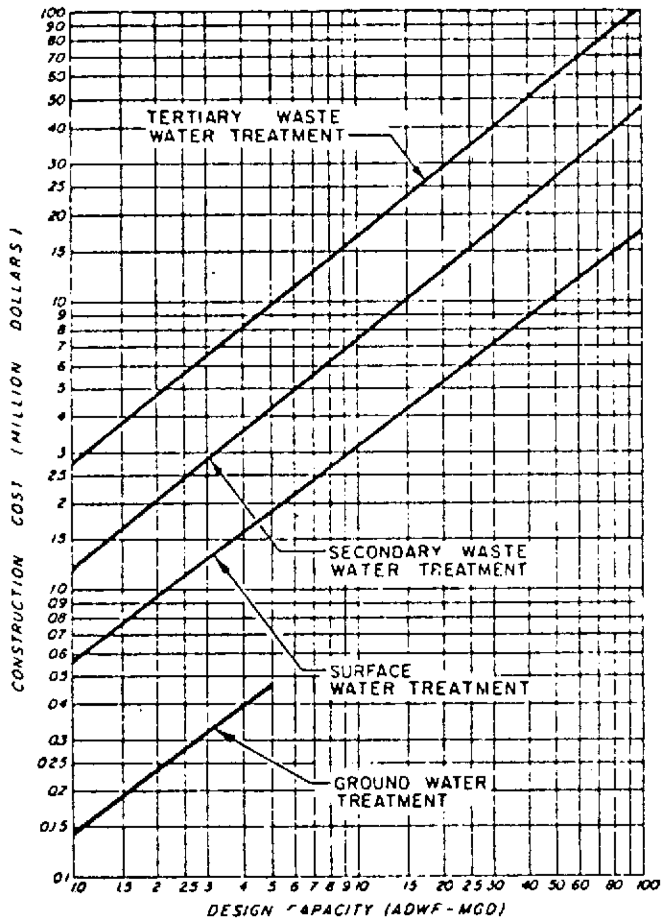


Figure D-3. Construction Cost of Treatment Facilities (ENR=2000)[6] and maintenance facilities, and other basic components. Enlargement costs provide for additional construction necessary to increase the plant capacity. Enlargement costs are estimated as 80 percent of initial construction costs.

Demineralization Facilities. Estimated costs of demineralization of groundwater are presented in Figure D-4.

These costs are based on ocean water desalting by distillation, and groundwater and wastewater demineralization by either ion exchange or reverse osmosis. Construction costs for ocean water desalination are considerably higher than for groundwater or wastewater, primarily due to the much higher removal efficiencies required.

Operation and Maintenance Costs

Economic evaluation of alternative projects requires consideration of operation and maintenance as well as capital costs. Operation and maintenance costs include expenditures for labor, repairs, power, chemical, supplies, administration, and additional costs which vary from project to project. Operating costs presented herein are also based on an ENR Construction Cost Index of 2000.

Pumping Facilities. Total operation and maintenance costs for pumping facilities consist of power costs for the various flows and pumping heads, and other normal operating costs which are exclusive of power costs. Figure D-5 indicates operating costs for both of these categories. Power costs are based on rates for discharge heads ranging from 25 to 400 feet. The curve for costs exclusive of power includes allowances for labor, supplies, administration, replacement parts, and repairs necessary for efficient operation.

Storage Reservoirs. Operation costs of reservoirs are estimated to be about $1,000 per year for each installation to cover minimum routine maintenance. Additional maintenance costs for these facilities are approximately 1.2 percent of construction costs.

Water and Wastewater Treatment Facilities. Figure D-6 shows representative operating and maintenance costs

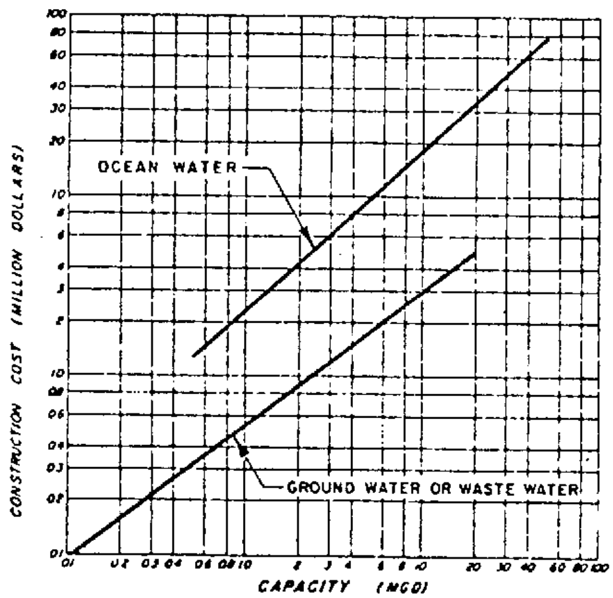


Figure D-4. Construction Cost of Demineralization (ENR=2000)[6]

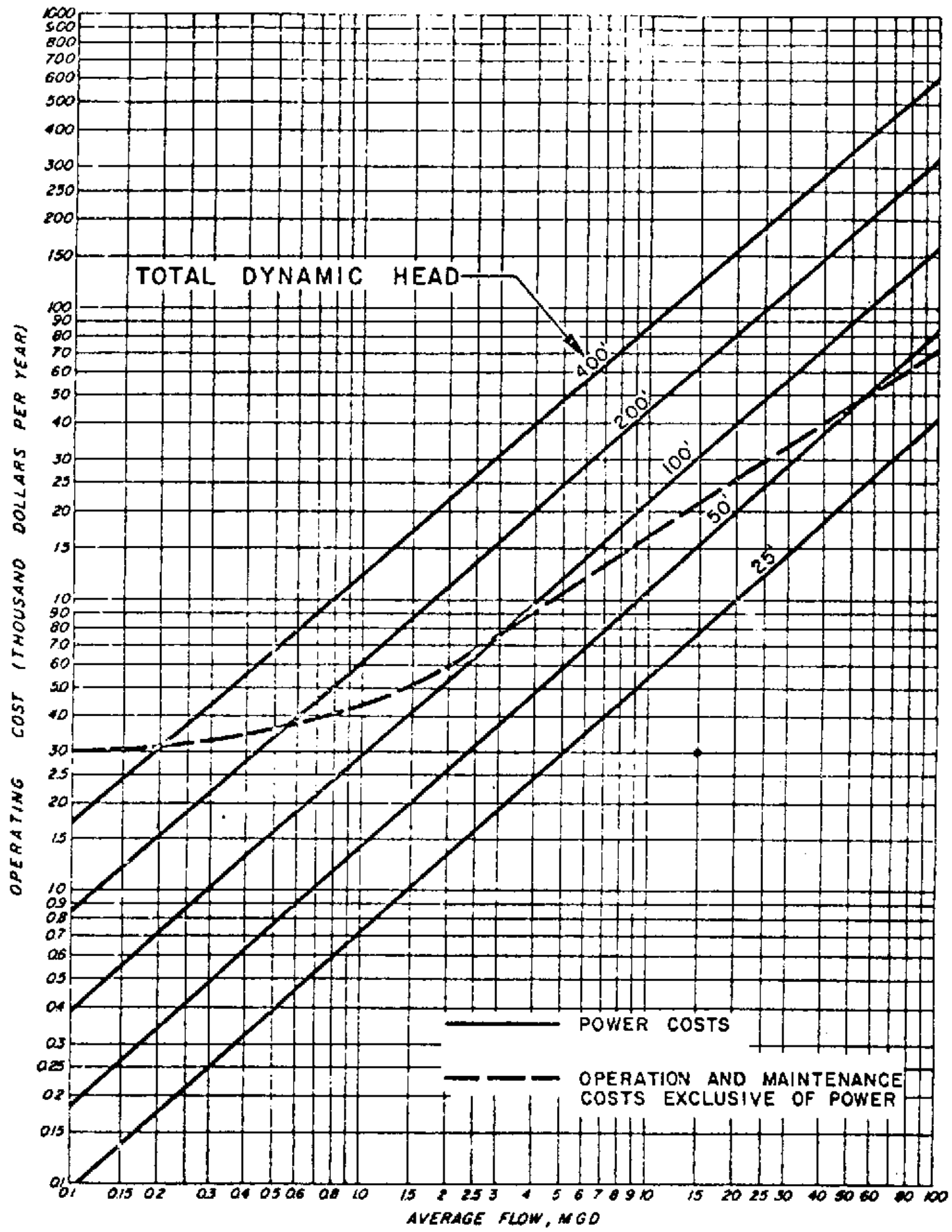


Figure D-5. Operating Cost of Pumping Facilities (ENR=2000)[6] for water and secondary and tertiary wastewater treatment facilities. Total costs include expenses for labor, power, repairs, chemicals, supplies, administration, monitoring, laboratory control, and other miscellaneous items.

Demineralization Facilities. Figure D-7 indicates the costs anticipated for ocean water desalting by distillation and groundwater and wastewater demineralization by either ion exchange or reverse osmosis processes. Desalting technology is presently developing so operation and maintenance costs are relatively high when compared with other water and wastewater treatment processes.

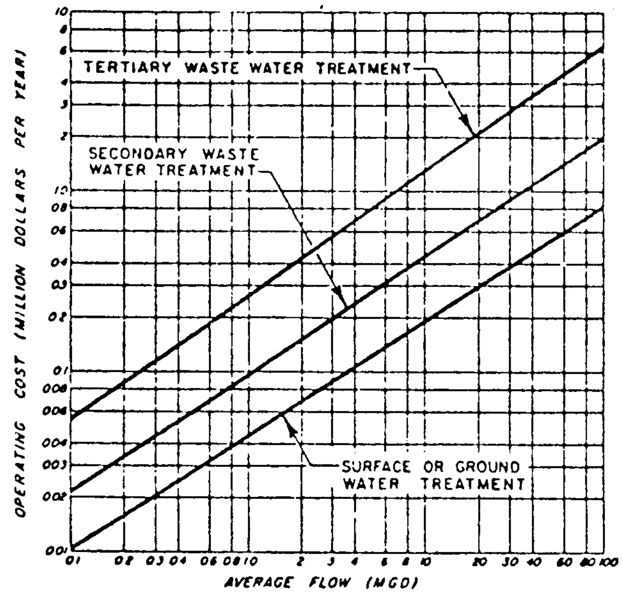


Figure D-6. Operating Cost of Treatment Facilities (ENR=2000)[6]

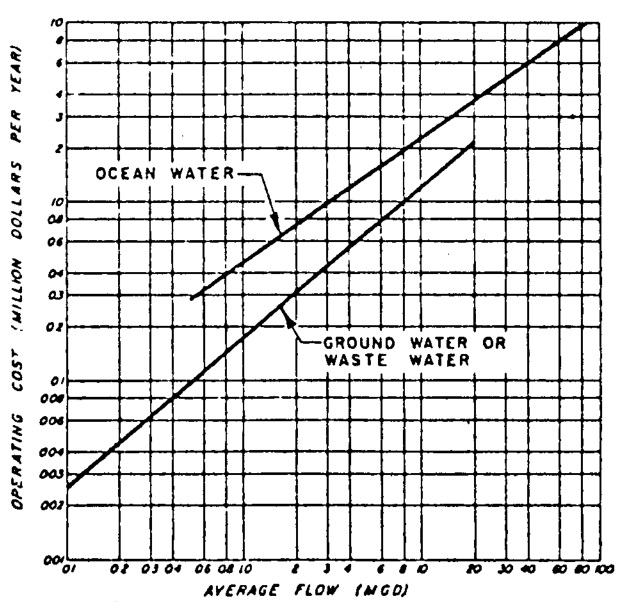


Figure D-7. Operating Cost of Demineralization Facilities (ENR=2000)[6]

APPENDIX D
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APPENDIX E

WASTEWATER TREATMENT PLANT DESIGN

CHANGES DUE TO FLOW REDUCTION

SOME WASTEWATER TREATMENT PLANT DESIGN CHANGES DUE TO FLOW REDUCTION

Two designs are presented here to aide in recognizing what unit process might be affected in wastewater treatment plant design. The first design calculations are for a normal design situation and the second design calculations are for a reduced flow situation.

<u>CASE 1</u> a. Complete mix secondary treatment facility

b. No flow reduction. Average daily flow is 1.3 MGC. 0.3 MGD of the average daily flow is due to infiltration.

c. In the design winter and summer temperature differences are assumed to have negligible effect on process kinetic constants.
86 mg/1

d. Substrate utilization coefficient, K = 0.2 1/mg-day

e. Microbial decay coefficient, K_d = 0.1 $days^{-1}$

f. True yield coefficient, Y_T = 0.5

g. 5-day biochemical oxygen demand = 0.7 ultimate BOD

h. Influent substrate concentration, S_o = 150 mg/1 BOD_5

i. No nitrification taking place

j. Soluble effluent concentration,

$S_e = 10$ mg/l BOD_5

k. Maximum allowable effluent BOD_5 of 20 mg/l

STEP 1: Substrate utilization rate, $q = K_d S_e$

$= 0.2(10) = 2.0 \text{ days}^{-1}$

STEP 2: Assume MLVSS concentration, x = 2000 mg/l

STEP 3: Aeration tank volume, $V_a = \frac{Q(S_o - S_e)}{x\ q}$

$= \frac{1.3(150 - 10)}{2000(2.0)} = 0.0455$ MG

STEP 4: Sludge Age, $\frac{1}{\theta_c} = Y_q - K_d = (0.5)(2.0)$

$- 0.1 = 0.9 \text{ days}^{-1}$

$\Theta = 1.11$ days

STEP 5: Observed yield coefficient, $Y_{OBS} = \frac{Y_T}{1 + K_d \Theta_c}$

$= \frac{0.5}{1 + 0.1(1.11)} = 0.45$

STEP 6: Active Biomass Production,

$X = Y_{OBS}(8.34)Q(S_o - S_e)$

$X = 0.45(8.34)1.3(150 - 10) = 683$ lbs/day

STEP 7: Oxygen Requirements, $O_2 = 8.34(Q)(\frac{S_o - S_e}{.7})$

$- 1.42\ X$

$O_2 = 8.34(1.3)\frac{(150 - 10)}{.7} - 1.42(683)$

$= 1,198.5$ lbs/day

CASE 2 a. Complete Mix Secondary Treatment Facility

b. 25% reduction of residential flows. No reduction of infiltration.

$\therefore Q = (1.3 - 0.3)0.75 + 0.3 = 1.05$ MGD

c. Influent Substrate Concentration:

$$\frac{150\ mg/l}{x\ mg/l} = \frac{1.05\ MGD}{1.3\ MGD} \quad X = 186\ mg/l$$

d. All other initial conditions are same as in Case 1.

STEP 1: $q = 0.2(10) - 2.0\ days^{-1}$

STEP 2: MLVSS = 2000 mg/l

STEP 3: $$V_a = \frac{1.05(186 - 10)}{2000(2.0)} = 0.0462\ MG$$

STEP 4: $\Theta_c = 1.11\ days^{-1}$

STEP 5: $Y_{OBS} = 0.45$

STEP 6: $X = 0.45(834)1.05(186 - 10) = 694$ lbs/day

STEP 7: $$O_2 = 8.34(1.05)\left(\frac{186 - 10}{.7}\right) - 1.42(694)$$
$= 1,216.3$ lbs/day

The net effect of this flow reduction is a slight increase in volume requirements for the aeration tank and probably a decrease in the necessary clarifier volume. Thus it is hard to know what the effects are on capital costs. Solids handling costs would increase as a result of flow reduction due to the need for removing more total solids to maintain an effluent concentration. The oxygen requirement would also be increased thus increasing operating costs in this area. Chlorine requirements would be decreased. The overall effect of a flow reduction, assuming a gravity flow system, would probably be an increase in operating costs from a design standpoint and possibly a slight increase in capital costs. If tertiary treatment were present a decrease in chemical costs would be found.

The net benefit of this design shows an increased efficiency in removal of pollutants and thus a decrease in the pollutional loading on the stream. Less total amounts of pollutional material are entering the stream to maintain the same effluent quality.

This is a rough estimate as to the effects of flow reduction, actual operation data would have to be used to account for the complexities of unsteady flow and other characteristics of wastewater treatment.