AD-A070 869 SOUTHERN ILLINOIS UNIV CARBONDALE DEPT OF GEOGRAPHY F/G 13/2
THE ROLE OF CONSERVATION IN WATER SUPPLY PLANNING.(U)
APR 79 D D BAUMANN, J J BOLAND, J H SIMS DACW72-78-C-0022

UNCLASSIFIED IWR-CR-79-2 NL

1 OF 2
AD
A070869

LEVEL II

12

The Role of Conservation in Water Supply Planning

Contract Number DACW72-78-0022

APRIL 79

Contract Report 79-2

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

United States Army
Corps of Engineers
...Serving the Army
...Serving the Nation

Institute for Water Resources

The Role of Conservation in Water Supply Planning

Prepared by:

Duane D. Baumann
Southern Illinois University
John J. Boland
The Johns Hopkins University
John H. Sims
George Williams College
Bonnie Kranzer
Southern Illinois University
Philip H. Carver
Dartmouth College

Department of Geography
Southern Illinois University, Carbondale

for

United States Army
Corps of Engineers
...Serving the Army
...Serving the Nation

Institute for Water Resources

APRIL 1979 IWR Contract Report 79-2

Copies may be purchased from:

National Technical Information Service
U. S. Department of Commerce
Springfield, Virginia 22151

This report is not to be construed as necessarily representing the views of the Federal Government nor of the U.S. Army Corps of Engineers.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: IWR Contract Report 79-2 — 2. GOVT ACCESSION NO.: CR-79-2	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): The Role of Conservation in Water Supply Planning	5. TYPE OF REPORT & PERIOD COVERED: Final
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Duane D. Baumann, John J. Boland, John H. Sims, Bonnie Kranzer, Philip H. Carver	8. CONTRACT OR GRANT NUMBER(s): DACW72-78-C-0022
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Geography, Southern Illinois University	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: USA Engr Institute for Water Resources, Kingman Building, Fort Belvoir, Virginia 22060	12. REPORT DATE: April 1979
	13. NUMBER OF PAGES: 117
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Conservation, water supply, planning

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report has formulated a definition of water conservation, assessed the adequacy of knowledge on the available conservation measures, and identified the requirements and needs for implementation.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411 257 LB

TABLE OF CONTENTS

PREFACE

Although not a new concept, water conservation recently has gained national prominence in water resources management and planning especially since President Carter's water policy message of June 6, 1978. Recent experience with the President's water policy statement has shown that while conservation is a popular concept, it is poorly defined. In order to explore the opportunities to implement water conservation, two fundamental questions have arisen: (1) simply, what is conservation; and, (2) what is the effectiveness and efficiency of the full range of conservation measures.

The work documented in this report was conceived and planned by the U.S. Army Engineer Institute for Water Resources (IWR) in the Spring of 1978. In accordance with the plan developed by IWR this project was designed to address these needs: (1) to formulate a clear, explicit, conceptual and operational definition of conservation; and, (2) to assess the adequacy of information on the effectiveness and efficiency of available conservation measures. A.J. Fredrich, Director of IWR, and Donald Duncan, Senior Policy Specialist from the Office, Chief of Engineers provided the initial impetus for this project. Through their efforts and the work of Kyle Schilling of the IWR staff, who served as project manager, a group of Corps planners and engineers was assembled to guide the project. This group included representatives from the Director of Civil Works Planning and Engineering Divisions, as well as, the Waterways Experiment Station, the Hydrologic Engineering Center and the Southwest Division.

We wish to emphasize the importance of this collaborative process. To date, our meetings have resulted in greater clarity in the formulation of a definition of conservation and have provided more lucid articulation of the major problems in implementing conservation. Moreover, in this exchange it is our judgment that a clearer understanding of the problems and prospects was gained by all who participated in the working meetings. We are especially grateful to

Kyle Schilling and Robert Harrison for their continual assistance in the provision of information on water conservation. We are also grateful to the following persons for their detailed comments on earlier drafts of this report: David G. Arey, Richard Astract, Ronald Beazley, Nancy Baumann, James Crews, J. Ernst Flack, Ronald Lindsey, Charles Malone, Vernon Hagen, Ted Hillyer, Daniel Okun, William Pearson, David Rahubka, Clifford Russell, William E. Sharpe, and Gilbert F. White. Finally, the constructive criticism of the following persons were useful in the formulation of the definition of conservation: Jared Cohen, Robert Haveman, J.W. Milliman, Clifford Russell, and M.G. Wolman.

This report has formulated a definition of water conservation, assessed the adequacy of knowledge on the available conservation measures, and identified the requirements and needs for implementation.

I. INTRODUCTION

In the past few years, the role of water conservation in the management and planning of water resources has become increasingly important. A number of factors account for this shift: First, new reservoir sites have become increasingly scarce. Second, concern for environmental quality has grown. Third, ground water resources are increasingly inadequate to meet the demands of urban areas. Fourth, political, economic and institutional problems of interbasin transfers have proliferated; today it is nearly impossible to plan for transfer of water from one basin to another. Fifth, the costs of water resource development have risen enormously in the last decade as a result of the increase in the price of energy, the increase in the cost of money, and the rise in water quality standards as manifested in the passage of federal legislation, such as the Federal Water Pollution Control Act Amendments (1972), the Safe Drinking Water Act of 1974, and the Clean Water Act of 1977. Finally, the demand for urban water has continued to increase. In combination, these factors have created a situation which directs attention to the possibilities of water conservation.

In his Water Resources Policy Reform Message of June 6, 1978, President Carter reasserted his commitment to the concept of water conservation:

> Managing our vital water resources depends on a balance of supply, demand, and wise use. Using water more efficiently is often cheaper and less damaging to the environment than developing additional supplies. While increases in supply will still be necessary, these reforms place emphasis on water conservation and make clear that this is now a national priority.

On July 12, 1978, all federal agencies were required to implement the three basic specific tasks.[1]

(1) Implement the water conservation policies applicable to each agency's operations;

(2) Identify each agency's programs having significant water use or conservation impacts and which are not covered by other water conservation initiatives...;

(3) Determine within 90 days potential administrative or legislative changes that could be made in order to eliminate wasteful and unnecessary water use and to promote and achieve water conservation objectives in or through the programs identified.

To most persons, water conservation is a noble and laudable goal, but in the formulation and implementation of water conservation policies, a formidable obstacle is immediately encountered: what exactly is conservation?

Clearly, an answer to that question is needed, an explicit definition of conservation is required, before an agency can begin to formulate policy. In an attempt to fill that need, the U. S. Water Resources Council (1979) discussed water conservation as:

> Water resource planning, which fully incorporates conservation, shall be based upon systematic evaluation of alternative water resource management strategies (to include structural and nonstructural measures). General types of program, project and policy alternatives to be fully considered separately or in combination are:
>
> (1) Reduce the level and/or alter the time pattern of current and future demand for selected purposes to make water available for alternative uses;

---

[1]Memorandum from President Jimmy Carter to Heads of Executive Departments and Agencies entitled "Water Conservation and Floodplain Management in Federal Programs." Washington, D.C.: The White House, July 12, 1978. In another memorandum, Improvements on Planning and Evaluation of Federal Water Resources Programs and Projects (July 12, 1978), President Carter stated that "...The Principles and Standards shall be modified to accomplish the full integration of water conservation into project and program planning and review, as a component of both the economic development and environmental quality objective..."

(2) Modify management of existing water developments to enhance availability of water for additional uses; and,

(3) Increased management of runoff and flows to change location, timing, and/or amount of water.

Similarly, in a recent report by the U. S. Department of Interior (1978), Water Conservation Opportunities Study, the goal of water conservation is defined as "...the wise and judicious use of available supplies." The same ambiguity concerning the meaning of conservation prevails in a report by the ad hoc Committee on Water Resources, Commission on Natural Resources of the National Academy of Sciences. While the objective of the report is to "...provide guidance and assistance in formulating a water conservation research program" for the U. S. Office of Water Resources and Technology, an explicit definition of conservation is absent: in fact, the report does not distinguish between water conservation and comprehensive, efficient water supply management. More specifically, the full range of management alternatives are emphasized:

> The Committee considers that water conservation consists of making better and more efficient use of water resources. But water conservation objectives should be broad enough to include better management of supplies--better hydrologic forecasts, more effective use of ground water, more flexible facilities (such as interconnection of systems and reallocation of storage)--as well as reductions in demand (p. 7).

The question still stands as to what is the difference between the objectives of the water conservation program and the conventional objectives of efficient water supply planning and management?

In summary, these definitions (as has been the tradition in the history of conservation) leave something to be desired; while laudably comprehensive, they lack precision. The result is conflict at worst, and confusion at best. Thus, the concept of water conservation may mean reduction of use to some, development of new supplies to others, and the curtailment of certain uses of water to others. To the economist, efficiency has one meaning, and to the agronomist, another. The problem of formulating a theoretically sound, yet practical definition of conservation is not new, indeed, it has plagued the conservation movement from its inception.

Since the historic Conference of Governors in 1908 in Washington, D.C., the term conservation has yielded to many interpretations. Gifford Pinchot, considered by many to be the father of the conservation movement in this country, stated that, "Conservation is the use of natural resources for the greatest good of the greatest number for the longest time." More specifically, Pinchot identified three objectives in conservation (Pinchot, 1947):

(1) Wisely to use, protect, preserve and renew the natural resources of the earth;

(2) To control the use of natural resources and their products in the common interest . . . and;

(3) To see that the rights of people to govern themselves shall not be controlled by great monopolies through their power over natural resources.

Who indeed, would either desire or dare to disagree with such goals? However, a critical analysis of Pinchot's definition of conservation as ". . . the use of natural resources for the greatest good of the greatest number for the longest time" must conclude that, however appealing the prose, it fails as an operational definition. It will not serve as a guide in the formulation of national policy. What is the greatest good? Who determines what the greatest good is? How should it be determined? Who are the greatest number? What does "longest time" mean? How far into the future can we hope to plan?

Analysis of Pinchot's three more specific purposes of conservation also reveals difficulties. For example, the concept of conservation as wise use (as opposed, say, to one of preservation) has been interpreted in numerous ways. To some wise use is interpreted to mean that renewable resources should be used before non-renewable resources. Others feel that resources should be utilized at a rate that ensures a constant supply, as exemplified in the practice of sustained yield in forest management. Yet, other interpretations insist that the more abundant resources should be used first.

And so the arguments have run for seventy years. An agreed-upon operational definition of conservation is non-existent. The meaning of the term conservation ranges from resource development to the preservation and protection of the resource base (Hays, 1959). These different interpretations reflect different interests and values; to some, a resource is the physical substance itself, to others, it is its market value and to yet others, its beauty. The question is always from what perspective is the resource being considered--economic, ecological, aesthetic, moral. Each of these worlds claims conservation as its own. Perhaps the most extreme example of conflicting stances is that provided by those who see conservation in the light (or darkness) of the Malthusian conviction that demand will outstrip resources leading to a social catastrophe, as against those who see scarcity as the mother of research and development and thereby invention. If the former fear depletion of natural resources for future generations, the latter attempt to be reassuring by citing the empirical case of new discoveries, new technology, new skills, and thus new resources.

In the context of this history of vague, conflicting, and tendentious meanings, attempting a definition of conservation is an act either of bravery or folly; it is sailing a hazardous course through the depths of economic theory and ideological commitments. But a definition is a necessity if the management of water resources is to be informed. Hopefully then, it is courage that accompanies this brief review of some of the more major errors to be avoided in reaching for conceptual clarity of the term conservation.

The first and greatest temptation is to define conservation from the perspective of a <u>single</u> resource. To do so is enviably but deceptively simple, for the conserving of one resource necessitates the depleting of another. It is foolishness to ignore economic relationships, or, more simple, the reality of costs. As Gordon (1958) states:

> It seems quite plausible to suggest that if a resource is not yielding its maximum, it is being wasted. The error in the proposition can be discovered if one asks what other resources must be expended in order to achieve this maximum...We cannot maximize the total product of all resources taken independently, for the respective maxima will prove to be incompatible with one another. (p. 115)

Still following Gordon's argument, only those attempts to provide for the future deserve to be called conservation that are not "carried out at the expense of some other form of investment." To be truly conserving, a program must demonstrate that the saving of a resource is "more productive of future incomes than alternative forms of wealth creation."

Of course, to face this fundamental economic fact takes fortitude; it requires acknowledging the awesome difficulties in identifying what the alternatives are. More, it requires a tolerance for enduring ambiguity in attempting to estimate their value.

In our judgment, a second perspective on conservation to be avoided is the popular one which equates it with the "wise use of resources." Although theoretically defensible in that it assimilates the concept of conservation into the general economic problem of maximizing output, it does so at the expense of violating the everyday meaning of the word "conserve," and prohibits distinguishing those wise uses of resources which save them for future use from those wise uses of resources which don't.

Granted the economic interrelatedness of resources just posited argues that such a distinction is ultimately idle; that is, the depletion of a given resource, if wisely done, will, by definition, be an act of conservation in the context of all resources. Nevertheless, it is practically useful to maintain at a less abstract level of analysis the distinction between actions that save or spend a given resource. Thus, while the term conservation might very properly be applied to a comprehensive energy program that saved gas and oil by the greater use of coal, it would be absurd in such a situation to assert that one was conserving coal.

The next pitfall to be avoided in moving toward a definition of conservation is implicit in the earlier exhortation to face the fact that conservation has costs. There we spoke of the fortitude necessary for the enormous task of determining values (costs) in order to be assured that any single act was indeed conservation. Now we must speak of another virtue -- courage. It is the best word to characterize the strength needed to enter the world of values. But enter it one must. It is nonsense to insist that conservation can avoid the arena of value competition. Benefit/cost analysis is a necessary part of a definition of conservation, and values are unavoidably part of estimating benefits and costs. Rather than beating a hasty retreat, one must turn and face the field.

To do so requires analysis and assessment of all that is most intangible -- aesthetics, politics, and philosophy. It requires conscious consideration of the governing values, attitudes, and beliefs of society, indeed, it requires confrontation with the sacred.

Too often both so-called conservationists and anticonservationists refuse to become involved in such insubstantial but real issues. Twenty years ago Galbraith (1958) pointed his finger at this weakness:

> If we are concerned about our great appetite for materials, it is plausible to seek to increase the supply, to decrease waste, to make better use of the stocks that are available, and to develop substitutes. But what of the appetite itself? Surely this is the ultimate source of the problem. If it continues its geometric course, will it not one day have to be restrained? Yet in the literature of the resource problem this is the forbidden question. (p. 92)

He then goes on to show that the Twentieth Century Fund, in its attempts to balance resources and use, took "present levels of consumption and prospective increases as wholly given." And that the President's Materials Policy Commission "began by stating its conviction that economic growth was important and, in degree, sacrosanct."

Galbraith is making two points here. One, of course, is that ideological denial or blindness interferes with the raising of the most pertinent conservation issues. But second, even when philosophical configurations do appear, they do so unexamined. They are "given" or "assumed" rather than deliberately identified and weighted.

But to deny or ignore or avoid ideological issues is not to disable them; they remain with their power intact. It is far more effective to formally admit them as necessary elements to any conservation decision. There are or can be real conflicts between present and future, between individuals and communities, between federal and state governments, between thrift and prodigality in consumption, between private enterprise and government control, and between the general welfare and individual freedom. And each of the antagonists in these struggles can marshal its rationale, its ethic, and its power. They are, then, factors that necessarily figure in conservation.

This argument is certainly not meant as an admonition to decision-makers merely to be politic. Rather, it is a serious insistence that values must figure into the cost/benefit analysis of a conservation decision. Further, it is to emphasize, indeed, stand in awe of, the stature of the value consequences that can be involved. It is one thing to argue the merits of maintaining a canyon in its natural state versus flooding it by way of building a dam to better use water; it is quite another to debate decisions that would effect the ratio of public versus private management of resources, or lead to redistribution of wealth, or change the life style of a nation. If it can be reasonably argued that different political systems have different advantages and disadvantages in times of war, it can also be reasonably argued that they have different advantages and disadvantages regarding the management of natural resources. The implication is clear: resource decisions have implications for political life. In estimating ultimate costs, it may prove frugal to place ideology above efficiency.

To be so immersed in the world of values when attempting to estimate the costs and benefits of a conservation decision is undoubtedly discomforting to those whose responsibility it is to manage the nation's resources. But an effort to escape from ideology would be as effective as a man attempting to extricate himself from quicksand by pulling on his beard. It simply can't be done. It follows then, that any definition of conservation which holds the promise of being realistically useful must incorporate the assessment of values.

A Definition of Water Conservation

To be helpful in achieving the objective of this study, a definition of water conservation must possess two major attributes: it must be precise and it must be practical. A precise definition will permit clear distinctions to be drawn between those practices which are conservation and those which are not;

a practical definition will facilitate the testing of specific proposed practices, so as to clearly determine whether they do indeed constitute conservation.

Since water is but one of the scarce resources required to provide water supply to users, and reductions in water use may be accompanied by increased use of other resources, not all practices that reduce use of water should be considered desirable. Only those which reduce the use, or loss, of water without disproportionately increasing the use of other resources deserve to be labeled conserving. Thus, the first axiom of the definition of water conservation is that the beneficial effects of the reduction in water use (loss) must be considered greater than the adverse effects associated with the commitment of other resources to the conservation effort.

Where all beneficial and adverse effects are measurable in monetary units, this test amounts to the familiar benefit-cost analysis. Where some effects are essentially non-monetary in nature, the desirability of the practice may be more difficult to determine. The problem of incorporating non-monetary impacts into analysis is not unique to water conservation issues, however, as it characterizes all aspects of natural resource management. Of course, this issue will not be resolved here: we only emphasize the necessity of considering all beneficial and adverse effects, whether expressible in monetary terms or not.

However, this criterion of conservation alone is but a restatement of the familiar doctrine of "wise use." A second factor must be introduced if we are to be able to continue the desirable practice of distinguishing between various types of water management practices, most notably between those that save and those that use water. The crucial element to be added is the conception of conservation as dealing exclusively with demand.

Given some level of supply, conservation consists of reducing the use of water, reducing the loss or waste of water, or increasing the recycling of water, so that supply is conserved, or made partially available for future or alternate uses.

Of course, although conservation is clearly a demand management strategy, neither its definition nor its impacts can be separated from supply-side considerations. Only when supply has been specifically defined with respect to its location in space and in the hydrologic cycle can water management practices be divided into those which are conservation practices and those which are not. For example, measures taken to reduce seepage from a reservoir would qualify as supply augmentation practices when the supply is defined as release from the reservoir, but as conservation practices when the supply is measured as inflow to the reservoir. Hence, any definition of conservation requires an explicit definition of water supply as located in space and in the hydrologic cycle.

It is clear, therefore, that the essence of conservation is reduced use. If water use is seen in the broadest sense, it should be apparent that reducing water losses and increasing water recycling (in industrial uses, for example) are identical with reducing water use. Defining water use from the viewpoint of the organizations responsible for water distribution, the effect of recycling is to reduce use (withdrawal from the distribution system). Water conservation, therefore, implies a reduction in water use, or in water losses.

Reduction, in this sense, is logically defined in a with/without framework. Conservation practices are those which result in a level of water use at some future time which is less than the level would have been at that time, had the practice not been implemented.

Combining these considerations, it can be said that a water management practice constitutes conservation when it meets two tests:

(1) It conserves a given supply of water through reduction in water use (or water loss); and

(2) It results in a net increase in social welfare.

The first test insures that the practice results in a reduction in use, while the second establishes that overall benefits exceed costs (that the practice is consistent with the conservation of all scarce resources).

We are thus led to the following definition:

> Water conservation is any beneficial reduction in water use or in water losses.

This definition is elaborated by considering the meaning of the various terms.

Reduction--A reduction in water use occurs when a water management practice is implemented which has as a result a reduction in water use at some time, as compared to the level of water use expected in the absence of the practice (with/without comparison). Note that decreased water use at some time may be accompanied by increased water use at another time. Such a practice could still qualify as water conservation provided the other test (beneficial reduction) is met. It should also be noted that as defined here water conservation could occur fortuitously. That is, water management practices directed toward other purposes may also happen to result in "beneficial reduction in water use or water loss." However, the interest here is with deliberate, intended actions.

Beneficial--A reduction in water use is beneficial if the aggregate of all beneficial effects resulting from implementation of the water management practice exceeds the aggregate of all adverse effects occasioned by such implementation. The practice should result in a net increase in social welfare, thus assuring that all scarce resources are being conserved. When all beneficial and adverse effects are measurable in monetary terms, a beneficial reduction occurs when the present value of the stream of expected future benefits exceeds the present value of the stream of expected costs.

Water use--Water that is, for some purpose, withdrawn, diverted, or physically segregated from supply so that it is temporarily or permanently unavailable for other purposes is considered water used. Water uses are, therefore competitive by definition. No use can be increased without reducing, in some way, the availability of the supply for other uses.

Water losses--A quantity of water which, having once been defined as a part of a water supply, is no longer available for use is considered water lost. If the water supply is measured at the forebay of a reservoir, for example, water losses include seepage and evaporation from the reservoir, as well as spills from storage and leakage from the transmission and distribution systems.

It is important to note that water conservation, as defined here, is not a new or different water management technique. Water conservation practices are, instead, a specific subset of those practices which comprise efficient management of water resources. If some means could be devised, such as optimal pricing policies at every level of water distribution, that would make the self-interest of each supplier and user of water coincide with the social interest, no further attention to water conservation practices would be required.

In actual fact, however, optimal pricing policies are not universal, and the supply, distribution, and use of water is characterized by significant market failures. It becomes the task of the planner, therefore, to consider the efficient allocation of the water resource at every stage of distribution and use, since no efficient self-allocating mechanisms can be presumed to exist. Among the desirable management practices which may be considered by the planner in this context are some which involve reductions in the use of water, and it is these practices which we define as "water conservation."

II. SUMMARY AND APPRAISAL OF CONSERVATION MEASURES

Introduction

Under average year conditions, total freshwater withdrawals for all off-stream uses in the United States were 338.5 billion gallons per day (bgd) for 1975. Within 25 years, the projected freshwater withdrawals are expected to decline to 307 bgd, resulting from an expected implementation of conservation measures including water recycling (U.S. Water Resources Council, 1978).

The single greatest demand for water is for irrigation: 47 percent of the total national withdrawal use and 81 percent of the consumptive use[1] (Table I). The withdrawal demands of steam electric generation are 26 percent and manufacturing 15 percent of the total. Water withdrawn for domestic use accounts for only 6 percent of the national total withdrawals.

Upon first inspection, the greatest potential for savings in water use from the application of water conservation measures would seem to be in the agricultural sector. However, according to the U. S. Water Resources Council (1978) the potential for the greatest reduction in withdrawal use lies in the manufacturing sector: withdrawals of water for manufacturing purposes are expected to decline by the year 2000 to only 19.7 bgd or from 15 percent of the national total to only 6 percent. Water use in irrigation and steam-powered generation are expected to remain relatively unchanged.

---

[1] According to the U. S. Water Resources Council, withdrawal of water is that amount taken from a surface or ground water source. Consumptive use is that portion of withdrawn water not returned to the source.

TABLE I

Summary of Withdrawal and Consumptive Use Relationships by Industry Sector (billion gallons per day)

Type of User	Withdrawals (bgd)	Withdrawals (percent)	Consumption (bgd)	Consumption (percent)	Consumption as a percent of withdrawals (percent)
			1975		
Agriculture (Irrigation, Livestock)	160.7	47	88.3	83	55
Steam Electric Generation	88.9	26	1.4	1	2
Manufacturing	51.2	15	6.0	6	12
Domestic	23.3	7	6.3	6	27
Commercial	5.5	2	1.1	1	20
Minerals	7.1	2	2.2	2	31
Other	1.8	1	1.3	1	72
Total, Region 1-21	338.5	100	106.6	100	32
			2000		
Agriculture (Irrigation, Livestock)	155.3	51	94.4	70	61
Steam Electric Generation	80.1	26	10.5	8	13
Manufacturing	19.7	6	14.7	11	75
Domestic	30.3	10	8.1	6	27
Commercial	6.7	2	1.4	1	21
Minerals	11.3	4	3.6	3	32
Other	2.4	1	1.7	1	71
Total, Regions 1-21	305.8	100	134.4	100	44

Source: U.S. Water Resources Council (1978)

The U. S. Water Resources Council notes, however, that potential savings of water for irrigation could be 20 to 30 percent.

To the extent that water conservation may be seen as a means of avoiding water shortages, or of avoiding specific expensive and/or damaging new supply projects, the national aggregate figures have little relevance. Water shortages are local phenomena, and it is the nature of local water uses which determines the applicable conservation measures.

Important savings from water conservation might be overlooked by concentrating solely on the aggregate, national picture. For example, since domestic water use accounts for only 6 percent of the total national withdrawal, one might conclude that the potential savings from conservation measures would be insignificant. In fact, however, from a local perspective, water conservation measures might result in the delay of capital outlays for the development of a new source of supply and enormous savings to the community, both financial and within the environmental arena.

This chapter is a summary and an appraisal of the actual efforts to conserve water in the domestic-commercial sector, the industrial-manufacturing sector, and the agricultural sector. Within each of these areas, the effectiveness and economic efficiency of conservation measures are summarized and evaluated in order to identify areas of additional information and research.

Urban Water Use (domestic, commercial and institutional)

WATER SAVING DEVICES

In-house water usage by function has been estimated as follows (Howe, et al., 1970):

Function	Percent of In-house use
Toilet Flushing	45
Bathing	30
Laundry and Dishes	20
Drinking and Cooking	5
	100

Due to the extreme variation reported in per capita water use, estimates of the efficiency of conservation measures are equally variable. Although many sources exist that compile various demand reduction devices, three of the most extensive are those of Bailey et al. (1975), Nelson (1977) and the Corps of Engineers (1976). Most of the devices cited in these compendiums are listed as cost-effective, based primarily on the data furnished by the manufacturers of such devices. Estimates of water savings from specific devices by Bailey et al. (1975) and Nelson (1977) are found in Tables II and III respectively.

The above studies as well as others all indicate that substantial reductions in residential water usage can be realized by the implementation and maintenance of the various methods. Because of the varied per capita water use and varying efficiencies of each device, only properly designed empirical studies can ascertain their real value. Unfortunately, it is in this domain that the water conservation literature is most sparse.

A few studies have been conducted, however, which furnish data derived from the actual installation, usage and analysis of water saving devices. One study was performed by the Washington Suburban Sanitary Commission (WSSC), and reported in the "Final and Comprehensive Report Cabin John Drainage Basin Water-Saving, Customer Education, and Appliance Test Program" (WSSC, 1973). Four

TABLE II

Water Savings vs. Cost for Plumbing Devices

Hardware Device	Water Savings		New Construction Estimated Cost		Old Construction Estimated Cost	
	gpcd+	gpd*	Matl.	Installed Cost	Matl.	Installed Cost
1. Limiting Flow Valves for Shower	6	24	15	15	35	50
2. Limiting Flow Valves for Lavatory	0.5	2	25	25	45	68
3. Limiting Flow Valves for Kitchen Sink	0.5	2	25	25	45	68
4. Aerator for Lavatory and Kitchen Sink	0.5	2	2	2	2	2
5. Thermostatic Mixing Valve	2	8	80	90	80	100
6. Batch-type Flush Valve (1) for Water Closet	7.5	30	25	40	75	105
7. Batch-type Valves (2) in Dual Cycle	15.5	62	55	70	120	158
8. Urinal with Batch-type Flush Valve	7	28	125	148	150	175
9. Shallow Trap Water Closet	7.5	30	20	20	80	110
10. Dual Cycle Water Closet	17.5	70	10	10	100	130
11. Vacuum Flush Toilet (100 Homes)	22.5	90	--	(110)**	---	295
12. Vaccum Flush Toilet (Single Homes)	22.5	90	--	115	---	1520
13. Washing Machine with Level Control	1.2	5	35	35	35	35

+ gal/capita-day (gal/person/day)
* 4 member household
** Negative cost, i.e., cost reduction

Source: Baily et al. (1975).

TABLE III

	Water Savings gpcpd	Reduction in Household Water Use (%)[a]	"Approximate" Additional Cost[b]	Remarks
Flow Control Devices - Faucets				
Kitchen Sink Faucets..................	0.5	0.8%	65¢ to $5 ea[c]	Installed on kitchen sink hot and cold water. 2-1/2 gpm flow rate
Lavatory Faucets.....................	0.5	0.8%	65¢ to $5 ea[c]	Installed on bathroom lavatory hot and cold water, 2-1/2 gpm flow rate
Aerators.............................	0.5	8.8%	$1 ea	Installed on kitchen sink and lavatory faucets
Insulation of Hot Water Pipes...........	2.0	3%	50¢/ft.	Slit foam tubing
Flow Control Devices - Showers:				
Flow Control Head or "In-Line" Fitting	7.5	12%	65¢ to $5 ea[c]	3 gpm flow rate
Thermostatic Mixing Valve............	2	3%	$24 ea	Installed on kitchen sink and shower/bath
Reduced Water Toilet Devices:				
Shallow Trap Toilet..................	7.5	12%	$13 ea	Based on water requirement of 3-1/2 gallons per flush
Flush Valve Toilets..................	7.5	12%	-	
Toilet Dam...........................	5	8%	$6 ea	Savings higher with some toilets
Displacement Bottles.................	2.5	4%	20¢ ea	2 1-quart bottles displacing 1/2 gallon per flush
Specialty Systems:				
Minuse Shower........................	14	22%	-	
Vacuum Flush Toilet..................	22.5	35%	-	
Compressed Air Toilet................	25	39%	-	

[a]Household water use taken as 64 gpcpd (excludes outside irrigation).

[b]Materials only and based on cost over and above "normal" practice. Prices should be considered as "ball park" estimates only.

[c]Price varies depending on materials. Low value is for plastic insert. High value is for chrome plated brass fittings.

Source: Nelson (1977).

thousand eight hundred water saving devices such as water closet inserts, pressure reducing valves and flow controllers were installed in 2,400 dwelling units. The residential units comprised apartment complexes, townhouses and single family dwellings.

The results indicated that three types of toilet inserts had satisfactory performance but needed various amounts of maintenance. Reductions in household water use ranged from 16 percent to an actual increase in use. The most important conclusion found in this study was that although each device proved to provide real reductions in water usage, the crucial variable in the extent of the savings was in the follow-up adjustment and maintenance categories.

Another study which actually tested devices in the home was that of Cohen and Wallman (1974). Tables IV-XI show the results of the demonstration project which installed water saving devices in eight single family homes. Tests of recycling laundry and bath water were also installed in three homes. The study concluded that net cost savings could be attained by the use of flow reduction devices. The wash water reuse system appeared to be feasible in terms of manageability, operation and applicability, but further research was suggested.

Public water use as well as commercial water use is more heterogeneous than residential water use, but in terms of water saving technology, many of the same methods can be employed. Flush valves are widely used in commercial applications and vacuum toilet systems (using only 10 percent of the water required for a standard flush) have been successfully used in hotels, office buildings, and housing in Europe (Watkins, 1970).

Sharpe (1978) reports that the use of low-flow shower heads in a controlled experiment produced reductions in dormitory usage of 37.5 - 62 percent. The WSSC reported a reduction in 12-20 percent by employing shower head flow controls

TABLE IV

Water Savings Obtained With Shallow Trap Flush Toilet

House-hold	Conventional toilet		Shallow Trap toilet		Water Savings		% reduction in total water usage
	No. of Occupants	lpcd	No. of Occupants	lpcd	lpcd	% reduction	
1	5.1	36.8	5.2	20.6	16.2	44.0	11.2
2	2.0	103	2.0	76.3	26.7	26.1	7.0
3	4.0	41.4	4.1	35.6	5.8	14.0	3.7
4	4.0	72.0	3.4	50.0	22.0	30.6	10.0
5	2.5	113	2.4	113	0	0	0
6	10.1	45.5	9.9	27.6	17.9	38.8	9.4
			Average savings		14.8	25.6	6.9

Source: Cohen and Wallman (1974)

TABLE V

Water Savings Obtained With Dual Flush Devices

	Conventional Toilet		Dual Flush devices: Sink bob		Dual Flush devices: Econo-flush		Water Savings: Sink-bob			Water Savings: Econo-flush		
Household	No. of occupants	lpcd	No. of occupants	lpcd	No. of occupants	lpcd	lpcd	% Reduc. of Flush	% Reduc of Total	lpcd	% Reduc of Flush	% Reduc of Total
2	1.5	74.6	1.5	55.8	1.5	49.8	18.8	25.2	4.9	24.8	33.2	6.5
7[a]	5.0	42.1	---	---	5.0	39.4	---	---	--	2.7[a]	6.4[a]	1.9[a]
8	4.1	69.5	4.1	47.4	---	---	22.1	32.0	12.3	---	---	---
					Average savings		20.5	28.6	8.6	12.4	16.6	3.3

	lpcd	% Reduction of Flush	% Reduction of Total
Overall average savings	16.5	22.6	6.0

[a]Water savings set = 0 based on statistical analyses

Source: Cohen and Wallman (1974)

TABLE VI

Water Savings Obtained With Flow Limiting Shower Heads

House-hold	Conventional shower heads		Flow limiting shower heads				Water savings					
			13.3 lpm		9.5 lpm		13.3 lpm			9.5 lpm		
	No. of occu-pants	lpcd	No. of occu-pants	lpcd	No. of occu-pants	lpcd	lpcd	% Redu. of bathing	% Red. of total	lpcd	% Redu. of bathing	% Red. of total
1[a]	5.1	14.6	5.2	16.1	---	---	-1.5	-10.3	-1.0	---	---	---
2	2.7	46.3	2.5	35.8	---	---	10.5	22.7	2.8	---	---	---
3[a]	4.0	11.0	---	---	4.1	10.1	---	---	---	0.9	8.2	0.6
4[a]	4.0	16.2	---	---	3.4	14.6	---	---	---	1.6	9.9	0.7
5	2.5	40.2	2.4	32.2	---	---	8.0	19.9	3.1	---	---	---
6	10.1	28.6	---	---	9.9	23.8	---	---	---	4.8	16.8	2.5
7[a]	5.0	25.4	5.0	25.8	---	---	-0.4	-1.6	-0.3	---	---	---
8	4.1	20.9	4.1	27.6	---	---	-6.8	-32.5	-3.8	---	---	---
					Average savings		3.7	8.5	1.2	1.6	5.6	0.8

	lpcd	% Redu. of bathing	% Redu. of total
Overall avg. savings	2.7	7.1	1.0

[a]Water savings considered statistically insignificant (set = 0) for calc. of average savings.

Source: Cohen and Wallman (1974)

TABLE VII

Wash Water Recycle System : Flow Reduction Summary

Household and Phase I & III average inlet	Type of re-use	Net storage volume liters	Toilet lpd		Bath & Laundry lpd		Lawn Sprink-ling lpd	Feed water lpd	Tank over-flow lpd	Average flow reduction[b]		
			Phases I & III	Phase II	Phases I & III	Phase II				lpd	lpcd	% Red.
#6 1900 lpd	toilet flush.	455	488	266	622	750	---	15.5	500	432	43.7	23
	toilet & lawn	455	448	337	662	794	106	44.5	396	510	51.5	27
	lawn sprink.	455	448	---	662	732	402	22.4	352	380[a]	38.4[a]	20[a]
#7 715 lpd	toilet flush.	305	210	193	282	265	---	10.6	83	189	37.8	26
	toilet & lawn	305	210	204	282	334	15.5	4.9	119	220	44.0	31
#8 735 lpd	toilet flush.	332	286	194	195	262	---	18.2	86	268 (176)	65.4 (42.9)	36[c] (24)
								Overall average[c]		305	44.0	26

[a]Not included in overall average, atypical reuse system.

[b]Note on calculation procedure - Homes #6, 7 and 8 had reduced flow toilets and showers during Phases II but not during Phases I and III. To put the data on the same bases with no reduced flow fixtures during all phases, the following was done:

- Effects of reduced flow showers were neglected.
- The flow reduction possible was assumed to be the average water used for toilet flushing during Phases I and III, plus any lawn watering in Phase II, minus the average feed water required in Phase II. The feed water requirement could be higher but the effect is probably small unless there is insufficient bath and laundry water to provide for conventional toilet flushing. See note c below regarding home #8.

[c]For home #8, the bath and laundry water is not sufficient to provide for flushing conventional toilets. In addition to the procedure outlined under note b, flow reduction was calculated by another procedure. The flow reduction possible was taken as the bath and laundry water available during Phase II minus the tank overflow. The flow reduction values resulting from this assumption are shown in parentheses. These values are thought more appropriate for home #8 and were used in calculating the overall averages.

Source: Cohen and Wallman (1974)

TABLE VIII

Cost Summary - Bathroom Water Saving Devices

Water Saving Device	Material Cost-$	Labor Cost-$	Installed Cost-$	Operating cost-$	Expected Life,yrs.	Total Annual Cost-$/yr.
Shallow-trap flush toilet	60	15	75	0	20	3.75
Dual flush devices						
Sink-Bob	4	0	4	0	10	0.40
Econo-Flush	14	0	14	0	10	1.40
Saveit	6	0	6	0	10	0.60
Flow limiting shower heads						
13.3 lpm	6	0	6	0	15	0.40
9.5 lpm	8	0	8	0	15	0.53

Source: Cohen and Wallman (1974)

TABLE IX

Cost Summary - Wash Water Recycle Systems

	Prototype Recycle Systems Diatomite Filter	Prototype Recycle Systems Cartridge[a] Filter	Projection for mass produced recycle system (Diatomite filter)
A. Initial cost			
Storage sys.---	$175	$175	$70
Filter sys.----	135	60	100
Pressurization sys.-----	115	115	85
Disinfectant feeder--------	20	20	20
Valves, pipe, fittings------	95	80	75
Total Mat'l Cost--------	$540	$450	$350
Labor Cost	100	90	50
Total Installed Cost--------	$640	$540	$400
B. Annual Operating cost			
Filter media---	$3.50	$38.80	$3.50
Electric power--	12.00	1.20	7.00
Disinfectant----	5.50	5.50	5.50
	$21.00	$45.50	$16.00
C. Total annual cost			
Expected life years------	15	15	15
Total cost per year--------	$63.50	$81.50	$43.00

[a]Fram filter selected for cost analysis.

Source: Cohen and Wallman (1974)

TABLE X

Cost Comparison

Flow reduction device		Cost per unit vol. of flow reduction $/1000 liters	Typical water rates $/1000 liters	Typical sewer rates $/1000 liters	Septic tank system - poor soil $/1000 liters	Net Savings $/year
Shallow trap water closet		0.15	0.16 - 0.42	0 - 0.13	---	$.25 to 9.80
Dual flush devices	Sinkbob	0.02	0.16 - 0.42	0 - 0.13	---	$4.10 to 15.60
	Econoflush	0.07	0.16 - 0.42	0 - 0.13	---	$1.72 to 9.20
	Saveit	0.04	0.16 - 0.42	0 - 0.13	---	$2.40 to 10.20
Flow limiting shower heads	13.3 lpm	0.08	0.16 - 0.42	0 - 0.13	---	$1.10 to 5.32
	9.5 lpm	0.22	0.16 - 0.42	0 - 0.13	---	$.52 to 3.53
Wash water recycle system	Prototype	0.57	0.16 - 0.42	0 - 0.13	0.40	$-45.70 to -2.30[a] - - - - - - $-1.30 to 27.60[b]
	Mass-produced	0.39	0.16 - 0.42	0 - 0.13	0.40	$-25.20 to 18.20[a] - - - - - - $19.20 to 48.10[b]

[a]Net savings per year based on water and sewer rates

[b]Net savings per year based on water rate and septic system cost

Source: Cohen and Wallman (1974)

TABLE XI

Water Savings Summary

Unit Tested		No. of units tested	Average no. of occupants	Water Savings lpcd[a]	% reduction in total water usage
Wash water recycle system		3	6.3	44.0	26.0
Shallow trap water closet		6	4.5	14.8	6.9
Dual flush device	Sink-Bob	4	2.8	20.5	8.6
	Econo-Flush	4	3.3	12.4	3.3
Flow limiting shower head		11	4.6	2.7	1.0

[a]lpcd = liters per capita-day

Source: Cohen and Wallman (1974)

in 25 single family homes (WSSC, 1973). Further studies revealed that the reduction from these devices may have been as low as 1 percent (Comptroller General, 1978).

Sharpe (1978B, p. 34) summarizes the state of water saving devices in water conservation. He concludes that these "devices offer significant advantages over pricing and metering" in terms of meeting national water conservation goals. While such a conclusion is dubious, at best, Sharpe does qualify this by stating that "pricing and water conservation devices need to be complementary." He further states that many constraints in the usage of these devices exist, as there is a great lack of verifiable data on their effectiveness, there is a lack of reliable or unbiased data on their actual performances and there is a general lack of availability of these devices in customary plumbing fixture outlets. Thus, research in water use reducing technology is still in an incipient stage. It is plagued by the above problems as well as the problems pertaining to the evaluation of projected savings versus real savings taking follow-up checks and maintenance into account.

Water Recycling

Sharpe (1976) states that recent studies pertaining to the recycling of wastewater from the sink, bathtub and laundry have indicated satisfactory performance for reuse in toilet flushing. This can be done by use of simple filtering and disinfection. Feldman (1977) cites an example of an internal recycling system currently in use at the Eaton Company office in Cleveland. The solid wastes are consumed by anaerobic digestor and the water (which is treated to drinking quality) is used in the restrooms and for lawn sprinkling. Grand Canyon National Park has also been using a recycled wastewater system. Wastewater is stored in a tank and then connected to the toilet reservoir.

At the residential level, recycle systems are extremely rare. Milne (1976) claims that no complete residential recycling systems are as yet commercially available.

In addition to the recycling experiments cited earlier by Cohen and Wallman (1974), McLaughlin (1975) designed, built and tested his own recycle system. By diverting wastewater from bathing and clothes washing to large drains, the water was then pumped through a swimming pool filter and used in a conventional ilet. Water consumption was reduced by 22 percent.

Sharpe (1976) also describes an experiment by the EPA in which two of three homes that had installed wastewater recycle systems did not experience septic tank problems. Prior to the installation of the systems these homes had experienced problems. This EPA experiment yielded a 26 percent reduction in sewage flow.

In general, wastewater reuse systems are infrequently used, difficult to install and on the residential level will require attitudinal changes as well. Studies have shown that the public is ready to accept the idea in principle (Pagorski, 1974) but hesitant in terms of actual personal contact (Bruvold and Ongerth, 1974).

Horticultural Practices

Further reductions in water usage can be realized by changes in residential, commercial, and public horticultural practices. Many technological alternatives exist in the forms of lawn and garden irrigation controls (Feldman, 1977). Greater efficiency can be achieved in the timing and duration of lawn sprinkling and by using appropriate vegetation adaptable to the climate.

Sharpe (1978c) reports that in the arid and semi-arid regions of the country, domestic water use is divided almost equally between indoor and outdoor uses. He claims (1978c, p. 11) that, "About 44 percent of total residential water use in California is used outside the home. Of this about 90 percent is used to irrigate lawns, gardens, and shrubs while the remaining 10 percent is used for car washing." The accuracy of these estimates, however, are not known.

Both metering and pricing appear to be effective tools in the reduction of outdoor water use. Linaweaver, Geyer and Wolff (1967) classify sprinkling as a consumptive use and segregate it from in-house domestic use. They have found (1967, p. 271) that, "Meters barely influence domestic or household use, but have a considerable effect on sprinkling." In their study of Boulder, Colorado, Hanke and Boland (1971) report that lawn sprinkling is the largest and most important component of seasonal use. Boulder residents reduced their sprinkling usage by more than 50 percent with the installation of meters and a change from a flat rate to a metered rate. Price elasticities also appear to be significantly higher for water used outside the home (Sharpe, 1978c). Lupsha, Schlegel, and Anderson (1975) also address the topic of urban landscape and residential sprinkling.

Uno (1975) reports that a reduction of usage by as much as 50 percent can be achieved by using an efficient residential sprinkling system. Flack (1976) suggests that controls similar to building and plumbing codes be extended to horticultural practices and lawn sizes.

Social Alternatives

The WSSC has provided an excellent example of a public relations campaign designed to reduce water consumption. Brigham (1976) reports that water conservation measures were instrumental in achieving reductions in monthly sewer flow ranging from 6.5 percent to 17.9 percent between 1973 and 1974. On January 1, 1978 the WSSC adopted a conservation-oriented rate schedule, that was developed in cooperation with citizens' groups. The WSSC is continuing its public education program which includes the distribution of a handbook of water-saving ideas, water-saving workshops, slide-speaker programs, product data on water-saving devices, television and radio advertisements, bumper stickers, plumbing code changes, distribution of toilet leak detector kits, plastic bottles for reduced toilet flushes and shower head flow reducers.

Other communities have succeeded in implementing conservation strategies in order to achieve desired goals. Sharpe (1978B) cites Gettysburg and Springettsbury (Pennsylvania) as two such examples. Another example is Elmhurst, Illinois (Fulton 1978). It is of great importance to note, however, that all of the successful programs have had a multi-pronged attack as a common denominator. For example, public education was used in conjunction with changes in technology, code revisions, construction moratoriums, sewer line extension bans, etc. Of the myriad of available combinations, the effective campaigns have selected a diverse cross section of alternatives.

Price

If conservation is defined as above, then economic theory states that all that is required to achieve conservation is to set the price of water equal to the relevant marginal cost. Unfortunately, there are several practical difficulties that hamper this procedure. These difficulties include estimation of costs, revenue constraints, choice of price structure, and barriers to consumer information.

The economically efficient price is equal to the expected value of both the marginal cost of physical structures to convey water (both financial and environmental) and the opportunity cost of water in its most likely alternative use. Both of these costs are difficult to quantify. Marginal production cost is the difference in the future utility costs from a reduction or increase in water use. The forward-looking nature of these costs makes them difficult to estimate. Similarly, the opportunity cost of water is difficult to measure even if the alternative use is known. Both costs can vary widely even over periods as short as hours or days.

There are several factors which tend to make the marginal-opportunity cost of water greater than average historical cost (e.g. the utilities seldom pay for raw water, federal water and sewer subsidies, negative externalities from facilities, and rising costs because the inexpensive sources are utilized first). Since most utilities are prevented from collecting revenue in excess of average historical cost this presents a problem. Increasing block rates can be used to deal with this problem (Gysi and Loucks, 1971), but block rates introduce inefficiences when all customers are not confronted with the same marginal price (Carver, 1978). Since there are very few factors which tend to cause the efficient price to be below average historical cost (Bonem, 1968, notes that the positive externality of using water to beautify a lawn is one example) then declining block rates offer no advantage and should be eliminated.

The above difficulties do not diminish the importance of price. The problem of calculating the efficient price must be solved before it can be known if a water use reduction is beneficial. If the price for urban water is at an inefficient low level then economically justified water-saving devices will not be voluntarily installed regardless of the amount of information supplied. Without price at or near the efficient level, spontaneous introduction of appropriate water saving devices in existing homes cannot be expected.

Even when the price is at the efficient level, information problems can interfere with urban water conservation. It is difficult for a consumer to interpret the price of water since so few consumers know the amount of water used for various tasks (Abbott, H. E., K. G. Cook and R. B. Sleight, 1972). If the rate structure is other than a simple uniform price then the consumers' task is further complicated. When confronted with innovative rates, consumers have sometimes acted in an apparently irrational manner (Carver, 1978). The failure of consumers to install economically justifiable water saving devices can also be due to lack of information on available appliances. Water represents a very small portion of most consumer's budgets so they cannot be expected to spend a great deal of time on the subject.

Metering

Meters are required if pricing is to be used to achieve water conservation. Researchers using time series data have found that the installation of water meters followed by implementation of use-based rates reduces water use substantially. Reductions of from 27 to 50 percent have been reported (*The American City*, 1972; Hanke, 1970; and Leopold, 1960). Linaweaver, Geyer and Wolff (1967), using cross-sectional data, found that metered areas had significantly lower sprinkling use than flat-rate areas. However, they found little difference between the domestic use of metered and flat-rate areas.

Metering has additional advantages. If a system is universally metered it aids in leak detection. Granger (1955) reports that through a single program of universal metering, unaccounted for water was reduced from 60-70 percent to 6-20 percent. Metering also enables the enforcement of water rationing during long duration water shortages (see Drought Management, below).

No cost-benefit studies of metering were found in the literature. In addition to the reasons given above, it appears to enjoy popular support. Seventy-five percent of the drought area respondents to the Abbott, Cook and Sleight (1972) survey supported metering. Denver, Reno, and New York are among the remaining few U. S. cities which do not have metering for a large fraction of their customers. Time-of-day metering does not appear to be economically justifiable for residential customers, but may be useful in reducing peak demands of larger customers as shown by the Milwaukee experience (Middlemas, 1961). Peak seasonal demands can also be lowered by seasonal pricing (8 percent in Dallas; Rice, I. N. and L. G. Shaw, 1978) but if sewer costs are considered the overall economic impact of higher summer prices is likely to be negative (Carver, 1978). Little research has been conducted on the effects of individual meters for apartment units as is advocated by some (Milne, 1976).

Urban-Residential Price Elasticity

Price elasticity is roughly equivalent to the expected percentage change in quantity of water used in response to a one percent rise in price; for example, a 2 percent reduction in water use that resulted from a 5 percent increase in price would imply a price elasticity of -.4. On the other hand, if the reduction of water use had been 3 percent, then the price elasticity would be -.6. Table XII gives elasticity values calculated by several investigators. The variation

TABLE XII

Estimated Elasticities of Demand for Water

Investigator	Year	Type of Analysis	Price Elasticity
Gottlieb	1952	68 Kansas cities	-1.02
	1952	19 Kansas cities	-1.24
	1957	84 Kansas cities	-0.69
	1957	24 Kansas cities	-0.68
	1958	24 Kansas cities	-0.66
	1963	Kansas Cross-Sectional	-0.95 (mean)
Seidel and Baumann	1957	American cities Cross-Sectional @.45/1,000 g	-0.12
Renshaw	1958	36 Water service systems, cross-sectional	-0.45
Fourt	1958	34 American cities, cross-sectional	-0.39
Wong et al.	1963	Northeastern Illinois, cross-sectional	-0.31 (mean)
Heaver and Winter	1963	Ontario cities	-0.254
Hedges and Moore	1963	Northern California irrigation	-0.19
Howe and Linaweaver	1963-1965	21 Residential domestic Public sewers	-0.23
		Seasonal use	-1.16
Gardner and Schick	1964	42 Northern Utah Water systems, cross-sectional	-0.77
Flack	1965	54 Western cities, cross-sectional @ .45/1000 g	-0.12
		All Cities @.45/1,000 g	-0.65
Ware and North	1965	634 Georgia residences	-0.67
Bain, Caves, and Margolis	1966	41 Northern California Cities	-1.10
		Irrigation	-0.64
	1966	41 California cities, cross-sectional	-1.099

TABLE XII (CONTINUED)

Investigator	Year	Type of Analysis	Price Elasticity
Burns *et al*.	1970's	Stratified 2 price comparison	-0.20 to -0.38 in-house -0.27 to 0.53 sprinkling
Young, R. A.	1973	Tucson time-series 1946-1971	-0.20 (reanalysis)
Pepe, *et al*.	1975	4 South Carolina cities, 2 and 3 year time series	0.00 to -0.51
Grunewald, *et al*.	1975	150 rural Kentucky cross-sectional	-0.92
Hogarty and McCay	1975	Blacksburg, Va. 2 year time-series	-0.50 to -1.41
Camp, R. C.	1978	228 Mississippi households; cross-sectional	-0.24 to -0.31
Carver, P. H.	1978	13 Washington, D.C. utilities 6 yr. time-series cross-sectional	0.00 to -0.1 (short run)
	1978	Fairfax Co. (VA) 4 yr. time-series of a innovative price structure	-0.02 to -0.17
Turnovsky	1969	Industrial Massachusetts cross-sectional	-0.47 to -0.84
DeRooy	1974	New Jersey chemical cross-sectional	-0.89 cooling -0.74 processing -0.74 steam generation
Lynne, *et al*.	1978	Miami, FL. cross-sectional	-1.33 dept. stores -0.89 grocery stores -0.14 to -0.30 hotels eating and drinking: not significantly different from zero
Conley	1967	24 S. California communities, cross-sectional	-0.625 (mean)

TABLE XII (CONTINUED)

Investigator	Year	Type of Analysis	Price Elasticity
Turnovsky	1969	19 Massachusetts towns, cross-sectional	-0:225 (mean)
Bruner	1969	Phoenix	-0.03
Grima	1970	91 Observations, cross-sectional	-0.93
	1972	Ontario cities, winter	-0.75
Wong	1970	Chicago, 1951-61 times series	-0.15 (mean)
		Four community size groups, cross-sectional	-0.54 (mean)
Ridge, R.	1972	Cross-sectional Industrial	-0.3 malt liquor -0.6 fluid milk processing
Leone, Ginn & Lin		cross-sectional industrial	-0.3 to -0.4 paper -0.7 to -0.4 chemical -0.5 to -0.4 petroleum -0.7 to -1.1 steel

Source: Amended from U.S. Army Corps, 1976 exhibited between these studies results in part from small sample problems and from differences in the relative size of various sectors of water use represented. However, taken together they clearly demonstrate that consumers do indeed respond to changes in price.

Another source of dispersion in the estimates arises because time series estimates are indicative of short run effects while cross-sectional estimates are more indicative of long run effects. Economic theory indicates that the long run effects should be greater. Short (1 year) and long run (5 years) elasticity values of -0.1 and -0.4 would not seem unreasonable based on the evidence in Table XII. In actual practice the effects of moderate price changes might be masked by weather variations or system growth. The price changes referred to must be real (not a result of general inflation). (Note that if water rates remain constant in an inflationary economy, then the real price of water has fallen.)

Care should be exercised when applying the above elasticities where innovative rates (such as increasing block) are to be employed. Consumer behavior in the presence of large differences between average and marginal price is not well understood. Note that reductions in water use attributable to a price increase and those resulting from reductions from the installation of water saving devices (see above) cannot be added since one of the major components of the price related reductions is the installation of water saving devices.

System Leakage

C. W. Howe (1971) presents results from a sample of 91 cities that indicate that most systems use less than the economic amount of leakage detection (value of water saved would exceed cost of detection). Application of the economic amount of detection would save an estimated 2.4 million acre-feet or around 9 percent of current municipal system production. Howe estimates that repair and detection are economic for mains with losses greater than 3000 gal/day/main-mile. This is in close agreement with the criteria of Hudson (1978) of approximately 1,000-3,000 gal/day/main-mile. These results indicate that the current standard of 10 to 15 percent (Keller, 1976) unaccounted-for-water as a "tight system" may not be strict enough. McPherson (1976) expresses the opinion that conservation from leak detection has greater possibilities, in the near term, than household conservation. As an extreme case a 17 percent reduction in total production was reported in the unmetered system of St. John's Newfoundland from a leak detection program (Mitchell, 1957).

Of the steps that can be taken Hudson (1978) proposes: check registration of all meters, master and retail, meter all lines, record or estimate hydrant and other municipal uses, and conduct sonic inspections where indicated by leaks in excess of 1,000-3,000 gal/day/main-mile. East Bay (Oakland) Municipal Utility district has taken the further step of conducting sonic tests on all lines. In the first 2 years of the program $155,000 has been spent on 50 percent of the system for an estimated saving of approximately 4.0 mgd, or 2 percent of total production (Laverty, 1977). At a 6 percent rate of interest for an assumed 10 year life this project has a cost of approximately one cent per thousand gallons saved ($3-4 acre/foot).

Effects of Water Conservation on Sewage Treatment

Bohae, C. E., and R. A. Sierka (1978) performed simulations on the activated sludge process and determined that the optimal aeration tank volume is essentially unchanged by the concentration of the influent by water conservation programs. The increased concentration of influent had an almost proportional effect on the soluble substrate concentration of the effluent (although the mass load discharged is unaffected). What this analysis ignores, as pointed out by C. A. Cole (Sharpe, 1978), is that effluent BOD concentration is more dependent on residual suspended solids. The reduced volumes achieved by water conservation increase detention times and therefore increase the efficiency of primary treatment and secondary clarification. The result is that at a given mass loading, water conservation will increase the life of settling, clarification and disinfection tanks proportionate to the decrease in volume but will have little effect on the design life of activated sludge aeration tanks and sludge handling facilities. If discharge is limited by effluent concentration rather than mass loading the effects are more complex and could even increase costs. C.A. Cole (Sharpe, 1978) and T. P. Kohen and R. DeYoung (Sharpe, 1975) found that the reduced volume toilets (down to a level of 2.0 gal per flush) are not likely to cause flow problems in house connections or in sewer lines. However, according to Flack, Foster city, California, was reported to encounter septic conditions in sewers becuase of the low-flows during the past drought (Personal Communication, J. Ernie Flack, March 13, 1979).

Municipal Recycling

The National Academy of Sciences (1971) notes that "recycling and AWT may have a far greater impact than systems to augment fresh water supplies or than other methods of conserving existing supplies." There are four major potential uses for recycled municipal waste waters: industrial, agricultural, ground water recharge and direct reuse. Each of these methods of reuse has different problems and prospects. Table XIII (from Frankel, 1967) gives an indication of the costs of some existing reuse facilities in the U.S. It should be noted that reductions in urban water use will have a negative impact on the quantity and the quality (dissolved solids) of recycled municipal water (Bohae and Sierka, 1978).

TABLE XIII

Comparison of Estimated Cost of Reclaimed Sewage Effluent and Cost of Alternate Water Supply

Location	Type of Use	Cost of Reclaimed effluent $/ac ft.	Cost of Alternative Water Supply $/ac ft.	Reference
Pomona, Calif	Irrigation	6-7.50	20	1
San Bernardino, Calif	Irrigation	0.31	10	1
San Francisco, Calif	Park, Lakes	23	70	1
Taft, Calif	Irrigation	6	None Avail	1
Talbert, Calif	Irrigation	6	Unsatisfact	1
Abilene, Texas	Irrigation	no cost	80	1
Kingsville, Texas	Irrigation	no cost	65	1
San Antonio, Texas	Irrigation	no cost	25	1
Grand Canyon, Arizona	Lawn irrigation	120	550	2
Sante Fe, New Mexico	Golf course	49	75	2
Las Vegas, Nevada	Golf course	27	30	2
Big Springs, Texas	Oil refinery	16	57	2
Baltimore, Maryland	Steel Plant	11	44	1
Amarillo, Texas	Oil Refinery	14	45	1
Los Alamos, Texas	Power plant cooling water	24	92	2
Los Angeles, Calif	Groundwater recharge	18	42	3,4
Whittier Narrows, Calif	Spreading	16.85	14*	5

*Metropolitan Water District of Southern California rate for groundwater replenishment. Does not represent total cost of imported water. Future additions from the Feather River are estimated to cost from $50-$100/acre foot. (It is unclear what year dollars, most likely 1967.)

Source: R. J. Frankel, 1967, p. 291.

Industrial reuse of municipal waste water is not new. The Bethlehem Steel Plant in Baltimore, Maryland has been using secondary effluent for cooling steel for over 50 years at a cost of around 4¢/1000 gal. (Frankel, 1967). However, since in the past industry was rarely charged for water withdrawals, there was little incentive for industries to contract with municipalities for treated effluent.

The use of municipal waste waters for irrigation seems to hold more promise. The city of Tuscon is evaluating plans for sale of secondary treated effluent to irrigators (Ko and Duckstein, 1972). The cost of supplying the effluent ($1/acre-foot or $0.003/1000 gal) is much less than current ground water pumping costs (approximately $14/acre-foot). The costs of this technology are primarily associated with pumping effluent to the farms. Associated problems include clogging of spray nozzles and capillary pores in some heavy soils, toxicity of some chemical constituents in waste water (particularly boron) and health restrictions on the application to edible crops. The nutrients in the effluent can provide a distinct benefit (Shuval, 1977). Public acceptance of this form of reuse is not likely to be a problem but water rights laws and subsidized irrigation water may hinder adoption.

Ground water recharge systems using secondary effluent have been in existence in California for some time. They have encountered little public opposition (Bruvold and Ongerth, 1974). According to Frankel (1967) and Carmichael (1973), this form of reclamation is already economically feasible for arid areas similar to California. There are problems, though, in obtaining land for water spreading in urban areas such as Los Angeles, particularly "up stream" in the sewage system where the new plants can reduce loads in trunk sewers. As a result of these difficulties Carmichael (1973) predicts reclaimed water will not increase substantially from its current miniscule level of 0.2 percent of Southern California water supply.

There does appear to be another possibility that could contribute substantially to California's water supply. In the past, plans for injecting Los Angeles effluent as a measure to halt salt water intrusion along coastal areas have been rejected because of concern for costs and water quality. Instead Colorado River water has been used at a charge of $14/acre-foot by the L. A. Muncipal Water District (Frankel, 1967). More recently, PL 92-500 (the Water Pollution Control Act Amendments of 1972) has provided funding for increased treatment at coastal cities. The technical indications from the Orange County project are that good quality potable ground water can be produced by injecting tertiary effluent (lime coagulation, ammonia stripping, recarbonation, filtration, carbon adsorption, and break point chlorination). Construction of the full scale project (30,000 acre-feet/yr) began in 1972 (Shuval, 1977, pp. 238-239). The Orange County Water District anticipates from its municipal waste water a total yield of 30,000 acre-feet/year from waste water injection, irrigation and recharge (Cline, 1978). This type of development could have a substantial impact on municipal water supply in California costal areas. Inland cities in the West are likely to have their effluent recycled in an unplanned way, since most rivers and available acquifers are fully utilized. Discharges from coastal cities, on the other hand, represent a loss of fresh water to the ocean. Coastal ground water injection could help correct this situation. An alternative use of potential aquifers might be for the storage of surface supply. This use of ground water recharge has a potential for greatly reducing evaporation losses from storage compared to reservoirs.

Direct municipal reuse is currently being practiced in Windhoek, South

Africa (Hattingh, 1978). The process uses maturation ponds for the secondary effluent (14 days retention time). The water then undergoes algae flotation, foam fractionation, break point chlorination, and adsorption of organics onto activated carbon. The plant contributes approximately 15 percent of the total water production. No problems have been experienced with health or public acceptance. The cost of the process (not including the maturation ponds) is approximately 50¢/1000 gal. (Shuval, 1977). Professional opposition has been expressed to this type of reuse in the U. S. (American Water Works Association, 1971 and National Water Commission, 1973). In the absence of a professional consensus, public attitudes may be a problem.

At present, no cities in the United States are processing effluent for direct potable use. One of the few U. S. experiences in this area occurred from October 1956 to March 1957, when Chanute, Kansas, treated and reused water for its municipal supply. While the quality of the renovated water met the standards established by the U. S. Public Health Service (1962), the chemical composition deteriorated markedly, the water had a pale yellow color and an unpleasant taste and odor, and foaming occurred when the water was agitated (Metzler, et al., 1958). Earlier, in late 1939 and 1940, another community, Ottumwa, Iowa, also recycled renovated waste water; again, no health problems were observed (Brown, 1940).

In a pilot project, plans are being made to recycle renovated waste water in Denver, Colorado, for all uses including water for drinking. Currently a small demonstration plant (1 mgd) is under construction and a substantial research effort concerning water quality and health has been launched. Within ten years, it is possible that Denver may be recycling renovated waste water at the rate of 100 mgd.

In an experiment in Santee, California, recreational lakes were filled with treated effluent. The lakes served as a scenic background for picnicking, boating, fishing, and swimming, in successive stages. The swimming experiment was closely investigated and, although viruses were commonly isolated from raw sewage, none was ever measured in the input to a final contract chlorination process which preceeded discharge into the lakes.

Effluent from the municipality of Lubbock, Texas is currently being used for crop irrigation and for ponds for cattle drinking. The reclaimed wastewater is also destined for a series of recreational lakes (Canyon Lakes Project), and is also being used by the Southwestern Public Service Company for cooling purposes and is also being used for irrigation on the Texas Tech. campus (Bertram, 1978).

According to Baumann, et al. (1976), the current economic practicability of water reuse can be discussed in light of the experiences of Colorado Springs, Colorado, and Whittier Narrows, California. These are special cases which may, however, come to represent more general trends characterizing the future of water reuse in municipal supply systems. In Colorado Springs, reuse is viewed as a relatively inexpensive source of supply costing approximately one-third as much as deriving the city's potable water supply from extensive transmountain diversions (City of Colorado Springs, 1970). Whittier Narrows, which is using treated sewage to recharge an aquifer, has calculated the cost of providing secondary treated effluent as approximately equal to the cost of buying its potable water from the Los Angeles Metropolitan Water District (MWD).

In both Colorado Springs and Whittier Narrows, only three cost factors were utilized to determine the efficiency of reuse. These were the costs of (1) an alternative source of water; (2) the necessary treatment to provide an effluent of suitable quality; and (3) the provision and operation of a plant to produce the effluent. The costs of reuse were then compared with the costs of the alternative source. Generally, for such analyses, only a comparison with the costs of providing water from conventional sources is used to indicate the efficiency of reuse.

Drought Management

Table XIV presents the results from a number of cases where short term water use restrictions have been applied. For any measure to be effective, it appears that the public must be convinced that a crisis exists. Bans on outside use then produce immediate and effective results. The percentage reductions depend then on the fraction of total use in this category. The Washington Suburban Sanitary Commission experience (when a treatment plant failed) indicated that people are willing to limit inside use voluntarily but must be told the specific recommended practices (number of toilet flushes, loads of wash, etc.). For longer duration events reductions of 50 percent (and in some cases more) can be achieved for metered areas by monthly rations per connection, where fines are imposed for excess use.

There have been a number of surveys which have produced information relating to public perception of water conservation programs. H. E. Abbott, K. G. Cook and R. B. Sleight (1972) found very strong objection to dyeing the water or giving the water an unpleasant taste to warn consumers to save water. They found voluntary measures as effective as compulsory and recommend that voluntary methods be tried first. W. H. Bruvold (undated) found that the public feels that controls should be mandatory and strictly enforced. He also found strong sentiment for per capita rations rather than percentages based on previous use.

TABLE XIV

SUMMARY OF PAST DROUGHT MANAGEMENT MEASURES

Investigator (location)	Year	Restriction Imposed	Resulting Decrease
Groopman (N.Y. City)	1968	Ban outside use and appeals	10-22%
Anderson, R.W. (Pawtucket, RI)	1967	Ban on outside use and appeals	16-18%
Abbott, *et al.* (17 Eastern utilities)	1972	Voluntary and compulsory bans on outside use and appeals	18-50%
Jezler (Sao Paulo, Brazil)	1975	Ban on outside use limits on household use	26%
E.A.I. (Washington Suburban Sanitary Commission)	1977	Ban on outside use, appeals to specific acts	40%
Bollman (Marin Co., CA)	1977	Ban on outside use Rationing with fines	25% 63%
National Water Council (Great Britain)	1976	Ban outside use	25%
		Rotating cut-offs and ban outside use	40-50%
Larkin, D.G. (Oakland, CA)	1978	Rationing with fines	38%
Miller (Denver, CO)	1978	Limit outside use to 3 hrs every 3rd day	21%
Griffith (Los Angeles, CA)	1978	Appeals and limited industry cutbacks with some mandatory controls	10-20%
Robie (California)	1978	Voluntary	up to 20%
		Rationing	up to 50%

M. O. Ertel (1977) points to the need for public participation in planning while the National Water Council (Great Britain) (1977) warns against hard and fast rules that cannot adjust to social factors. C. A. Ibsen and J. A. Ballweg (1969) found television the most effective medium for informing and appealing to the public.

There has been little negative reaction to recent droughts. F. H. Bollman and M. A. Merritt (1977) found that 80 percent of the Marin County respondents rated the 46 gal/cap/day restriction (pre-drought use was 125 gal/cap/day) as moderately or not inconvenient as opposed to extremely inconvenient or cause of great hardship. Abbott, Cook and Sleight (1977) found that 80 percent of the Eastern U. S. respondents who had experienced a water shortage did not want restrictions in normal times but one-half were not willing to pay 10 percent more to insure adequate supplies.

In the aftermath of drought, several investigators have found continued water savings. Groopman (1968) found 6-8 percent savings two years after the New York drought. Larkin (1978) estimates that the Oakland area use will stabilize at 15 to 20 percent below the previous level. Data from 1978, a year after the drought, indicate that Marin County, California water use remained 20-25 percent lower than the level previous to the drought. If this reduced per capita usage continues, individuals will not be able to reduce their use as much in future droughts. If future supplies are based on reduced per capita usage, options for dealing with drought may be substantially narrowed.

Industrial Water Use

Current Use Patterns

Steam-electric generation, manufacturing and mining accounted for 26, 15, and 2 percent of withdrawal and 1, 6, and 2 percent of consumption of fresh water in the U. S., respectively. Of the fresh water obtained for the manufacturing sector 14 percent was supplies by public water systems. Commercial use, wholly supplied by public systems, accounted for 2 percent of all withdawals and 1 percent of consumption (The Second National Assessment of Water Resources, 1978).

Within the manufacturing sector paper, chemical, petroleum (including coal) and primary metals accounted for 85 percent of withdrawals: the respective percentages are 15, 24, 9 and 32. These water uses are not evenly distributed over the country. For example, in both the Colorado and Great Basins the data on paper, chemical and petroleum industries were suppressed in the 1968 census of water use to avoid violating the privacy of the few individual firms. There are tremendous variations in water use among industries, among processes within an industry and among firms. Fewer than 1000 firms in only 8 four-digit SIC industry groups were responsible for almost three-quarters of all manufacturing withdrawals. Similarly, there is a large variation in the amount of water reductions that can take place. For example, the lower Mississippi basin reported a value for the amount of intake water per dollar value added for all manufacturing which was more than three times the national average. California and the Colorado Basin reported values of 0.35 and 0.44 times the national average (Leone, et al., 1974). The amount of water withdrawn to manufacture one ton of finished steel is reported to vary between 1.9 to 65 thousand gallons, for one gallon of refined petroleum product: 2 to 44 gallons, and for 100 pounds of sugar from sugar beets: 75 to 3,200 gallons (WCTF, 1978).

Methods of Achieving Water Conservation

The amount that water use can be reduced depends on how that water is used. Three of the major types of use in industry are water for cooling, other process water, and water that is incorporated into the final product. The percentages of water used in cooling for the four major water using manufacturing industries are 28, 60, 57, and 91 for paper, chemicals, primary metals and petroleum respectively. Of these industries only chemicals incorporate a substantial amount of water in the final product. For steam-electric generation cooling accounts for virtually all present use but air pollution control systems (scrubbers) will be an important future use. There is considerable variance in the amount of water consumption by these systems ranging around 10 percent of cooling water consumption. Withdrawals for cooling can be substantially reduced through the use of wet cooling towers and recirculation. Unfortunately, this technology will increase the amount of water consumed. To reduce consumption it is necessary to use dry cooling towers or fin-fan cooling. In addition to being expensive these technologies also use more energy than wet cooling towers. Soil warming is also a potential cooling technology. In some cases changing the process so that lower temperatures are required can reduce water use for cooling.

The reduction of water used in processing is more complicated. The two main avenues are to change to a process that requires less water or to treat the water and recycle it internally. Materials recovery can help lower the cost of this recycling substantially. Process water is not generally "consumed" in large quantities but when the water quality is degraded this water may not be available to other users. Better treatment of effluents as mandated by P. L. 52-500 (The Water Pollution Control Amendments of 1972) is an important part of water conservation in industry.

Table XII includes some price elasticities that refer to industrial water use. B. T. Bower (1966) notes that intake water use per unit of production has fallen 14 and 30 percent in the pulp-paper and petroleum industries in 5 and 10 year periods (respectively) before 1959. According to Leone, Ginn, and Lin (1974) in U. S. manufacturing intake per unit of product fell by 36 percent in the period 1954 to 1968. Even larger gains can be expected in the period from 1968 to the present as a result of P.L. 92-500 (The Water Pollution Control Act Amendments of 1972). Regulations submitted by the Environmental Protection Agency normally require the recycling of water within each plant to the maximum extent possible. These regulations have enforced many of the adjustments that would take place in the event of a rise in the price of water. Therefore the industrial price elasticity values listed in Table XII are likely to overestimate the present responsiveness to price.

Brewer and McAuley (1976) have considered this problem in estimating price responsiveness for non-contact cooling, cotton textile finishing processing, kraft paper-making and steel-making. Only in the textile plant would it be economical to reduce water intake at any price below 75¢/1000 gal. This indicates that substantial water conservation measures are already being implemented under P.L. 92-500. Research is needed on what further water conservation methods can be implemented in industry.

These conservation measures are likely to have a substantial impact on drought management programs. Russell (1970) found that large reductions in water use during the Massachusetts drought were obtained by industries installing water conserving devices. As a result of P.L. 92-500 many of these devices are now in place. It is therefore unlikely that short-term reductions comparable to those found by Russell can be achieved without reducing plant output.

Agricultural Water Use

Price

Reduction of agricultural water use represents the greatest water conservation challenge. Irrigation accounts for 46 percent of withdrawals and 81 percent of consumptive use in the U.S., most of it in the water-short West (Water Conservation Task Force (WCTF), 1977). While the potential is great, so, too are the difficulties. Federally supplied water (about 20 percent of the total) costs irrigators between $1.00 and $10/acre-foot (0.3¢-3¢/1000 gal). There are few opportunities to revise or renegotiate these existing contracts as most are of long duration (WCTF, 1977). Water supplied by private irrigation districts is often not charged on a per unit basis. These districts are supported by flat charges or by tax revenues. Private withdrawers are dependent primarily on water rights which may be (for administrative reasons) difficult or impossible to sell. In all of these cases, costs faced by individual irrigators fail to reflect full social costs of water used, and thus do not provide appropriate incentives for conservation. Other incentives may be present, however, especially where supply failure would result from unconstrained use.

Several proposals have been made to correct this situation. When Federal water contracts are renegotiated the price should be raised to the level of the marginal cost of the water. Over 75 percent of the land irrigated in Wyoming, Colorado, Utah, Idaho, Montana and Washington has water delivered through some type of group water organization, while in Oregon, California, Arizona, New Mexico, North Dakota and South Dakota the figure is over 50 percent (1969 U.S. Census of Agriculture). Many of these organizations (primarily irrigation districts) have little incentive to price water rationally and therefore will do so only if required.

Water rights should be quantified by permit systems and sale of these permits should be allowed. Provisions in these sales will have to be made for users of return flows from the permitted user. One of the more innovative proposals has been made by Angeliedes and Bardach (1977). They advocate a system called water banking. Under this system water rights or allocations under irrigation districts could be "loaned" to other users for either short or long periods of time. They argue that such a plan is not incompatible with existing institutional structures.

Whatever the plan finally adopted, it is clear that drastic changes in the price (or resale value) or irrigation water are needed if conservation is to be achieved in agricultural water use. The Irrigation Efficiency Task Force (Boone, 1978, p. F-4 and 5) states "Institutional and social factors that contribute to low irrigation efficiencies include present-day interpretation and administration of water laws and decrees, attitudes that land and water are free resources to be used as desired, limited financial capabilities, conflicts between water use instream or for wetland habitat, shortage of technical assistance and education to water user; and limited understanding of the value placed on water resources by the public."

Changes in Technology and Water Use Practices

There are substantial changes in both consumptive use and withdrawals for irrigation that can be achieved using existing technology. Major areas include lining irrigation ditches, changing from surface to sprinklers or drip irrigation, and changes in water use practices such as mulching and tillage practices, drought resistant crops, and most importantly a more careful application of water to coincide with stages of plant growth. This latter change in management practice requires the installation of a complex and flexible off-farm storage and conveyance system and many changes in on-farm delivery systems. It also requires technically sophisticated management capability and increased manpower both at the farm and irrigation district levels. The amount of water savings from increased efficiency will vary widely from place to place depending on soil conditions, climate, the type of crop and on the level of efficiency already achieved. The Water Conservation Task Force (1977) estimates that a 20 to 30 percent reduction of the withdrawals for agriculture is possible from these measures.

Hedlund (1975) estimates that if a program of high efficiency irrigation were implemented it would cost $5.7 billion and reduce withdrawals by 48 million acre-feet (27 percent) and consumptive use by 7.4 million acre-feet. Boone (1977) provides smaller estimates for changes in water use from such a program of 38.6 million acre-feet in withdrawal (22 percent) and 3.3 million acre-feet in consumption. His costs though are more than twice as large: $14.6 billion. What is even more surprising than the variance is the high level of these costs. Using an interest rate of 6 percent and an assumed life of 10 years the range of costs is $15-50/acre-foot of withdrawals and $100-600/acre-foot for consumption. For a project near the Bay area (California) to replace surface irrigation with piped water and sprinklers, Gilbert (1977) estimates a cost of $50/acre-foot reduction in withdrawals. By way of comparison Young and Martin estimated the net return to farmers from irrigation water from the Central Arizona Project as $20/acre-foot (Barbera, 1978, p. 128). If these figures are representative, then the cost-effective approach to conservation is not to increase irrigation efficiency but to remove water from agriculture, although there are likely to be some conservation measures which are cost-effective. The United States Department of the Interior (1978) also concludes that many water conservation programs cannot be justified solely on the basis of a strict economic efficiency criteria. The environmental aspects for increasing irrigation efficiency are not promising either. One of the major ways to reduce consumptive use is to line ditches and remove phreatophytes. Both of these activities can destroy wildlife habitats.

Drought Management

Under current Western water law the method of allocating water during a shortage is that senior appropriators receive their full water right and junior appropriators receive nothing. This is clearly not an efficient allocation structure. Under some projects and irrigation districts the allocations are more even but usually some differences exist based on seniority.

There appears to be less ability to reduce water use in agriculture (while maintaining production) than in municipal use (Robie, 1978). During the 1977 California drought agricultural losses were held to the surprising small level of $800 million considering the severity of the drought and the multibillion dollar size of California agriculture. Two major factors contributed to this success. Many of the irrigators who were cut off were able to drill wells to maintain production. As a result ground water was depleted 4.2 percent in 1976 and a further 8.4 percent in 1977. The other major factor was the shift of water from rice growers in the Sacramento Valley to orchards and vineyards in the Central Valley in exchange for cash. As a result, few of these investments were lost. While these two events represent special cases they illustrate two important features that should be part of the necessary planning for agricultural water shortages: (1) Plans should be made to transfer water from grains and other low value crops to save perennials; (2) Sufficient ground water should be left in place to provide a contingency reserve with allocation going to those who cannot obtain ground water.

Summary and Conclusions

Past research has focused upon the opportunities of water conservation in residential use, with less attention directed toward industrial and agricultural reduction in water use. Following a brief assessment of the effectiveness of conservation measures, two major problems are addressed: the question of economic incentives for efficient water use and the problem of social acceptance in water conservation planning.

Information on the effectiveness and efficiency of the full range of conservation measures is sketchy and frequently derived from poorly designed empirical studies or based upon *a priori* judgments. Information on implementation costs and social acceptability under different environmental situations is sparse; indeed, such information is insufficient for consideration of implementing water conservation measures. Finally, most estimates were calculated by estimating changes in water use *before* the implementation of a conservation program and *after* implementation. Hence, the effect of other factors on determining water use remain unknown. What is required is a with-without framework: that is, what is the water use pattern *with* a specific conservation measure and what is water use *without* the conservation measure? Only then is the true effect of conservation on water use known.

Agricultural water use represents perhaps the greatest water conservation challenge. The potential savings are greater than in any other sector but the institutional, socio-economic and political problems are substantial. Engineering studies and limited field observations of the water-saving effects of various measures are available. Little is known of the possible means of implementation of the measures in the current institutional and economic context. Greater promise appears to lie in the area of expanding resale rights of water rather than increasing the price of water which would involve large transfers of real income from the farmers.

The enactment and implementation of P.L. 92-500 appears to have provided a substantial impetus to water conservation by industry. However, the actual effects in specific industries and at specific locations have not been well documented. Because the reduction in water use was not the primary purpose of the act there exists the possibility that further conservation measures could be implemented.

An important class of water conservation measures are those which create economic incentives for efficient use of water. These measures require that all water uses be metered, and that appropriate prices be levied on water used. A substantial literature is available which describes the sensitivity of water use to changes in water price (the price elasticity of water demand). Economic theory shows that when price is set equal to the relevant marginal cost (which includes the marginal costs of water storage, transmission, distribution, and treatment facilities as well as the marginal opportunity cost of the water), water users will be motivated to reduce water use to the optimum level--further reductions would not be beneficial to society as a whole.

In practice, however, marginal cost varies from season to season, from day to day, from time to time in the same day, and from place to place in the distribution system. A rate structure that attempts to reflect this variation would, through its complexity, exceed the capabilities of a cost-effective metering technology, as well as the ability of the water user to respond to changing price signals. Further, water distribution agencies are typically constrained to cover their costs, and to not over-collect revenues. Since marginal costs bear no necessary relation to average or total costs, the overall rate level must be based on total, rather than marginal cost considerations.

In spite of these constraints, considerable latitude exists for choosing a rate structure that provides improved incentives for water conservation. Conventional practice dictates the use of decreasing-block rate structures, which tend to encourage, rather than discourage, water use. These structures carry the double penalty of inefficiency and complexity. An often-suggested alternative, increasing-block pricing, may reduce overall water use, but at the cost of continued allocative inefficiency and complexity. Many other rate forms--including level prices, seasonal prices, summer surcharges, etc.--show promise as water conservation measures. Actual implementation has been rare, however, and few careful evaluations appear in the literature. Although this report has not attempted to review the rate-making policy literature, established principles are available to assist in the evaluation of rate-structure changes as water conservation measures.

As the preceeding review indicates, the data on individual, public, and institutional conservation behaviors are so gravely incomplete that it is difficult to generalize on either the current efficacy or the future promise of those conservation efforts that may be termed "social." There is one exception: it is certain that this is an area of dramatic opportunities. Thus, as the drought crises have demonstrated, a public can be persuaded to effect major reductions in their use of water when convinced of the need to do so. And, a public can learn to live (indeed, to enjoy) recycled wastewater. And, a public can be moved to save money. But in none of these cases is the causal relationship simple; there are conditions, complicated and confounding, that are attached. Pricing works, if such and such, education works, if ..., and the public will cooperate with drought crisis management, if .... In some, research has succeeded most in demonstrating the considerable complexities of individual and public conservation behaviors.

Similarly, institutionalized behaviors, whether the practices of private enterprise or the strictures of government, clearly can have enormous impact on conservation. Thus, for example, water rights law and federal contracts governing irrigation sets the context within which the agricultural use of recycled wastewater must be seen; and legislation that sets manufacturing standards is the necessary framework for viewing conservation possibilities for industry. Again, however, research to date is illustrative, successful in demonstrating both the importance and the complexities of the issues involved but resistant to the formation of general conclusions.

III. EVALUATION OF WATER CONSERVATION MEASURES

Water conservation measures, when implemented, have the effect of reducing the scale, and/or altering the timing of water resource projects. The planning of such projects, therefore, should include full consideration of all feasible water conservation measures, to be certain that the most efficient combination of water supply and water conservation measures is chosen. This section discusses the notion of feasibility as it applies to potential water conservation measures, and presents an approach to consideration of specific measures. Application of information obtained to the planning process is discussed in Section IV.

Identifying Potential Water Conservation Measures

APPLICABILITY

The first task in the process of identifying potential water conservation measures is to determine applicability. Of the universe of possible water conservation measures, some of which are identified in the literature, some finite set of measures is applicable to the water uses and water users actually under study. Only those measures which meet the test of applicability need be identified and subjected to further analysis.

In most cases, the nature of a proposed water resource project will suggest potential water conservation measures. Wherever water is provided for some beneficial use, various means of reducing the amount of water used, or of reducing the amount of water lost and thus not available for use, can be devised. Other measures are available which may reduce leakage of water from transmission and distribution systems, or losses from storage facilities through evaporation and seepage. Water conservation measures can be proposed for certain in-stream uses of water, such as navigation and recreation. Changes in the physical configuration of a project, or in the mode of operation of a project, may reduce the quantity of water required to provide in-stream uses, with or without some change in the quantity or quality of the services provided.

Water conservation measures may affect all uses of a given water resource, they may affect only certain uses, or they may affect only certain beneficiaries of a specific use. For example, where both M & I and agricultural uses are provided, water conservation measures may be applied to all sectors of use. Or, they may be applied to municipal water for residential lawn irrigation only. Measures may apply to users in one political jurisdiction and not to those in another. They may apply at some times of the year and not at others. Partial implementation practices may be dictated by questions of feasibility (legal or institutional means may exist for implementing a particular measure in one jurisdiction or for one user class, but not for others) or efficiency (the benefits provided by a conservation measure may exceed the cost only for certain users, or at certain times).

An important distinction can be drawn among potential water conservation measures with respect to duration of implementation. In most cases, conservation measures are considered long-term, or permanent. These measures will be implemented as part of, or coincident with the planned project, and will typically remain in effect throughout the project life. Certain circumstances of water supply, however, will dictate consideration of short-term, or contingent conservation measures. These measures are to be implemented only as needed, and only as long as needed. Such measures would include those incorporated into a contingency plan for drought management, where temporary reductions in water use would be undertaken during periods of possible water supply failure.

Some conservation measures may be considered for either long-term or contingent use; it is important to note that implementation cost, effectiveness, and resulting benefits may differ substantially according to the planned duration of implementation. Lawn sprinkling restrictions, for example, may be included as long-term measures when they are to be practiced during each growing season, regardless of supply conditions. Alternatively, such restrictions may be invoked only when reservoir levels fall below some critical value, thus qualifying as contingent water conservation measures.

It is important that the most complete possible list of potential water conservation measures be given at least initial consideration in each planning exercise. The literature, as summarized in this report and elsewhere, can be used to develop an initial list of measures possibly applicable to the water uses being planned. Consideration of the characteristics of expected uses and of the project itself may suggest additional meausres. Feasibility tests can then be applied to the complete list, and those measures which are found feasible, or potentially feasible, are subjected to full evaluation. No potential measures should be excluded at this stage because they appear inefficient or undesirable. The complex impact of water conservation, possibly altering the basic configuration and timing of a project, suggests that intuition is unlikely to be a reliable analytical tool.

FEASIBILITY

Once a list of applicable water conservation measures has been developed, it must be determined which measures are capable of implementation, or feasible. Feasibility can be defined with respect to various types of considerations, such as social, political (including legal), institutional, technical, and economic feasibility. Because the economic feasibility of water conservation measures is dependent upon the economic characteristics of the water resource development being planned, consideration of this issue must be postponed to a later stage of the planning process. Other types of feasibility, however, are usually independent of overall project characteristics, and can be investigated at the outset. In this way, infeasible measures can be removed from the list of potential water conservation measures, reducing the scope of later analysis.

Great caution and restraint should be exercised before labelling a measure "infeasible." Virtually all water conservation measures will appear to have barriers to implementation. Since measures under consideration are actions or policies which are not now in use, it will not be difficult to provide reasons for their disuse. But to say that a measure is infeasible is to assert that implementation would be not just difficult or even undesirable, but impossible. Difficulty (as expressed by implementation procedures and costs) and desirability (as described in terms of beneficial and adverse effects) are separate issues and will be topics for later analysis; they do not alter feasibility. When in doubt, it is better to classify a measure as "potentially feasible" than to exclude it as "infeasible" and thereby leave key questions unanswered. Examples of the distinctions which should be observed among the terms "feasible," "potentially feasible," and "infeasible" are given in the following paragraphs.

Social feasibility

A potential water conservation measure is socially feasible when there is no reason to expect a broad consensus of public opinion to develop in opposition to its implementation, so as to block such implementation. In some cases, public opposition to some measure, such as conservation-oriented pricing policy, may be anticipated but it may also be true that a properly executed program of public participation in the planning process and public information dissemination could win sufficient acceptance. Where this strategy is a possibility, the conservation measure should be considered potentially feasible.

There is no question but that assessment of social feasibility is a precarious process--it is not a world of hard data. The dimensions to be measured are the elusive ones of values, attitudes, and beliefs; and the methodologies necessary are the "soft" ones of the social sciences. But they are sufficient to the task, namely, to guide the policy-maker in estimating public response.

Since by their very nature, beliefs, attitudes and values are not forever set and irreversible but are indeed subject to change over time, it follows that any proposed measure could be considered as at least potentially feasible. But while this is logically the case, it would not be empirically so. Given some realistic parameters of time and effort, of place and society, it is more reasonable to say that any policies or procedures that are congruent with the most basic tenets of our society's value system, such as equality, freedom, and private property, may be considered as socially feasible or potentially feasible.

Therefore, great caution should be exercised against being trapped by pessimism into premature judgments regarding the social infeasibility of a conservation effort. When properly informed, the public is capable of discerning its own best interests.

Political feasbility

While social feasibility considers the interests of the public in a broad sense, political feasibility reflects a more narrow conception, namely, the ability of the public, some subgroup of the public, or one or more individuals to block implementation through the political process. Implementation can be blocked by establishing or maintaining legislation which conflicts with the proposed measure; by establishing or maintaining regulations which preclude implementation; by failing to grant necessary licenses, permits, or permissions; by failing to cooperate with implementing organizations or agencies; or, when the government is the implementing agency, by simply failing to implement the measure. Any or all of these actions or inactions may be in response to political perceptions of social infeasibility, or in response to special interests or dissenting views, including those of political leaders and agency administrators.

As with social considerations, political infeasibility will often be difficult to determine. The political process is characterized by change, both regular (following elections) and irregular (shifting priorities). What appears infeasible today, perhaps even because of legislative prohibition, may become fully feasible within a few years when the mood of the electorate and their representative changes. With respect to political considerations, as with social considerations, measures should probably be categorized as either feasible or potentially feasible, seldom as infeasible.

Institutional feasibility

Most water conservation measures require some implementing institution. A government agency, a public utility, a private business organization, or some other body must take responsibility for implementing and maintaining the specified water conservation practice. Sprinkling regulations must be decreed and enforced, water-saving plumbing fixtures must be specified and provided to buyers, plumbing codes must be adopted and enforced, etc. Because of these special requirements, institutional feasibility is discussed separately from political feasibility. The separation is an artifical one, however, and the previous discussion applies here with equal force.

In some cases, the necessary institution(s), together with all required legal and administrative authority, will be already available as required for specific water conservation measures. These measures then possess institutional feasibility. More often, it will be found that certain changes in existing institutions, new institutions, and/or changes in legal and administrative authority are required before a measure may be fully implemented. If such changes appear plausible, and would be likely undertaken as a result of conditions attached to the planned water resource development, or in response to opportunities provided by the water resource development, the measures are potentially feasible with respect to institutional barriers. On the other hand, if the necessary changes appear unlikely to be accomplished on the basis of circumstances presently foreseen or expected to result from the planned water resource development, the potential water conservation measure may be institutionally infeasible.

Technical feasibility

While questions of technical feasibility are inherently more straightforward and susceptible to analysis than those of social, political or institutional feasibility, they are sometimes confused with issues of technical effectiveness, to be considered later. For example, the installation of re-designed water closets may be expected to result in a 10 per cent overall reduction in residential water use. Suppose that, because of double- and triple-flushing and other problems, the actual reduction is less than 2 per cent. This is not an issue of feasibility, but one of effectiveness.

A potential water conservation measure is technically infeasible when its performance is such that implementation is actually blocked. In the above example, the poor performance and increased cost of the fixture could result in so much opposition to their installation that further installations would be stopped, indicating, in this case, technical infeasibility. Where a conservation measure has been documented as effective under certain circumstances, such a measure when considered for the same or similar circumstances must be considered technically feasible. When considered for substantially different circumstances, or when an unproved measure is being considered, conclusions of potential feasibility, or infeasibility may be reached.

It should be acknowledged, indeed, emphasized, that the determination of what is socially, politically, institutionally, and technically feasible will necessarily involve those responsible for water management in matters and processes alien to them. The values, attitudes and beliefs of the public in general and of various interest groups in particular, were once more or less ignored and are now, in these days of activism, more or less dreaded, by resource planners. It is essential that such professionals not only open their minds to social realities, but develop competencies in their identification, measurement, and management. It is only such knowledge and skill that will control the frustration and anxiety that would otherwise interfere with the intelligent assessment of costs and benefits of potential conservation efforts. It must be recognized that there are dangers in enlarging the arena of professional concerns if nothing is done to encourage a correlative increase in professional expertise.

POTENTIAL WATER CONSERVATION MEASURES

The identification of potential water conservation measures, as described above, begins with the preparation of a list of all measures applicable to the purposes of the specific water resource development under consideration. Measures may be suggested which affect all users and sectors of use, or which affect only a few. Measures may be employed continuously, or seasonally. They may be long-term, or contingent. They may consist of regulations, recommendations, pricing policies, or modifications to water-using appliances.

Each applicable conservation measure must be tested for social, political, institutional, and technical feasibility (economic feasibility is to be determined later as part of the overall project evaluation). Measures which are found to be infeasible on one or more counts can be deleted from further consideration. Those which are either feasible or potentially feasible on all counts are retained for further analysis. Where a measure is found potentially feasible, the circumstances under which it would become clearly feasible should be stated, so that subsequent analysis can continue to take notice of the conditional nature of the measure's feasibility. The resulting list of feasible and potentially feasible measures constitutes the set of potential water conservation measures which must be subjected to full analysis in the context of the water resource development being planned. Prior to such analysis, however, the implementation characteristics and the expected results of each measure must be determined.

Implementation Characteristics

Implementation of a water conservation measure requires that an agency or organization having the necessary legislative or administrative authority take the requisite actions. It may also require certain voluntary actions on the part of water users, whether in response to requests for conservation, or to various types of incentives. In every case, financial and other resources must be committed to the implementation of the water conservation measure. In order to determine the cost of resources so committed, the implementation process must be described in some detail, identifying the responsible agency or organization, determining the timing and coverage of the measure, and noting any specific costs of implementation.

RESPONSIBLE AGENCY

The first step in describing the implementation process for a proposed water conservation measure is the identification of the agency or organization that must assume responsibility for implementation. (In some cases, responsibility may be shared by several organizations.) Occasionally, the responsibility for actual implementation may rest with a federal agency, as when the Corps of

Engineers would direct the installation of water-saving plumbing fixtures at a Department of the Army installation. In most cases, though, implementation will occur at the state or local level, within a private industry, or voluntarily by individual water users.

Where water-saving plumbing fixtures are to be installed on a mandatory basis in new or remodeled structures, the usual implementation vehicle would be local plumbing codes. The state or local agency or agencies with responsibility for modifying and enforcing these codes would then constitute the responsible agency or agencies. If homeowners and business owners are expected to replace or modify existing plumbing fixtures (changing shower heads or installing flow reducers in existing heads, for example), they will only do so as a result of a public information campaign designed to acquaint them with the benefits of reducing water use, and with the costs and techniques for making the requested changes. In many cases, such a campaign would be conducted by the local water utility, whether a public agency, an autonomous authority or commission, or an investor-owned company. Sometimes, a state agency may assist, or perform the function itself. Similarly, conservation-oriented pricing policies, general appeals for voluntary reduction in water use, and restrictions on residential lawn irrigation would likely be implemented by the local water authority.

Changes in the pattern of utilization of water for agricultural purposes may be implemented by the water supply authority, by farmers' organizations, through extension agents, or by state or county government agencies. Water conservation measures applying to in-stream uses of water, such as those affecting water use for navigation or recreational purposes, would likely be implemented by the federal or state agency operating the related facilities, although they could occur in response to regulations issued by state water resource agencies.

Measures undertaken to reduce losses from reservoirs or transmission facilities would be implemented by the respective operating agencies.

COVERAGE AND DURATION

Following determination of the responsible agency, the probable plan of implementation must be outlined for each conservation measure, indicating the coverage and the duration of implementation. While specific measures typically apply only to one type and sector of water use, they may or may not apply to all users within that sector. Changes in plumbing codes, for example, might affect only those municipal water users who occupy new or remodeled premises. Sprinkling regulations affect only those residential users who attempt to irrigate lawns and gardens. It is also possible that questions of political or institutional feasibility may limit the coverage of a specific measure to users within a certain political jurisdiction, omitting nearby areas served by the same water source.

Another aspect of coverage applies wherever a significant period of time is required for full implementation. While sprinkling restrictions may be considered nearly instantaneously effective, when seen in the context of a normal planning period, conversion to water-saving plumbing fixtures by alteration of plumbing codes may require many years to become essentially complete. A program to detect and correct distribution system leaks may extend over five to ten years. In all such cases, a forecast of implementation rate be prepared, indicating the expected coverage of the conservation measure at various intermediate times, as well as at the end of the implementation period.

Even where the implementation period is not a concern, the date of first implementation and the period for which the conservation measure is expected to be effective (if less than the planning period) must be determined. If a long-term measure is under consideration, it may also be necessary to know whether or not the conservation practice is continuous (certain measures, such as sprinkling restrictions, may be in effect only during certain months of the year). Contingent measures require more careful analysis. The likely contingency plan must be developed, setting forth the circumstances under which the proposed measure would be invoked, the estimated frequency of such occurences, and the expected duration of each. Generally, this will require probabilistic analysis of future supply and demand conditions, perhaps including simulation analysis of supply deficits.

IMPLEMENTATION COSTS

All water conservation measures are associated with implementation costs, and these costs often comprise several different types and may be borne by several different entities. Perhaps the simplest example would be an appeal, via mass media and mailings, for voluntary, modest reductions in household water use. The responsible agency incurs certain costs in preparing and disseminating the conservation message, including printing and mailing costs. Individual water users may accept minor inconveniences in rearranging their water use habits, but it may not be resonable to associate economic costs with these changes.

On the other hand, severe household water use restrictions, such as those imposed in parts of California during 1976-77, may involve costs at several levels. The responsible agency must prepare and disseminate the conservation message and associated restrictions, the restrictions must be policed and enforced, and many individuals can incur substantial private costs ranging from time and inconvenience associated with re-using gray water to lost investment in shrubbery and lawns. Requirements for water-saving appliances may create private costs due to accelerated retirement of old fixtures and/or cost differentials on new, water-saving devices.

Generally, implementation costs can be classified by type (direct and indirect) and by incidence (public sector, private sector, user category, etc.). Direct costs are those which appear as actual and separable dollar outlays, such as mailing expenses by a public agency, or the additional cost of a water-saving appliance to a private individual. Indirect costs are experienced by public agencies and by private business organizations when time and resources are diverted from other agency activities, even though dollar outlays are not increased, or when joint costs are involved. Individuals experience indirect cost in analogous ways--time and effort must be expended, and inconvenience accepted. While direct costs are readily observable, and can be estimated and forecast with some confidence, indirect costs are rarely, if ever, determined. In the case of individuals, a suitable measure for indirect cost would be the amount which the individual would voluntarily pay to avoid the conservation practice, but this valuation is unlikely to be available. Further discussion of indirect costs appears below in the description of other adverse effects.

Predicted Results

The major result expected from the implementation of a water conservation measure is, of course, a reduction in the use (or loss) of water, either in general or at specific times. The benefit associated with such a reduction can only be valued in the context of the water resource development planning process, as discussed in Section IV of this report. Since conservation measures frequently alter the nature of water-using activities, they may also create beneficial and adverse effects beyond those stemming from implementation, discussed above, or from water saving. These paragraphs discuss means for predicting the quantity of water expected to be saved by specific conservation measures, and of identifying and predicting other beneficial and adverse effects.

EFFECTIVENESS

The effectiveness of a water conservation measure is defined as the quantity of water per unit time which is expected to be saved through implementation of that measure. Where the measure under consideration is a long-term measure used intermittently, or a contingent measure, effectiveness must be further qualified with respect to the relevant time period. Predictions of effectiveness are obtained as follows:

$$E_{ijt} = R_{ijt} \cdot C_{ijt} \cdot Q_{jt}$$

Where: E_{ijt} = effectiveness of conservation measure i for use sector j at time t, in quantity per unit time (e.g., gallons per day)

R_{ijt} = fraction reduction in the use (or loss) of water for sector j, at time t, expected as a result of implementing measure i.

C_{ijt} = coverage of measure i in use sector j at time t, expressed as fraction of sectoral water use affected by conservation measure.

Q_{jt} = Predicted unrestricted water use in sector j at time t, in quantity per unit time (e.g., gallons per day).

The first term of the above expression, R_{ijt}, must be obtained from the literature or from engineering analysis of the measure under consideration. (A broad sample of the literature is summarized in Section II, above.) Two difficulties are likely to arise in transferring estimates from literature sources. First, many reported data are not measures of actual results, but *a priori* estimates of other investigators. Even where measures have been implemented and overall reductions in water use achieved, the actual effectiveness of individual measures may not have been determined. Second, effectiveness data may not be reported with respect to the affected sector of water use, but stated as a fraction of some larger aggregate. For example, the effectiveness of lawn sprinkling restrictions may be given as a fraction of overall municipal water use, rather than as a fraction of seasonal residential use. The former result is likely to be unsuitable for application to a different community, where the structure of municipal water use may be quite different. Unless actual measurements of fractional reductions in water use for the affected water use sector are available, engineering estimates, either prepared for the purpose or obtained from the literature, must be relied upon. Attention should be given to the consequences of error in these estimates, and alternate calculations employing upper and lower bounds are recommended.

The term describing fraction coverage, C_{ijt}, is obtained from the implementation plan, discussed above. It reflects two aspects of implementation: the partial coverage inherent in certain measures (voluntary reductions are limited to those who choose to comply, other measures may be feasible to implement only in certain areas), and the possibility of progressive introduction of some types of measure (gradual conversion of plumbing stock, phased leakage control program, etc.). It should be noted that, for dimensional consistency, the coverage term must be expressed as a fraction of water use affected, rather than of users affected. Where users are expected to be either approximately equal in their use of water, or to be randomly distributed with respect to implementation (users covered by the measure exhibit the same use distribution as those not covered), it may be sufficient to employ the fraction of users covered as an estimator for C_{ijt}.

The need to provide predictions of unrestricted water use in each sector of water use affected by a potential water conservation measure (Q_{jt}) requires the preparation of a substantially disaggregated forecast of future water use. Depending upon the conservation measures under consideration, separate forecasts may be required for residential water use (possibly further disaggregated to seasonal and non-seasonal use), commercial use, industrial use, public and unaccounted use, agricultural use, and for any in-stream uses that may be the focus of conservation efforts. For best results, these individual forecasts should be prepared as part of a single, integrated forecasting process, so that consistent assumptions are employed throughout. The use of rules-of-thumb (e.g., estimating commercial water use at 15 per cent of municipal water use) is likely to result in substantial error, as individual communities vary widely in the structure of their water use. Care should be exercised in the classification of apartment water use, as many communities consider this commercial in nature, although it would be responsive to residentially oriented conversation measures. When contingent conservation measures are under consideration, the water use forecasts employed must reflect the structure of water use expected under circumstances which would require the imposition of the conservation measure. For example, if the conservation measure would be imposed only during an unusually hot, dry period in the summer, seasonal (sprinkling) water use may well be expected to be higher than average at that time.

OTHER BENEFICIAL EFFECTS

Beyond the reduction in water use, water conservation measures may produce beneficial effects which can be identified and described independent of full analysis of a water supply plan. Some of these beneficial effects can be described in monetary terms, while others may appear in forms for which no monetary equivalents are available. In either case, all beneficial effects should be identified, and expressed in monetary terms where possible, or in other (preferably quantitative terms).

Examples of beneficial effects for which monetary estimates can be obtained include the effect on household energy consumption of reductions in the use of hot water (through flow reducers in shower heads, etc.). Increased recycling of water by industrial firms may, aside from the implementation cost, produce beneficial effects as a result of the temperature or location of the recycled supply as compared to the original water source. Non-monetary benefits may be experienced when water users feel an increased sense of satisfaction, or well-being, as a consequence of the implementation of water conservation measures. While such beneficial results are plausible, they have not been generally reported in the literature.

OTHER ADVERSE EFFECTS

In addition to implementation costs, discussed above, water conservation measures may produce a variety of adverse effects on water users, some reflected in monetary terms, and some essentially non-monetary. Where water conservation by industry or in agricultural uses requires increased attention to process control or to crop growth, the increased effort can be expressed in monetary terms as an adverse effect of the conservation measure. Restrictions on water use for residential lawn irrigation may lead to re-landscaping with more drought-resistant species, with accompanying monetary cost. Overall reductions in water use may reduce the volume and increase the strength of municipal wastewater, in some cases causing increases or decreases in treatment cost.

On the other hand, some conservation measures serve to reduce the satisfaction, or well-being, of water users in ways that cannot be readily expressed in monetary terms. Residential users may be annoyed by the need to occasionally double-flush a water-saving water closet, or by the inconvenience of adhering to sprinkling restrictions. The community as a whole may feel a sense of loss at the appearance of brown lawns and dying shrubbery during a summer drought accompanied by sprinkling restrictions. Other adverse impacts on environmental quality may arise from water conservation.

In concept, some adverse effects of this type should appear as leftward shifts in the demand curve for water. This results not only in less water being used at a given price (effectiveness), but in each unit of water being associated with lower marginal willingness-to-pay by the water user. In other cases, the water conservation practice may have the effect of providing the same amount of consumer satisfaction from a specific water use, but requiring less water to achieve that satisfaction. If all other water uses by that class of user remain unaffected, the result would be a demand curve which is above the former curve in some area, and below it for larger quantities. Less water would be demanded at the same price, but it would not necessarily be true that total willingness-to-pay is less as well.

These cases suggest the difficulties which are likely to attend any effort to obtain monetary valuations of some types of adverse effects on water users. Lacking any alternative, then, most such effects must be treated as non-monetary in nature, and analyzed descriptively, rather than quantitatively. Little guidance is available for identifying and describing these non-monetary adverse effects, but their possible existence should be recognized and specific expected effects described wherever feasible.

Social Welfare Impacts

Conservation measures should be included in water resource development plans to the extent that they provide benefits which exceed the additional costs. The above paragraphs discuss those beneficial and adverse effects (including implementation costs) of conservation measures which can be determined in isolation, that is, which do not depend upon the nature of the water resource development under consideration. The most important benefits, however, derive from the effectiveness of the water conservation measure--the reduction in level and/or pattern of water use which the conservation measure produces. Such reductions may alter the optimal configuration or timing of the water resource development, thus reducing costs. Prior to incorporating the consideration of conservation measures into the project planning process, several additional issues should be reviewed, including problems of aggregation, of incorporating risk and uncertainty, and of discounting future benefits and costs.

AGGREGATING BENEFITS AND COSTS

The previous paragraphs discuss the identification and measurement of specific beneficial and adverse effects associated with specific conservation measures. In most cases, however, the object of the planning exercise will be to select the set of conservation measures which provides the largest amount of net benefits. Identifying this optimal set is complicated by the fact that many conservation measures are interactive: benefits or costs associated with simultaneous implementation of several measures may be different from the sums of benefits and costs for the individual measures. Inattention to this problem may result in overestimating both costs (certain implementation costs may be shared by several measures) and, more seriously, benefits (incremental effectiveness of additional measures may decline as more measures are implemented). There may also be circumstances, particularly in the case of contingent, drought-oriented measures, where a properly chosen set of conservation measures may be more effective in aggregate than the sum of the individual measures.

Interactions with respect to implementation cost are probably most likely to appear for measures directed at municipal and industrial water use. A wide variety of conservation techniques and approaches are possible for this class of water use, and many of them depend, in part, on similar public information efforts. While specific measures may involve specific costs, such as costs of modifying or replacing plumbing fixtures, certain costs of initiating and promoting a multi-measure program may be joint costs.

Perhaps the most prominent example of interaction among measures with respect to effectiveness appears when one of the measures under consideration is a revised pricing policy. Since the effect of a higher unit price for water is to stimulate a variety of self-imposed conservation measures on the part of water users, little can be said about the effectiveness of a combined program of conservation-oriented pricing and other conservation measures directed to the same users. Only where it is quite apparent that a specific conservation measure would not be voluntarily adopted by any significant number of users in response to the pricing change can the effectiveness of such a measure be added to that expected from the price change. Studies of response to pricing changes (other than trivial changes) suggest that this would rarely be the case. Great care must be exercised, therefore, in attributing water use reductions to conservation measures which are to be imposed in conjunction with conservation-motivated changes in the pricing strucutre.

Even without price changes, other possibilities for interactions exist. In particular, appeals for voluntary conservation can be expected to provide reductions which rapidly diminish as the number of mandatory conservation measures in effect increases. The effectiveness of such measures as restrictions on residential lawn irrigation depends upon any other regulations which may be in effect, such as prohibitions of automatic sprinklers, or limitations on the number of connected hoses. Pressure-reducing valves may provide a smaller reduction in total water use when sprinkling restrictions are in effect.

Because of these interactions affecting both cost and effectiveness, the list of potential water conservation measures under consideration may require reconsideration. Certain measures included on the list may be interactive with other included measures. This property requires that the interactive measures be considered in combination as well as individually, so that the best means of implementation can be determined.

Not all measures are interactive, and those which are interactive with some measures may not be interactive with others. Combinations of interactive measures chosen for analysis must meet the same applicability and feasibility conditions described above for individual measures, and should represent a reasonably complete set of substantially interactive combinations applicable to the water use or uses under study. What constitutes substantial interaction must be left to the judgment of the planner, but the inclusion of combinations of measures is obviously not helpful unless the effectiveness, implementation cost, or other beneficial or adverse effects are more than trivially different from the sums of these effects for the individual measures.

The result of these considerations is an augmented list of potential water conservation measures, a list which includes not only individual measures which can be considered alone or in any combination, but certain specific combinations of interactive measures. In every case, estimates of the effectiveness, implementation cost, and other beneficial and adverse effects of every measure or combination of measures included on the augmented list must be provided.

RISK AND UNCERTAINTY

The true future impact of water conservation measures, of course, cannot be known with certainty. The predictions of implementation cost, effectiveness, and other beneficial and adverse effects are characterized, in varying degree, by risk and uncertainty. Briefly, <u>risk</u> refers to a situation where, although future values are not known with certainty, information is available concerning the distribution or range of possible future values. In this case, expected values can be estimated, reflecting the central tendency of the unknown future value. <u>Uncertainty</u>, on the other hand, refers to the situation where little or nothing is known of the distribution of future values: no objective probabilistic statements can be made concerning the significance of specific forecasts.

Estimates of implementation cost and of other beneficial and adverse effects are probably subject to risk and uncertainty to a degree similar to that of estimates of other costs and benefits required in the project planning process. No special attention to risk or uncertainty seems required, other than appropriate use of the precautions, sensitivity analyses, or alternate calculations normally associated with benefit-cost analysis.

The estimates of conservation effectiveness, however, require some comment. As outlined in Section II of this report, careful and controlled measurements of effectiveness are available for only a few conservation measures. Moreover, these measurements are frequently based on observations of very limited numbers of water users, and may be severely restricted with respect to the conditions of implementation.

Such data, therefore, should be regarded as highly uncertain. One procedure that might be used would include the identification of reasonable upper and lower bounds as well as the most likely level for effectiveness, based on the literature and on independent estimates as required. Alternate calculations would then be carried out to determine economic feasibility at each of the bounds. Measures which are feasible at both bounds can be included, using the most likely estimate of effectiveness for final project evaluation. Measures which are feasible at the upper, but not at the lower bound of effectiveness may be included as conditional strategies, pending more reliable information on their impact.

In some cases, especially where existing information permits only conditional acceptance of a conservation measure, trial implementation of the measure for a small sample of water users may provide the necessary data. Where available estimates of effectiveness span a very wide range, for example, even a very limited experiment may reduce uncertainty sufficiently to allow the measure to be included in the conservation plan, or eliminated from further consideration. Conditional measures, therefore, may be proposed for limited adoption, then fully implemented or abandoned, depending on the results of the limited application. The objective of such an approach would be to discourage premature elimination from consideration of potentially applicable conservation measures.

FUTURE BENEFITS AND COSTS

Consistent with the practice of benefit-cost analysis, future monetary benefits and costs associated with conservation measures must be discounted to present value as of some chosen base year, or amortized to uniform annual net benefit or cost. Either of these procedures requires the specification of a discount rate so that benefits or costs occurring at one time can be transformed into equivalent sums at other times. Special complications arise in the case of conservation measures, however, because many of the monetary benefits and costs are measured outside the federal government sector. Implementation costs, in particular, are often borne by local government agencies, by private sector business organizations, and by private individuals.

To be consistent with the NED accounts, which provide the chosen measure of project net benefit, all monetary benefits and costs associated with a conservation measure must be discounted at the same federal discount rate used to evaluate the remaining elements of the project. Care must be taken, however, that benefits and costs are properly placed in time before discounting. Otherwise, errors will occur because of the divergencies which exist among discount rates appropriate to various governmental agencies and private sector activities.

For example, a local government may implement a major reconstruction of a portion of its water distribution system. The purpose of the reconstruction is to reduce leaks, thereby conserving water. The work is financed by selling a bond, which will be paid back from water rate revenue over the next 25 years. The annual debt service payment will be a function of the cost of the project and of the interest rate at which the bond was sold. The government first experiences the cost when the construction project is implemented; the customers of the water utility experience the cost when the debt service payments are made. The cost to society occurs, however, at the time of construction. It is then that financial and other resources are committed to this use and rendered unavailable for other uses. The fact that water users must make periodic payments in the future to service the bond indicates only that income is transferred from users to bondholders; no social cost in incurred in the process. The full implementation cost at the time of construction would be discounted at the federal rate to present value, or annualized value, then included with other monetary benefits and costs.

In every case where confusion occurs as to the identity of the actual benefit or cost, it should be remembered that the impact on society is the guiding principle. A cost is incurred when resources are actually transferred to other uses; a benefit occurs when a larger or more valuable output of goods and services is actually available for consumption. The financial obligations of local governments, or other entities, should never be confused with proper measures of cost or benefit. When these conventions are observed, and the federal discount rate is used for all discounting, future benefits and costs can be estimated in a manner fully consistent with the NED account.

Summary

This section outlines the steps necessary to determine applicability, feasibility, implementation cost and conditions, effectiveness, and other adverse and beneficial effects for individual water conservation measures and combinations of measures. These are the aspects of analysis which can be carried out for individual measures independent of the water resources planning framework within which the measure is being considered: these steps constitute measure-specific analysis.

Table XV indicates the major steps. Analysis begins by selecting from the universe of possible water conservation measures those which are likely to be applicable to a given planning area. Measures which can be found clearly infeasible on social, political, institutional, or technical grounds are removed from the list; feasible or potentially feasible measures are retained.

The resulting potential water conservation measures are analyzed to determine the agency responsible for implementation, the planned coverage and duration, the implementation costs, the expected effectiveness, and other adverse and beneficial effects (including environmental effects). When this information is available for each potential water conservation measure, then these measures can be considered in the context of the water resources planning problem to determine the most advantageous water conservation plan. This project-specific analysis is discussed in the next section.

AD-A070 869 SOUTHERN ILLINOIS UNIV CARBONDALE DEPT OF GEOGRAPHY F/G 13/2
THE ROLE OF CONSERVATION IN WATER SUPPLY PLANNING.(U)
APR 79 D D BAUMANN, J J BOLAND, J H SIMS DACW72-78-C-0022

UNCLASSIFIED IWR-CR-79-2 NL

2 OF 2
AD
A070869

END
DATE
FILMED
8-79
DDC

Table XV

MEASURE – SPECIFIC ANALYSIS

UNIVERSE OF POSSIBLE MEASURES

↓

APPLICABLE TO WATER USES IN PLANNING AREA ?

↓

FEASIBLE OR POTENTIALLY FEASIBLE ?
(Social, Political, Institutional, Technical)

↓

POTENTIAL MEASURES

↓

DETERMINE : RESPONSIBLE AGENCY
COVERAGE AND DURATION
IMPLEMENTATION COSTS
EFFECTIVENESS
OTHER BENEFICIAL EFFECTS
OTHER ADVERSE EFFECTS

IV. PLANNING AND FORECASTING WATER CONSERVATION

The Role of Water Conservation

NON-STRUCTURAL MEASURES

In his July 12, 1978 directive on "Improvements in the Planning and Evaluation of Federal Water Resources Programs and Projects," the President directed the Water Resources Council to ". . . require the preparation . . . of a primarily non-structural plan as one alternative whenever structural project or program alternatives are considered . . ." Non-structural measures are currently defined by the Water Resources Council as "complete or partial alternatives to the traditional structural measures in addressing water resources problems and needs."

Full implementation of the President's directive will require the consideration of non-structural measures as components of all water resource programs or projects, as well as the formulation of primarily non-structural plans to be evaluated as alternatives to conventional, primarily structural plans. Non-structural measures include many supply augmentation and demand reduction strategies, among them, of course, the practices that have been defined in this report as water conservation measures. More specifically, the President's July 12 message also requires the Water Resources Council to ". . . accomplish the full integration of water conservation into project and program planning and review, as a component of both the economic development and environmental quality objective . . ."

Consideration of water conservation measures, therefore, must be a part of the water resource planning process, both on its own merits and as one aspect of the consideration of non-structural measures. This section describes the integration of water conservation measures with plan and program formulation and evaluation, and the role of water conservation measures in insuring the full consideration of non-structural measures. The previous section describes the evaluation of specific conservation measures, and outlines a procedure for developing a list of potential water conservation measures, including combinations of interactive measures where required.

Independent analysis of each potential measure can, given an adequate description of the nature of the water use affected, provide forecasts of effectiveness (in terms of quantity reduction in water use), implementation cost, and other costs and benefits. The national economic development (NED) benefit expected to result from the reduction in water use, however, cannot be determined except in the context of a specific proposed project or planning situation. This section describes the development and use of NED benefits associated with specific water conservation measures and water conservation plans.

REGIONAL STUDIES

Level A: Framework Studies

Framework studies and assessments prepared for major regions of the country include forecasts of future water uses throughout the study region. These forecasts must be contrasted to assessments of available supplies in order to provide information on the adequacy of existing water resource policies and programs in the region.

One means of meeting regional water needs is to reduce water use wherever feasible through the application of water conservation measures. Criteria are required to determine which conservation measures should be considered, and which of those should be included in a water resource plan for the region. The effect of included measures on water supply requirements must be determined, as well as the various economic impacts of the implementation and use of water conservation measures.

Level B: River Basin Studies

Regional or river basin plans are prepared for specific areas and include the development of long-range schedules of priorities for water resource projects. In developing such schedules, the use of water conservation measures can materially alter the nature of the water supply projects required in a region, as well as changing the optimal timing and, sometimes, the sequence of the projects programmed.

Criteria are needed for the definition and analysis of alternative water conservation plans, so that the sensitivity of future facilities requirements to water conservation programs and costs can be determined. Water conservation measures must also be included in primarily non-structural plans which will be compared to the conventional structural approaches to meeting future needs.

Level C: Project Planning

NED Plans

The Principles and Standards require that evaluation of a proposed water resource project include the development of a plan configuration which emphasizes the national economic development (NED) objective. Criteria are needed to select water conservation measures which can be incorporated into the NED plan. Each such measure must produce beneficial NED effects which bear a larger ratio to adverse NED effects than that associated with the plan without the water conservation measure. When all such measures have been identified and included, the benefit/cost ratio of the plan will have been increased as a result of the water conservation measures incorporated.

Environmental Quality Plans

Another requirement of the Principles and Standards is a proposed plan which emphasizes the environmental quality (EQ) objective. Since water conservation measures reduce water use, they may, in some supply circumstances, increase the quantity of water released to the natural environment, a beneficial effect on EQ. In cases where water is abstracted from one basin, and waste flows returned to another, reducing the magnitude of the diversion may result in beneficial EQ effects in one basin and adverse EQ effects in the other. Also, the conversation measures themselves may create beneficial or adverse EQ effects. Such effects must be balanced against one another to determine whether a net improvement in EQ has resulted.

The EQ plan should include all water conservation measures which make a net contribution to the EQ objective, without reducing the contribution to the NED objective (NED benefit should at least equal NED cost). Criteria are needed to identify the qualifying conservation measures, and to determine their effect on the project or program.

Primarily Non-Structural Plans

Modifications to the Principles and Standards now under consideration will require the development of a plan which makes maximum use of non-structural measures, including water conservation measures, provided that such measures have a positive net effect on either the NED or EQ objectives. Criteria are needed to identify all potential measures which provide NED benefits at least equal to NED costs, and EQ beneficial effects at least equivalent to EQ adverse effects. These qualifying measures would form the basis of the primarily non-structural plan. The evaluation of this plan would rely, in part, on estimates of the beneficial and adverse effects of the conservation measures included.

Other Plans

Additional plans are sometimes developed to reveal the major trade-offs available between the NED and EQ objectives, or for other reasons. Water conservation measures are potential additions to any such plan, provided their incorporation does not alter its basic purpose. The water conservation measures must produce a plan which is at least as desirable as the plan without the conservation measures, and which reveal the same trade-off or other feature. Criteria are needed for choosing appropriate water conservation measures for such plans, so that the best possible use of conservation practices can be insured.

Water Conservation Plans

BENEFITS, COSTS AND CONSERVATION

Effectiveness

Previous sections discuss the identification and analysis of potential water conservation measures, including the combination and re-analysis of sets of measures which are expected to be substantially interactive. For every such measure, or set of measures, some estimate of effectiveness must be prepared. Effectiveness is defined as the quantity reduction in water use which the conservation measure can be expected to achieve. It is the quantity of water which is rendered available for other uses, or which need not be supplied, as a direct consequence of implementation of the conservation measure.

In the case of long-term conservation measures applied to community and industrial water use, effectiveness can be stated in terms of reduction in mean annual water use (in million gallons per day, for example). Where the seasonal use is critical in determining the scale of supply facilities, a separate estimate of effectiveness in reducing seasonal use may also be developed. Contingent conservation measures applied to community and industrial water use during times of drought have the effect of reducing the magnitude of the peak use which must be supplied, given any future level of average use (they reduce peak/average ratios).

Conservation measures applied to agricultural water use, or to in-stream uses, demonstrate effectiveness in similar ways; they reduce the total quantity of water which must be diverted to that use, so that a quantity of water equal to the reduction is available for other uses. In many cases, the effect of water conservation measures on return flows will also be of interest, especially where these return flows constitute a portion of the water available to downstream users.

To prepare estimates of conservation effectiveness requires a water use forecasting method that is capable of reflecting the impact of individual conservation measures, which often apply to a single sector of use, on aggregate water use. In the case of community water supply, the forecasting method must be disaggregate, estimating future water use separately for the various sectors of water use (residential, commercial, etc.). It will also be necessary to estimate seasonal water uses separately, and to forecast water use in all sectors in terms of various explanatory variables, including price. Per capita requirements forecasting techniques, widely used in water resource planning, are not suitable; they are capable of producing only the most approximate sort of estimates of conservation effectiveness.

If potentially interactive measures have been successfully identified, combined, and considered in various combinations, the effectiveness estimates obtained for the potential measures and sets of measures will be additive. If two or more measures or sets of measures from the list are to be implemented concurrently, their combined effectiveness can be found by summing the individual estimates of effectiveness. Related estimates of implementation cost, and of other beneficial and adverse effects, can also be summed to obtain estimates for the combination of measures.

Effectiveness estimates must be obtained throughout the planning period so that the time pattern of benefits can be properly defined. This requires forecasts of water use with and without the conservation measure at intervals (five year intervals, for example). The water use reductions thus defined will be assumed to indicate a smooth curve which plots effectiveness as a function of time. Implementation costs, and other beneficial and adverse effects which may be stated in monetary units, have already been calculated in present value terms, since they do not depend upon project characteristics for their final evaluation.

Benefit Estimates

The NED benefit associated with the implementation of a water conservation measure is the increase in the value of goods and services produced by the economy as a whole which results from the decrease in water use. Assuming a well-functioning market system, this increased value will be expressed as the value of the water conserved, when applied to the most valuable alternative uses. A lower bound is placed on this benefit measure, however, by the cost of water supply. If the water not used as a result of conservation is, instead of being diverted to another use, simply not supplied, then the resources otherwise devoted to collecting, storing, pumping, and treating this increment of water are freed for other uses in the economy. Regardless of the potential value of alternative uses, the benefit resulting from not using water can never be less than the resource cost of supply.

Foregone supply costs, then, are taken as the measure of NED benefit. They constitute a lower bound on the range of possible benefits, since it is conceivable that alternative water uses exist which would more than justify the cost of supply. In practice, foregone supply costs are unlikely to diverge greatly from the value of the alternative use except where water is artificially rationed by some administrative means, or where the absolute supply of water is a binding constraint. Foregone supply costs, then, are taken as a conservative and practical measure of the NED benefit resulting from a reduction in water use.

Foregone Supply Costs

A reduction in water use implies that certain costs associated with water supply can be avoided. In the case of community water supply, some costs of pumping and treating water are variable with the quantity of water supplied, and reductions in water use can be expected to bring about reduced costs. Where future water demands will require augmentation of existing supply facilities, however, additional cost savings appear. These arise because water conservation measures reduce the quantity of water required at any given time in the future, permitting planned facilities to be constructed later than originally programmed. When construction and other costs are deferred, the present value cost of the capacity expansion program is reduced. The amount of reduction is attributable to the water conservation measure implemented.

In order to simplify the task of determining costs foregone as a result of water conservation, when a number of potential conservation measures may be evaluated before choosing those to be implemented, a parametric approach will be taken to the cost-water use reduction relationship. In order to do so, it will first be necessary to make the following assumption regarding the effectiveness of water conservation measures: once implemented, no water conservation measure becomes less effective over time. In other words, the quantity of water not used as a result of some measure never falls with time, it remains the same or becomes greater. Where this assumption cannot be admitted (where a service area is contracting, for example), the parametric approach described below cannot be used; costs foregone must be calculated separately for each conservation measure.

It must also be assumed that a forecast of future water use without conservation measures exists for the entire planning period. The actual forecasts may be prepared for selected years throughout the planning period (at five year intervals, for example) and the intervening years' levels found by interpolation. The no-conservation water use forecast, when combined with the non-decreasing-effectiveness assumption, supports the following treatment of the impact of water conservation measures on future water use. When a water conservation measure is implemented at the beginning of year i, and its effectiveness is determined for that year, it will be assumed that the entire water use forecast from (and including) year i forward is reduced by the amount of the calculated effectiveness. If, at a later time, the effectiveness of the previously implemented measure is found to be greater, all water use forecasts from that year forward are reduced by the additional amount. This convention allows statements to be made about the impact of each measure on required future supply facilities, without the need to consider the full time pattern of water use at each step.

The supply cost-water use reduction function must be constructed for each year for which a water use forecast is made. This function will indicate the effect on annual costs of reductions in total water use, ranging from a small increment (smaller than the effectiveness of the least effective measure considered) to a large reduction comparable in magnitude to the sum of the effectivnesses of all measures considered. Annual costs include operating and maintenance costs as well as the proper annual share of all capital costs. The proper annual share is defined, for simplicity, as the sum of the annualized costs of all capital facilities then in use. As each supply augmentation project is placed in service, its costs are reflected as equal annual sums throughout the expected useful life of the project. In order to maintain these calculations on an equivalent basis with the NED account, the actual capital outlays by the local utility are annualized at the Federal discount rate to obtain the annual costs. Such costs can be treated as avoidable because of the non-decreasing-effectiveness assumption noted above.

The cost basis of the supply cost-water use reduction function is established by the cost structure of the Federal project under consideration, plus the costs already incurred or programmed by the local water agencies, and any other costs which will be necessary to maintain water supply in the future. As the amount of reduction increases, for any given year, the costs foregone will consist, at first, of avoidable costs of pumping and treatment. As the reduction reaches the capability of the last programmed supply increment, the annual costs associated with that increment will be avoided, causing a steep upward shift in the curve. Further reductions will continue to reduce operating costs until the next supply increment can be shed, shifiting the curve upward again. The final curve will show the expected change in total annual cost which will result from water use being any specified quantity below the forecast value.

A similar supply cost-water use reduction curve must be developed for each forecast year. When all curves are available, they can be used to estimate the time sequence of foregone costs associated with any water conservation measure of water conservation plan (set of measures). This step requires the preparation of an additional set of water use forecasts which incorporate the conservation measure under consideration. The conservation forecast is subtracted from the no conservation forecast to obtain the water use reduction for each forecast year. Each water use reduction yields an estimate of annual cost foregone (using the supply cost-water use reduction function for the appropriate year). The sequence of foregone costs can then be discounted to present value to produce a single estimate of the cost foregone as a result of implementation of the water conservation measure.

Feasible Conservation Measures

Using the procedure outlined above, NED benefits can be estimated for each of the potential water conservation measures (or interactive sets of measures) previously identified. The total NED benefit for each measure should then be compared to the total NED cost (implementation cost and other costs associated with lost consumer benefits). All benefits and costs have been converted to present value as of some base year, and all discounting has employed the Federal discount rate.

Each potential measure for which NED benefits at least equal NED cost should be retained for further examination; other measures may be discarded at this point.

Next, beneficial and adverse effects affecting the EQ objective should be compared for each measure. In most cases, the EQ effect of a water conservation measure is limited to a reduction in water use and consequent increase in the water released to the natural environment, a possible beneficial effect. There are situations where this is accompanied by adverse effects, such as the reduction of return flows to another, water-short basin, or the undesirable appearance of brown lawns and gardens. In these situations, some difficulty may be encountered in comparing the effects. Wherever the adverse effect clearly outweighs the beneficial effect, the measures can be eliminated from further consideration. Otherwise, it should be retained as potentially feasible on EQ grounds.

The final list of measures which are feasible on both NED and EQ grounds may be arranged in order of decreasing NED benefit/cost ratios, and used as the basis of water conservation plans. In practice, several such lists must be prepared. Since the Federal project cost figure in the benefit estimation, benefits differ, depending on which Federal project is considered. There must be, therefore, an NED list of feasible measures, an EQ list of measures, a primarily non-structural list of measures, and perhaps other lists.

DEVELOPING WATER CONSERVATION PLANS

NED Plans

NED plans are those Federal project configurations which emphasize the NED objective. Since individual water conservation measures contribute to the NED objective in various ways, it may not be desirable to include all feasible measures in the NED plan. A criterion must be developed for selecting those specific conservation measures to be incorporated in the NED plan.

According to the Principles and Standards as well as agency guidance Federal projects are designed to produce the largest net benefit. Since a Federal project without conservation and the same project incorporating one or more conservation measures comprise mutually exclusive alternatives, the formulation having the highest net benefits would be preferred on NED grounds. Conservation measures should be added to the NED plan, therefore, only to the extent that they increase net benefits.

As each feasible conservation measure, or combination of measures, is analyzed by planners, the structural components of the plan must be scaled down, or re-programmed, so as to meet the lower conservation induced levels of future water use. Those costs and benefits that vary future water use must be re-calculated, and the analysis should proceed until the addition of further measures lowers, rather than increases, net benefits of the plan.

As discussed above, the principal benefit of a water conservation measure is the foregone supply cost which results from the lower level of water use. Incorporating the water conservation measure into the project plan, therefore, involves a reduction in project cost. Where conservation measure benefits consist entirely of supply costs foregone, any conservation measure having a benefit-cost ratio greater than unity will both increase project net benefits and project benefit-cost ratio. When the net benefits of the project have been maximized, the combination of structural and non-structural (water conservation) measures thus obtained is the NED plan. The set of water conservation measures included therein is the NED water conservation plan.

EQ PLANS

The development of the EQ project plan, and the EQ water conservation plan, proceeds in a manner analogous to that described for the NED plan. Here, however, the purpose is to maximize the net improvement to the EQ objective (excess of EQ gains over EQ losses). Conservation measures are chosen from the

EQ list. Each measure which results in a net improvement in the EQ objective is retained until no further measures can be accomodated, or until the list of feasible measures has been exhausted. The resulting project is the EQ plan, and the water conservation measures included constitute the EQ water conservation plan.

Primarily Non-Structural Plans

Here, again, the process is similar to that described for the NED plan. The primarily non-structural list of conservation measures is employed, and measures are added so long as additional projects provide net increases with respect to either the NED or the EQ objective. The resulting project plan is the primarily non-structural plan, and the water conservation measures incorporated therein constitute the primarily non-structural water conservation plan.

Other Plans

Where other Federal plans are put forth, either to delineate tradeoffs between the NED and EQ objectives, or for other purposes, each such plan can be associated with a particular desired characteristic. For example, a plan may attempt to show the EQ advantage of accepting a specified, non-optimal level of NED net benefits. Conservation measures can be added to such a plan, provided that they do not disturb the desired characteristic. In the above example, measures could be added which did not reduce either the NED net benefit or the EQ net beneficial effect. The measures successfully incorporated in this way would constitute the water conservation plan for this project plan.

Summary

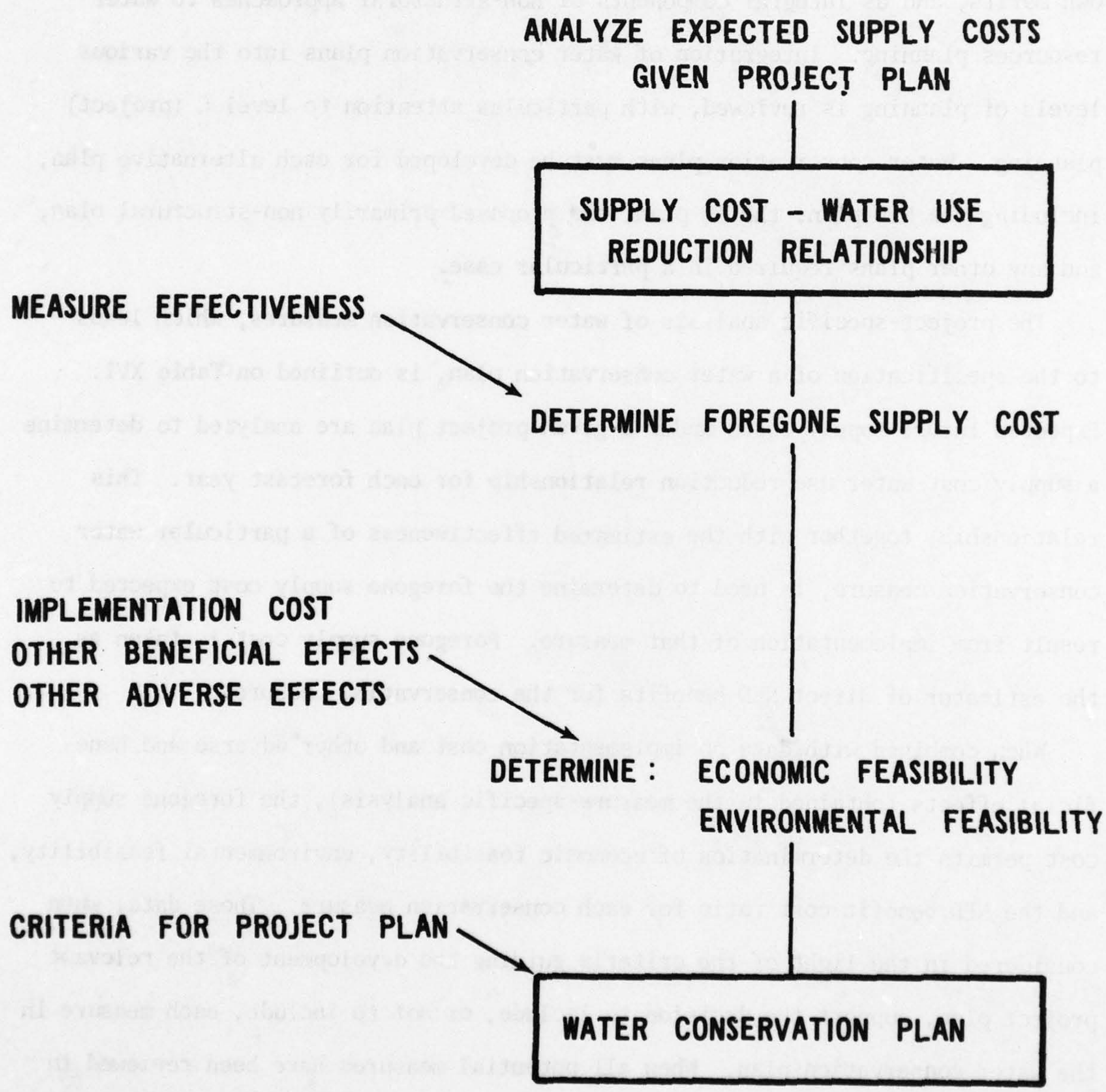
The role of water conservation measures is discussed in terms of their own merits, and as integral components of non-structural approaches to water resources planning. Integration of water conservation plans into the various levels of planning is reviewed, with particular attention to level C (project) planning. Water conservation plans must be developed for each alternative plan, including the NED plan, the EQ plan, the proposed primarily non-structural plan, and any other plans required in a particular case.

The project-specific analysis of water conservation measures, which leads to the specification of a water conservation plan, is outlined on Table XVI. Expected future supply costs under a given project plan are analyzed to determine a supply cost-water use reduction relationship for each forecast year. This relationship, together with the estimated effectiveness of a particular water conservation measure, is used to determine the foregone supply cost expected to result from implementation of that measure. Foregone supply cost is taken as the estimator of direct NED benefits for the conservation measure.

When combined with data on implementation cost and other adverse and beneficial effects (obtained in the measure-specific analysis), the foregone supply cost permits the determination of economic feasibility, environmental feasibility, and the NED benefit-cost ratio for each conservation measure. These data, when considered in the light of the criteria guiding the development of the relevant project plan, support the decision to include, or not to include, each measure in the water conservation plan. When all potential measures have been reviewed in this way, the set of retained measures constitutes the water conservation plan appropriate to the project plan under consideration.

Table XVI

PROJECT – SPECIFIC ANALYSIS



V. SUMMARY AND RECOMMENDATIONS

Water conservation is any beneficial reduction in water use or in water losses. Water conservation is achieved when two conditions are fulfilled:

(1) When water use is reduced for a given supply; and,

(2) The result is a net increase in social welfare.

That is, only when a proposed measure results in a reduction in use and the overall benefits exceed the costs is conservation attained. In this context, water conservation measures are but a subset of all efficient water management strategies.

While the immediate purpose of conservation practices is to make the most efficient possible use of existing supplies, the ultimate effect is to substantially alter water supply planning practices. The fact that existing supply is utilized more efficiently has the effect of postponing and/or reducing the scale of projects designed to augment supply.

During the past few years numerous reports have been published describing the diverse and numerous technologies and policies that purport to achieve water conservation. The effectiveness and efficiency of these conservation measures have been summarized and appraised. There are several major weaknesses inherent in most of the estimates such that caution is warranted when a particular measure or policy is being considered. Many of the estimates have not been derived from analyses of carefully designed empirical studies. The effectiveness of estimates are most frequently a priori judgments and are seldom derived from the measurement and analysis of actual effects. Clearly, a major deficiency is the lack of analysis as to how water saving devices perform in actual practice. There were no studies which measured the effect of specific conservation measures, which properly controlled for the effect of other factors which may alter water use: many studies simply compare water use after implementation to water use at some previous time. Hence, costs estimates and information necessary for implementation of conservation measures in water resources management and planning are poorly understood and are a priori at best.

Based upon a review of the literature and discussions with several persons involved in water resource management and planning, there appears to be little known concerning the range of possible environmental effects of water conservation. For example, where water conservation measures result in increased streamflow below impoundments, what is the nature of the expected beneficial environmental quality effect? Or, what about the environmental effects in those situations where conservation measures result in a reduction of return flows? This would be a problem only where the return flow occurs somewhere other than shortly below the impoundment point on the same stream.

Finally, in the analysis of all beneficial and adverse effects, there is need for a more careful measurement and assessment of conservation measures. The method of analysis must focus not only upon specific measures, but also upon the effects of combinations of conservation measures. The information requirements, method of analysis, and the salient problems have been identified in this report (Chapters 3 and 4). The evaluation methodology takes into consideration all feasible water conservation measures so that the most efficient combination of water supply and water conservation measures is derived.

The analytical approach described in this report has not been applied anywhere when considering water conservation measures effects on water supply management and planning. Because such an analysis does not follow the process of traditional water planning procedures, obstacles will be formidable. For example, planners are not accustomed to including demand-side options in water resource planning. The analytical techniques and the available options are likely to be alien. The close relationship between demand management (water conservation) and supply management (conventional planning) demands careful analyses. The unfamiliarity of planners with the concepts involved suggests the use of several case studies.

For example, one consequence of our definition and approach to water conservation is the necessity to measure different values in order to estimate costs and benefits of a particular conservation program. While techniques are available to measure the different values and preferences, it is unlikely that most water resource planners are sufficiently familiar to undertake the appropriate analyses. In fact, it will probably require a first step--to sensitize them to the fact that such information is relevant to the consideration of water conservation measures in water resource management and planning.

Hence, there is a clear need to demonstrate the necessary procedures for incorporating the consideration of water conservation measures into water resource planning in order that the planners can clearly see the approaches and techniques illustrated in the context of a specific case.

While this report has provided the conceptual basis of water conservation planning and proposes a methodology, it is unlikely that the concepts and approaches will be implemented. It simply is not possible to re-train an entire generation of planners with a theoretical report, with generalities and theoretical abstractions. Since planners, as others, learn how to prepare conventional plans by reviewing completed conventional plans prepared by their predecessors, we recommend that model plans be prepared at a few selected sites and be available to those who are faced with implementing water conservation measures into the planning process. Water resources planning is currently undergoing dynamic change; hence, the need has never been greater for a prototype water resource plan that includes a comprehensive evaluation of all feasible water conservation measures.

REFERENCES

Abbott, H. E., K. G. Cook, and R. B. Sleight. "Social Aspects of Urban Water Conservation." Century Research Corporation. Prepared for the Office of Water Resources Research. August 1972.

Anderson, Raymond W. "Pawtucket, Rhode Island and the Drought." Journal of New England Water Works Association 81 (1967):301-303.

Angeliedes, Steven P. and Eugene Bardach. "Water Banking by Local Districts Would Increase Flexibility and Reduce Waste." Discussion Paper. Berkeley: Graduate School of Public Policy, University of California. 1977. DRAFT.

Bailey, J. R., R. J. Benoit, J. L. Dodson, J. M. Robb, and H. Wallman. "A Study of Flow Reduction and Treatment of Waste Water from Households." For the Federal Water Quality Adm., Program #11050 FKE, Contract #14-12-428. Groton, CT: General Dynamics, Electric Boat Division. December 1969. (Summarized in Water and Sewage Works 85:57-66.)

Barbera, R. J. The Evaluation of Public Projects: Problems of Federal Versus State Objectives. Johns Hopkins University, Unpublished Ph.D. Dissertation. 1978.

Barnett, Harold and Chandler Morse. Scarcity and Growth: The Economics of Natural Resource Availability. Baltimore: The Johns Hopkins Press. 1963.

Baumann, Duane D., Daniel Dworkin, Scott Sebastian, Barbara Andrews and David Holtz. Planning Alternatives for Municipal Water Systems. Indianapolis: Butler University, Holcomb Research Institute. 1976.

Bertram, James E. "Water Reuse in Agriculture, Industry and Recreation." In Planning for Water Reuse, pp. 121-126. Edited by Duane D. Baumann and Daniel M. Dworkin. Chicago: Maaroufa Press, Inc. 1978.

Bohae, Charles E., and Raymond A. Sierka. "Effect of Water Conservation on Activated Sludge Kinetics." Journal of Water Pollution Control 50 (No. 10, 1978):2313-2326.

Bollman, Frank H. and Melinda A. Merritt. "Community Response and Change in Residential Water Use to Conservation and Rationing Measures: A Case Study -- Marin Municipal Water District." Presented at the fall conference of the AWWA, San Jose, CA. October 10, 1977.

Bonem, G. W. "On the Marginal Cost Pricing of Municipal Water." Water Resources Research 4 (February 1968):191-193.

Boone, Sheldon. Irrigation Use and Management - June, 1978 Review Draft. Denver: Soil Conservation Service, Cooperative Irrigation Study. 1978.

Bower, Blair T. "The Economics of Industrial Water Utilization." In Water Research, pp. 143-173. Edited by Allen V. Kneese and Stephen C. Smith. Baltimore: Johns Hopkins University Press. 1966.

Brewer, Robert and Patrick H. McAuley. "An Analysis of Price/Cost Sensitivity of Water Use in Selected Manufacturing Industries." U.S. Department of Commerce: Bureau of Domestic Commerce Staff Study. June 1976.

Brigham, Arthur P. "Effective Use of Communications Tools to Manage Water Demands and Wastewater Loads." Paper presented October 1976 at Conference on "Planning Alternatives for Municipal Water Systems."

Brown, H. A. "Super Chlorination at Ottumwa, Iowa." Journal of the American Water Works Association 32 (No. 4, 1940).

Bruvold, W. H. and H. J. Ongerth. "Public Use and Evaluation of Reclaimed Water." Journal of the American Water Works Association 66 (No. 5, 1974):294-296.

Bruvold, William H. "Consumer Response to Urban Drought in Central California." NSF Grant #ENV77-16171 (Copies available from author at School of Public Health, University of California at Berkeley.)

Burton, Ian and Robert W. Kates. "Slaying the Malthusian Dragon: A Review." Economic Geography 40 (January 1964):82-89.

Carmichael, J. "Water Recycling in Southern California." In Our Environment: The Outlook for 1980 (Part 1 of Our Environment: Water), pp. 237-255. Edited by A. J. Van Tassel. Lexington, MA: Lexington Books. 1973.

Carver, P. H. "Price as a Water Utility Management Tool Under Stochastic Conditions." Unpublished Ph.D. Dissertation. The Johns Hopkins University, University Microfilm, Michigan, #78-17935. 1978.

City of Colorado Springs. 1970 Annual Report. Colorado Springs, Colorado: Department of Public Utilities. 1970.

Cline, Neil M. "The Experience/Evaluation of Water Reuse in Orange County, California." In Planning for Water Reuse, pp. 127-138. Edited by Duane D. Baumann and Daniel M. Dworkin. Chicago: Maaroufa Press, Inc. 1978.

Cohen, Sheldon, and Harold Wallman. Demonstration of Waste Flow Reduction From Households. Groton, CT: General Dynamics, September 1974. U.S. EPA-670/2-74-071, Environmental Protection Technology Series.

Cole, C. A. "Impact of Home Water Saving Devices on Collection Systems and Waste Treatment." In Proceedings - Conference on Water Conservation and Sewage Flow Reduction With Water-Saving Devices, pp. 47-56. Edited by W. E. Sharpe and P. W. Fletcher. Institute for Research on Land and Water Resources. Pennsylvania State University, Information Report No. 74, July 1975.

Commission on Natural Resources, ad hoc Committee on Water Resources. Water Conservation Research. A report to the Office of Water Research and Technology. Washington, D.C.: National Academy of Sciences, October 2, 1978 (mimeo).

Comptroller General of the United States. Municipal and Industrial Water Conservation - The Federal Government Could Do More. Report to the Congress of the United States, the United States General Accounting Office. April 3, 1978.

Ecological Analysis Incorporated. "Water Supply Study for Montgomery and Prince George's Counties, Maryland." October 1977. Washington Suburban Sanitary Commission's (Maryland) (WSSC) Water-Saving and Waste-Reduction Program (Other sources: internal memos, press releases, and personal communications with Michael P. Bork, Walter A. Klein and Arthur P. Brigham and Richard Shagogue).

Ertel, M. O. and S. G. Koch. "Public Participation in Water Resources Planning: A Case Study and Literature Review." Amherst, MA: Water Resources Research Center, University of Massachusetts. 1977.

Feldman, S. L. A Handbook of Water Conservation Devices. NSF/RANN Grant #APR76-19369. Worcester, MA: Graduate School of Geography, Clark University. November 1977.

Flack, J. "Management Alternatives for Reducing Demand." Paper presented October 1976 at the Conference on Planning Alternatives for Municipal Water Systems.

Frankel, R. J. "Economics of Artificial Recharge for Municipal Water Supply." Washington: Resources for the Future. March 1967.

Fulton, Neil R. "How Elmhurst, Illinois Cut Water Use, Increased Sewage Capacity and Saved Itself $400,000 in the Bargain." In The Water Conservation Challenge, pp. 22-25. Bloomington, MN: The Upper Mississippi River Basin Commission. May 10, 1978.

Galbraith, J. "How Much Should A Country Consume?" In Perspectives on Conservation. Edited by Henry Jarrett. Baltimore: The Johns Hopkins Press. 1958.

Gilbert, J. B. and Associates. Water Conservation Reuse and Supply - San Francisco Bay Region. Prepared for the Association of Bay Area Governments. 1977.

Gordon, Scott. "Economics and the Conservation Question." The Journal of Law and Economics 1 (October 1958):110-121.

Granger, G. A. "Water Conservation Through Metering." Journal of the American Water Works Association 17 (February 1955):122-123.

Griffith, Evan L. "Southern California's Drought Response Program." Journal of the American Water Works Association 70 (February 1978):74-78.

Groopman, Abraham. "The Effects of the North-East Water Crisis on the New York Water Supply System." Journal of the American Water Works Association 60 (January 1968):37-47.

Gysi, Marshall, and Daniel P. Loucks. "Some Long-Run Effects of Water Pricing Policies." Water Resources Research 7 (No. 6, December 1971):1371-1382.

Hanke, S. H. "Demand for Water Under Dynamic Conditions." Water Resources Research 6 (October 1970):1253-1261.

Hanke, S. H. and John J. Boland. "Water Requirements on Water Demands." Journal of the American Water Works Association 63 (No. 11, 1971):677-681.

Hattingh, W. H. J. "Selected Health Aspects of Reclaimed Water in South Africa." in Planning for Water Reuse, pp. 27-36. Edited by Duane D. Baumann and Daniel M. Dworkin. Chicago: Maaroufa Press, Inc. 1978.

Hays, Samuel P. Conservation and the Gospel of Efficiency. Cambridge: Harvard University Press. 1959.

Hedlund, John D. "Meeting Future Water Requirements by Water Conservation." Presented at the 1975 Winter Meeting of the American Society of Agricultural Engineers, December 15-18, 1975. Paper No. 75-2557.

Herfindahl, Orris C. "What is Conservation?" Resources for the Future, Reprint No. 30, Washington, D.C. August 1961.

Howe, C. W. "Savings Recommendations with Regard to Water-System Losses." Journal of the American Water Works Association 63 (May 1971):284-286.

Howe, C. W., C. S. Russell and R. A. Young. Future Water Demands: The Impact of Technological Change, Public Policies and Changing Market Conditions on Water Use Patterns of Selected Sections of the U.S. Economy. Washington, D.C.: National Water Commission. 1970.

Hudson, W. D. "Increasing Water System Efficiency Through Control of Unaccounted-for Water." Journal of the American Water Works Association 70 (July 1978): 362-365.

Ibsen, C. A. and J. A. Ballweg. Public Perception of Water Resource Problems. Blacksburg, VA: Water Resources Research Center, Virginia Polytechnic Institute. 1969.

Jezler, Harold. "When the Reservoir Almost Went Dry." Journal of the American Water Works Association 67 (June 1975):331-335.

Keller, Charles W. "Analysis of Unaccounted-for Water." Journal of the American Water Works Association 68 (No. 3, 1976):159-162.

Ko, S. C. and L. Duckstein. "Cost-Effectiveness Analysis of Wastewater Reuses." Journal of Sanitary Engineering Division ASCE 98 (SA6) (December 1972):869-881.

Konen, T. P. and Raymond DeYoung. "An Investigation of the Performance and the Effects of Reduced Volume Water Closets on Sanitary Drainage, Sewers, and Sewage Treatment Plants." In Proceedings - Conference on Water Conservation and Sewage Flow Reduction With Water-Saving Devices, pp. 155-172. Edited by W. E. Sharpe and P. W. Fletcher. Institute for Research on Land and Water Resources. Pennsylvania State University, Information Report No. 74. July 1975.

Larkin, Donald G. "The Economics of Water Conservation." Journal of the American Water Works Association 70 (No. 9, 1978):470-474.

Laverty, Gordon L. "Easy Bay Conserves Water with Surveys, Sonar." Willing Water. American Water Works Association (December 1977):12-13.

Leone, Robert A., J. Royce Ginn, and An-Loh Lin. Changing Water Use in Selected Manufacturing Industries. The National Bureau of Economics. Submitted to U.S. Army Engineer Institute for Water Resources, Contract No. DACW31-72-C-0044, Report No. 74-10. October 1974.

Leopold, L. B. and W. B. Langbein. A Primer on Water. U.S. Department of the Interior, U.S. Geological Survey. 1960.

Linaweaver, F. P. Jr., John C. Geyer, and Jerome B. Wolff. "Summary Report on the Research Project." Journal of American Water Works Association 59 (No. 3, 1967):767-782.

Lupsha, Peter A., Schlegel, D. P. and Anderson, R. U. Rain Dance Doesn't Work Here Anymore, or Water Use and Citizen Attitudes Towards Water Use. Albuquerque: University of New Mexico, Division of Government Research. 1975.

McLaughlin, Everett. "A Recycle System for Conservation of Water in Residences." In Proceedings - Conference on Water Conservation and Sewage Flow Reduction With Water-Saving Devices, pp. 133-142. Edited by W. E. Sharpe and P. W. Fletcher. Institute for Research on Land and Water Resources. Pennsylvania State University, Information Report No. 74. July 1975.

McPherson, M. B. "Conservation in Household Water Use." Paper presented at Conference on Planning Alternatives for Municipal Water Systems. October 1976.

Metzler, Dwight, et. al. "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas." Journal of the American Water Works Association 50.

Miller, W. H. "Mandatory Water Conservation and Tap Allocations in Denver, Colorado." Journal of the American Water Works Association 70 (February 1978):60-63.

Milne, Murray. Residential Water Conservation. Davis: University of California, California Water Resources Center. Report No. 35. March 1976.

Mitchell, Robert D. "Water Supply of Saint John's Newfoundland." Journal of the New England Water Works Association 71 (1957):173-187.

National Academy of Sciences. Potential Technological Advances and Their Impact on Anticipated Water Requirements. Washington: National Academy of Sciences. June 1971.

The National Water Council (Great Britain). The 1975-1976 Drought. London: National Water Council. 1977.

Nelson, John Olaf. North Marin's Little Compendium of Water Saving Ideas. Marin County, CA: North Marin County Water District. March 1977.

Pagorski, Albin D. "Is the Public Ready for Recycled Water?" Water and Sewage Works 121 (June 1974):108.

Pinchot, Gifford. Breaking New Ground. New York: Harcourt, Brace and Co. 1947.

Rice, I. M. and L. G. Shaw. "Water Conservation - A Practical Approach." Journal of the American Water Works Association 70 (1978):480-482.

Robie, Ronald B. "California's Program for Dealing with Drought." Journal of the American Water Works Association 70 (February 1978):64-68.

Russell, C. S., Arey, D. G., and R. W. Kates. Drought and Water Supply. Baltimore: Johns Hopkins University Press. 1970.

Sharpe, William E. "Water Conservation With Water Saving Devices." Paper presented November 1976 at the "New Jersey Conference on Water Conservation," Rutgers University, New Brunswick.

Sharpe, William E. "Water and Energy Conservation With Bathing Shower Flow Controls." Journal of the American Water Works Association 70 (February 1978):93-97.

Sharpe, William E. "Residential Water Conservation With Water Conservation Devices." In The Water Conservation Challenge, pp. 32-37. Bloomington, MN: The Upper Mississippi River Basin Commission. May 1978 B.

Sharpe, William E. Domestic Water Conservation Research Plan. Report prepared for the Office of Water Research and Technology, July 7, 1978 C.

Shuval, Hillel I., editor. Water Renovation and Reuse. New York: Academic Press. 1977.

U.S. Army Corps of Engineers. Water Conservation Measures for the New York Metropolitan Area. Northeast U.S. Water Supply Study. Special Studies Branch. January 1976.

United States Department of the Interior. Report on the Water Conservation Opportunities Study. Bureau of Reclamation and Bureau of Indian Affairs. September 1978.

U.S. Public Health Service. Drinking Water Standards. Washington, D.C.: U. S. Government Printing Office. 1962.

U.S. Water Resources Council. The Nation's Water Resources, The Second National Assessment. Washington, D.C.: U.S. Water Resources Council. October 1977.

Uno, Gordon. "Be Water Wise, Water Conservation: Its Up To You." Denver, CO: Denver Water Department. December 1975.

Watkins, A. M. "Sanivac - Revolutionary Vacuum Toilet." Popular Science 197 (August 1970):97+.

Washington Suburban Sanitary Commission. Final and Comprehensive Report Cabin John Drainage Basin Water-Saving, Customer Education and, Appliance Test Program. Hayattsville, MD. February 14, 1973.

"Why Metering Makes Sense." The American City, pp. 72-73. April 1972.

Baumann, Duane D.
The role of conservation in water supply planning / by Duane D. Baumann, John J. Boland ... [et al.] -- Fort Belvoir, Va. : U.S. Institute for Water Resources ; Springfield, Va. : available from National Technical Information Service, 1979.
117 p. (IWR contract report ; 79-2)
"Dept. of Geography, Southern Illinois University for U.S. Army Corps of Engineers, Institute for Water Resources."
Bibliography: p. 111-117.
1. Water conservation. 2. Water supply. 3. Water conservation - Planning. I. Title. II. Boland, John J., joint author. III. Series: U.S. Institute for Water Resources. IWR contract report ; 79-2.