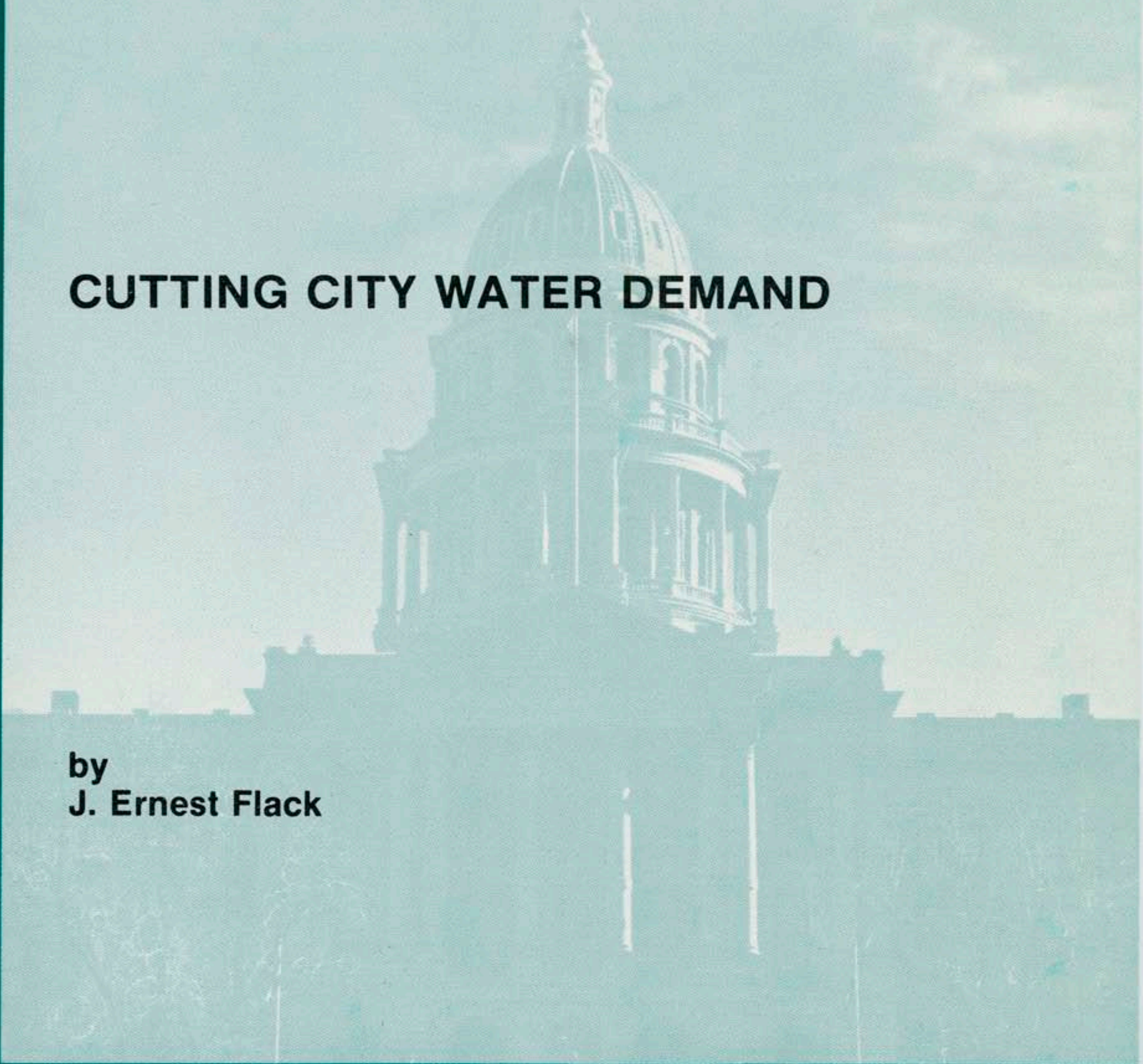


CUTTING CITY WATER DEMAND

by
J. Ernest Flack

COLORADO WATER RESOURCES
RESEARCH INSTITUTE

Information Series No. 36

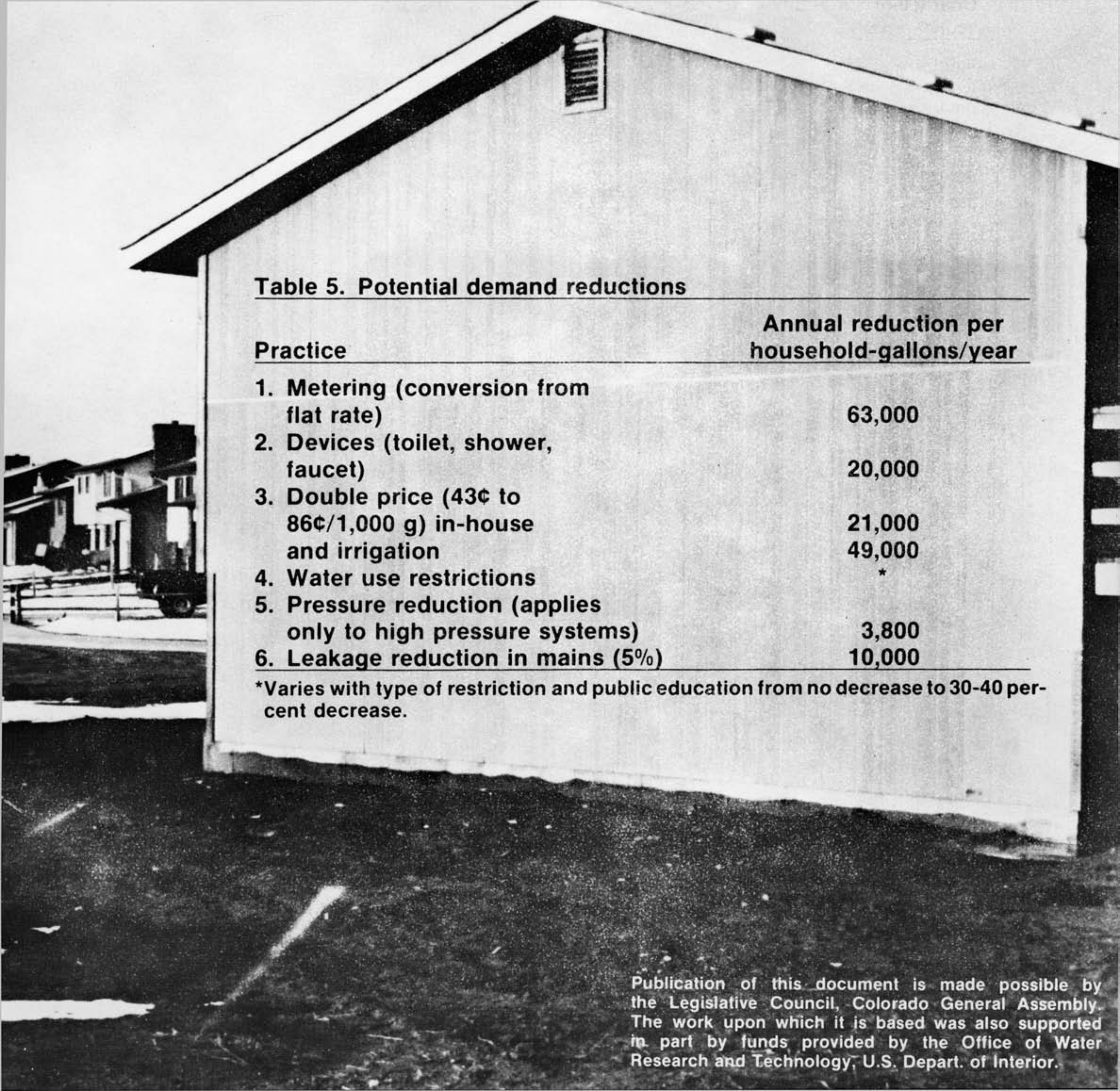


Table 5. Potential demand reductions

Practice	Annual reduction per household-gallons/year
1. Metering (conversion from flat rate)	63,000
2. Devices (toilet, shower, faucet)	20,000
3. Double price (43¢ to 86¢/1,000 g) in-house	21,000
and irrigation	49,000
4. Water use restrictions	*
5. Pressure reduction (applies only to high pressure systems)	3,800
6. Leakage reduction in mains (5%)	10,000

*Varies with type of restriction and public education from no decrease to 30-40 percent decrease.

Publication of this document is made possible by the Legislative Council, Colorado General Assembly. The work upon which it is based was also supported in part by funds provided by the Office of Water Research and Technology, U.S. Depart. of Interior.

CUTTING ITY WATER DEMAND

Methods of Residential Water Conservation

Water conservation can be defined as making more efficient use of existing supplies through structural, operational, economic and socio-political means.

The need for residential water conservation was recognized by the National Water Commission which declared, "In planning to meet future demands for municipal and industrial water, full consideration should be given to the possibilities for reducing water withdrawals by metering, by imposition of pricing systems that encourage more efficient use of water, by changes in building codes, by reducing leakage, and by other measures, as an alternative to increasing supply, or as a means of minimizing the necessary increase" (National Water Commission, 1973, pp. 168-169).

Public Law 92-500 establishes a legal mandate for water conservation by requiring reductions in the total flow of wastewater to treatment facilities (92nd Congress, 1972, Section 104 [0] [1]). More recently, the President issued memorandums to heads of executive departments and agencies requiring changes to achieve water conservation in loan and grant programs for water supply and treatment, in housing assistance programs and in agency operations of all kinds. (The White House, July 12, 1978).

Implementation of water conservation programs, in order to be successful, requires a commitment by the water utility management, good relations between the water using public and the utility and an acceptance by the water customer that conservation is both necessary and desirable.

In the following sections some of the methods of attaining water conservation by urban users are summarized.

Structural Methods

The municipal utility may implement structural means of reducing the demand for residential water through metering and flow control devices. Metering of customers causes customers to be sensitive to price because they are charged for water on the basis of use. Other structural means include flow restrictions and reduced system pressure. Hydraulic flow controllers physically restrict the rate of water flow available to consumers.

The consumer can implement structural alternatives by installing water-saving devices, flow controllers and recycling systems. Water-saving devices are plumbing fixtures and appliances that perform the same function as standard equipment but use less water. Flow-controlling devices restrict the rate of flow in the individual residence. Home recycling systems are based upon segregation of wastewater flows in the home using water quality as the criterion and involving treatment and successive reuse of the wastewater effluent.

Operational Methods

Detecting and repairing leaks and restricting use are the major operational means of conserving water. They are chiefly under the control of the utility. System leakage is responsible for large quantities of unaccounted-for water in some communities. Procedures for detecting and correcting most system leaks have been found to be cost-effective in terms of

> A recent Congressional Research Service study has emphasized two problems in implementing water conservation programs:
> *"Impediments to . . . efficient use which merit attention include:*
> *—the ingrained idea that per capita use of water must continually increase to maintain our standard of living.*
> *—the failure to establish a price for water which is commensurate with its value in use." (Viessman, et al., 1978).*

Continued on next page

the value of the water saved. System leakage greater than about 15 percent is considered intolerable if cost of treated water delivered exceeds 50 cents per 1,000 gallons. Detecting and repairing home fixture leakage is the homeowner's responsibility.

Delivery restrictions are a common conservation technique. Residential water use restrictions may be applied specifically to exterior water uses such as lawn irrigation and the filling of swimming pools or, in severe instances, to the total volume delivered per customer.

> **"Economic ways of conserving water includes pricing policy, incentives, penalties, and demand metering"**

Excess pressure can result in excess delivery and a high rate of leakage. System pressure reduction to 50 or 60 pounds per square inch reduced demand (in several instances). At the household level, several utilities have reduced delivery by installing pressure reducers in the household tap if pressures are above 60 psi.

Economic Methods

Economic methods of demand reduction can be accomplished solely by utility actions. Economic ways of conserving water include pricing policy, incentives, penalties and demand metering. Adopting a constant unit price or an increasing block rate structure, as contrasted with the typical flat rate or declining block rate, raises the cost of water to the user and makes him more sensitive to how much he uses. Incentives include rebates, tax credits or other rewards for conserving water. Penalties or fines can be imposed for wasting water. Demand metering allows a higher price to be charged for deliveries during periods of peak demand. This encourages reduced usage during peak demand periods, which may allow the utility to defer increasing system capacity.

Social Methods

Public education and development of a conservation ethic is necessary in any conservation program. Instruction in how water is used and explanation of various conservation alternatives are the key to their adoption.

Building code modifications are a means of legally mandating the use of low water-consuming plumbing fixtures. By requiring water-saving equipment in all new homes and all remodeling plans, significant water use reductions are possible.

The consumer can affect lawn water usage through alternative horticultural practices. The use of native species of plants and landscaping techniques can reduce sprinkling requirements. Installation of improved sprinkling equipment, drip irrigation systems, and carefully controlled irrigation utilize the available water more efficiently.

The functional dials of a water meter, when translated into dollars and cents of cost, can reduce the amount of water demanded by a residence.

Planning a Water Conservation Program

The several methods of reducing municipal water delivery demand (conservation) previously described may be used singly or in combination to fit specific circumstances. The limited information available about how much reduction can be expected from each method is given in the following sections. The reader is cautioned, however, not to estimate potential demand reduction by adding reductions from two or more methods because they may affect each other. For example, installing flow-restricting devices or doubling the price increase each produces about the same effect; however, it is unlikely that, after installing the device, doubling the price would result in as large a reduction as indicated.

Typical Residential Delivery Demand

In planning a water conservation program it is useful to assume a "typical household" for which average water uses and delivery demand can be applied. Such a household might be: a family of four persons, two bathrooms, dishwasher, clothes washer and garbage grinder. The lawn size is 8,700 square feet. Other characteristics of house and residents are assumed not to influence water demand.

The water service is metered and the price of water is 43 cents per 1,000 gallons.

The lawn is irrigated six months of the year. The annual volume of water delivered for irrigation is approximately equal to the potential evapotranspiration corrected for rainfall during the growing season, or 1.9 feet which is equal to 85 gpcd.

Surface runoff and deep percolation from lawn irrigation is assumed to be 3.8 percent of the water applied for this metered home. Sanitary sewer flow is assumed to be equal to in-house delivery; that is, very little water is actually consumed in the home. Sanitary sewer flow plus runoff and deep percolation constitute the return flow volume for this typical household.

In-house water demand serves as the baseline for estimates of other demands. Table 1 shows the amount of water used for various functions "on the average" in the metered home in gallons per capita per day (gpcd). The daily demand is 64 gpcd for in-house use and 85 gpcd for lawn irrigation or a total annual average use of 149 gpcd.

Table 1. **In-house water demand**

Function	*gpcd*	%
Toilet	25.0	40
Bath/Shower	20.0	30
Lavatory/Sink	3.0	5
Laundry	10.0	15
Dishwasher	3.0	5
Culinary	3.0	5
Total	64.0	100

Summary of Residential Delivery Demand

Using the estimates of the previous section, water delivery demand characteristics of a city of 40,000 population with 10,000 taps are shown in Table 2 - on page 9.

Reductions Possible in Delivery Demand

Metering

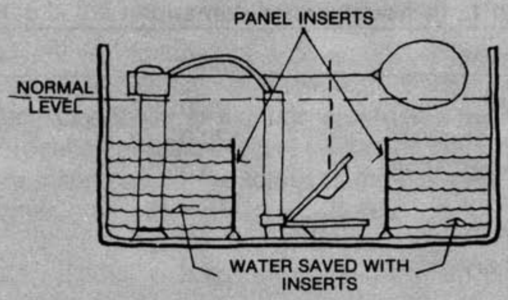
Based on Bryson's investigation of water demand in Denver (Bryson, 1969), a conservative estimate of the effects of metering compared with flat-rate water usage is a reduction of 43 gpcd. The significance of this saving is apparent if one notes that in a flat-rate community serving 10,000 customers, metering will save sufficient water to serve 3,300 additional customers. Metering has been shown to be cost-effective at water costs of 60 cents/1,000 gallons if the meters can be installed at initial costs under $383 per meter (Weakley, 1977, p. 146).

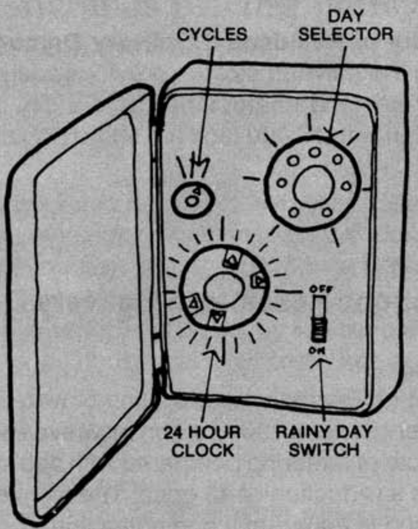
Water-Saving Household Devices

Water-saving household devices cover a wide range of plumbing fixtures and household appliances. For remodeling, it is assumed that the following are sufficiently low-cost, are easy to install and maintain, and are least disruptive to water use habits:

Continued on next page

WATER-SAVING HOUSEHOLD DEVICES





ELECTRIC CONTROL CLOCK

SHOWER HEAD WITH VOLUME CONTROL

1. Install plastic bottles or dams in the toilet water closet to reduce water usage per flush.
2. Install low-water-using shower heads.
3. Install faucet aerators.

The plastic bottles or dams are estimated to save about 4,000-6,000 gallons per year per household. The shower heads save about 12,000 gallons per year per household, and the aerators 3,000 gallons. The total savings are estimated at about 20,000 gallons per year per household or 14 gpcd. Because of their low cost, all these devices are cost-effective.

If 10,000 households installed such devices, water savings could exceed 200 million gallons per year. This would be enough water to serve more than 1,000 additional households.

To be effective, it is necessary that many households install the devices. This is not difficult in new housing areas where plumbing and building codes can require the devices. For remodeling, however, a concerted public education program is necessary, in addition to availability of the devices at little or no cost.

Pricing

The economic incentive for using less water depends on consumer attitudes and needs. Certain uses are valued highly and change very little with price, while other uses change substantially with price.

The change in demand for water with change in price — called elasticity of demand — is expressed as

$$E = \frac{\Delta Q}{Q} \div \frac{\Delta P}{P}$$

where, ΔQ is change in demand
Q is original demand
ΔP is change in price
P is original price

If E is known, the change in demand ΔQ can be computed for a change in price, ΔP.

In-house demand is less price elastic than lawn irrigation. With a given price increase, the relative change in household use will change (decrease) less than irrigation usage. Similarly, industrial usage is usually considered to be even less elastic than residential usage. Table 3 gives some typical price elasticities for various categories of demand.

Table 3. **Price elasticities of water demand**

Demand section	*Elasticity*	*Source*
Residential	-0.225	1
Domestic	-0.26	2
Irrigation (West)	-0.703	1
Average day	-0.3953	2
Maximum day	-0.388	1
Commercial-Industrial	-0.10	3
Government	-0.25	4

Source: 1. *Howe and Linaweaver, 1967.*
2. *Burns et al., 1975.*
3. *Hanke and Davis, 1974.*
4. *Roussos and Flack, 1977.*

Pricing theory and response have been investigated by many authorities. Several pricing methods have been devised in an effort to cut back on the quantity of water demanded and to proportion the costs equitably among consumers. Peak demand rates and increasing block rates are two pricing structures that can promote water conservation. A peak demand rate used by municipal water utilities attempts to place a surcharge on sprinkling use. One procedure is to charge an extra fee for water used above some base allotment computed for each customer individually. For instance, a residential user may be charged significantly more per unit of water demanded any time his monthly usage exceeds 130 percent of his average winter monthly demand.

Another conservation scheme is increasing block rates — charge large water users higher rates for additional units.

As an example of the water savings that can result from a price increase, assuming the elasticities of Table 3 are applicable, Table 4 shows the water demands by categories of a totally metered community at water prices of $0.43/1,000 gallons and $0.86/1,000 gallons.

The net result of doubling water prices from $0.43 to $0.86 per 1,000 gallons is a 21 percent reduction in demand.

Water Use Restrictions

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

Water use restrictions may help save water; they usually always reduce peak demand. Greeley, Colorado, has had voluntary restrictions on lawn watering for decades (Alleman, 1977). These have had little effect on average water usage. Voluntary restrictions in this case are on an odd-numbered house — odd day scheme. In another case restricting lawn sprinkling to specified hours on given days actually resulted in increased usage because lawns were irrigated during those times whether or not they needed it (Brauer et al., 1976).

> **"Peak demand rates and increasing block rates are two pricing structures that can promote water conservation"**

As an example of the effect of restrictions where irrigation was allowed only every third day, the Denver Water Department estimated that water consumption in the summer of 1978 was reduced by 16.5 percent in June, 2.7 percent in July, and 3.2 percent in August, or a saving of 2,470 million gallons. Usage in September was unusual in that, despite the restrictions, water use was actually 9.5 percent greater than the estimated demand without restrictions, probably because precipitation in September was unusually low.

During the 1976-77 California drought, San Francisco Bay Area utilities were able to accomplish significant water demand reductions through both

Continued on next page

voluntary and mandatory rationing. Large-scale reductions were achieved even in cases where the majority of the water customers polled felt the rationing policies were unfair. For residential customers per capita allocations were considered more equitable than percentage reductions from previous usage (Bruvold, 1978). The news media were credited with the major role in alerting and reinforcing public attitudes and favorable response to rationing as necessary because of the water shortage (Hoffman, 1978).

> "The effect of urban water conservation on downstream receiving streams can be an important consideration"

Even after the drought the effects of conservation persisted into 1978 when rainfall was at or above normal levels. The experience gained from the California drought indicates that rationing programs initiated as a result of water shortages have spill-over effects both in terms of time and space. Not only did conservation habits persist over time, but during and after the crisis utilities with more ample reserves exhibited reduced water demand as a result of publicity about shortages and rationing in a nearby utility.

Pressure Reduction

A reduction in pressures to the range of 40 to 60 pounds per square inch can reduce water delivery and leakage in systems with high line pressures. Similarly, household tap pressure reducers which lower pressures to the same range will prolong the life of many plumbing fixtures and household water-using appliances as well as reduce water delivery. Household pressure reducers may make a 10 percent reduction in flow for faucets and shower heads where high system pressures prevail.

System Leakage Reduction

Several means have been developed for detecting water distribution system leaks. Howe found that leak detection and repair were cost effective for leaks which lost more than 3,000 gallons per day per mile of main (Howe, 1971).

Return Flow Implications of Municipal Demand Reduction

The effect of urban water conservation on downstream receiving streams can be an important consideration, especially in low flow periods. The effects are of two kinds. One is the reduction in sewage flow which results in less treated effluent entering the receiving stream. In many locations downstream, direct flow and storage appropriations are dependent on these effluent return flows for their diversions.

The second effect of a conservation program is in the reduction in lawn watering. Since the effect of a concentrated conservation program is to reduce watering to or below the consumptive use requirement for a good lawn, the deep percolation and surface runoff component of applied water is virtually eliminated. If the ground water is hydraulically connected with the receiving stream, the effect on the stream is similar to that of reduced direct discharge to that stream.

Decreases in return flow as a result of conservation programs are difficult to generalize because the analysis is extremely site specific. It depends on hydraulic, hydrologic, and geologic conditions that exist at the site. In a rough estimate of the effects of metering on lawn irrigation return flow for the city of Denver, Bryson estimated that return flow under existing flat rate conditions is about 20 cubic feet per second during the late summer months as measured on the South Platte River. The installation of meters would eliminate most of this return flow (Bryson, 1969, p. 48).

Water conservation programs as applied to commercial and industrial water users would have similar effects on return flow.

Potential Reduction in Delivery Demand

The reduction in delivery demand which can be expected from different conservation practices is shown in Table 5 (opp. p. 1). The total per household reduction cannot be estimated by adding together the individual items because some of the various practices tend to affect the consumer in the same way. For instance, doubling the price of water has some of the same effects on water use as device installation, and it is doubtful that, after water-saving devices were installed, doubling the price of water would result in as large a reduction as indicated. In addition, because retrofitting of devices will not be accomplished by all households in a system, the total demand reduction must be corrected by the percentage actually installing the devices.

The ratio of peak day to average day demand would probably stay about the same under conservation programs. Peak day demand will decrease proportionately with the reduction in average day demand.

> **"installation of water-saving devices in households . . . can result in significant . . . savings"**

The effect of the water conservation programs is thus to reduce domestic use from 64 gpcd to 53 gpcd by the use of water-saving devices in 80 percent of all residences and, further, to reduce domestic use to 41 gpcd by doubling the price of water. Lawn sprinkling would be reduced from 85 gpcd to 51 gpcd by the same price increase. Overall usage would drop from 149 gpcd to 92 gpcd or a 38 percent decrease. Three cautions on accepting these values need emphasis. They are (1) that the elasticities of demand are correct, (2) the two programs are additive, and (3) that a remarkably high 80 percent of all households would install and keep in good repair the water-saving devices.

Peak day to average day ratios would probably stay about the same under the conservation programs with the peak day demand decreasing proportionately with the reduction in average day demand.

Effect of Conservation Programs on Revenue

Based on the values just presented, the before and after revenue picture is readily illustrated. The total demand of 2,175 million gallons at 43 cents/1,000 gallons before conservation would produce $935,250 in revenues per year. After conservation the demand of 1,351 million gallons at 86 cents/1,000 gallons would equal $1,161,860 or an increase of 24 percent in the revenue. Of course, if demand did not drop as much as estimated, revenue would be even higher. On the other hand, installation of water-saving devices at the original price of water would result in a $68,600 per year loss in revenue. Ignoring elasticity effects, this loss could be recovered by an increase in the price of water from 43 cents to 47 cents/1,000 gallons.

Conclusion

It has been demonstrated that installation of water-saving devices in households, if done on a community-wide basis, can result in significant water savings. Likewise, large price increases, assuming universal metering which in itself is a major water saver, will result in substantial drops in water demand especially for lawn sprinkling. Water conservation without a price increase will result in a drop in revenue for the utility. Thus, the complex interplay of various water conservation programs on water demand, return flows and revenue requires skill and judgment to make meaningful projections of future water demand.

REFERENCES

Alleman, D., "Water Conservation Seminar", Fort Collins, Colorado, April 4, 1977.

Brauer, D., et al., "A Study of Water Use and Its Conservation in Northern Colorado", CE 539/Econ 691 Report, University of Colorado, 1976.

Bruvold, William H., "Consumer Response to Urban Drought in Central California", NSF Grant #ENV77-16171, June 1978.

Bryson, Samuel G., "Water Metering Experiments for the Flat-Rate Denver Residences", M.S. thesis, University of Colorado, 1969.

Burns, D.R.J., et al, "The Effect of Price on Residential Water Demand", Project Report CE 539/Econ 691, University of Colorado, 1975.

92nd Congress (1972), *Federal Water Pollution Control Act, Amendments of 1972,* Public Law 92-500, October 18, 1972.

Continued on next page

Flack, J. Ernest and George J. Roussos, "Water Consumption under Peak-Responsibility Pricing", *Journal American Water Works Association,* Vol. 70, No. 3, March 1978, pp. 121-126.

Flack, J.E., "Management Alternatives for Reducing Demand", in *Municipal Water Systems,* D. Holtz and S. Sebastian, Eds., Indiana University Press, 1978, pp. 200-210.

Flack, J.E., W.P. Weakley and D.W. Hill, "Achieving Urban Water Conservation", Completion Report No. 80, Environmental Resources Center, Colorado State University, 1977.

Hanke, S.H. and R.K. Davis, "New Strategies for Water Resource Planning and Management", in *Priorities in Water Management,* University of Victoria, British Columbia, 1974, pp. 117-139.

Hoffman, Mark, "Urban Drought in the San Francisco Bay Area: A Study of Institutional and Social Resiliency", Bilateral U.S.-Argentina Workshop on Droughts, Mar del Plata, Argentina, December 4-9, 1978.

Howe, C.W., "Savings Recommendations with Regard to Water System Losses", *Journal American Water Works Association,* Vol. 63, No. 5, 1971, pp. 284-286.

Howe, C.W. and F.P. Linaweaver, Jr., "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure", *Water Resources Research,* Vol. 3, No. 1, 1967, p. 13.

National Water Commission (1973), *Water Policies for the Future,* Washington, D.C., USGFO No. 5248-00006.

Viessman, Warren, Jr., Malcolm M. Simmons and Christine Demoncadu, "The Nation's Water Outlook to the Year 2000", Congressional Research Service, Library of Congress, January 27, 1978, p. iii.

Weakley, Wade P., "Residential Water Conservation", M.S. thesis, University of Colorado, 1977.

The White House, July 12, 1978.
  - Memorandum for Heads of Executive Departments and Agencies, "Water Conservation and Floodplain Management in Federal Programs".
  - Memorandum for the Secretaries of Housing and Urban Development, Agriculture and Administrator of the Veterans Administration, "Water Conservation in Housing Assistance Programs".
  - Memorandum for the Administrator of the Environmental Protection Agency, Secretaries of Agriculture, Commerce, Housing and Urban Development, "Water Conservation Provisions in Loan and Grant Programs for Water Supply and Treatment".

This publication is one in a series designed to help meet the challenge of providing information on how the natural water system works and how it can be reconciled to the complex demands placed on water by society today. It was prepared by the Colorado Water Resources Research Institute to assist legislators, policy makers, and water resources planners and managers to better understand specific problems and issues.

The most predictable feature of water policy at the present time is change. Changes are occurring in the demands on water supplies, in the values people place on water resources and also in the institutional and legal foundations of public water administration.

This era of change emphasizes water resources administration and management rather than water resources project development. The focus is upon improving management of existing water supplies rather than on the development of new supplies.

Norman A. Evans, Director
Colorado Water Resources
Research Institute

Table 2. **Characteristics of metered municipal demand: 40,000 population - 10,000 homes.**

A. Annual in-house demand	40,000 × 64 × 365 = 934 M.G.
B. Annual irrigation demand	40,000 × 85 × 365 = 1,241 M.G.
C. Annual total demand	40,000 × 149 × 365 = 2,175 M.G.
D. Peak day demand (Factor 2.1)	40,000 × 149 × 2.1 = 12.5 M.G./day
E. Peak day demand per capita	149 × 2.1 = 313 gpcd
F. Peak hour demand (Factor 5.3)	40,000 × 149 × 5.3 =31.6 M.G./day
G. Peak hour demand per capita	149 × 5.3 = 790 gpcd
H. Irrigation return flow	40,000 × 85 × .038= 129,000 gpcd = 47.2 M.G./yr.
I. Annual total return flow (A+H)	934 + 47.2 = 981 M.G. = 2000 Ac. Ft.

Table 4. **An example of the change in water demand with price.**

(Millions of gallons per year)

Demand Sector	*Demand @ $.43/ 1,000 gal.*	*Elasticity*	*Demand @ $0.86/ 1,000 gal.*	*Difference (decrease)*
Industrial/ Commercial	65.0	-0.1	58.5	6.5
Residential				
Household	50.0	-0.225	38.75	11.25
Irrigation	50.0	-0.395	30.25	19.75
Governmental	20.0	-0.25	15.0	5.0
System loss	18.0	-	18.0	0
Totals	203.0		160.50	42.50 (21%)