THE ROLE OF PRICING IN WATER RESOURCES MANAGEMENT

Michael Hanemann
Department of Agricultural & Resource Economics
University of California, Berkeley

1. Introduction

My purpose in this paper is to discuss the role of pricing in promoting integrated water resources management from a US perspective. I will organize this discussion around three topics – institutions, behavior, and the design of a pricing policy. This reflects my view that a pricing strategy should not be designed in isolation; it needs to be tailored to the circumstances at hand, pertaining in particular to the institutional framework within which it will operate and the distinctive interests and behaviors of the people whom it will affect.

My discussion is based on my own experience conducting research and teaching water resource economics in the US, as well as working with various state and local water agencies including serving as the economics staff for the California State Water Resources Control Board from 1987 to 1990.

I will start with a few general remarks. Water is an economic commodity not because people necessarily feel towards water in the same way that they feel towards other market commodities but because it generally requires the use of scarce resources – the raw water itself may or may not be scarce, but it is generally costly to provide a convenient and reliable public water supply system. I view pricing and other economic tools as a means to an end, namely the provision of adequate water to meet people's needs and wants in an environmentally sustainable manner and at a reasonable cost. Whether or not it is a useful or optimal means to this end is not a matter of dogma but rather an empirical question whose answer will vary with the circumstances and will depend on how the pricing is designed and implemented.

Why are we discussing this topic? Why is water so special? Many of my colleagues in the field of water resource economics have argued against what they call "the myth that water is different." Water is essential for life but, they point out, so are food, shelter and clothing. If those are normally handled by the market, why is water different? Why should there be a distinctive public interest in the provision of water?

I agree with my colleagues up to a point. In the US and elsewhere, there is a history of wasteful or dubious public investment in water resources projects, many of them benefitting special interests at the cost of the general taxpayer, that were rationalized on the grounds that water is essential to life and, therefore, there is an overriding public interest in its provision. In these circumstances, a strong dose of scepticism is entirely appropriate when one is faced with calls for new public investment in, let alone subsidies for, water resources development.

However, I believe there is also a valid economic case for the view that water *is* different in some ways that *can* justify distinctive public concern and involvement. This case is based on certain physical features of water that can have specific economic implications connected with economies of scale, externalities, and water as a public good. With respect to public water supply, in particular, the following argument can be made. In a primitive economy, while a family or a small group of individuals can, if necessary, secure its own food, shelter and clothing by own its own efforts, in an arid environment the same may not be true for water. Although the circumstances are different in a modern, market economy, a similar conclusion may apply. While groundwater users are typically self-supplied and some industrial users are self-supplied with surface water for cooling purposes, to have a public water supply from a surface water source typically requires a collective action because of substantial economies of scale associated with the storage, conveyance, and treatment of water. This is not true in general with the supply of food, shelter and clothing – a decentralized market provides those commodities more effectively than it provides public water supply.

It should be noted, in this regard, that the water supply industry is exceptionally capital-intensive relative to not only manufacturing industry in general but also other utility industries such as electricity, natural gas and telecommunications. For example, annual investment in fixed assets in the US water and wastewater industry amounts to about 43% of gross annual revenues; after water, the other most capital-intensive industries are communications (SIC 48) and electric services (SIC 491), in which annual investment averages 18% and 16% of gross annual revenues, respectively.

Not only is public water supply extremely capital intensive but also the capital tends to be very long-lived – the physical capital associated with surface water storage and conveyance can have an economic life of 50 or 100 years, much longer than the economic life of capital in manufacturing or other utility industries. The unfortunate corollary is that mistakes last for a long time – erroneous investment decisions cause harm for much longer in the water supply industry than in most of the rest of the economy. The capital intensity strengthens the case for integrated water resources management.

The collective aspect of public water supply highlight the social dimension of water resources management. I am reminded of the literature on famine, where Amartya Sen and others have argued that the problem of dealing with famine in developing countries is fundamentally one of social organization. While clearly physical resource constraints matter, failure in the provision of a public water supply is fundamentally a problem of social organization and behavior. As I will argue below, pricing is of practical value largely (although not exclusively) to the extent that it can promote beneficial forms of social behavior. This is a key objective in the design of an effective pricing strategy.

The remainder of this paper is organized as follows. Section 2 deals with what I consider some of the important institutional aspects of the US water system. Section 3 summarizes some important features of water use in the US. Section 4 presents my observations on how one might go about the design of a pricing strategy.

2. Water Resources Management in the United States

In order to summarize some of the distinctive features of US water resources management, it is useful begin with some taxonomy. A water resources system may be characterized in terms of four components: the water resources *in situ*, whether surface water or groundwater; the abstraction of the resource, whether diversion of surface water or pumping of groundwater; the conveyance of water from the point of abstraction to the area of use; and the local distribution of water to end users within the area of use. In the case of urban (but typically not agricultural) water use, there are often several other components relating to water quality: the purification of water prior to delivery to end users; the collection of used water in the form of sewage, sewage treatment, and the disposal of treated sewage effluent and treatment by-products. It is also necessary to distinguish between wholesale and retail water supply agencies: retail agencies serve the end user, while wholesale agencies abstract water and supply it to the retail agencies.

In this section, I will highlight four structural features of the US water supply industry that I believe have a major impact on how well it functions from an economic point perspective: (1) the multiplicity of agencies involved in water supply and consequent dispersal of authority; (2) what might be considered defects in the ownership structure of in-situ resources; (3) the largely public ownership structure of wholesale and retail water supply, and consequent lack of economic regulation; and (4) the lack of coordination between the water supply industry and two other utility industries, electricity supply and sewerage, whose actions sometimes affect urban water use behavior at the retail level more significantly than those of the retail water supply industry itself.

In the US, separate agencies are typically associated with different elements in the water supply system. Groundwater for both agricultural and urban uses is typically self-supplied by individual end-users, without the mediation of any water supply organization. Surface water is not generally self-supplied, with a few important exceptions such as cooling water in electricity generation, and a variety of different agencies may be involved in its supply. For example, retail water supply in the city of Los Angeles is provided by the city government through the Los Angeles Department of Water and Power (LADWP). Some of the water supplied by LADWP comes from surface water sources and groundwater wells which it owns locally; some of it is surface water imported by LADWP from the Owens Valley and tributaries to Mono Lake, about 400 miles the north-east of Los Angeles; and some is is surface water supplied to LADWP by the Metropolitan Water District of Southern California (MWD), a wholesale water supply agency created by LADWP and several neighboring cities to meet regional water supply needs in Southern California (see Figure 1A,B). MWD, in turn, obtains its supply partly by diversions from the Colorado River, about 100 miles east of Los Angeles, and partly by purchases of water from the California State Water Project (SWP). The SWP is a water storage and conveyance system operated by the California Department of Water Resources which obtains water from tributaries of the Sacramento River in the Sacramento Valley, about 500 miles north of Los Angeles, and delivers it to irrigation users in the San Joaquin Valley as well as urban users in Southern California. Thus, a wholesale agency, SWP, supplies another wholesale agency, MWD, that supplies a retail agency, LADWP. Moreover, sewerage is handled separately, by the county of Los Angeles – the sewerage service is provided on a county-wide basis in Los Angeles while water is supplied in the county by a number of separate retail agencies, of which LADWP is just the largest. While LADWP's customers pay sewerage charges based on their usage of LADWP water, and the sewerage charge is collected by LADWP on its water bill and passed on to the county government, the pricing and management of sewerage is entirely separate from, and uncoordinated with, the pricing and management of water supply. Although the sewer bill is typically larger than the water bill and therefore could have a large impact on water use behavior, water managers appear to give it little consideration.

INSERT FIGURES 1A,B AROUND HERE

The multiplicity of agencies associated with the supply of water to the residents of Los Angeles is by no means uncommon. It makes water pricing a complicated matter – when you talk of using prices or other economic approaches to allocate water, are you thinking of the abstraction of water in the form of local groundwater pumping by LADWP? Or are you thinking of the diversion and storage of local streamflow by LADWP, of Colorado River water by MWD, or of Sacramento River water by SWP? Or are you thinking of the wholesale supply of water by SWP to MWD? Or the wholesale supply of water by MWD to LADWP? Or the retail supply of water by LADWP to end users? These all involve different agencies with different perspectives, different constraints, and different legal powers. Therefore, the proper role of pricing or the proper approach to water resource allocation is something that will be different for different agencies at different tiers of the supply chain – there is not going to be a single prescription or formula or rule of thumb that can be applied globally throughout a water supply system within a single province, let alone a single country. As an example to be discussed at greater length below, marginal cost pricing of water cannot be taken mechanically as the optimal approach to water allocation regardless of the circumstances.

One consequence of the multiplicity of agencies is a disjunction that is often found, in my experience, between where in the supply chain carefully chosen pricing might have its greatest impact on both actual water using behavior and actual human welfare and where in the chain there is the greatest interest in promoting the use of pricing. In my experience, it is often the retail agency level which may offer the greatest opportunity for influencing water use behavior and water-related social welfare, while the most interest in using improved water pricing to this end is to be found in central government agencies associated with wholesale supply. For example, one of the most significant efforts in recent years to improve the pricing of irrigation water in the California is the 1992 Central Valley Improvement Act, which mandates the US Bureau of Reclamation to adjust its wholesale contracts for water from the central valley Project so that there is increasing block pricing with respect to the last 20% of the contracted water supply – sharply higher prices are charged for this last increment of water. While this is fine in principle, there is nothing to prevent irrigation districts from charging a retail price which merely averages in the high price for the last 20% of water with the lower price for the first 80%. What one wants, in my view, is to change how the retail agencies price water and how they also promote irrigation efficiency through related non-price programs such as water use audits, the provision of advice on irrigation, low interest loans for improved irrigation equipment, etc. In economic terms, there is a principal-agent problem where the principals are the wholesale suppliers (in California, for example, the Bureau of Reclamation, the State Water Project or

MWD), the agents are the retail irrigation or urban water supply agencies, and the problem is for the principals to create a mechanism that induces the agents to adopt policies that the principals prefer but are not necessarily in the agents's own interests. This can be done but, besides a wholesale rate structure, it involves institutions and mechanisms that reinforce the pressures for behavioral change by end users. I describe below how this is being done in California with urban water agencies under the 1991 Memorandum of Understanding on Urban Water Conservation.

Two additional features of the governance of water resources in the US complicate efforts from the center to promote water use efficiency at the end use level. One is the dispersal of political power associated with a federal system and the separation of powers, which makes it harder for a government agency controlling the abstraction of water by a wholesale agency, say, to effectively influence the use of water by customers of a retail agency that the wholesale agency supplies. The second feature is US water law and practice with respect to the ownership of surface water and groundwater resources.

As an crude generalization, in the US neither the federal government nor the state governments are in any real position to levy abstraction charges for withdrawals of groundwater or surface water. For both surface water and groundwater, water law is a matter of state law rather than federal law, except for matters involving water on or underlying public lands owned by the federal government or water diversions from interstate rivers such as the Colorado River. With groundwater, to a greater or lesser degree most US states follow the English Common Law rule that groundwater is the property of the overlying land owner – he owns whatever water he extracts from any well located on his property. While a few US states require a permit for groundwater extraction, and some of those may levy an administrative charge for the issuance of a permit, I do not believe that any state government would be able politically at this time to levy an abstraction charge for the purpose of creating an economic incentive to reduce groundwater pumping. Although the property rights regimes for surface water in the US are different than, and more diverse than, those for groundwater, essentially the same conclusion applies. The right to surface water is a usufructuary right tied to the ownership of riparian land, in the case of riparian rights, or the historical timing of initial appropriation, with appropriative rights. While state governments generally have an overriding authority to regulate surface water diversions and use, including the power to promote the beneficial use of water, I do not believe they would be able politically to levy an abstraction charge for surface water diversions for the purpose of creating an economic incentive reflecting the social scarcity value of water, say, or the negative externalities associated with water diversions. In short, there is *no* scarcity charge in the US for the abstraction of groundwater or surface water. While the state governments can regulate the use of water, water *in situ* is effectively a private resource over which they do not assert ownership, certainly not to the point where they could levy an abstraction charge.

Turning from the abstraction of water, to its storage, conveyance and distribution, the single most important structural feature of water supply in the US is that it is largely in the hands of the public sector – far more so than any other public utility industry. With respect to urban water use, only about 14% of the total US population are served by private investor-owned water supply organizations – in California, the figure is closer to 5%. The remained are served by public, government-owned water agencies. With electricity, by contrast, a substantial majority of the population is served by investor-owned organizations. The key consequence of this ownership structure is that there is a vast difference in economic regulatory oversight of the water industry compared to electricity. For water supply – whether urban or agricultural – there is virtually *no* economic regulation in the US. For electricity, there is a substantial regulatory framework built around state Public Utility Commissions (PUCs), dating from the early years of this century, and augmented in the 1970's by institutions created to deal with the energy crisis, such as the California Energy Commission. The original rationale for public utility regulation in the US was to prevent exploitation of consumers by suppliers who might otherwise engage in monopoly pricing, something it was assumed would *not* arise with publicly owned utilities which were therefore exempted from PUC regulation. The view of utility regulation changed dramatically in the 1970's with the onset of both the environmental movement (concerned at that time especially with the spread of nuclear power) and the energy crisis that threatened supplies of oil and natural gas. The focus of regulation shifted from the narrow objective of price control to the broader objective of promoting economic efficiency in both the generation of electricity and its end use. The policy tools intended to discourage inefficient and unnecessary investment in new generating capacity included the promotion of marginal cost pricing, a greater emphasis on demand side management, and the adoption of improved methods of forecasting both energy demand and supply. These objective were equally relevant for both public and private electric utilities, and the new regulatory institutions that emerged in the 1970's were designed to cover both sectors of the electricity industry. The California Energy Commission, for example, was given authority to regulate demand forecasting and supply costing by all electric utilities in California, both public and private.

However, none of the new regulatory apparatus for electricity carried over to the water industry, even though one could argue that water faces problems quite similar to those faced by the electricity industry in the 1970s. Moreover, at least until recently in California, the PUC's regulatory oversight of investor-owned water utilities was materially different from its oversight of investor-owned electric utilities – for water it still focuses narrowly on price regulation and has not been broadened to a general concern for efficiency. In consequence, the only substantive regulation of the US water supply industry is public health related.

In short, the urban water industry in the US today closely resembles the electric utility industry of the 1950's and 1960's prior to the energy crisis. Water has been relatively inexpensive, supplies have been pretty adequate, at least until recently, and there was no need to innovate. Now, demand is growing quite rapidly in many areas, new supply looks to be relatively expensive, and there are intermittent problems of shortage caused by drought. Moreover, water suffers from the disadvantage, compared to electricity, of being extremely expensive to transport: while electricity is relatively expensive to store but cheap to transport, the opposite is true for water. Consequently, whereas electric utilities can deal with temporary shortages by buying and selling power long distance over a grid, water utilities are essentially on their own – they must get by with whatever water they have in storage. This puts an even greater premium on accuracy and efficiency in resource planning and management. However, while there is now a clear need to improve the planning and management of water resources in the US, there is still an institutional vacuum – there remains nothing remotely comparable to regulatory infrastructure for electricity and natural gas that emerged in the 1970s. An example of this vacuum is the State Water Resources Control Board (SWRCB) in California, which, on paper, holds ultimate authority over all use of water in California and is charged by the State constitution with ensuring that all water be put to beneficial use. The SWRCB has always refused , and still refuses, to become involved with the financial and economic aspects of water resources management; its view is that, since the State PUC has authority over financial and economic details of investor-owned water utilities, it should stay away from financial and economic issues entirely and limit its actions to water quality regulation and water rights-type quantity allocations.

Because of the water industry's relatively backward state, it is not surprising that some of the most important steps toward improving the efficiency of end-uses of water in recent years have come from sources outside the water industry.

The two most significant changes in California, for example, have been enactment of the 1980 and 1992 State Plumbing Codes mandating water-efficient toilets and showers, and the 1991 Memorandum of Understanding on Urban Water Conservation. The 1980 Plumbing Code was enacted by the State Legislature following the drought of 1976-77, and imposed efficiency standards of 3.5 gallons per flush (compared to the then conventional 5.5 gallons per flush) for toilets sold in California after January 1, 1980 and flow rates of 2.75 gallons per minute for showerheads and faucets (compared to a then conventional 4.5 gpm flow rate). The 1992 Plumbing Code, passed during the 1991 drought, lowered the standard to 1.6 gallons per flush for toilets and 2.5 gallons per minute for showerheads. There appears to be a fairly high rate of compliance with these codes and their influence has been quite substantial due to the relative rapid turnover of home ownership, with consequent likelihood of remodeling. It is estimated that, by 1990, the 1980 Plumbing Code had impacted about 28% of all single-family dwelling units in Southern California, whether new construction or through remodeling or retrofitting.

The Plumbing Codes were imposed on the California urban water industry by the state legislature. The 1991 Memorandum of Understanding on Urban Water Conservation (MOU-UWC) was voluntarily negotiated by representatives of the major urban water agencies and environmental groups in California – but under some duress, since the SWRCB had otherwise threatened to reduce MWD's right to transfer water for urban use in Southern California unless it did something to raise water use efficiency. The MOU-UWC, which has now been signed by more than 200 urban water suppliers covering almost all the state's urban population, commits the signatories to implement a set of water conservation practices, known as "best management practices" (BMPs), subject to two qualifications: a supplier would be exempted from a BMP if there was a legal barrier to its implementation, or if an economic analysis conducted according to prescribed guidelines demonstrated that the BMP would not be cost-effective for that agency. The current set of BMPs is shown in Table 1. The MOU established a California Urban Water Conservation Council (CUWCC), with members drawn from the water industry and environmental groups, which was empowered to develop guidelines for the analysis of cost-effectiveness, and to study additional conservation measures that, if found to be cost-effective, could be added as new BMPs and would then become mandatory for the signatories. Under this process, the CUWCC added two new BMPs in 1997, items 6 and 10 in Table1.

INSERT TABLE 1 AROUND HERE

I helped to negotiate the MOU-UWC, and I regard it as a significant accomplishment. However, it has some important limitations which should not be overlooked. The most important is the conservation practices that are omitted from Table 1. SWRCB was not willing to push MWD very hard. Consequently, after 20 months of negotiation, there was agreement only on those BMPs with which MWD was already in compliance. Any practice *not* currently being implemented MWD or its retail agency customers could *not* be identified as a BMP. Examples of such practices are shown in Table 2: this is a list of "Potential BMPs" which were commended to the CUWCC for further study. An item I advocated that was blocked from inclusion among even the Potential BMPs in Table 2 was some form of efficiency standards or landscape design standards targeted specifically at landscaping and outdoor water use in new residential construction. I was successful in obtaining the inclusion of item 11 in Table 1, Conservation Pricing, which commits retail water (and sewer) service agencies to eliminate rate schedules with decreasing block pricing and rate schedules entirely independent of the level of usage, but otherwise commits to them to little more specific than using pricing to "provide incentives to customers to reduce average or peak use, or both." BMP 2 in Table 2, which refers more specifically to "seasonal rates; increasing block rates; connection fee discounts; grant or loan programs to help finance conservation projects; financial incentives to change landscapes; variable hookup fees ties to landscaping; and interruptible service to large industrial, commercial or public customers" made it only as far as the Potential BMP list.

INSERT TABLE 2 AROUND HERE

Note that the only two additions to the BMPs since 1991 are item 10 in Table 1, which requires wholesale water supply agencies such as MWD to offer technical and financial assistance to the retail agencies they supply to promote water conservation, and item 6, which involves financial incentives to be offered by water agencies for customers who choose high-efficiency (typically front-loading) clothes washing machines. Neither appliance efficiency standards (item 2) nor any other item from Table 2 has yet been promoted to the official BMP status of Table 1.

At the same time that the negotiations for the MOU-UWC were initiated in January 1990, parallel negotiations began between agricultural water supply agencies and environmental groups for an MOU on agricultural water conservation. These negotiations were far more difficult, and an agreement was not reached until July 1996 – the process took five and a half years, compared to one and half years for the urban MOU. Moreover, the agricultural BMPs, exhibited in Table 3, are considerably more anodyne than those of the urban MOU. The difference is due to the tenacious desire of the agricultural water districts to preserve their status quo, the lack of support from the governor for any reform of water management, and the ending of the drought in 1993. At this point, 20 agricultural water agencies, representing about one tenth of the most active irrigation districts and about one third of the irrigated acreage in the state, have signed the agricultural MOU.

INSERT TABLE 3 AROUND HERE

In my assessment, the quantitative impact of the MOU-UWC on urban use has so far been small but definitely positive (the impact of the agricultural MOU has surely been negligible). Although, by construction, the largest urban water agencies were already in compliance with the BMPs at the time they were adopted, a substantial number of smaller urban water agencies was out of compliance in 1991 but has since come into compliance. Moreover, the signatories to the MOU-UWC and the CUWCC have been energetic in following it up by commissioning research and publishing a variety of reports, handbooks, and technical guidance documents relating to urban water conservation. There exists a significant potential for even greater accomplishments, especially if some of the Potential BMPs in Table 2 were to be adopted. Nevertheless, at this time the greater impact on the efficiency urban water use in California has come from the Plumbing Codes, which have by now directly impacted perhaps a quarter to a third of all single-family residence in the state, reducing their water use by about 10% per affected household.

The fact that one of the two new urban BMPs deals with water-efficient clothes washing machines is significant because it reflects an interest of the energy industry in promoting water conservation. A non-trivial component of household energy use is associated with heating water for bathing, washing clothes, and washing dishes; whatever reduces water use in these appliances also reduces the household's consumption of energy to heat this water. For the past ten or fifteen years, there have been efforts at both the federal and state government level to encourage greater energy- and water-use efficiency in clothes and dish washing appliances. At least until 1997, by contrast, the water industry has been reluctant to concern itself with any appliances other than toilets and showerheads.

In some non-coastal states, and coastal state with sewage treatment or disposal problems, another impetus for water conservation has come from the US Environmental Protection Agency (EPA), concerned that the growth in the volume of sewage may exceed the treatment capacity or, more especially, the disposal capacity of existing sewage treatment plants. In inland areas, treated sewage effluent is typically discharged to rivers and streams, and in arid areas this effluent may constitute a substantial proportion of the stream flow. To prevent water quality degradation in these areas, the EPA has sought to reduce urban water use and thereby lower the volume of sewage effluent. This has occurred in Denver and Phoenix, for example. Most residential water users in Denver were not metered, but in the 1980's the EPA compelled the city to install meters for its residential users. Until interventions like this from the EPA, the water supply agencies have tended to be rather oblivious to what was happening with sewage treatment. When this sewage-driven intervention has occurred, it has tended to be more brutal and more effective than the usual anaemic regulation to which the water industry is subjected.

3. Patterns of Water Use in the US

Having discussed some institutional aspects of water resources management in the US, I turn now to a discussion of patterns of water use, especially urban water use, in the US.

Irrigation is practiced mainly in the arid areas of the US such as California, Washington, Idaho, Nevada, Utah, Arizona, New Mexico, Texas and Florida, as well as in areas dependent on groundwater such Texas, Oklahoma, Kansas, Nebraska , Montana and Wyoming. In these irrigated states agriculture is the dominant use of water, typically accounting for 80-85% of total water use. In areas irrigated with surface water, the dominant mode of irrigation is still some form of furrow or flood irrigation. In some groundwater dependent areas, sprinkler irrigation with a center pivot is also very common.

In California, irrigation now accounts for 34 million acre feet (MAF) out of a combined urban and agricultural use of 43 MAF, or about 79%. The total irrigated area in California is about 9.5 million acres, implying an overall average application rate of about 3.6 acre-feet per acre (AF/A). Irrigation application rates vary with the crop, the irrigation method, the soil, and cultural practices. Table 4 and Figure 2 provide some indication of water application rates for different crops in California. Table 4 gives the crop evapotranspiration (ET) – i.e., the theoretical water requirement – for the main crops grown in different regions of the state. If irrigation were 100% efficient, this would also correspond to the actual irrigation application, but this does not usually occur. The field irrigation efficiency is defined as the ratio of theoretical ET to actual irrigation application. For example, cotton grown in the Tulare Lake sub-basin of the San Joaquin Valley has an ET of 30 inches (2.5 AF/A). Suppose the actual application rate is 49 inches (4.1 AF/A); then, the field irrigation efficiency is about 61% (= 30/49). Given the crop ET, the lower the efficiency, the larger the application rate. While crop ET is known from past agronomic research, the field irrigation efficiency is something that varies according to how the grower farms, and therefore needs to be measured empirically. Figure 3 gives some results on actual application rates observed in Kern County, part of the Tulare Lake sub-basin, based on a survey of 50 farmers by Lloyd Dixon. For cotton with flood/furrow irrigation, the irrigation efficiency ranged from about 93% (= 30/32) down to about 61%.

INSERT TABLE 4 AND FIGURES 3 AND 4 AROUND HERE

Even more striking evidence of the variability in agricultural water use is shown in Figure 4. This is field level data on water application rates by about a dozen growers in Broadview Irrigation District, a small district of about 10,000 acres on the west side of the San Joaquin Valley. 32 fields, representing about 60% of district's acreage, are planted to cotton, and the figure shows the distribution of applied water across these fields. The ET for cotton in this area is about 27 inches (2.3 AF/A). One farmer deficit irrigated, applying less than the ET; 5 farmers applied more than 4 AF/A, for an irrigation efficiency of 58% or less; and the modal application was 3.6 AF/A, an irrigation efficiency of 64%. All of these farmers faced the same flat rate price per acre foot for water, they all have similar soil, and they were all growing the same crop using the same irrigation technique (furrow). In terms of any conventional economic analysis, they should all be making exactly the same input choice – but they clearly are not. This type of variability in water use behavior is entirely overlooked in both planning exercises and academic studies of irrigation demand.

The figure given above for total agricultural water use in California is likely to be something of an underestimate because of inadequacies in the available data. If farmers relied exclusively on surface water deliveries from their irrigation district, it would be a straightforward exercise to calculate their irrigation application rate. But, if they rely partly or wholly on groundwater, this is more difficult because, as noted earlier, groundwater is typically self-supplied, and efforts to monitor groundwater pumping by farmers in California have been fiercely resisted. In the absence of good measurement of groundwater pumping in California, the official estimates of irrigation use in California are guesses based on *assumptions* about field irrigation efficiency. In my experience, the guesses tend to be somewhat over-optimistic, leading to some understatement of actual irrigation usage. Moreover, since groundwater pumping is computed as the different between known surface water deliveries and the "estimated" total irrigation application, the result is to understate groundwater pumping to some degree. There may even be some official wishful thinking in areas that rely entirely on surface water. The data in Figure 5 are consistent with this, since they imply a modal irrigation efficiency for cotton in Broadview of 64% and an average of 68%, while the official figure used by the California Department of Water Resources is 70%.

Tables 5 and 6 provide some information on costs of irrigation supply to agricultural users. These data come from a very small sample of irrigation districts, and are likely to be somewhat unreliable. Nevertheless, the basic message is correct, that the cost of irrigation water in the Central Valley is mostly in the range of $15 - 40 per acre-foot (AF), but is higher in the southern end of the San Joaquin Valley, the Tulare Lake Basin, where it reaches up to $80/AF. It should be emphasized that these are retail rates and not, for example, the wholesale rates charged by the Bureau of Reclamation's Central Valley Project (CVP. The CVP rates are now generally in the range of $10-20/AF. Estimates of the actual historical cost of CVP water are about $45-75/AF. Several factors contribute to the subsidy associated with CVP water, the chief one being that there is no charge for interest on the funds borrowed by the federal government to finance construction, even though the repayment period will now extend to about 70-90 years. Moreover, repayment is based on the historical cost of the project, and not the marginal replacement cost. Another factor contributing to the subsidy is that the Bureau signed 40-year fixed-price contracts when the project was inaugurated in the 1950's, not anticipating the escalation in energy costs during the 1970s. This threw the project into an operating deficit as the revenues from the sale of CVP water failed to cover the operating and maintenance costs, let alone repay the capital costs. These deficits will eventually be paid off (still without an interest charge) over the next 40 years under new contracts being renegotiated under the 1992 Central Valley Improvement Act.

INSERT TABLES 5 AND 6 AROUND HERE

While the pricing of CVP water in California is certainly egregious, it should be realized that this accounts for only a small fraction of total agricultural water use in the state – only about 15%. The CVP typically supplies about 8.3 MAF of irrigation water, but about 3.1 MAF of this goes to what are known as exchange contractors – pre-existing irrigators along the Sacramento and San Joaquin Rivers who had previously diverted river water but agreed to end their diversions at the request of the CVP in exchange for free delivery of CVP supplies. Since the exchange contractors gave up their existing water rights, they cannot be said to be subsidized by the current arrangements. Thus, it is the CVP's non-exchange contractors who are being inappropriately subsidized, and their usage amounts to about 5.2 MAF out of the total agricultural use of 34 MAF.

The other major wholesale project, the State Water Project (SWP) is much smaller – it delivers about 2.5 MAF annually – and involves little subsidy. There is no interest subsidy, nor any fixed price contracts, and the wholesale water rates are adjusted each year to keep up with changes in operating costs. Also, whereas the CVP tends to average costs over widely disparate users, the SWP uses spatially-differentiated conveyance charges that closely reflect the actual delivery cost for each user, with wholesale rates that reach about $80/AF for irrigation districts at the southern end of the San Joaquin Valley.

However, the bulk of irrigation water in California does not come from either the CVP or the SWP but instead comes about equally from groundwater (15 MAF) or from locally owned and operated surface water storage projects (about 16 MAF), neither of which is subsidized along the lines of the CVP. However, the retail water prices in these areas typically end up being in same type range as those associated with CVP water, at the low end, or SWP water, at the high end. This is not entirely a coincidence: in Kern County, SWP water is deliberately priced at the retail level so that it is roughly competitive with the cost of groundwater pumping.

Table 7 provides some comparable information on retail water rates for industrial and commercial users in California, and Table 8 summarizes the cost comparison between agricultural and urban water in California. Retail rates in the major urban areas of California are now generally in the range $500-650/AF, or six to eight times more expensive than retail rates for agricultural users.

INSERT TABLES 7 AND 8 AROUND HERE

Why do urban users pay so much more for their water than agricultural users? The explanation cannot be agricultural subsidies since, as we just noted, the preponderance of agricultural water does not receive a subsidy. Moreover, there is no difference between agricultural and urban users with respect to the scarcity price of water, since *no* user in California pays any charge for abstraction. There are several components to the answer. For example, many of the local water storage and conveyance systems that supply irrigation users were built a century ago and have long paid off their capital costs. But the main reason is the difference in distribution and treatment. Within an irrigation district, water is conveyed using gravity and is not available on demand; for an urban user, water is conveyed under pressure and is available at the turn of a faucet. Moreover, urban water is treated to the level of potability. The difference in distribution and treatment make urban water a different commodity, and a much more expensive one, than agricultural water.

The larger point is that, both in California and in the US generally, the cost of water is essentially the cost of the plumbing – conveyance from the point of abstraction to area of use, treatment, and local distribution within the area of use. This explains the divergence between the wholesale and retail prices of urban water – in Los Angeles, for example, the cost of water delivered to the city's boundary from various sources – MWD, Owens Valley and Mono Lake, and local sources – averages less than $200/AF and the difference between this and the retail price of about $600/AF is the cost of operating the local distribution system plus the cost of operating LADWP. It also explains why nationally the retail price of urban water does not vary with any consistent spatial pattern. It is not the case, for example, that urban water is more expensive in California than in the rest of the US. To the contrary, even though Los Angeles is far more arid than, say, Boston, the retail cost of water is lower in Los Angeles than Boston. The explanation is the difference in the costs of local distribution – Boston has a very old pipe system going back, in some case, to the late 1700s with a high cost to maintain this distribution system, while Los Angeles has a much newer distribution system.

Turning now to urban water use, this typically consists of residential, industrial, commercial, and public uses, as well as some minor use for other purposes such as fire-fighting, line-cleaning, and system losses. Overall urban water use in MWD's service area, covering about 15 million people living along the Southern California coast from Oxnard to San Diego, amounts to about 195 gallons per capita per day water (gpcd) in a typical year with normal weather conditions and a normal economy. A breakdown of this total among its various components is shown in Table 9.

INSERT TABLE 9 AROUND HERE

By far the largest component of urban water use in the MWD service area is residential. The second largest component is commercial, and industrial comes third. This is a striking change from what one would have found up to, say, 1975; industrial use would have been 10-15% of total urban use, and would have been the second largest component, ahead of commercial. Over the past 25 years, industrial water use throughout the US has fallen quite dramatically, not just relative to the volume of output or employment but also in absolute terms. In California, for example, industrial freshwater intake fell from 1.33 million acre-feet in 1973 to 0.86 million acre-feet in 1983 despite the growth of the California economy during that decade. The evidence suggests that the downward trend in industrial water use has continued, although perhaps at a slower rate. While higher water prices and changing manufacturing technology have played some role, the main reason for the decline in industrial water use is water pollution control regulation by the federal and state governments since the early 1970s, which has greatly encouraged manufacturing firms to recycle water and reduce their use of water for waste product disposal. This is yet another example of the *economic* linkages between water supply and sewage which arises because they both generate costs associated with the use of water in industry. These may involve different technological choices, but those choices are inter-dependent.

In Table 9, leakage and other system losses are put at under 5% of total water use. This could in fact be an underestimate because leakage is a sensitive topic for water agencies and they have a tendency to downplay it. In general, it is a function of the age and condition of the pipe network. Boston, with its ancient pipes - still wooden in some cases – was said in the 1960s to have a leakage rate over 40%.

Residential water use can be divided into use by single-family units versus multi-family units. The two types of unit generally have different patterns of water use, for both economic and demographic reasons. The major economic difference is that the residents of multi-family units are usually not metered and billed individually; instead, there is a single bill for the entire building. Another major difference is that there tends to be less outdoor space per resident in multi-family units, and the maintenance of the landscaping, including irrigation, may be controlled by a building manager rather than by the residents individually. Demographically, multi-family units are often associated with smaller family sizes, although the opposite may be true in lower income areas where large households may live in apartment units because they cannot afford to buy a home of their own. Also, multi-family units may have somewhat fewer water-using appliances than single-family units. The non-metering of individual dwelling units within multi-family structures reduces the incentive to fix leaks or avoid waste; however, the other differences all tend to reduce per capita use in multi- family versus single-family residences. Overall, the net effect is generally lower per capita use in multi-family units. In the MWD service area, for example, residential water use in a normal year area is now estimated to average about 150 gallons per capita per day (gpcd) for single-family units and 110 gpcd for multi-family units.

INSERT TABLE 10 AROUND HERE

Table 10 presents data on the breakdown of these totals among various end uses. This shows that about one third of the water used in a single-family home – but only about one fifth of that used in a multi-family home – goes for outdoor uses. Although outdoor residential use is smaller than indoor use, it is more important than indoor use as a source of variability across space and time. Indoor water use in single-family residences is generally likely to be found somewhere in the range of, say, 70-110 gpcd; outdoor use in single-family residences can range anywhere from less than 30 gpcd to over 100 gpcd. outdoor residential water usage depends crucially on lot size, soil characteristics and climate conditions. The type of landscaping also has a substantial effect, for example turf versus xeriscape. The type of turf itself can make a difference; warm-season turfgrasses such as bermudagrass require about 20% less water in California than cool-season turfgrasses such as Kentucky bluegrass. Beyond these physical considerations, however, there is an essential behavioral component in outdoor water use. People choose to adopt one style of landscaping rather than another, and they water their landscape with different degrees of knowledge, care and attentiveness.

By way of illustration, Figure 5 shows the results from a 1990 survey of 515 single-family residential landscapes located in MWD's service area. The survey compared actual outdoor water use with the irrigation that was required given the size and the landscaped area and the type of ground cover. The researchers found that only 11% of the households irrigated their yards at levels within ±10% of what was required for their yard. The remaining 89% of the households irrigated incorrectly from an agronomic point of view. About 39% of the households over-irrigated in the sense of applying at least 10% more water per unit area than was required by the type of ground cover that they had, while 50% under-irrigated, in the sense of applying at least 10% less than the required irrigation. Lot size was an important factor here: households with landscape areas of less than 3,500 square feet all over-irrigated, while those with landscape areas greater than 8,000 square feet all under-irrigated. While the overall effect in aggregate was under-irrigation, I would argue that there would be a net social gain if those who over-irrigated could have reduced their water use.

INSERT FIGURE 5 AROUND HERE

The heterogeneity in water use behavior surely extends to indoor residential water use, but here we have less information because until very recently there was no field measurement of actual end use behavior. There is a wealth of engineering information on water usage by specific appliances under theoretical operating conditions, but until recently there were no studies to monitor water-related appliance ownership or water usage patterns within individual homes. For example, we know that, following the 1992 Plumbing Code, all new homes in California have toilets which use 1.6 gallons per flush (gpf) as opposed to 3.5 gpf under the 1980 Plumbing Code. But, what we do *not* know is how many times per day a person flushes the toilet, whether people flush more often with ultra-low flush 1.6 gpf to conventional 3.5 gpf toilets, whether they modify their toilets (e.g., by placing a brick in the toilet bowl), or whether toilets leak and how people deal with this. In short, there is a *behavioral* component in addition to the engineering component of indoor water use, and this is not yet well understood.

Table 11 offers some confirmation of the enormous variability within a population of urban water users. This shows the size distribution of water use per residential account, based on individual account data for all the single family residences served by LADWP (approximately 403,500 accounts). About 20% of the households use less than 200 gallons per account per day (gpad), accounting for 6% of the total single family residential usage; the median usage is about 360 gpad; three quarters of the households use less than about 500 gpad; 10% of the households use more than about 700 gpad, accounting for about 27% of total usage; and 3% of the households use more than 1200 gpad, accounting for 12% of the total usage. All of these households face exactly the same charge for water, which at the time consisted of a small connection charge plus a single flat rate per unit volume. Obviously, they differ in household size, income, lot size and other characteristics, but LADWP has no data by which this can be tracked at the individual account level. While the variation in demographics explains some of the difference in water use, another — I suspect quite large – component is caused by sheer variation in preferences and behavior.

I should emphasize that heterogeneity in behavior is by no means limited to residential water use. From my experience with other types of micro-data, including data on industrial and agricultural water use – see for example Figure 4 – I am convinced that variation in individual behavior is a fundamental fact of life. This is both bad news and good news. It is bad news because it causes great difficulty for the researcher – people who otherwise seem similar to the researcher have different patterns of behavior, which makes their behavior hard to model and hard to predict. It is good news for the policy analyst because it means there is some potential scope for changing people's behavior if the right incentives can be found.

In the case of electricity, considerable effort has been expended in the US over the past 15 years to measure appliance ownership and end use behavior within the home; with water, the first end-use study in the US was completed last year under the sponsorship of the AWWA Research Foundation. This involved detailed measurement of end uses of water for 100 households in each of 12 cities covering 24 hours per day for 2 weeks in the summer and 2 weeks in winter. I and other are now analyzing these data; preliminary results of the analysis show there is the same type of diversity of behavior as in Figure 5 or Table 11 for both outdoor use and various indoor end uses. For outdoor water use, climate variables clearly have a systematic effect. Aside from this, most variables have low t-statistics and most regression equations have very low R^2 statistics.

A consequence of the heavy reliance on engineering data and the relative lack of measurement of actual water usage is that water planners' estimates of per capita urban use are likely to be fairly unreliable. All of the California water plans since 1980 have assumed that, whatever urban per capita consumption is now, it will decline in the future because of conservation efforts such as the 1980 and 1992 Plumbing Codes and the 1991 MOU on urban water conservation. This may well be too optimistic. I will give two examples. First, until 1992 California planners had assumed that indoor water use averaged about 77 gpcd in a traditional non-conserving single-family home and about 60 gpcd in a conserving home, based on information from a 1984 engineering study of indoor water use. Adjusting for the proportion of houses affected by the 1980 Plumbing Code, the overall estimate of single-family indoor water use in the MWD service area was about 73 gpd. The data were revised in 1993 to the figures shown in Table 9, which now put indoor single-family residential use at 97 gpcd, a substantial increase. Second, if one allows for changes in weather and the drought, the evidence suggests that the *marginal* per capita urban water use in California – i.e., the increment in total urban use divided by the increment in population – significantly exceeds the *average* per capita urban water use by about 10-15%.

Why the increase, when one would have expected reductions in water use due to the 1980 and 1992 Plumbing Codes, as well as other conservation measures introduced during the 1980s? Several factors appear to be involved. Much of the new development is taking place in interior areas that are naturally hotter and thus involve more outdoor use. The new homes may be located on larger lots with a greater need for outdoor watering than the existing residence. The new homes may contain more water-using appliances than the average in existing residences. And, in some cases, their appliances may use more water than existing appliances. For example, whereas the typical capacity of a bath tub in a home used to be 50 gallons, some baths now on sale in California have capacities of 80 - 100 gallons. Thus, while there have been some real gains from existing conservation measures aimed at toilets and showerheads, there may also be some *other* changes in appliance characteristics and in appliance ownership and usage that are *offsetting* these gains.

In summary, when one reviews what is currently known about urban water use in the US, one finds a large variation over both time and space that I believe are not adequately accounted for in the existing literature.

Figure 6 gives examples of the variation over time, showing the historical trend of per capita urban water use in Los Angeles over the period 1940-90, San Francisco 1920-190, and statewide in California 1940-95. All exhibit the effects of the two droughts in 1976-7 and 1987-1992 (the main brunt was not felt until 1989 in San Francisco and 1991 in Los Angeles). After the first drought, it took until about 1984 for per capita urban water use to return to its pre-1976 levels. It is still too soon to say what will be the long-run effects of the more recent drought. Note the secular growth in per capita consumption between 1940 and 1970 – an increase of about

60% in Los Angeles, about 100% in San Francisco, and about 35% statewide. These increases were almost certainly not due to price changes, since prices hardly fell in real terms during this period. They are consistent with income growth, since household income certainly did grow during this period. But, I do not believe that income growth *per se* adequately explains these changes, or the differences in growth rates between Los Angeles, San Francisco and the rest of the state's urban population. I believe that changes in lifestyle, changes in appliance design, changes in appliance ownership, and changes in housing style are also involved – these are not uncorrelated with income growth, but I would regard them as independent forces. Such variables are not factored into the demand functions for urban water that are to be found in the literature.

INSERT FIGURE 6 AROUND HERE

Similarly with comparisons over space, especially those across countries. Table 11 shows per capita urban use in a variety of US cities and in several other countries besides the US. What is striking is the substantial differences in per capita water use across countries. There are certainly differences in income and retail urban water price between the US and these other countries. It is indeed possible that retail water prices are lower in the US than several of these other countries. But, I doubt that income and price alone adequately explain the differences in per capita consumption. Again, I believe that there are other factors involving differences in lifestyle, social custom, and housing style that may also be correlated with price and income but are best considered as independent forces. These remain to be explored and charted in future research.

INSERT TABLE 11 AROUND HERE

In this context, I should mention the existing econometric literature in the US measuring the price and income elasticities of the residential (single-family) demand for urban water. When one examines this, there it turns out to be a substantial difference between studies that use cross-section data and those that use time series data. The majority of the literature uses cross-section data and typically finds elasticities of about -.25 – .35 for overall residential use, and about .7 - 1.0 for outdoor or seasonal water use. The few time series studies have focused on overall residential use and produce very low elasticities – typically under 0.05. My own view is that time-series estimates are in principle more relevant than cross-section estimates for many policy applications. Hence, I tend to believe that, for residential water use in the aggregate, the price elasticity is quite low. However, I also believe that there are significant cases with a higher price elasticity of demand; these include both outdoor/seasonal demand and certain subgroups of residential users who are masked in the aggregate data. Aggregate data have been used in the vast majority of cases; the relative handful of studies in the US that use disaggregated data on individual users have been confined to very small subsamples of 100-200 users. It is not entirely clear whether these samples are large enough or representative enough to provide very precise information on elasticitiesof demand for specific user groups or end uses. The lack of adequate disaggregated data on water use in the US has in my view been a significant barrier to progress in our understanding of urban water use behavior. I am now in the process of analyzing a data set consisting of all the residential accounts served by LADWP, both single family and multi-family, over the period 1986-1998. During this time there were both a drought and several major changes in rate structure, including a switch to an increasing block rate structure to be described below. I have demographic variables by the census block group (about 100 households in each block group) as well as weather information for about 15 different locations within the LADWP service area. Hopefully these data will be able to shed light on both the seasonal price elasticities of demand and the effects of aggregation on the estimation of these elasticities.

4. The Design of a Pricing Strategy

Piped water supply was introduced into most US cities in the second half of the nineteenth century. There was generally no metering, at least for individual residential and commercial users, payment for water service was either through an annual property tax payment or a monthly connection fee common in the US. These pricing structures tended to remain common even after metering was introduced for individual accounts. Pricing based on the volume of water consumed became common for residential and commercial accounts in the 1950s. However, some major cities have remained without metering and quantity charges until recently, including Denver which metered in the 1980s and New York city which is currently in the process of metering. In California, Sacramento and several other cities in agricultural areas do not have metering for residential or commercial accounts.

When consumption-based charges were introduced they commonly involved some sort of quantity discount for large users, in the form a declining block structure. The same was true at the time of charges for electricity service. In the 1970s, electric utilities switched largely to increasing block rate structures. Water utilities changed more slowly. During the 1980s there was a gradual change to constant water rate structures, and during the 1990s a change to increasing block rates is beginning to occur. This is reflected in the data presented in Figures 7 and 8. Figure 7 shows the results of a national survey of 121 water utilities in 1992. Declining block rates are the most structure in the Mid-west and the South; constant rates are the most common structure in the Northeast and the West. Figure 8 shows the results of surveys of California water utilities over the period 1991-95, documenting a switch from constant (uniform) rate structures to increasing block (tiered) rate structures. In April 993, LADWP switched from a constant rate structure to an increasing block rate structure that I designed as an adviser to a Blue Ribbon Citizens Commission appointed by the Mayor. The new rate structure survived a major political challenge with the election of a new mayor from a different political party in July 1993, and was reaffirmed in 1995.

In this section, I want to discuss why and how I designed this structure and my general philosophy towards rate design.

The first point I want to make is that there are multiple possible objectives in designing a rate structure. The major possible objectives include:

(A) Raising revenue – raising a sufficient amount of revenue (financial sustainability), in a stable manner (stability) and without uncertainty (predictability).

(B) Allocating costs among different uses and user groups (social equity, political acceptability).

(C) Changing behavior, by providing effective incentives to users.

(D) Promoting economic efficiency both in the use of water and with respect to investment in new water supply.

In addition, there may be several subsidiary objectives such as

(E) Ease of administration, transparency, simplicity

(F) Avoiding negative environmental externalities and promoting ecological sustainability.

These objectives tend to have conflicting implications for rate design. For example, if the objective is to raise the welfare of some particular user group, this can be achieved by reducing what they pay, but that might in turn diminish their incentive to use water sparingly or efficiently, as well as conflicting with the goal of raising revenue. If the objective is revenue stability or predictability, this can best be attained through fixed charges that are not affected by variation in consumption; but that, too, diminishes incentives to use water sparingly or efficiently. Conversely, consumption-based charges can promote conservation and efficiency in water use, but can lead to varying and uncertain revenue streams because of changes in water use behavior.

Thus, optimal rate design depends crucially on the objectives. These are likely to vary with circumstances, which means that no single approach to rate design can be globally optimal.

Whether for urban or agricultural uses, most rates that I have observed have been designed with the chief emphasis on raising revenue. The focus is *backward looking* – raising revenue to recover costs incurred in the past, whether to pay off revenue bonds or otherwise. This can be viewed as prudent – or risk averse – behavior on the part of engineers and bureaucrats. They want to provide water for their customers as inexpensively as possible. Their overriding concern is to cover existing financial obligations; future financial obligations can be dealt with later. In my view, this is *not* an unreasonable approach so long as (i) there is an adequate supply of water and (ii) there is no foreseeable need for future investment in the water supply system. In those circumstance, an emphasis on raising revenue (A) is understandable, at least as long as (1) this does not conflict excessively with social goals (B), and (2) the same objective cannot also be attained through marginal cost pricing, which would provide for efficiency (D).

The situation is different, in my view, when either (i) or (ii) fails to hold. In that case a *forward-looking* perspective needs to be applied to rate design, emphasizing the goals of changing water use behavior (C) or promoting efficiency (D).

I make a distinction between these two goals for a purpose. Economic efficiency means essentially setting price at the margin equal to marginal cost, appropriately measured. Conversely, changing behavior requires creating incentives that (a) people will notice, and (b) they feel they can respond to. Depending upon the nature of consumer demand, and also depending on the nature of marginal costs, the two objectives may or may not coincide. In any event, there is certainly a difference in how they are implemented. The emphasis in marginal cost pricing is on identifying and measuring marginal cost. In my experience, this is typically a mixture of engineering and economics. What is usually left out is any detailed analysis of the water users' behavior. This is technically unnecessary – as long as price is set equal to marginal cost, theory tells us, the outcome will be an economic optimum regardless of what the demand function looks like. Therefore, why bother to study the demand function? By contrast, understanding how water is used and what underlies consumer's behavior is central to implementing a pricing approach aimed explicitly at changing water consumption behavior.

It is the nature of the cost function for water supply that makes pricing water difficult. To illustrate this, imagine a fairy tale water utility that obtains its water supply from a spring deep in a forest. The spring is guarded by elves who also are responsible for installing and maintaining the distribution network that serves the utility's customers. For all these services the elves charge the water company $0.05 per hundred cubic foot (ccf) of water delivered to the utility's customers. The staff of the utility consists of one retired elf who handles all the billings and management; being an elf, he works for free. In these circumstances, ratemaking is simple: everybody would surely agree on $0.05/ccf as the appropriate retail price for water. What makes this a fairy story is not the amazingly cheap price for water but rather the amazingly simple cost structure. The water utility only incurs costs as and when water is delivered. The costs vary directly with the volume of water delivered. All units of water delivered cost the agency exactly the same amount of money. The real world is different in every respect. As noted earlier, the water industry is highly capital intensive; most of its costs are capital costs incurred when capital assets are installed, rather than operating costs incurred as water is delivered. Once installed, the capital is not very malleable. The capacity of the system cannot be quickly expanded if more water is suddenly needed, not can it be dismantled and disposed of profitably if less water is needed. Hence the obsession with recovering historical cost. Hence, also, there tends to be wide difference between average and marginal cost. In these circumstances, deciding on a price is complicated.

This is exacerbated when the utility faces different supply costs for different elements of its supply. LADWP, for example, has five main existing sources of supply, and one potential future source of supply, with sharply differing costs. Local surface and groundwater cost well under $100/AF. Water imported from Owens Valley and Mono Lake costs around $100/AF. Water from MWD costs around $250/AF. Water saved through conservation programs, such as subsidizing toilet retrofits, costs around $300-400/AF. Reclaimed sewage treatment plant effluent, used for outdoor irrigation, costs around $600-800/AF. And desalination, which is an option for the future, is estimated to cost about $1500/AF. With costs varying like this, marginal cost pricing becomes problematic. There are essentially two difficult questions: (1) Which is the marginal source, whose cost is to serve as the benchmark for pricing? (2) Which uses or users of water should be charged this marginal cost?

The first question is more than just an engineering question; it touches on important issues of utility management and decision making. Setting that aside, the second question is even more problematical because, whatever is identified as the marginal cost, if this were applied to every unit of water supplied by LADWP this would raise a considerable excess revenue. In my experience, this was simply not feasible for LADWP. Earning a surplus, even if it was rebated to customers in a lump sum manner, was administratively unacceptable. Politically, the various user groups fought strenuously to be allocated the cheaper water, and allocating this to no one (i.e. charging everybody the marginal cost) was infeasible. Thus the challenge was to find a way whereby *some* uses or users of water faced prices based on marginal cost, without raising revenues grossly disproportionate to costs. Moreover, the rate revision in Los Angeles was being undertaken in the midst of a major drought in 1991-92, when there was great concern that existing water supplies would be inadequate to meet the future growth in water demand.

It seemed to me that an appropriately designed increasing block rate structure could meet the city's needs. However, rather than using a rate structure with many separate rate tiers, I wanted to provide a simple and clearly visible signal to water users to encourage water conservation; for that reason, I recommended a structure with just two main blocks, plus a separate lifeline component. I felt that to have substantially more blocks would produce small differentials between the rate blocks that be less likely to be noticed, thus diluting the signal to water users. The upper of the two blocks was set equal to an estimate of long run marginal cost. This varied seasonally, with system capacity costs folded into the summer long run marginal cost reflecting the fact that this is the period of peak demand. The lower block was designed primarily to raise revenue to cover water system costs, as was set approximately equal to average cost (this did not vary seasonally). The rates at the time were $1.71/ccf for the lower block; $2.27/ccf for the upper block in winter, and $2.92/ccf in summer. We felt that the differential between the lower and upper blocks, while based on the difference between average and marginal cost, was sufficiently pronounced that it would be salient to water users and motivate them to consider conservation in order to minimize the amount of their use that was priced at the upper block rate.

For this to be effective, it was necessary to pay careful attention to the location of the switching point between the two blocks. My notion is that it was not necessary for users to actually be in the upper block for the incentive to work – they just needed to be sufficiently close to it that it would impinge on their attention. To allow for the differences among different types of residential water user, which greatly affect both the equity of water conservation (equal treatment of equals) and the effectiveness at inducing behavioral change, the Blue Ribbon Committee and I recommended *different* switching points for different groups of customers. The goal in the two-block rate structure was to use the upper block to target water use consumption that was less reasonable socially and also more likely to be price elastic (responsive to price incentives). To this end, LADWP's single-family residential customers were divided up into separate groups based on lot-size and climate zone. There were three separate climate zones, and 5 lot-size groups (lots up to 7,500 sq ft, 7,500-11,000 sq ft, 11,000-17,500 sq ft, 17,500 sq ft - 1 acre, and lots larger than one acre). This classification of climate zone location and lot size produced 15 different categories for single-family residential users in LADWP's service area. While the lower and upper rate blocks were the same for all users, there was a separate switching point from lower to upper block for each category; the switching point was lower for the smaller lot sizes and cooler temperature zone, and highest for the largest lot size and warmest climate zone (see Table 13).

Two criteria were employed for specifying the location of the switching points. One criterion was to place the switching point at around 125% of the median water use within that category, the notion being that use beyond this was likely to be accepted as excessive relative to the practices of other households in similar circumstances. The other criterion was to locate the switching point for each residential group at a level that placed reasonable and efficient indoor and outdoor use within the lower block while targeting usage beyond this level for the upper block, based on an analysis of indoor use, lot size, and efficient ET corresponding to the climate zone and lot size associated with the category. The rationale for this criterion is that, as noted above, the existing econometric literature on determinants of urban water use suggests that outdoor water use is quite highly price-elastic. The two criteria generally produced consistent results, with the ultimate determination of the switching point being based on a case-by-case assessment. Thus, the goal was to tailor the price incentives created by an increasing block rate structure to the specific circumstances of each residential user category in a manner that was seen as fair and that would focus specifically on the water use behavior generally identified as most likely to be price-responsive.

The rate structure proposed by the Committee was adopted by the city council with some modifications, primarily breaking the highest lot size category into two subcategories and rasing the switching point for some categories. These changes were not entirely unconnected with the fact that some influential individuals owned among the largest residential lots in the Los Angeles. There has been general satisfaction with these rates, and water usage in LADWP has stayed down since 1995, but it is still too soon to say how much of this is due to the new rates and how much to the lingering effects of the drought – this is the focus on my ongoing research.

I can report, however, that a rate structure like this has worked successfully in an agricultural setting. In 1990, Broadview irrigation district adopted a two block rate structure. The lower block was set at $16/AF, essentially the district's average cost. The upper block was set at $40/AF, intended as a somewhat punitive level. The notion was that farmers would still be free to use high levels of irrigation if they wished – they would just have to pay a heftily for this privilege. The switching point was set equal to 90% of the current average irrigation application, 2.9 AF/A. The impact of the new rate structure was immediate – compare Figure 9 with Figure 4. Within one year, much of the right tail of the distribution of water use melted away. In the second year, *no* farmer in Broadview used more than 2.9 AF/A, and the entire right tail had vanished.

The logic of this approach is that it focuses on changing the mean amount of water used by *changing the shape of the distribution* rather than by shifting the distribution bodily to the left. In my view, this is a more practical strategy for two reasons. First, the low-end users may already be relatively efficient, so that it is both expensive and a hardship for them to reduce their use further. Second, the high-end users are likely to have more unexploited opportunities for reducing their use, and socially there may be a stronger case for targeting them since they are deviating so far from the group norm with their high levels of use

In closing, I am inclined to recommend against a mechanical application of marginal cost pricing conducted through a formal and arms-length relationship between a regulatory agency and the water supply agency. I would emphasize process over pricing per se. In my view, the larger goal of any regulatory agency may not be so much to set prices as to influence and change behavior – both the behavior of the water supply agencies that it oversees and the behavior of their customers who are the end-users of water. I am not dogmatic about right and wrong approaches to pricing water in California, or anywhere else. My approach is pragmatic. The underlying goal is to influence water managers' and water users' behavior. In what direction one wants to influence these behaviors, and how this can best be accomplished, requires judgment and will vary with circumstances.

FIGURE 1A: CENTRAL VALLEY OF CALIFORNIA

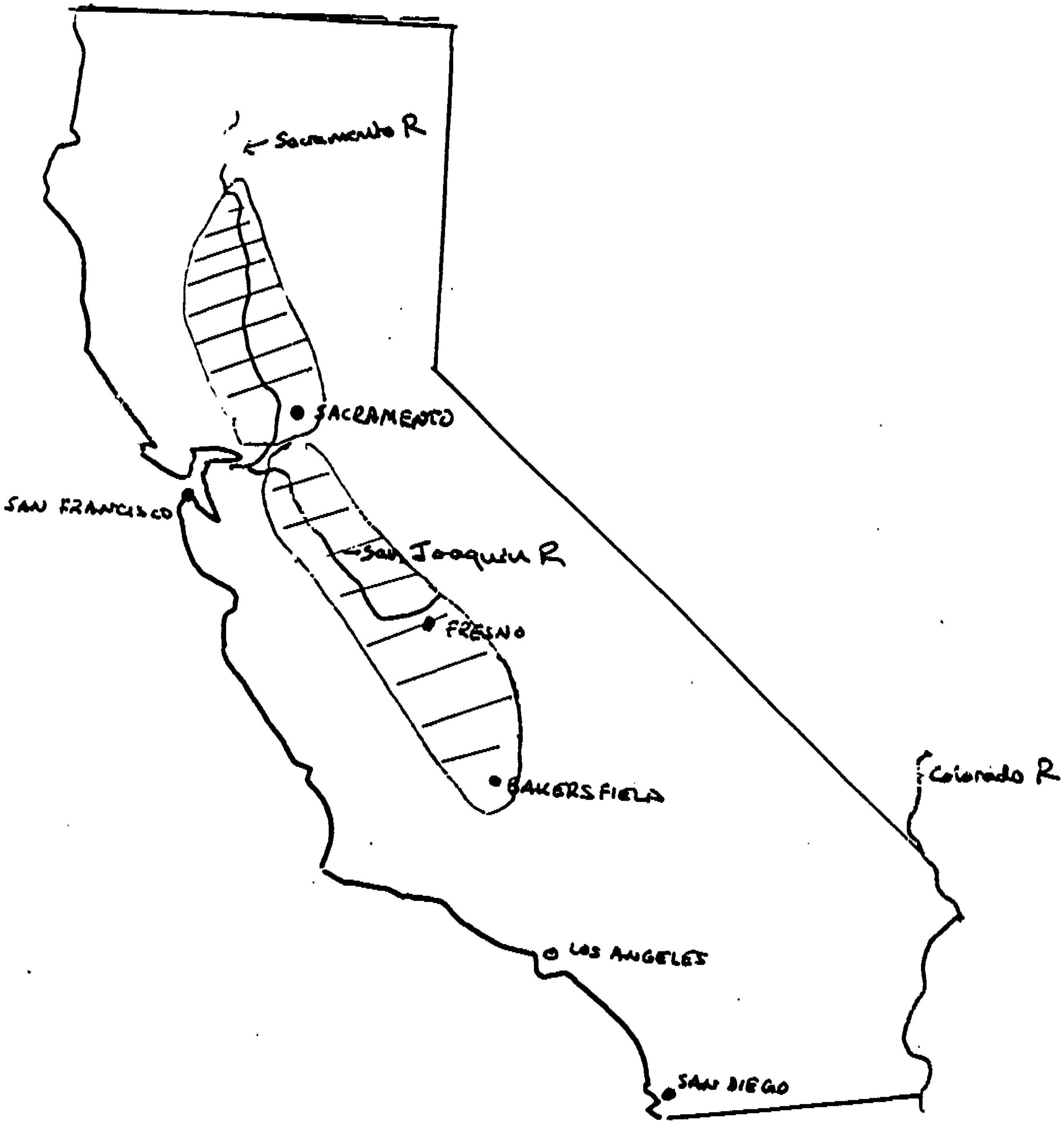


FIGURE 1B: MAJOR WATER PROJECTS IN CALIFORNIA

FIGURE 2 : PLANNING REGIONS OF CALIFORNIA:

FIGURE 3:

95% Confidence Intervals of Water Application Rates
For Various Crop-Irrigation Technology Combinations

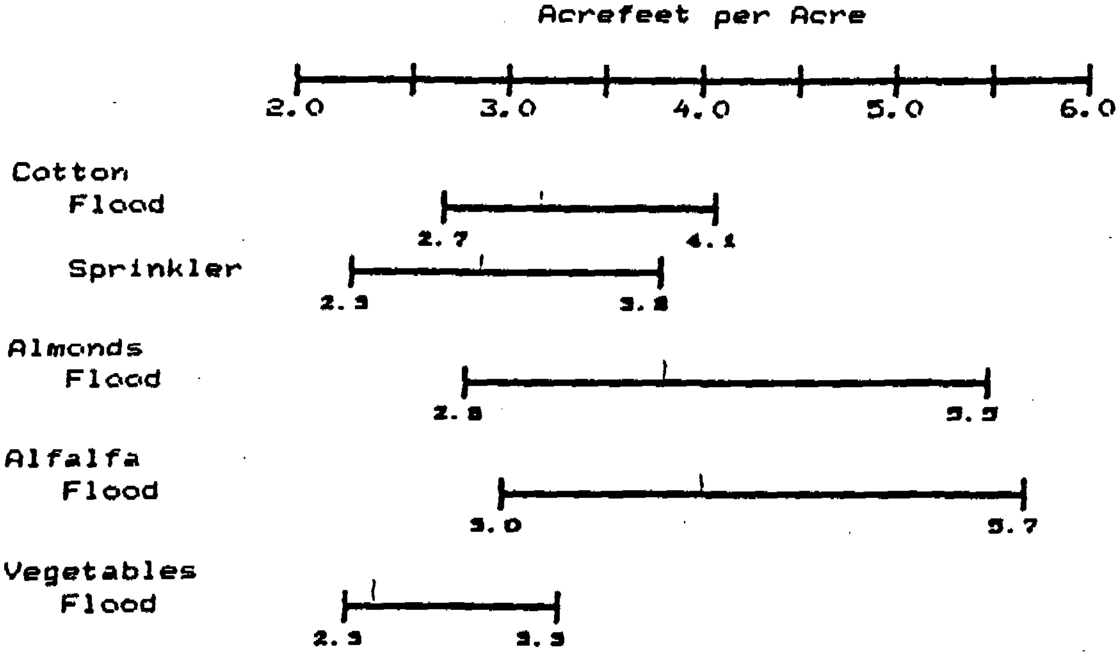


Figure 4

APPLIED WATER USE (AF/ACRE) FOR COTTON

Broadview Water District 1989

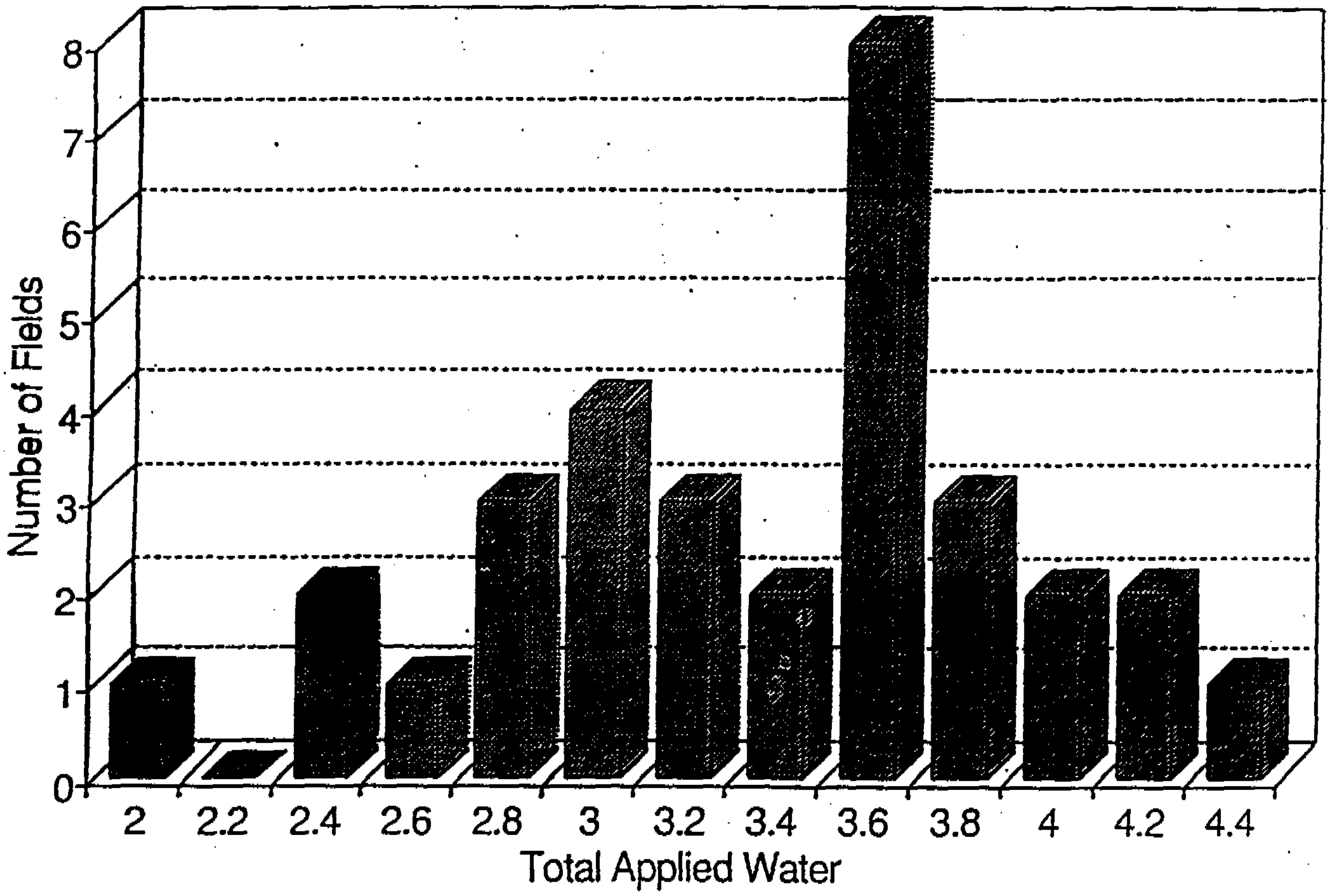
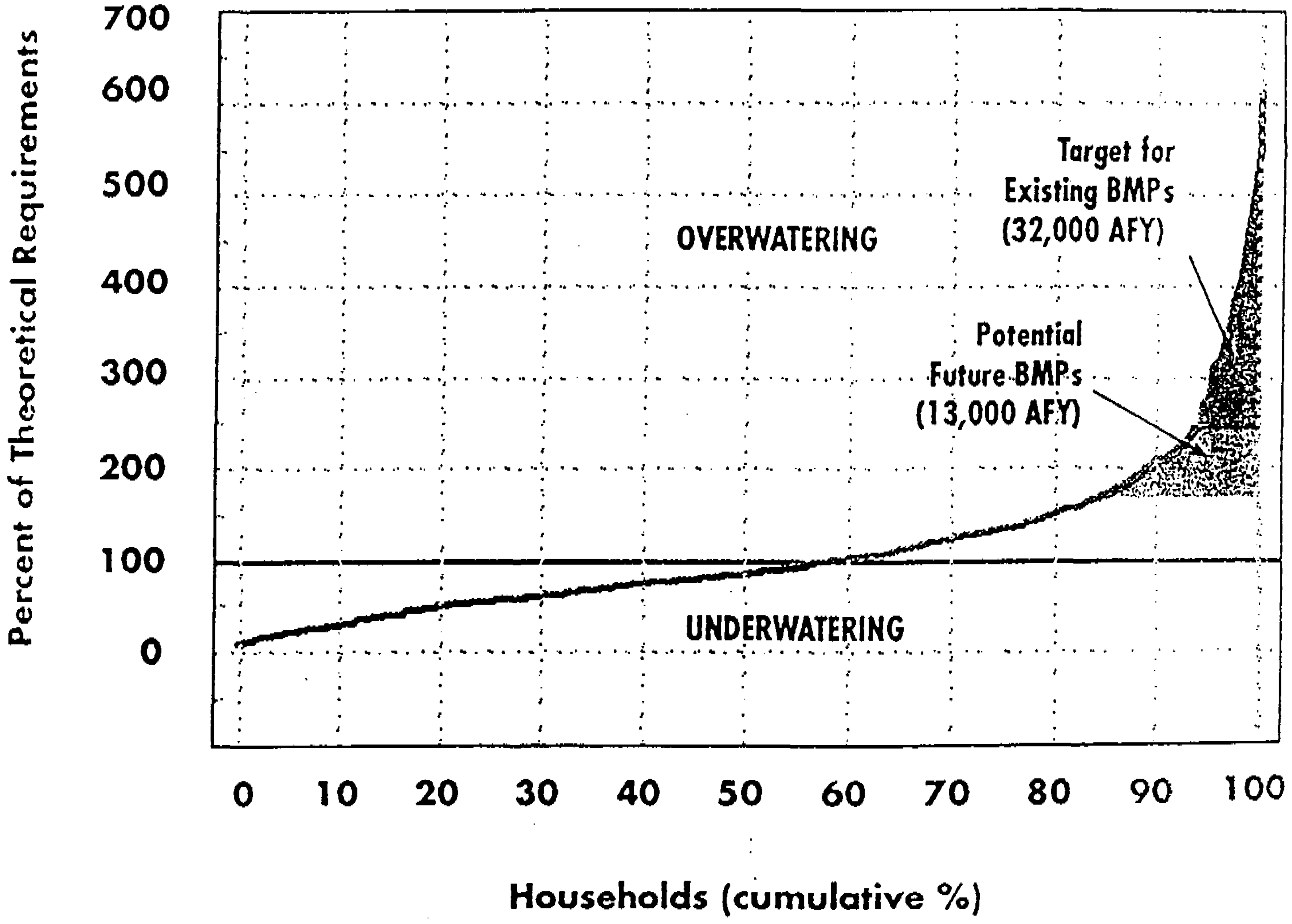


FIGURE 5:

SINGLE FAMILY RESIDENTIAL IRRIGATION
SUMMER (MAY - OCTOBER 1990)

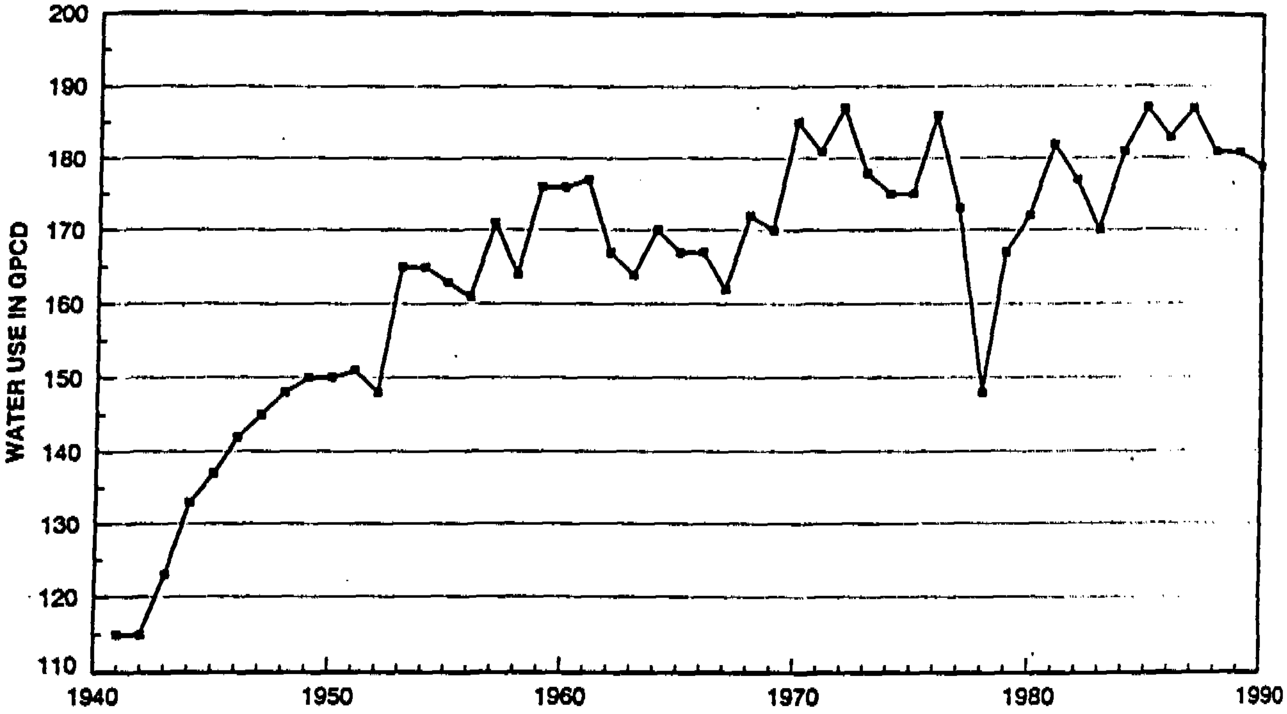


From: SWC Exhibit 3b, Figure 8

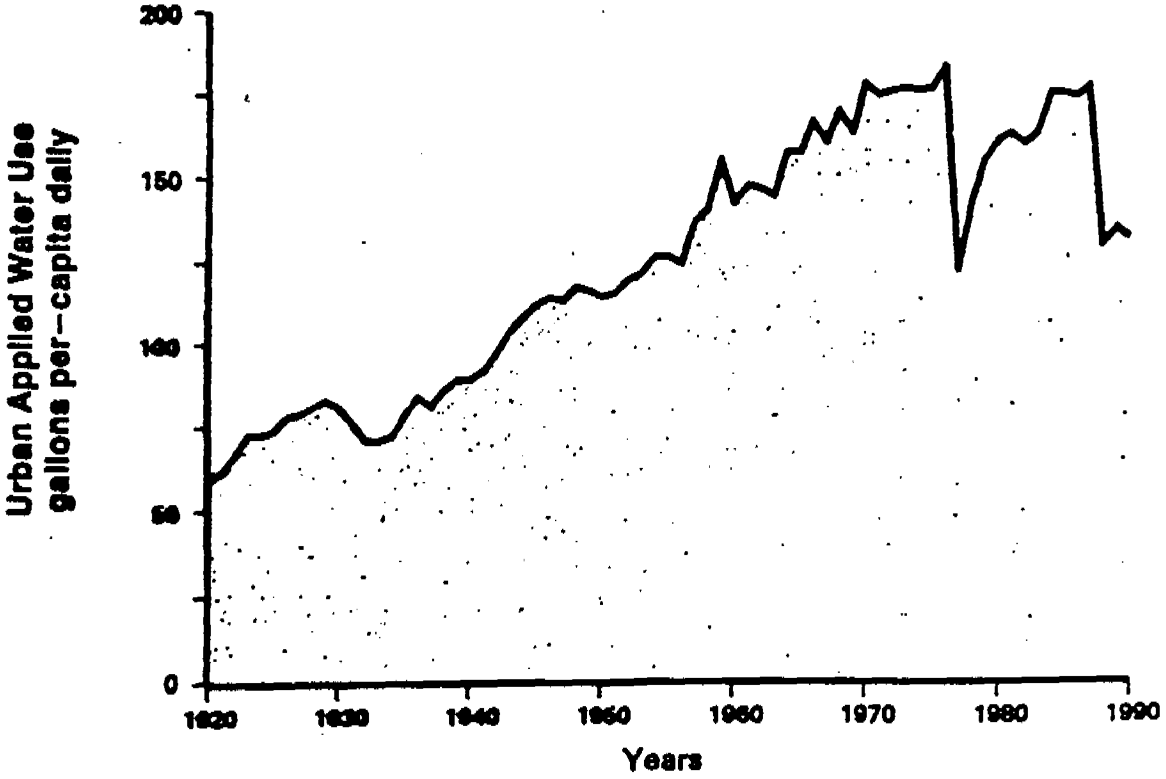
FIGURE 6:

~~PROBLEM~~: URBAN PER CAPITA WATER USE OVER TIME

(A) LOS ANGELES



(B) SAN FRANCISCO



(c) STATEWIDE IN CALIFORNIA

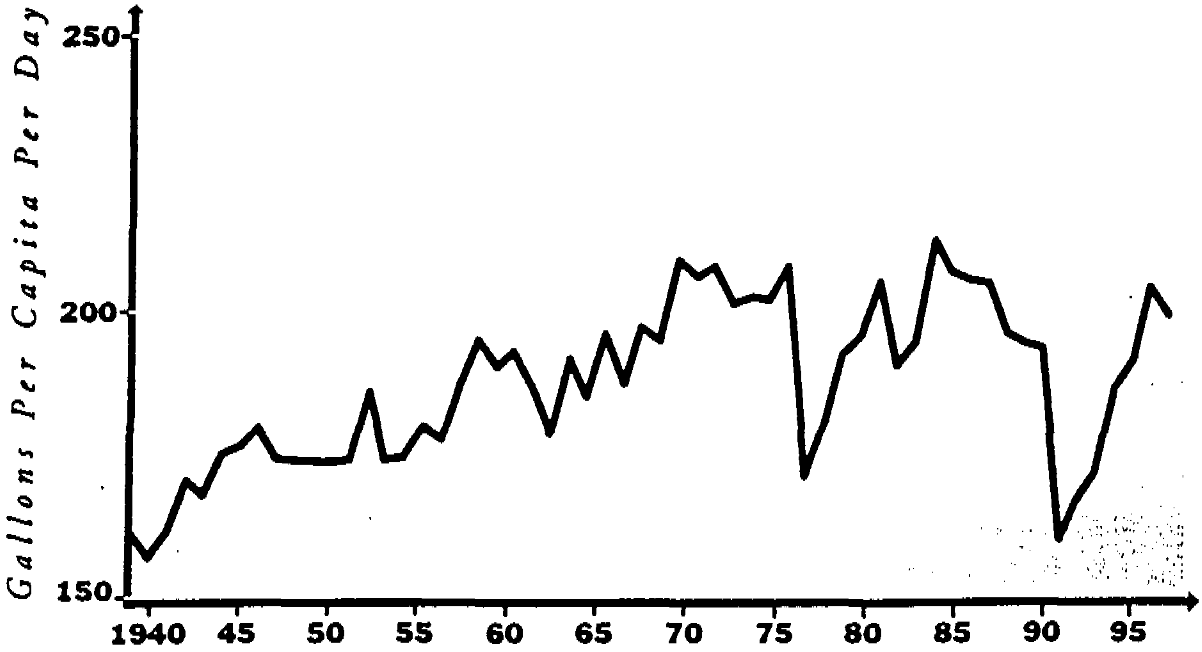


FIGURE 7: WATER RATE STRUCTURES USED BY RATE SURVEY RESPONDENTS—1992

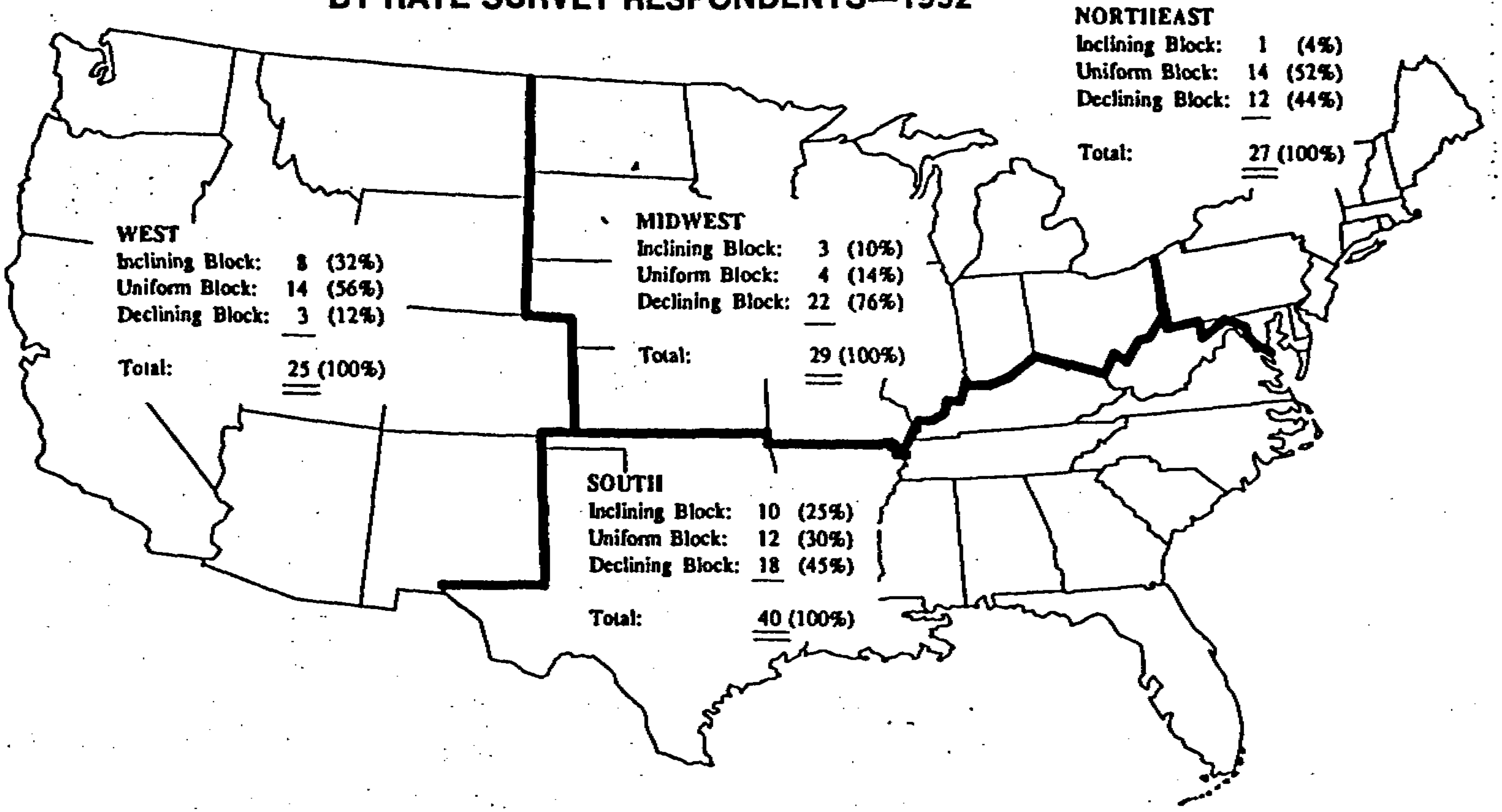


FIGURE 8:

CALIFORNIA WATER RATE STRUCTURE TRENDS
BLACK & VEATCH RATE SURVEY

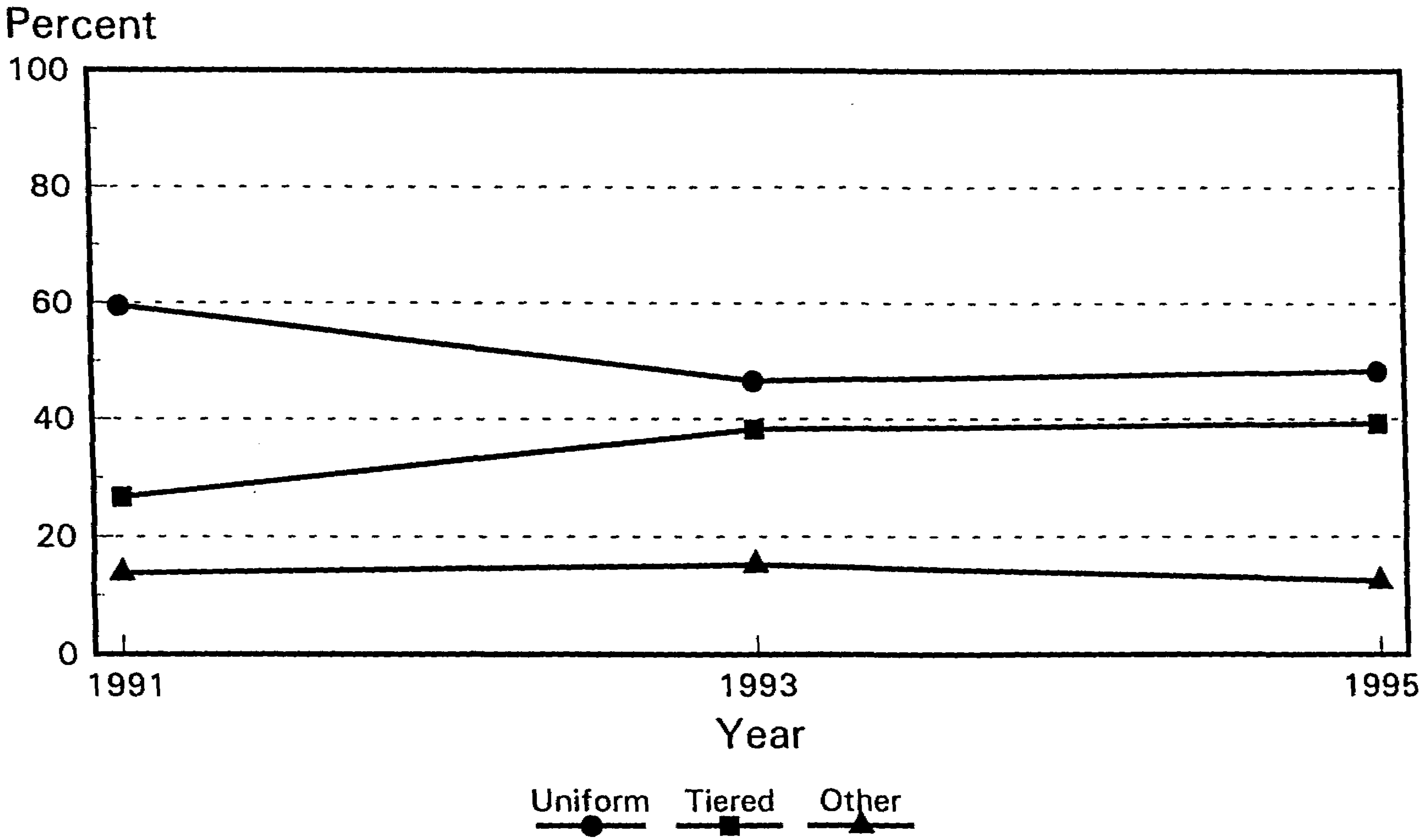


Figure 9

APPLIED WATER USE (AF/ACRE) FOR COTTON

Broadview Water District 1990

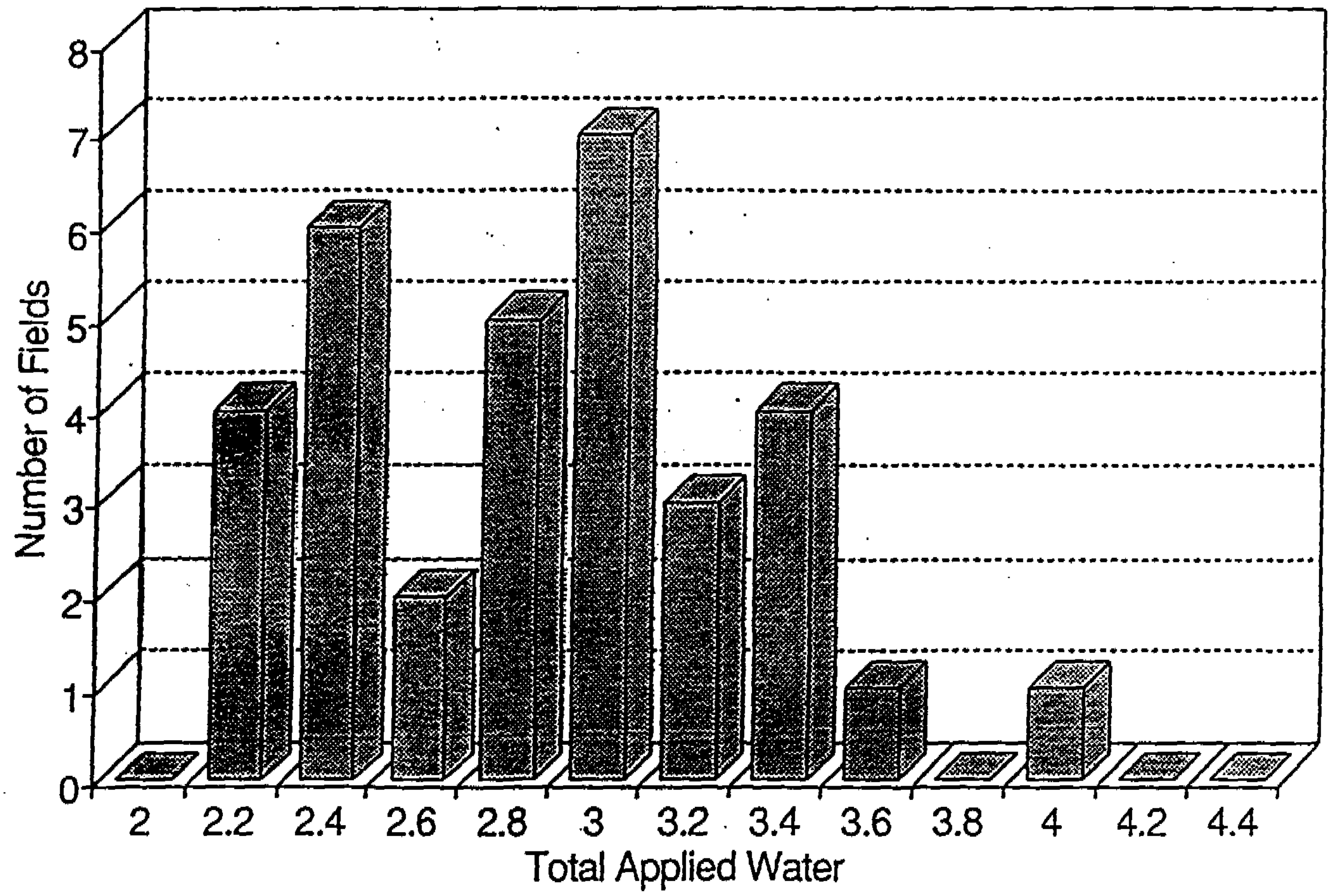


TABLE 1:

Urban Best Management Practices (1997 Revision)

BMP 1	Water Audit Programs for Single-Family Residential and Multifamily Residential Customers
BMP 2	Residential Plumbing Retrofit
BMP 3	System Water Audits, Leak Detection and Repair
BMP 4	Metering With Commodity Rates for All New Connections and Retrofit of Existing Connections
BMP 5	Large Landscape Conservation Programs and Incentives
BMP 6	High-Efficiency Washing Machine Rebate Programs (New)
BMP 7	Public Information Programs
BMP 8	School Education Programs
BMP 9	Conservation Programs for Commercial, Industrial, and Institutional Accounts
BMP 10	Wholesale Agency Assistance Programs (New)
BMP 11	Conservation Pricing
BMP 12	Conservation Coordinator
BMP 13	Water Waste Prohibition
BMP 14	Residential ULFT Replacement Programs

TABLE 2: POTENTIAL BEST MANAGEMENT PRACTICES

1. RATE STRUCTURES AND OTHER ECONOMIC INCENTIVES AND DISINCENTIVES TO ENCOURAGE WATER CONSERVATION.
2. EFFICIENCY STANDARDS FOR WATER USING APPLIANCES AND IRRIGATION DEVICES.
3. REPLACEMENT OF EXISTING WATER USING APPLIANCES (EXCEPT TOILETS AND SHOWERHEADS WHOSE REPLACEMENTS ARE INCORPORATED AS BEST MANAGEMENT PRACTICES) AND IRRIGATION DEVICES.
4. RETROFIT OF EXISTING CAR WASHES.
5. GRAYWATER USE.
6. DISTRIBUTION SYSTEM PRESSURE REGULATION.
7. WATER SUPPLIER BILLING RECORDS BROKEN DOWN BY CUSTOMER CLASS (E.G., RESIDENTIAL, COMMERCIAL, INDUSTRIAL).
8. SWIMMING POOL AND SPA CONSERVATION INCLUDING COVERS TO REDUCE EVAPORATION.
9. RESTRICTIONS OR PROHIBITIONS ON DEVICES THAT USE EVAPORATION TO COOL EXTERIOR SPACES.
10. POINT-OF-USE WATER HEATERS, RECIRCULATING HOT WATER SYSTEMS AND HOT WATER PIPE INSULATION.
11. EFFICIENCY STANDARDS FOR NEW INDUSTRIAL AND COMMERCIAL PROCESSES.

TABLE 3:

Efficient Water Management Practices for Agricultural Water Suppliers in California

List A—Generally Applicable EWMPs

- Prepare and adopt a water management plan
- Designate a water conservation coordinator
- Support the availability of water management services to water users
- Improve communication and cooperation among water suppliers, water users, and other agencies
- Evaluate the need, if any, for changes in institutional policies to which the water supplier is subject
- Evaluate and improve efficiencies of the water supplier's pumps

List B—Conditionally Applicable EWMPs

- Facilitate alternative land use
- Facilitate using available recycled water that otherwise would not be used beneficially, meets all health and safety criteria, and does not cause harm to crops or soil
- Facilitate financing capital improvements for on-farm irrigation systems
- Facilitate voluntary water transfers that do not unreasonably affect the water user, water supplier, the environment, or third parties
- Line or pipe ditches and canals
- Increase flexibility in water ordering by, and delivery to, water users within operational limits
- Construct and operate water supplier spill and tailwater recovery systems
- Optimize conjunctive use of surface and groundwater
- Automate canal structures

List C—Other EWMPs

- Water measurement and water use reporting
- Pricing or other incentives

TABLE 4

Ranges of Unit Evapotranspiration of Applied Water

(acre-feet/acre per year)

Crop	NC	SF	CC	SC	SR	SJ	TL	NL	SL	CR
Grain	0.3–1.5	0.2–0.4	0.2–0.4	0.2–0.2	0.2–1.6	0.3–0.9	0.6–1.2	1.6–1.6	0.2–0.2	2.0–2.0
Rice	–	–	–	–	3.0–3.4	3.3–3.6	3.6–3.7	3.5–3.5	–	–
Cotton	–	–	–	–	–	2.3–2.5	2.5–2.5	–	–	–
Sugar Beets	2.4–2.4	1.5–2.3	1.4–2.5	2.2–2.2	1.7–2.7	2.1–2.7	2.4–3.3	2.8–2.8	–	3.8–3.8
Corn	1.0–1.8	1.8–1.8	0.6–1.8	1.4–1.6	1.4–2.3	1.8–2.0	1.9–2.0	1.9–1.9	2.4–2.4	1.7–2.6
Safflower	0.6–0.6	0.5–0.8	–	–	0.4–0.6	–	–	0.6–0.6	–	–
Other Field	0.9–1.8	1.0–2.0	0.6–1.3	0.6–2.2	1.2–2.0	0.6–1.6	1.2–2.1	–	2.2–2.2	2.0–3.5
Alfalfa	1.5–2.8	1.5–2.7	1.9–3.0	2.7–2.7	1.8–3.2	2.4–3.3	2.9–3.3	2.3–2.5	4.3–4.3	4.3–6.6
Pasture	1.4–2.6	2.1–3.0	2.0–3.0	2.7–2.8	2.1–3.3	3.0–3.3	3.0–3.5	2.4–2.6	4.3–4.3	4.3–6.6
Tomatoes	–	1.9–2.1	1.0–2.0	1.8–2.3	1.6–2.1	1.6–2.2	2.0–2.3	–	–	2.9–2.9
Other Truck	1.0–1.7	0.9–2.0	0.8–2.1	1.4–1.5	0.6–1.8	0.6–1.7	1.0–1.4	1.7–1.7	1.5–1.5	1.3–5.4
Almond/Pistachio	–	–	–	–	1.6–2.7	1.7–2.3	2.0–2.5	–	–	–
Other Deciduous	1.4–2.1	1.4–2.2	1.0–2.3	2.3–2.3	1.3–2.7	1.3–2.8	1.8–3.0	–	2.3–2.3	2.3–4.4
Subtropical	–	–	1.0–2.0	1.7–1.8	1.3–2.0	1.0–2.1	1.7–2.2	–	2.6–2.6	3.8–4.4
Grapes	0.5–0.8	0.5–0.9	0.8–1.3	1.2–1.5	0.9–2.0	1.0–2.1	1.9–2.2	–	2.4–2.4	2.4–3.3

NOTE:
1. The North Coast Region encompasses numerous climate zones, reflected by a large range of ETAW values for certain crops.
2. The Subtropical category includes olives, citrus, avocadoes, and dates, which have varying water requirements. Ranges of ETAW for this category reflect the relative acreages of each crop within a region.
3. The cooler Delta climate reduces ETAW in some San Joaquin Region units for certain crops.
4. Some variation in values is caused by similar crops (or the same crop) grown at different times of the year.

Note: For definition of regions, see [redacted] FIGURE 2.

TABLE 5:

DWR Survey of 1996 Agricultural Surface Water Costs[a]

Region	*1996 Total Deliveries (taf)*	*1996 Costs ($/af)*			*Water Rates Basis (number of agencies)*				
		Weighted Average	*Max.*	*Min.*	*By Acre*	*By Crop & Acre*	*By af Used*	*By Acre & af Used*	*Total*
North Coast	80	10	12	2	2	0	1	0	3
San Francisco Bay[b]	—	—	—	—	—	—	—	—	—
Central Coast	37	128	533	87	0	0	2	2	4
South Coast	92	373	604	131	0	0	1	7	8
Sacramento River	1,275	12	32	2	1	4	1	2	8
San Joaquin River	1,339	22	238	6	2	0	1	4	7
Tulare Lake	2,672	42	161	9	1	0	4	6	11
North Lahontan[b]	—	—	—	—	—	—	—	—	—
South Lahontan	18	61	61	61	0	0	1	0	1
Colorado River	3,403	13	14	8	2	0	0	2	4
Statewide	**8,916**	—	—	—	**8**	**4**	**11**	**23**	**46**

[a] Average retail costs to the farmer

[b] No responses

TABLE 6:

1992 Agricultural Ground Water Production Costs by Hydrologic Region

Region	**Ground Water Costs ($/acre-foot)**[†]
North Coast	10–70
San Francisco Bay	60–130
Central Coast	80
South Coast	80–120
Sacramento River	30–60
San Joaquin	30 - 40
Tulare Lake	40–80
North Lahontan	60
South Lahontan	20
Colorado River	90

[†] The range represents the average cost of specific locations within a region, and includes capital, operation, maintenance, and replacement costs.

TABLE 7:

1991 Commercial and Industrial Monthly Water Uses and Costs for Selected Cities

Region/City	Commercial				Industrial			
	Average Monthly Use (ccf)[1]	Number of Accounts	Typical Monthly Bill ($)[4]	$ per Acre–foot Cost	Average Monthly Use (ccf)[1]	Number of Ac-counts	Typical Monthly Bill ($)[4]	$ per Acre–foot Cost
North Coast								
Crescent City	73	441	64	379	1,079	8	697	282
San Francisco Bay								
San Francisco	49	22,133	53	471	253	144	208	358
Central Coast								
Santa Barbara	28	2,300	138	2,317	272	65	1,737	2,782
South Coast								
Los Angeles	81	50,449	85	457	120	6,318	119	433
Hemet	22	1,794	38	758	23	359	39	742
Sacramento River								
Chico	62	2.684	46	324	122	41	68	244
San Joaquin River								
Stockton	48	4.000	35	316	1.479	104	673	198
Tulare Lake								
Fresno	70	75	29	183	251	7	78	136
North Lahontan								
Susanville	49	503	65	576	100	12	103	447
South Lahontan								
Barstow	27	8.273	42	672	2.017	6	1.196	258

[1] *Hundred cubic feet (750 gallons)*

TABLE 8: COSTS OF WATER IN CALIFORNIA ($/AF)

	Agricultural Users	Urban Users
Price at point of abstraction	0	0
Wholesale price	5 - 15	75 - 250
Retail price	15 - 80	500 - 650

TABLE 9: . PER CAPITA WATER USE IN MWD SERVICE AREA (Under Normal Weather*)

SECTOR	WATER USE (gallons per capita per day)	PERCENTAGE BREAKDOWN
RESIDENTIAL	130	66.7%
COMMERCIAL & INSTITUTIONAL	33	16.9%
INDUSTRIAL	11	5.6%
PUBLIC USES	7	3.6%
FIRE-FIGHTING, LINE CLEANING, OTHER	5	2.6%
METER ERROR & SYSTEM LOSSES	9	4.6%
TOTAL	195	100.0%

*Annual rainfall of 13 inches and mean annual temperature of 65F.

TABLE 10: BREAKDOWN OF WATER USE IN SINGLE- AND MULTI-FAMILY RESIDENCES IN MWD SERVICE AREA

	WATER USE (gallons per capita per day)	
WATER USE CATEGORY	SINGLE-FAMILY	MULTI-FAMILY
INDOOR:		
Toilets	30	30
Showers/bath	27	25
Washing clothes	21	17
Cooking/cleaning	13	13
Dishwashing	6	4
Subtotal	97	89
OUTDOOR:		
Landscape irrigation, gardening	46	18
Cooling		1
Swimming pool, car washing, and other outdoor uses	7	2
Subtotal	53	21
TOTAL	150	110

TABLE 1: AVERAGE WATER USE IN 1988 BY LADWP RESIDENTIAL CUSTOMERS

ACCOUNT USAGE (gal/day)	# OF CUSTOMERS	CUMULATIVE PERCENT OF CUSTOMERS	CUMULATIVE PERCENT OF CONSUMPTION
0 - 75	13,381	3.3	0.4
75 - 150	31,041	11.0	2.6
150 - 200	32,740	19.1	6.0
200 - 250	39,100	28.8	11.1
250 - 300	41,172	39.0	17.7
300 - 350	39,832	48.9	25.1
350 - 400	35,474	57.7	32.7
400 - 450	30,251	65.2	40.0
450 - 500	25,102	71.4	46.8
500 - 550	20,422	76.5	52.9
550 - 600	16,406	80.5	58.2
600 - 650	13,239	83.8	62.8
650 - 700	10,803	86.5	66.9
700 - 800	15,475	90.3	73.4
800 - 900	10,308	92.9	78.3
900 - 1000	7,341	94.7	82.2
1000 - 1100	5,178	96.0	85.3
1100 - 1200	3,661	96.9	87.6
1200 - 1300	2,708	97.5	89.5
1300 - 1400	2,098	98.1	91.1
1400 - 1500	1,614	98.5	92.4
1500 - 1750	2,477	99.1	94.6
1750 - 2000	1,319	99.4	96.0
2000 - 2500	1,296	99.7	97.6
> 2500	1,086	100.0	100.0
TOTAL	403,524		

TABLE 12: PER CAPITA URBAN WATER USE (GPCD)

UNITED STATES	188
DENVER	228
PHOENIX	244
SALT LAKE CITY	240
TUCSON	168
CALIFORNIA	210
MWD SERVICE AREA	195
SAN FRANCISCO BAY AREA	190
SACRAMENTO VALLEY	298
PALM SPRING AREA	596
JAPAN	114
SPAIN	102
ITALY	100
FRANCE	84
UK	73
NORWAY	71
ISRAEL	52
GERMANY	50

Table 13 1994 BRC Recommended Temperature and Lot Size Breakpoints

Lot Size (sq. ft.)	*Summer Average Daily High*	*Number of Billing Units Charged at Low Initial Block Rate*	
		Winter	*Summer*
<7,500	<75°	13	16
	75–85°	13	17
	>85°	13	17
7,500–10,999	<75°	16	23
	75–85°	16	25
	>85°	16	26
11,000–17,499	<75°	23	36
	75–85°	24	39
	>85°	24	40
>17,499	<75°	29	45
	75–85°	30	48
	>85°	30	49
	1993 Rate Design Breakpoint		
all lots	all temperatures	22	28