RAND

Drought Management Policies and Consumer Surplus Losses: A Case Study of Alameda County Water District

Lloyd S. Dixon, Nancy Y. Moore, Ellen M. Pint

September 1993

Prepared for California Urban Water Agencies, California Department of Water Resources

ABSTRACT

This paper uses billing data from a sample of 599 single-family households in Alameda County Water District over the period 1982-92, local monthly weather data, tax assessor records and census data to estimate household water demand functions and to derive consumer surplus losses due to the California drought. Preliminary OLS demand curve estimates are upward-sloping at high prices because a steeply increasing block rate structure creates a correlation between high prices and high household water use. This suggests that more sophisticated econometric techniques are needed to model household behavior.

1. INTRODUCTION

In 1991, five years of drought in California culminated in severe water supply cutbacks in both agricultural and urban areas, and the establishment of a Drought Water Bank to transfer scarce water supplies to areas of critical need, including urban areas. Urban water users were required to make cutbacks of 15-30%. Although less severe, the drought continued into 1992, but appears to have been relieved by heavier precipitation in the winter of 1992-93.[1]

In assessing the economic impacts of the California drought, much of the attention has focused on losses suffered by agriculture and other water-dependent businesses, such as nurseries, landscape maintenance, construction, and hotels and motels. However, urban residential water users also suffered from losses in lifestyle, such as taking shorter showers, lost or degraded lawns and landscaping, and dirtier cars. The purpose of this paper is to quantify the consumer surplus losses incurred by single-family residential households in the Alameda County Water District service area.

Water utility operators responded to water supply shortages with various drought management policies intended to reduce water consumption. These included public education campaigns to provide information on the severity of the drought and methods of saving water; water audits of large users (particularly those with large turf areas) to find improvements that could be made in water use efficiency; distribution of conservation kits with items such as low-flow shower heads, toilet dams or displacement bags, leak detection dyes and tablets, and flow restrictors for kitchen and bathroom faucets; rebates for investments in ultra-low-flush toilets; voluntary and mandatory restrictions on types of water use, such as using water to clean hard

[1]This work has been funded by the California Department of Water Resources and California Urban Water Agencies. The authors thank Paul Piraino and Leasa Cleland at Alameda County Water District and Brown and Caldwell Consultants for providing the data; Jan Hanley and Bob Young for computer programming and consultation; and Roy Gates and Beth Lachman for assistance with ARC/INFO.

surfaces, runoff from landscape watering, using hoses without automatic shut-off nozzles, and frequency of landscape watering; and voluntary and mandatory restrictions on the quantity of water use, based on a percentage of past use or a fixed amount per household per billing period. Relatively few water utilities used higher water prices to induce lower consumption, and these were often described as "penalty rates" or "surcharges" for exceeding quantity restrictions rather than simply as price increases.

The Alameda County Water District used a relatively pure price scheme from July 1, 1991 through the end of the sample period in July 1992 to reduce water consumption by households in single-family residences. For bimonthly consumption of up to 28 hundred cubic feet (HCF), roughly 350 gallons per day, households paid $.90 per HCF, and water rates were doubled, tripled and quadrupled at higher rates of consumption.[2] However, households could file an appeal to receive more water at the lowest rate if there were more than four people in the household, and other drought management policies were also in effect. Those affecting single-family residences were public education programs beginning in 1986, distribution of conservation kits beginning in 1989, and use restrictions in effect from May 1, 1991 to April 1, 1993. The use restrictions were relatively mild, including prohibitions on using water in an irresponsible manner, landscape watering that resulted in flooding or runoff, using hoses to clean hard surfaces, and using hoses without an automatic shut-off nozzle.

To estimate consumer surplus losses, we first estimate a demand curve using data on bimonthly meter readings from a sample of 599 single-family households over the period from January 1982 to July 1992, the Alameda County Water District price schedule, and local monthly weather data. Households in the sample are matched to 1980 and 1990 census data at the block group level, providing data on median and per capita income, average number of persons per household, average number

[2]This price structure was in effect during the first six months of the scheme, from July to December 1991. Beginning in January 1992, the lowest block price was increased to $1.008 per HCF, and in July 1992, the increasing block structure was flattened somewhat. See Table 1.

of rooms and bathrooms per house, poverty status, employment status, etc., and 1992 tax assessor data on building size, lot size, and taxable value.[3] In addition to their use as predictor variables, the census data can be used to determine whether the drought management policies tended to have greater economic impacts in high or low income areas, for example.

Our preliminary demand curve estimates are based on each household's marginal price of water at its bimonthly consumption level. During most of the sample period, the price was constant for all levels of consumption. However, increasing block rates were in effect from July 1991 through July 1992. The increasing block rate structure creates a positive correlation between high levels of use and high prices for the periods when it is in effect. As a result, ordinary least squares (OLS) estimates on the entire sample of households yield a demand curve that slopes downwards at low price levels, but begins to slope upward at high price levels. Additionally, it is important to allow the slope of the demand curve to differ between households, so that differences in the elasticity of demand can be measured.

In future work, there are a number of possible approaches that may be taken to try to overcome these problems. Billings and Agthe [1980] show that the use of marginal prices ignores the income effect of changes in intramarginal rates. They recommend the use of a "difference" variable, defined as the difference between the household's actual water bill and the bill it would have paid if the marginal price had been charged for all units, to account for this income effect. Other model specifications may account for more of the household characteristics that determine household water use. In particular, interaction terms between the weather variables and lot size may explain more of the variance in household water use.

[3]California Proposition 13 fixed taxable property values at 1978 levels or the subsequent purchase price of the property. Although properties under the same ownership can be revalued downwards, they are not revalued upwards. Therefore, taxable values are not a good reflection of current market values.

However, it is likely that more sophisticated econometric techniques will be needed to get believable demand curve estimates. In our preliminary work, we have treated each bimonthly meter reading as an independent observation, and not taken advantage of the fact that we have a panel data set. Taking first differences of household water use to estimate changes in water demand would control for unobserved household characteristics that do not change over time. If the highest use households have consistently high water use, but still reduced their water consumption during the periods of increasing block rates, this should help to eliminate the problem of upward-sloping demand at high prices. Alternatively, a fixed-effects model could be estimated, which essentially allows each household to have a dummy variable for unobserved characteristics.

Another possible approach to the data is to estimate which block of the increasing block rate structure that each household's consumption will fall, then estimate water use conditional on the predicted block. Nieswiadomy and Molina [1989] implement this approach using two different methods, one involving two stage least squares and the other using instrumental variables. A third possibility is to use a maximum likelihood approach, which would jointly estimate the probability that the household is in a particular block, and the conditional probability of the level of use.

In the following sections, we describe the data used in this research, show our preliminary demand curve estimates, and derive some preliminary estimates of consumer surplus losses. However, we place very little confidence in the accuracy of these preliminary estimates.

2. DATA

Our data on water use come from Alameda County Water District (ACWD), which covers Fremont, Newark and Union City, California, in the East San Francisco Bay area, south of Oakland. As of 1991, ACWD served a population of about 270,000, with 70,000 customer accounts. Of these, approximately 63,000 are single-family household accounts, 2,200 multiple-family (e.g., apartment buildings), 2,400 commercial, 400 industrial and 1000 public authority accounts.

Bimonthly meter readings for a sample of 599 single-family households were collected from January 1982 through July 1992. Clusters of households in various parts of the district were sampled. This data was matched with the ACWD price schedule, monthly precipitation and maximum, minimum and average temperatures from the National Oceanic and Atmospheric Administration weather station in Newark, CA, and Alameda County tax assessor data. These data were collected for a water demand forecast conducted by Brown and Caldwell consultants for ACWD.[4] In addition, we obtained 1980 and 1990 census data at the block group level for the census tracts corresponding to the ACWD service area, and information on ACWD's drought management policies through a RAND survey of urban water agencies.[5]

ACWD's commodity charges for water over the period 1982-92 are shown in Table 1. The nominal water price was raised infrequently during the early to mid-1980s, so prices were falling in real terms for some years. As the drought began in the late 1980s, nominal prices were raised each year, and except for 1990, there was also a real price increase. In July 1991, ACWD introduced a steeply increasing block rate structure as a drought management policy. The base allowance per single-family household was 28 HCF per bimonthly billing period, or approximately 350 gallons per day. If consumption stayed within the

---

[4]See Brown and Caldwell [1992].

[5]RAND's Urban Water Agency Drought Impact Study is being funded by the California Department of Water Resources and California Urban Water Agencies (CUWA), of which ACWD is a member.

base allowance, households paid the flat rate price that had been in effect before the rate change. At higher levels of use, the water price was doubled, tripled and quadrupled. The price for the base allowance was increased in January 1992, but the rest of the rate structure remained the same. In July 1992, the single-family household allowance was increased to 30 HCF per bimonthly period, or 400 gallons per day, and the rate of price increase over the higher blocks became less steep.

ACWD also implemented other drought management policies aimed at reducing water use by single family households. A public education program including bill inserts, newspaper ads, school programs and public displays began in 1986. Conservation kits were distributed beginning in 1989. Restrictions on types of water use were in effect from May 1, 1991 to April 1, 1993. These restrictions included prohibitions on using water in an irresponsible manner that results in wastage, watering landscape in a manner that results in flooding or runoff, using hoses to clean hard surfaces, and use of a hose for any purpose without a shutoff nozzle. Households could also appeal to obtain more than the bimonthly 28 HCF allowance at the lowest block price if there were more than 4 household members. Ideally, the estimation of household water demand curves should take these other policies into account.

The Alameda County tax assessor data file originally consisted of 83,094 observations. Based on the use code, we eliminated all properties that were not single-family residences, resulting in a sample of 54,488 single-family households. There were 6 addresses in the sample of 599 households with water use data that did not match to the tax assessor data. These households were dropped from demand curve estimates that used house size and lot size as regressors. The tax assessor data also serve as a basis of extrapolation to determine predicted demand and consumer surplus losses for the entire ACWD service area.[6]

---

[6]The discrepancy between the 54,000 observations in the tax assessor data and the 63,000 single family accounts reported by ACWD requires further investigation.

Table 1

ACWD Single Family Residential Water Prices

Effective Date	Usage Level	Nominal Price	Real Price (1981=100)
January 1, 1982	All	$0.450	$0.4285
May 1, 1982	All	0.585	0.5537
January 1, 1983	All	0.585	0.5430
January 1, 1984	All	0.585	0.5255
July 1, 1984	All	0.673	0.5924
January 1, 1985	All	0.673	0.5727
January 1, 1986	All	0.673	0.5597
January 1, 1987	All	0.740	0.5950
January 1, 1988	All	0.777	0.6001
January 1, 1989	All	0.816	0.6018
January 1, 1990	All	0.857	0.5989
January 1, 1991	All	0.900	0.6055
July 1, 1991	0-28 HCF	0.900	0.5972
	29-38 HCF	1.800	1.1944
	39-48 HCF	2.700	1.7916
	>48 HCF	3.600	2.3887
January 1, 1992	0-28 HCF	1.008	0.6570
	29-38 HCF	1.800	1.1732
	39-48 HCF	2.700	1.7598
	>48 HCF	3.600	2.3464
July 1, 1992	0-30 HCF	1.008	0.6528
	31-48 HCF	1.260	0.8160
	49-64 HCF	1.512	0.9792
	65-80 HCF	1.764	1.1424
	>80 HCF	2.016	1.3056

SOURCE: Brown and Caldwell [1992], Alameda County Water District

Both the small sample of 599 addresses and the large sample of 54,488 addresses were matched to census block groups using the geographical information system ARC/INFO. All of the 599 addresses were successfully matched, but there were about 7500 non-matching addresses in the tax assessor file. Some of these non-matching addresses can potentially be matched by hand, or water demand and consumer surplus losses can be proportionately inflated to account for the missing households.

Census variables potentially affecting household water use include median household income, per capita income, number of persons per household, poverty status, employment status, number of rooms or bathrooms per house, and median owner costs with and without mortgage. In addition, predicted household consumer surplus losses for each census block group can be tested for correlation with these variables. For example, it may be of interest to learn whether consumer surplus losses were correlated with high or low income groups as a means of evaluating the fairness of drought management policies. A steeply increasing block rate structure is likely to impose more costs on high-use households, which could be correlated with high income, or with a large number of persons per household, and thus with low income.

3. DEMAND CURVE ESTIMATES

A preliminary analysis of the data was conducted using OLS estimates of simple demand curve specifications. Some illustrative results are shown in Table 2. Both house size and lot size are highly significant in explaining bimonthly water use, as are the current and lagged monthly precipitation and average temperature. However, the increasing block rate structure in effect for a few periods creates a correlation between the highest price levels and high levels of water use. Therefore, these demand curves become upward sloping at high levels of use for Models 1-3 and at all levels of use for Model 4. Another shortcoming of these simple OLS models is that they only explain about 25% of the variance in household water use.

Dummy variables for other drought management policies are successively introduced in Models 2-4. These dummy variables shift demand curves in the expected direction, but because they are contemporaneous with each other and with high water prices, they change the slope of the demand curve and tend to reduce the significance of each other and of the price variables. It appears to be impossible to separate the effects of price and other drought management policies using a simple OLS model. In contrast, the coefficients of the other variables are relatively stable as the drought management policy dummy variables are introduced.

The estimated demand curves in Models 1-4 are evaluated at median house size and lot size and average winter and summer precipitation and temperatures and graphed in Figures 1-4. This clearly illustrates the slope problem and the effect of introducing the dummy variables for other drought management policies. Estimated price elasticities on the downward-sloping portions of these curves are relatively low. The highest point elasticity on the Model 1 winter demand curve is -.33 at a price of 53 cents per HCF, and on the summer demand curve, -.20 at a price of 50 cents per HCF.

Model specifications using the census variables resulted coefficients that were insignificant and/or had the wrong sign. Median household income, for example, was collinear with house size and lot size, and often had a negative sign when all three variables were employed. It also tended to be less significant because of the greater measurement error involved in associating households with the median income for their block group rather than actual household income.

Table 2

OLS Demand Curve Estimates

Variable	Model 1	Model 2	Model 3	Model 4
Constant (t statistic)	-32.353 (-22.19)	-32.565 (-22.39)	-35.135 (-24.22)	-46.499 (-30.93)
House size	0.0064 (28.56)	0.0064 (28.51)	0.0064 (28.59)	0.0064 (28.74)
Lot size	0.0011 (19.62)	0.0011 (19.58)	0.0011 (19.63)	0.0011 (19.68)
Precipitation	-0.3524 (-5.14)	-0.4958 (-7.18)	-0.5574 (-8.11)	-0.3447 (-5.03)
Lagged Precipitation	-1.0039 (-16.72)	-1.1742 (-19.24)	-1.1863 (-19.55)	-1.1470 (-19.07)
Average Temperature	0.2865 (14.94)	0.2714 (14.17)	0.2583 (13.56)	0.3021 (15.94)
Lagged Average Temperature	0.6483 (34.95)	0.6001 (31.91)	0.5622 (29.94)	0.5562 (29.89)
Price	-29.714 (-13.81)	-16.529 (-7.08)	-3.5659 (-1.49)	15.569 (6.25)
Price^2	16.047 (18.34)	11.342 (12.16)	7.1227 (7.51)	1.5418 (1.60)
Public Education		-2.6509 (-14.30)	-0.9569 (-4.77)	-1.2959 (-6.50)
Conservation Kits			-4.2934 (-21.23)	-2.2570 (-10.48)
Use Restrictions				-7.6972 (-25.84)
Adjusted R^2	.2533	.2574	.2665	.2796

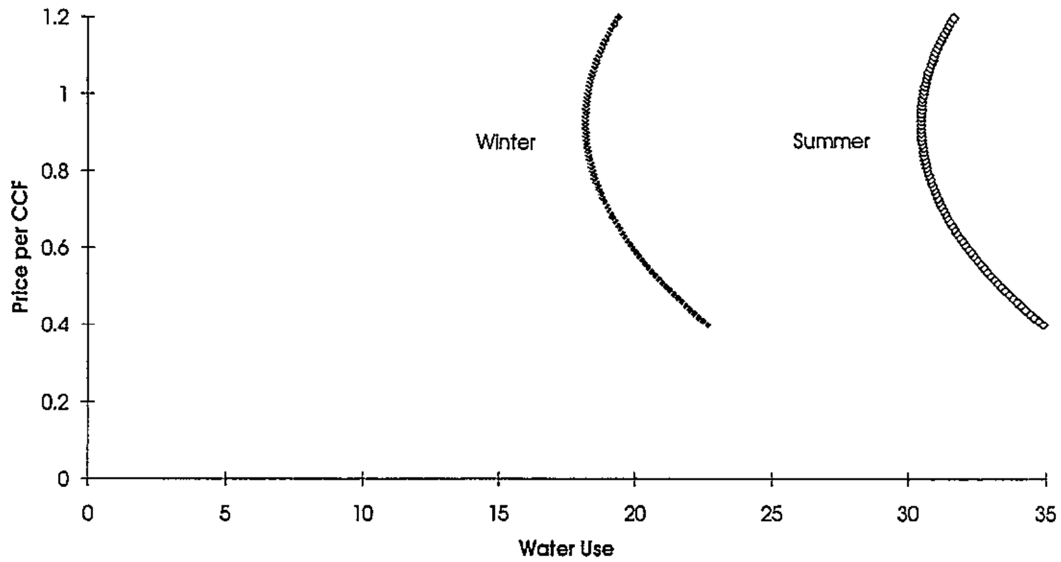

Figure 1-Model 1

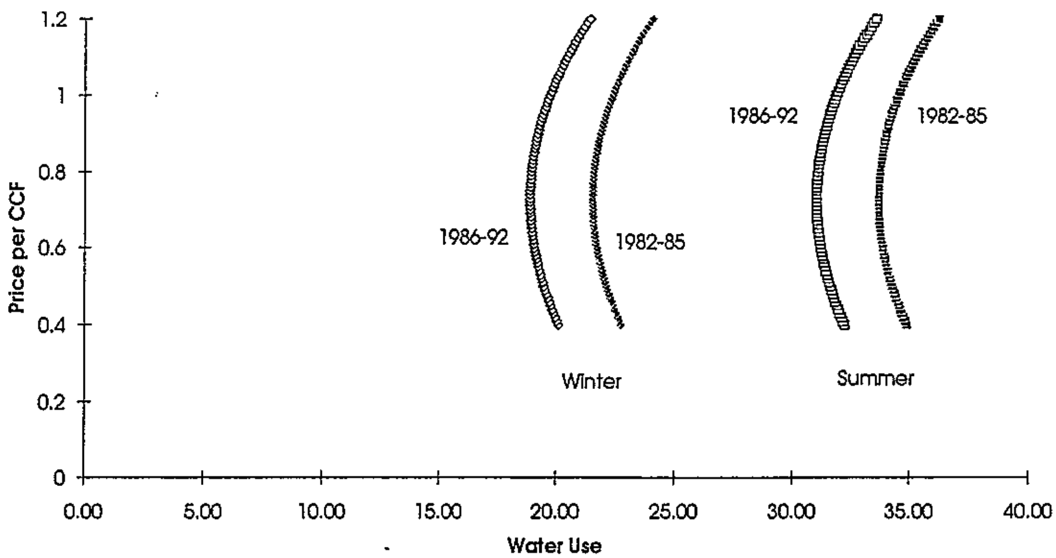

Figure 2-Model 2

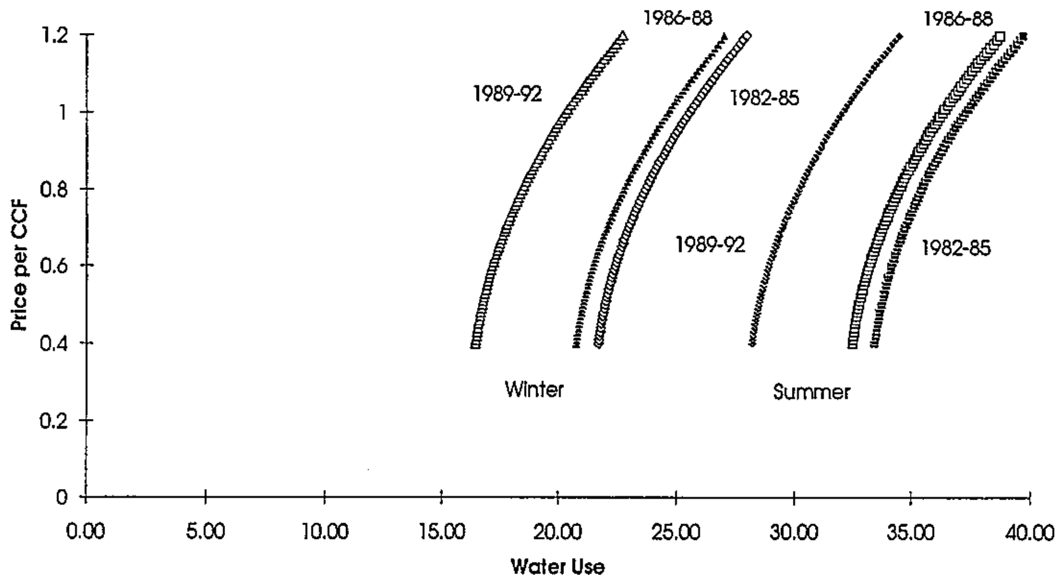

Figure 3-Model 3

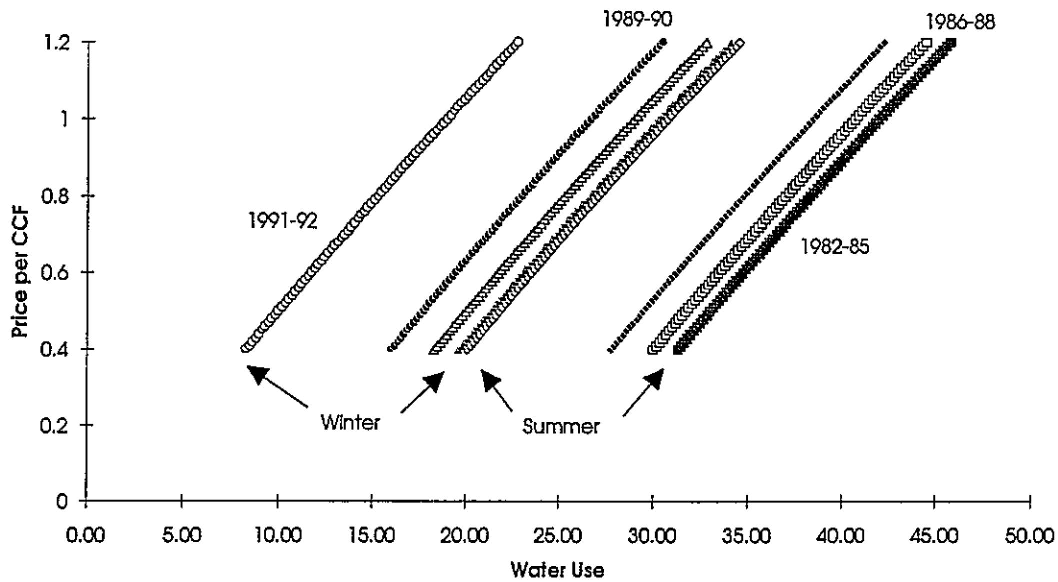

Figure 4-Model 4

4. CONSUMER SURPLUS LOSSES

In order to obtain a rough lower-bound estimate of the consumer surplus losses that would result if the downward-sloping portion of the Model 1 demand curve were correct, we extrapolated predicted consumer surplus losses to the entire 54,488 single-family households in the tax assessor file.[7] Bimonthly losses were predicted using weather data over the full years of 1991 and 1992 and the tax assessor data on the house size and lot size of each single-family residence. Because census variables were not used in Model 1, none of the households in the large file had to be dropped.

Estimates of the average consumer surplus loss per household relative to the 1990 price are shown in Table 3. The losses are summed across all households in Table 4. These estimates are reflated to current dollars. For the periods when increasing block rate structures were in effect, consumer surplus losses were computed only for households whose predicted use fell within the lowest block in order to avoid the upward-sloping portions of the demand curve. Higher-use households were likely to have suffered greater losses because of the higher prices in effect at the higher use levels. During the July-December 1991 period, the real price of water in the lowest block had fallen below the real 1990 price, so low-use households actually had a consumer surplus gain. The increase in the lowest block price in 1992 resulted in much higher estimated losses for 1992.

The consumer surplus losses can be subdivided into two parts: the higher price for water consumed that was paid to ACWD and the dead weight loss due to lower water consumption. If the same use reductions had been achieved without a price increase, this would measure the total consumer surplus loss. However, agencies that did not use price increases to achieve water cutbacks usually suffered from a shortfall in

[7]This should not be interpreted as a definitive estimate of consumer surplus losses, because of problems with the demand curve estimattion.

revenues that may have to be recovered in future periods, so they may have simply postponed consumer surplus losses from the drought.

Table 3

Estimated Average Consumer Surplus Loss per Household

Time Period	Total Consumer Surplus Loss	Transfer to ACWD	Loss of Value in Use
Jan.-June 1991	$ 1.68	$0.73	$ 0.95
July-Dec. 1991 (low use only)	-0.19	-0.08	-0.11
Jan.-June 1992 (low use only)	9.39	3.35	6.04
July-Dec. 1992 (low use only)	6.62	2.63	3.99
Total	$17.50	$6.63	$10.87

Table 4

Total Single Family Residential Consumer Surplus Loss

Time Period	Total Consumer Surplus Loss	Transfer to ACWD	Loss of Value in Use
Jan.-June 1991	$ 91,556	$ 39,872	$ 51,684
July-Dec. 1991 (low use only)	-9,229	-3,718	-5,511
Jan.-June 1992 (low use only)	501,955	179,084	322,871
July-Dec. 1992 (low use only)	348,452	138,653	209,799
Total	$932,734	$353,891	$578,843

4. CONCLUSION

Although the ACWD data set appears to be promising as a means of evaluating residential customer responses to an increasing block rate structure and other drought management policies, ordinary least squares regression is not adequate to deal with the complexity of the data. We intend to do further work with the data set using maximum likelihood and panel data techniques, which should provide better estimates of residential water demand curves and consumer surplus losses due to the drought.

BIBLIOGRAPHY

Billings, R.B. and D.E. Agthe, "Price Elasticities for Water: A Case of Increasing Block Rates," *Land Economics,* Vol. 56, No. 1 (February 1980), pp. 73-84.

Brown and Caldwell Consultants, "Water Demand Investigation and Forecast," mimeo, prepared for Alameda County Water District, November 1992.

Nieswiadomy, M.L. and D.J. Molina, "Comparing Residential Water Demand Estimates under Decreasing and Increasing Block Rates Using Household Data," *Land Economics,* Vol. 65, No. 3 (August 1989), pp. 280-289.