ECONOMIC LOSSES FOR URBAN WATER SCARCITY IN CALIFORNIA

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Abstract

The development of monthly economic loss functions is presented for major urban water users throughout California. These loss functions can be applied to drought or regulatory impact studies for urban water supplies or as economic performance indicators for regional or local water supply reliability simulation or integrated resource planning studies. The functions also are employed within the CALVIN economic-engineering optimization model of California's water supply system. The approach applies residential water demand elasticities for residential willingness-to-pay for water, an industry study for industrial willingness-to-pay for water, and assumed fixed commercial sector water use for 2020 population levels. While simple, this representation provides a consistent and understandable basis for economic valuation of urban water use for statewide and regional modeling. This work demonstrates the practicality of developing reasonable economic loss functions for urban water supply studies, rather than resting with conventional notions of water supply yield or water requirements. Using these economic loss functions, the estimated average annual cost to end users of urban water scarcity in California in 2020 for current operations, allocations, and infrastructure is $1.6 billion per year. Such valuations of urban water scarcity costs are useful for comparison with the costs of potential water investments to reduce water demands or increase water supplies.

Introduction

Relatively high population growth and increasing competition for water to fulfill environmental requirements in California are creating severe strains on the current water resources system and its management (DWR, 1998a). The growing complexity and controversy of California's water problems are requiring new forms of analysis and new ways to identify promising solutions, spanning the spectrum from permanent and temporary supply increases to long-term and drought-response demand management. As water scarcity becomes a recognized characteristic of California's drought-prone climate, traditional water supply planning and analysis methods based on fixed water requirements and the concept of system yield are proving inadequate and often controversial to address the range and multitude of proposed solutions. Economic valuation provides a simple, consistent, and understandable principle to help evaluate complex mixes of infrastructure and policy options to increase water supplies, reduce demands, and allocate resources, under hydrologic uncertainty in California.

Towards this end, methods and assumptions used to develop economic values of urban water use in California in 2020 are presented in this article. Values in this study approximate the willingness-to-pay of end users of urban water supplies for each additional unit of water along their demand curves (D-D curve in Figure 1). We first define maximum water demand as the amount users would take if water were priced at its current level (assuming typical utility average cost pricing) and had unrestricted availability (D_{max} in Figure 1). In any period when deliveries (Q in Figure 1) are less than the maximum demanded by users, economic losses represent the economic value or benefits that users would gain from additional water if deliveries were increased, at no change in price, to the maximum quantity demanded (shaded area in Figure 1). Losses reflect the total value or utility to customers of the foregone water use unadjusted for other costs or benefits that might be associated with delivery Q, such as reduced operating costs (supply curve S-S in Figure 1) or reduced customer water charges (Price line in Figure 1). While these economic loss functions have been developed for use in the CALVIN (California Value Integrated Network) statewide economic-engineering optimization model of California's inter-tied surface and groundwater system (Draper et al., in press; Jenkins, 2000a; Jenkins, 2000b; Howitt et al., 1999), they also have other local, regional, or statewide water planning uses, including post-processing of simulation model results or preliminary urban economic impact studies. The study applies these functions to estimates of 2020 urban water deliveries to estimate urban water user scarcity costs (foregone benefits) of $1.6 billion per year for California.

The following sections first describe how monthly urban residential demand functions are generated from available data and converted into economic loss functions. Then the approach, assumptions, and data used to estimate industrial water use values in California are developed. Limitations of the methods are discussed. Finally, application of the loss functions is presented for estimating urban economic losses in California for the year 2020.

Approaches to Valuing Urban Water Use

Econometric studies show that the economic value of urban water use varies with use type, season, location, quantity, and over time (Baumann et al., 1998; DWR, 1998a). For example, industrial and commercial uses of water at current levels of consumption typically have higher economic values than residential uses, while indoor use, which dominates winter residential water demand in California, has a higher economic value than outdoor use, occurring mostly in summer. As levels of water shortage or conservation increase, the marginal value of water also increases. Differences across water service areas in housing, socio-economic characteristics, level of conservation or efficiency, and other attributes of water users cause both the level and value of residential water use to differ by location (Jones et al., 2001; Baumann et al., 1998). Likewise, industrial water use and its economic value depend on the specific operations, size, water costs, and water efficiency of the mix of industries located in a given area.

Several methods were considered for estimating economic demand functions for urban water customers. These included: 1) constructing demand functions from observed prices, use levels, and estimates of the price elasticity of demand (the percent change in quantity demanded for a percent change in price); 2) using alternative costs of water shortage; 3) using contingent value studies of avoided water shortage; and, 4) mixed approaches combining costs of conservation programs with contingent valuation costs for urban water shortages. Each of these methods is discussed briefly below.

A relationship expressing the quantity of water demanded as a function of retail price provides an economically robust and theoretically rigorous direct assessment of the value of water use. Estimating a demand function for a specific situation is possible with knowledge of the price, the water demanded at that price, and the price elasticity of that demand. While much research has been directed at measuring the elasticity of residential water demand from empirical data, there is little information on the water demand elasticities of other urban sectors such as commerce and industry (Högland, 1999; Baumann et al., 1998). However, evidence supports the assessment that commercial and industrial water demand is less price elastic than residential demand (Baumann et al., 1998; USBR, 1997; CUWA, 1991). Estimated demand functions were recently applied (USBR, 1997) to assess urban water values in determining the urban economic impacts of the Central Valley Project Improvement Act (CVPIA) in California.

Numerous econometric studies exist for residential water demand in California, the most recent of which uses data from eight major urban water agencies representing 24% of California's population (Renwick et al., 1998). Table 1 lists price elasticity values for California reported in this and other studies. One elasticity study (Dziegielewski and Optiz, 1991) was found for nonresidential water use. No California studies of location specific differences or short-run behavior appear in this table. These data suggest a long-run average price elasticity of residential water demand ranging from -0.1 to -0.5 with winter estimates ranging from -0.1 to -0.2 and summer estimates ranging from -0.2 to -0.5. In the previously mentioned CVPIA analysis, short-run elasticity values applied to all urban water use sectors ranged from -0.1 to -0.2 while a value of -0.4 for residential and zero for commercial and industrial were used for the long-run estimate.

Several indirect methods have been proposed to estimate the economic costs of urban water scarcity. These include using alternative costs of shortage and conducting contingent valuation surveys of willingness to pay to avoid shortage. The alternative cost method is demonstrated using a two-stage linear optimization model that selects the least-cost mix of residential water-saving alternatives applied to eliminate or manage water shortages (Lund, 1995). Unfortunately, data are lacking to characterize the full costs of detailed conservation alternatives and actions adopted by end-users of water in a shortage. These concern the non-market costs of actions and alternatives related to transaction, aesthetics, information, convenience, and so on associated with changing habits and behaviors to reduce indoor and outdoor water use during shortages and deciding to install and use new water saving appliances and technology.

Two major surveys (CUWA, 1994; Carson and Mitchell, 1987) of California residents about the value of increased water supply reliability have applied contingent valuation methods to estimate the willingness-to-pay to avoid probabilistic shortages. The results from both these surveys are questionable in that they suggest a decreasing average willingness-to-pay for increasing water shortages. Furthermore, both used a question format, called the referendum format, which has been shown to produce unreliable, usually overestimated, values (McFadden, 1994). Improved survey designs (Griffin and Mjelde, 2000) continue to show inconsistent and somewhat overestimated values from contingent valuation surveys for small changes to the future probability of shortages.

For Southern Coastal California, the California Department of Water Resources has developed a mixed approach to estimating the economic costs of shortages to urban water demands (Hoagland, 1996). Program costs for drought and permanent water conservation actions (essentially alternative costs) are employed along with contingent valuation costs (Carson and Mitchell, 1987) for rationing to the household sector.

The method of using demand functions, based on estimated elasticities and observed prices and quantities, was preferred, given the shortcomings and severe data limitations in attempting to apply the indirect and mixed methods statewide. Consideration was also given to the ability to represent some of the factors affecting value, mentioned above, without requiring new data collection efforts. Through adjustments to elasticity and use of location specific prices, some of these factors can be accounted for in the demand functions. This study follows the approach of the CVPIA study in using estimated demand functions to assess residential water values. However, the assumptions and procedures used in this study differ in constructing 2020 demand functions, as do the assumptions and approaches used for valuing commercial, government, and industrial water use.

Residential Water Demand Function Methods and Data

In constructing monthly residential demand functions to represent urban water values in 2020 for this study, several important assumptions have been made. Limitations posed by these assumptions are discussed later in the paper. The assumptions include:

1. A constant price elasticity of demand (η) is assumed along the curve.
2. Seasonal effects on residential demand are included by varying long-term elasticity values for winter months (November through March), summer months (May through September), and intermediate months (April and October).
3. Geographic and regional differences in demand are incorporated into current (1995) demand functions by using observed residential retail water prices, observed residential water usage, and historic monthly use patterns of major water purveyors for each urban demand area.
4. Observed residential water use for each urban demand area is the total applied water use for that area multiplied by the residential fraction, based on current (1990) estimates of urban water use by sector (DWR, 1994). Total applied water use is computed from California Department of Water Resources data on population and total urban applied daily per capita water use (combined residential, commercial, government, industrial and unaccounted for water use) in 1995 by detailed analysis unit (DAU), the smallest geographic water planning unit for the state (DWR, 1998b). These water use estimates were developed from the state's long-term urban water production database (Jones et al., 2001).
5. A 2020 residential monthly demand function for each urban demand area is projected from the current monthly demand function by scaling the water quantity ordinate on the current curve by the ratio of the local population in 2020 to that of the current year. This approach avoids making assumptions about the retail price of water, the level of conservation, and the elasticity of demand in 2020. It also retains the present (1995) demand behavior of residential water users as the basis for the 2020 function.
6. Commercial and government demand for water are assumed to be price insensitive. These sectors' water use is added to the 2020 residential demand function (or residential loss function) by shifting it to the right by their projected water demand in 2020 for each urban area.
7. No attempt is made to adjust current (1990) urban water use proportions by sector to 2020 conditions.

In the price range over which residential price elasticities in California have been estimated empirically (see Table 1), assuming constant elasticity is reasonable. Furthermore, although elasticity would be expected to change with price along the water demand curve, adjustments to elasticity are difficult to make reliably. If deliveries remain within the price range of estimated elasticity, economic losses estimated using constant elasticity are a reasonable approximation. Losses for deliveries outside this range would tend to be underestimated. The other assumptions above are necessitated by lack of better data, particularly on a statewide basis.

Parameter and variable definitions used to derive 2020 demand functions appear in Table 2. Most urban areas encompass several of the state's DAUs and many urban water purveyors. In such cases, the parameters are population weighted averages of the data for the constituent units/agencies. Equations and their derivation are presented next.

The price elasticity of demand η is defined as:

$$\eta = (dQ/Q)/(dP/P) \qquad (\Delta Q/Q)/(\Delta P/P) \tag{1}$$

where P is the price at which the quantity Q is demanded. Assuming constant elasticity, equation 1 is re-arranged and integrated to produce the following demand function:

$$P = \exp\left[\{\ln(Q) / \eta\} + C\right] \tag{2}$$

where C is the integration constant. With an observed price (P_{obs}), observed level of water use (Q_{obs}) at that price, and an estimated η the constant is defined as:

$$C = \ln(P_{obs}) - \{\ln(Q_{obs}) / \eta\}. \tag{3}$$

If elasticity estimates were available for each urban water use sector, season, month, location, duration (long-run and short-run behavior), and so on, demand functions could be constructed from available price and use data for each combination of conditions. Unfortunately, at this time, region-wide elasticities have only been estimated for residential water use in California by season and for long-run behavior. Empirical studies currently provide insufficient information to make adjustments for location, month, sector, or short-run behavior, although a likely range of values can be suggested for short-run behavior. The effects of future technology change on empirically estimated price elasticities are also difficult to predict, although as water use becomes more efficient, reductions in price elasticity would be expected assuming current technology trends.

The computation of long-run 2020 demand functions for residential water use in each urban area in each month involves several steps, using variables and parameters defined in Table 2. First, the observed (1995) monthly residential demand functions are generated by computing an integration constant (equation 3) from the 1995 retail price (P_{1995} in \$/acre-foot), the 1995 level of residential water use in each month i ($Q_{obs\,i} = Q_{1995}$ x RESFRAC x $m_{R\,i}$) and the appropriate price elasticity estimate. P_{obs} is set equal to P_{1995} x 1000 to allow water quantities to be measured in thousands of acre-feet (taf) and η is set to the appropriate seasonal value for the month. The monthly curve is then scaled by the 2020 population increase (see example Figure 6). An adjusted constant for the scaled 2020 monthly demand curve is calculated analytically from the 1995 monthly constant and the 2020 to 1995 population ratio ($PR_{(2020/1995)}$) as follows:

$$C_{2020\,i} = C_{1995\,i} + \{\ln(1/ PR_{(2020/1995)}) / \eta_i\} \tag{4}$$

where $C_{1995\,i}$ and η_i are the month i values.

In the last step, the 2020 residential monthly demand functions are converted to economic loss functions on water deliveries. In doing this, zero loss is defined as occurring at the currently forecasted 2020 level of residential demand ("maximum" or target demand). Economic losses from residential deliveries less than the maximum demand are found by integrating the demand curve from the 2020 maximum residential demand left-wards to the delivery. This is done for scarcity levels (deliveries) down to a 50% residential water shortage. The monthly residential loss function derived by integrating equation 2 over the specified limits is:

$$LOSS(Q_{R\,i}) = [\exp(C_{2020\,i})/\{1+(1/\eta_i)\}] \text{ x } [Q_{2020\,i}\text{^}\{1+(1/\eta_i)\}-Q_{R\,i}\text{^}\{1+(1/\eta_i)\}] \tag{5}$$

where $LOSS(Q_{R\,i})$ is the economic loss of end users, in 1995 dollars, from delivering $Q_{R\,i}$ thousand acre-feet (taf) of water to the residential sector in month i of 2020, $C_{2020\,i}$ and η_i are the 2020 demand constant (equation 4) and elasticity, respectively, for month i, and $Q_{2020\,i}$ is the 2020 forecasted maximum residential demand for the month. $Q_{R\,i}$ must be less than or equal to

$Q_{2020\ i}$ in equation 5. Commercial and government 2020 target demands for the month are then added to the residential loss function, shifting it to the right, to produce the total loss function for residential, commercial, and government uses (see example Figure 7). Industrial use could be treated in the same way when economic data is lacking. This is not unreasonable in most areas of California where residential use makes up the vast majority of urban water demand.

In this application, the 2020 total maximum urban demand (all sectors combined) is simply the 1995 demand multiplied by the population ratio. No adjustments to per capita use levels in 1995 are made although projected reductions in per capita use for 2020 from increased water conservation could be used to define a lower 2020 forecasted demand in equation 5.

Industrial Production Loss Function Methods and Data

A recent survey of the cost of water shortages to different industries in California provides empirical data to characterize simple linear loss functions from water shortages in major industrial regions of California (CUWA, 1991). The method provides an indirect assessment of the value of industrial water use in these areas. The data are hypothetical, reflecting the survey responses from the sampled industries to questions about the economic value of production lost if water deliveries were cutback by 30% in 1991. These responses were combined with employment statistics by industry in each of 12 Bay and Southern Coastal Counties of California to generate regional industrial water scarcity cost estimates.

Industrial loss function variables and parameters are defined in Table 2. The steps to develop 2020 monthly industrial loss functions by county from these data are:

1. Compute the 2020 industrial target demand:
   $Q_I\ (taf) = Q_{1995} \times PR_{(2020/1995)} \times INDFRAC$
2. Compute the production loss rate from 1991 production lost in a 30% shortage:
   $INDLOSSRATE\ (\$/taf) = INDLOSS/(0.30 \times Q_I)$
3. Compute the 2020 monthly industrial target demand and assign it a zero penalty:
   $Q_{I\ i} = Q_I \times m_{I\ i}$ and $LOSS(Q_{I\ i}) = 0$
4. Compute the 2020 monthly loss for a 30% short water delivery in month i:
   $LOSS(Q_{I\ i} \times 0.70) = INDLOSSRATE \times 0.30 \times Q_{I\ i}$

Limitations

This section presents some limitations of the methods used to estimate the economic value of urban water use in 2020 for California.

Limitations on the demand function method. Separate water demand functions for commercial and government sectors could not be included because empirical estimates of their price elasticities are unavailable at this time. Assuming these sectors are price insensitive and including them as fixed requirements in the residential loss functions effectively prevents any shortages to their 2020 estimated demand.

The residential price elasticity estimates are only valid for current levels of conservation, over the empirically estimated price ranges, for long-run analysis, and for the portion of residential water use where customers pay the retail price of water. Residential users who do not pay the retail price are less sensitive to price changes. However, they have been aggregated with all residential water users. The value of urban water for drought situations should be based on the short-run elasticity of demand. By using long-run values, urban economic benefits derived from increasing deliveries will be lower bound estimates.

Difficulty projecting elasticities and water prices in 2020 has obliged using the 1995 demand function as the basis for 2020 residential water values. With projected increases in the level of conservation, 2020 demand may be more inelastic. Real prices also may be higher in 2020, leading to a reduced demand in 2020 than projected from 1995 prices and demand. This limitation tends to mitigate for the use of long-run elasticities.

The 1990 proportions of urban use by sector are assumed in 2020 because better statewide information is unavailable. While local and statewide changes will occur, these cannot be predicted consistently across the state with available data.

Target urban demands for 2020 represent an average condition. However, demand actually varies with hydrologic conditions, increasing in drier years and decreasing in wetter years. Monthly demand functions could be derived for different hydrologic year-types if data were available to characterize these variations across the state.

Limitations on the industrial production loss method. Production loss data is based on 1991 industrial activity and water use rates as no comprehensive information is available to project industrial activity and water use rates in 2020. While both these conditions are likely to change, there are far too many economic, technological, and policy unknowns to predict them in 2020.

The 2020 industrial target demand for each urban area is based on the portion of urban water used by industries in 1990 projected onto the total estimated 2020 water demand for this area. No better data are available to project changes in industrial water use statewide in 2020, however, production surveys indicate that the total volume of industrial water use in the state has remained relatively constant in recent years through greater water use efficiency and recycling in response to increasing wastewater discharge costs (Jones et al, 2001). The computed 2020 industrial target demand is then associated with the CUWA (1991) production loss data for the county that overlaps most closely with the urban demand area. It is not possible at this time to construct a more realistic non-linear industrial loss function because production loss data were unavailable for smaller magnitude shortages.

Clearly, the methods have many limitations. However, most do not bias results in an obviously systematic way. Exceptions are the use of the long-run elasticity for residential water demand and the assumption of zero elasticity for commercial and government use. In the former instance, short-run costs of urban water shortages will be underestimated. In the latter instance, urban economic losses will be higher than if commercial and government water values were represented.

System-wide application of valuation method

For the CALVIN model, the above method has been applied to develop system-wide economic loss functions for urban water use in California (Jenkins, 2000b; Jenkins, 1999). Urban water demands at the detailed analysis unit (DAU) for a statewide projected 2020 population of 47,507,399 are separated into three groups according to their water supply sources and size (Jenkins, 2000a). These three groups are explained next.

Demands excluded from analysis. Demands supplied fully by water sources outside the CALVIN optimization model and not part of CALVIN's intertied water supply system are excluded from the analysis. Typically, these lie in isolated coastal or mountain regions and represent 7.6% of the projected 2020 population.

Demands represented as fixed deliveries. Small demands that may be important to the mass balance accounting of water sources modeled in CALVIN's intertied surface and groundwater system are included as fixed diversion demands. They consist mostly of exclusive municipal and industrial groundwater users in California's Central Valley and several small surface water diverters at various other locations in the inter-tied system. About 12% of the statewide projected population in 2020 is represented by these fixed diversion demands that experience full deliveries of roughly 1.4 million acre-ft per year (1,700 million m^3/yr).

Demands represented by economic loss functions. Economically modeled urban water demand areas in CALVIN are generally large municipal and industrial water users with water supply systems integrated into the inter-tied California state-wide water distribution system and dependent on imported water from outside their service area boundaries. They account for about 80% of California's 2020 projected population. Two approaches are used to approximate the economic value of these urban water demands. The first approach combines all urban water use sectors and develops a single economic loss function, treating industrial water use in the same way as commercial and government use. It is applied to areas outside the twelve San Francisco Bay and South Coast Counties where industrial water use makes up a very small percentage of total urban use (1 to 2% in 1990) and production data are unavailable (DWR, 1993). The second approach separates industrial water use from residential and other water uses and develops two separate loss functions, according to the methodologies described above.

Urban water purveyors are aggregated into demand areas based on contiguous boundaries , a shared institutional framework, and a physically integrated system for managing water supply. This means that urban demand areas generally respect the boundaries of the major water supply agencies in the San Francisco Bay Area and in Southern California. Small water agencies expected to experience high growth in water demand by 2020 (high population growth) are represented as separate economic demands rather than as fixed diversions. Table 3 lists the economically represented urban demand areas developed for the CALVIN analysis.

Demand projections for 2020. Municipal and industrial urban water demands in California for 2020 are based on California Department of Water Resources 2020 DAU population projections, 1995 baseline per capita consumption levels by county, and climatologically average weather conditions (DWR, 1998a; DWR, 1998b). The exception is the Metropolitan Water District of Southern California (MWD) which provided hydrologically varying, consumption adjusted 2020 demands for this analysis. These data put the 2020 statewide population at 47.5 million and suggest a statewide average water use level in 1995 of 224 gallons per capita per day (848 lpcd). Under other assumptions, another set of population and per capita use data could easily be input into the spreadsheet software developed to process the inputs into economic loss functions for each urban demand area.

Statewide information on the breakdown of urban demand into residential, commercial, government/public, industrial, and unaccounted use in each of the ten hydrologic regions of California is available (DWR, 1994; DWR, 1993). This information reflects the most recent published statewide water production data.

Monthly demand pattern. For each urban area, annual demand is disaggregated into monthly demands. An overall monthly use pattern for each urban demand area is derived by population-averaging water agency monthly production data from the state's database (Jones et al, 2001). Figures 2 and 3 respectively, display the derived monthly use patterns for coastal and inland CALVIN urban demand areas. In urban demand areas with separate industrial loss functions, a statewide average monthly industrial use pattern (Figure 4), taken from the CUWA study (1991), is applied to the industrial portion of demand.

Water prices. The current price of water in each demand area, based on a California survey of residential water prices (Black and Vetch, 1995), is used to derive the residential demand functions according to equation 3. Analysis is done in present value dollars (1995). Where an urban demand area consists of several agencies, a population-weighted average price is used. Figure 5 shows the variation in 1995 residential water prices across the set of DAU's modeled in CALVIN. Prices of well over $600/af ($0.49/m^3) and up to $1,220/af ($0.99/ m^3) occur in the large coastal metropolitan areas of San Francisco Bay, Central and Southern California.

Example loss functions. The methods and data are demonstrated for the aggregated Santa Clara Valley (SCV) demand area listed in Table 3. SCV parameter values in Table 2 are used to estimate monthly residential demand functions and economic loss functions. The demand area consists of the combined water districts of Santa Clara Valley, Alameda County, and Alameda County Zone 7 in the San Francisco Bay area. Figure 6 shows the residential demand functions for the months of January, July, and April in 1995 and scaled up to 2020. These months represent the seasonally varying elasticity values of winter, summer, and intermediate, respectively. Figure 7 shows monthly loss functions for combined residential, commercial, and government sectors generated by integrating the 2020 demand functions in Figure 6 and adding the commercial and government target demand to the residential delivery level. Figure 8 shows monthly loss functions for SCV industrial water use in 2020 computed from the CUWA (1991) values for Santa Clara County reported in Table 2.

California urban water scarcity costs in 2020

The CALVIN economic loss functions described above were applied to estimates of urban water deliveries in year 2020 with present infrastructure and operating and allocation policies, under the range of hydrologic conditions represented by the 1922-1993 hydrologic record. Urban water deliveries are adapted from USBR (1997), Metropolitan Water District of Southern California, and California Department of Water Resources estimates. The resulting time series of water scarcity appears in Figure 9, with an average annual scarcity of urban water of 906,000 acre-ft (1,120 million m^3). Scarcity volumes vary between 0.6 and 0.8 maf/year (740-990 million m^3/yr) in non-drought years, but rise to almost 1.7 maf (2,100 million m^3) in drought years.

Figure 10 shows the resulting cumulative probability of scarcity costs in 1995 dollars and indicates how these costs are distributed among different parts of the state (aggregating results from urban demand areas listed in Table 3). The average cost of urban water scarcity is $1.6 billion/year. The San Francisco Bay area experiences scarcity in about 30% of years. The Central Valley urban areas experience small scarcities in almost all years, but these costs do not become large. Southern California urban areas always experience substantial water scarcity costs, which mount considerably in drought years. These Southern California results are verified by recent efforts of several water agencies in this region to acquire additional water through permanent purchases of water from agricultural users (Newlin et al., 2002).

A more detailed distribution of scarcity costs is mapped by DAU in Figure 11. Costs are shown on an annual average per capita basis using 2020 population estimates. A small number of DAU's experience some extremely high projected scarcity costs. These cases consist mostly of those Southern California inland DAU's expected to experience high population growth in the next 20 years. More moderate 2020 per capita scarcity costs occur in the established coastal DAU's with a history of water scarcity at current population levels.

Conclusions

Economic methods and data have advanced to where economic loss that approximates the value of water to end-users can be used to explicitly evaluate the performance of urban water supply systems. Economic losses allow more explicit consideration of tradeoffs in planning and operational decision-making and are more readily understood by the public and decision-makers than traditional "yield" or "shortage" indicators of water supply performance. This paper presents the development of such loss functions for roughly 80% of California's population. While the approach is rather simple, this simplicity allows for greater consistency and understandability in statewide and regional application. Results at local and statewide levels also appear reasonable.

The urban economic loss functions presented here have been used to estimate urban economic losses from water scarcity averaging $1.6 billion/year for California in 2020, based on current water availability, operations, and allocations. The ability to estimate such costs should be useful in assessing the benefit of infrastructure and management alternatives, and water conservation measures for comparison with their implementation costs.

The lack of field data and experience makes large-scale application of more complex and theoretically attractive approaches unsuitable at this time. This situation will improve with time, allowing more sophisticated estimates of economic losses from urban water scarcity. Simple approaches, such as that described herein, seem to provide useful results in the meantime.

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Table 1. Reported Price Elasticities[a] of Water Demand in California

Study / Report	Location and Sector	Season	Long-run or Short-run	Elasticity
Howe 1982	Western United States, single-family residential	Summer	long	-0.43
Weber 1989	East Bay Municipal Utility District, aggregated residential, price range $105-409/acre-ft ($0.09-0.33/m^3) in 1989 dollars	Winter Annual	long	-0.08 to 0.2 -0.1 to -0.2
CCWD 1989	Contra Costa Water District, residential	Annual Winter Summer	long long long	-0.2 to -0.4 very small -0.35
DWR[b] 1991	California, residential	Annual	long	-0.2 to -0.5
Dziegielewski and Optiz 1991	MWD of Southern California, single-family residential multiple-family residential overall weighted urban average combined commercial/industrial	 Winter Summer Winter Summer Annual Annual	long	 -0.24 -0.39 -0.13[c] -0.15[c] -0.22 -0.28[d]
Renwick et al. 1998	Bay Area and Southern California, 8 agencies, single-family residential, price range $205-1,851/acre-ft ($0.17-1.50/m^3) in 1989-96 dollars	Average Summer	long long	-0.16 -0.20

[a] compiled from Dziegielewski and Optiz (1991), USBR (1997) , DWR (1991, 1998a), and Baumann et al. (1998).
[b] California Department of Water Resources
[c] appears more inelastic than single-family residential because many multiple-family users do not pay the price of water and therefore appear insensitive to price changes
[d] may appear more elastic than residential due to impacts of changing wastewater discharge requirements during the analysis period (see CUWA 1991)

Table 2. Urban Economic Loss Variables, Parameters, and Example Data for "SCV"[a]

Parameter	"SCV" Data	Explanation	Source
P_{1995}	\$741/af [b] (\$0.6/m^3)	weighted average residential water price in 1995 of majority of water purveyors within each urban area	Black and Veatch 1995
$POPUL_{1995}$	2,280,590	1995 population of the represented urban area based on aggregating 1995 DAU data	DWR (1998b) data by detailed analysis unit
PCU_{1995}	197 gpcd[c] (746 lpcd)	1995 total urban applied water of the represented urban area expressed as daily per capita water use based on aggregating DAU data for 1995	"
Q_{1995}	503.7 taf [d] (621 million m^3)	1995 total applied water of the represented urban area, $Q_{1995} = PCU_{1995} \times POPUL_{1995}$	Derived
$POPUL_{2020}$	2,971,513	2020 population of the represented urban area based on aggregating DAU projections for 2020	DWR (1998b) projections by detailed analysis unit
PCU_{2020}	175 gpcd[c] (662 lpcd)	2020 total urban applied water of the represented urban area expressed as daily per capita water use based on aggregating DAU projections for 2020	"
$PR_{(2020/1995)}$	1.303	2020 to 1995 population ratio, $PR_{(2020/1995)} = POPUL_{2020} / POPUL_{1995}$	derived
RESFRAC	0.59	residential portion of urban applied water in 1990 after adjusting for unaccounted water	DWR 1994
INDFRAC	0.10	industrial portion of urban applied water in 1990 after adjusting for unaccounted water	"
COMFRAC	0.24	commercial portion of urban applied water in 1990 after adjusting for unaccounted water	"
GOVFRAC	0.07	government portion of urban applied water in 1990 after adjusting for unaccounted water	"
η_w	-0.15	state-wide winter long-term elasticity	estimate, Table 1
η_s	-0.35	state-wide summer long-term elasticity	"
η_i	-0.25	state-wide intermediate long-term elasticity	winter/summer avg.
$m_{R,i}$	0.054 (Jan) 0.076 (Apr) 0.112 (Jul)	monthly fractions for combined residential, commercial and government sectors based on weighted average monthly water use patterns of major water purveyors within each urban area	DWR 1994
$m_{L,i}$	0.074 (Jan) 0.083 (Apr) 0.103 (Aug)	monthly fractions of average industrial water use in California	CUWA 1991
INDLOSS	\$1,950 million[e]	total estimated value of production lost to industries in the represented County in 1991 for a hypothetical 30% water cutback	CUWA 1991

[a] *CALVIN "SCV" urban area = Santa Clara Valley Water District, Alameda County Water District, and Alameda County Zone 7, and other smaller purveyors, comprising DAUs 44, 45, 62 and 30% of 47, see Table 3.*
[b] *acre-foot = 1,233.5 m^3*
[c] *gallons per capita per day = 3.785 liters per capita per day*
[d] *thousands of acre-feet*
[e] *1991 dollars, Santa Clara County only*

Table 3. Economically Represented Urban Demand Areas in CALVIN

CALVIN Name	2020 Population	Max. Demand taf/yr (million m^3/yr)	Description of Major Cities, Agencies, or Associations
Central Valley			
Yuba City et al	210,450	63.8 (78.7)	Oroville, Yuba City
Sacramento Area	2,181,605	678.5 (837)	Sacramento Water Forum, Isleton, Rio Vista, PCWA, EID, W. Sacramento, N. Auburn
Stockton	421,575	94.9 (117)	City of Stockton
Fresno	1,142,125	383.7 (473)	Cities of Fresno and Clovis
Bakersfield	612,100	260.5 (321)	City of Bakersfield
Bay Area			
Napa/Solano	711,324	148.8 (184)	Cities of Napa and Solano Counties
CC WD	400,538	90.1 (111)	Contra Costa Water District
EBMUD	1,491,274	338.2 (417)	East Bay Municipal Utility District
SFPUC	1,501,900	238.0 (294)	San Francisco PUC City and County and other San Mateo County
SCV	2,971,513	657.7 (811)	Santa Clara Valley, Alameda County and Alameda Zone 7 Water Districts
Southern California			
SB-SLO	713,675	139.2 (172)	Central Coast Water Authority, including urban areas of Santa Barbara and San Luis Obispo
Castaic Lake	688,500	176.6 (218)	Castaic Lake Water Agency
SBV	878,944	282.5 (348)	San Bernadino Valley Water District
Central MWD	15,645,756	3,730.7 (4,602)	Mainly Los Angeles and Orange County portions of Metropolitan Water District of Southern California (MWD)
Eastern & Western MWD	2,251,030	740.0 (913)	Mainly Riverside County portion of MWD
Antelope Valley Area	1,079,650	283.3 (349)	AVEKWA, Palmdale, Littlerock Creek
Mojave River	1,075,775	354.9 (438)	Mojave Water Agency and Hi Desert Water Agency
Coachella Valley	628,820	600.7 (741)	Dessert Water Agecny, Coachella Valley Water Agency
SD MWD	3,839,800	988.1 (1,219)	all of San Diego County portion of MWD
TOTAL	38,446,354	10,250.2 (12,644)	

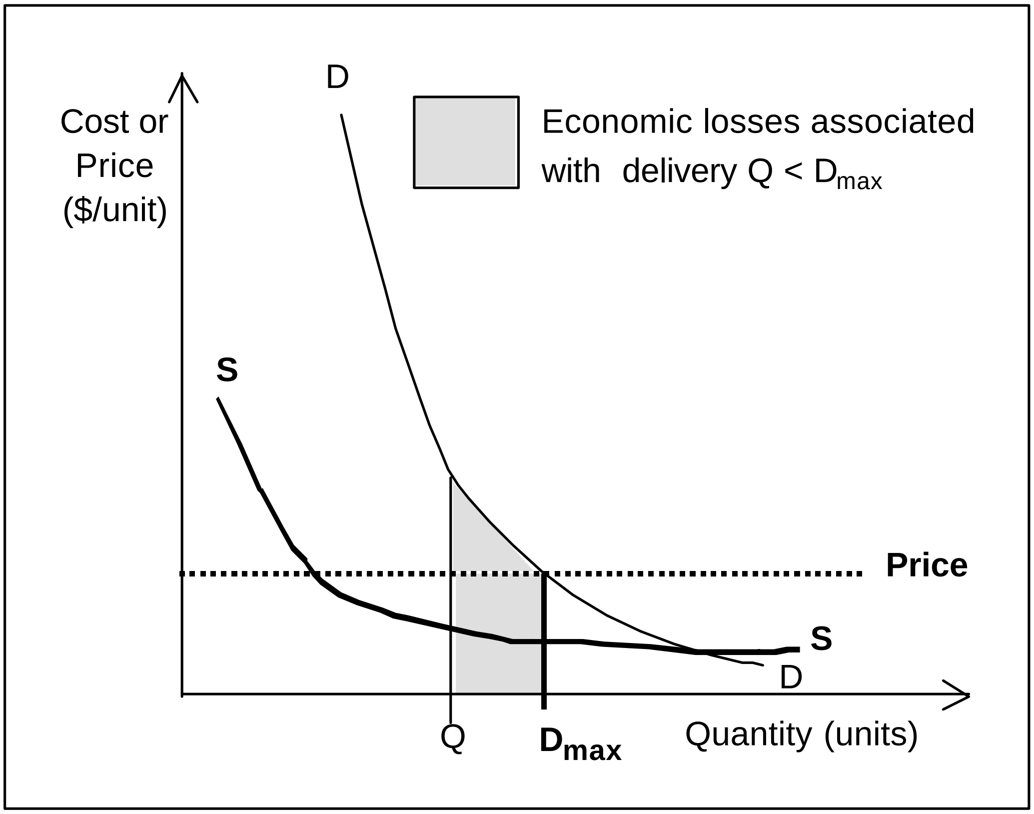

Figure 1. Urban Economic Losses from Water Scarcity

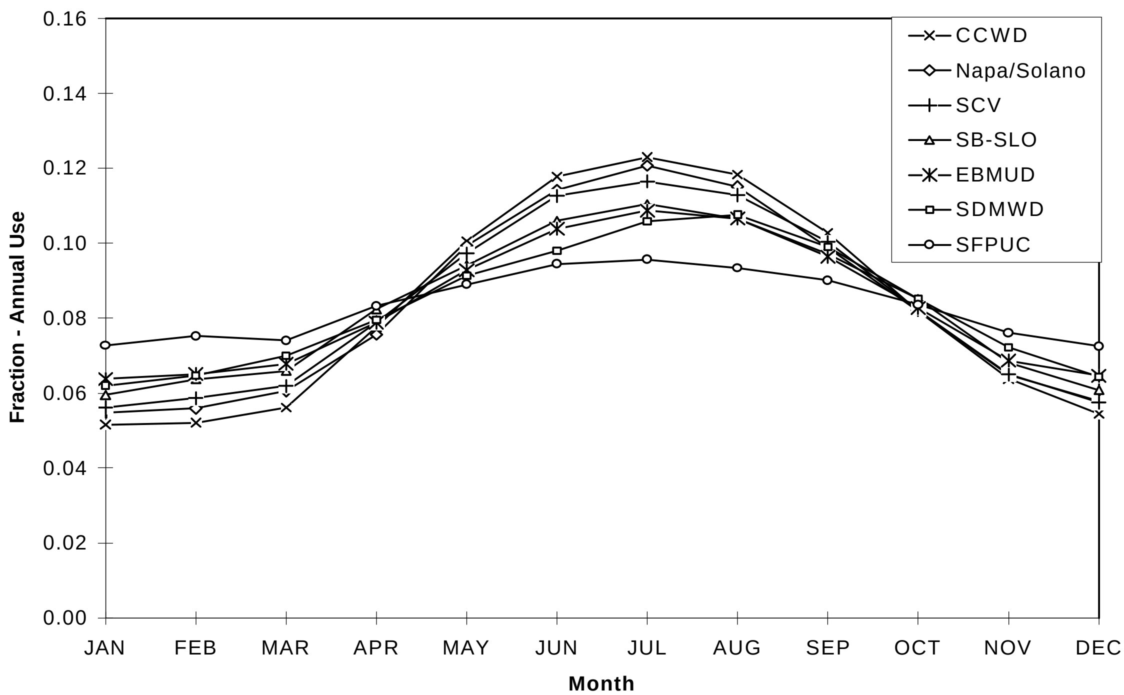

Figure 2. Coastal Monthly Urban Use Patterns

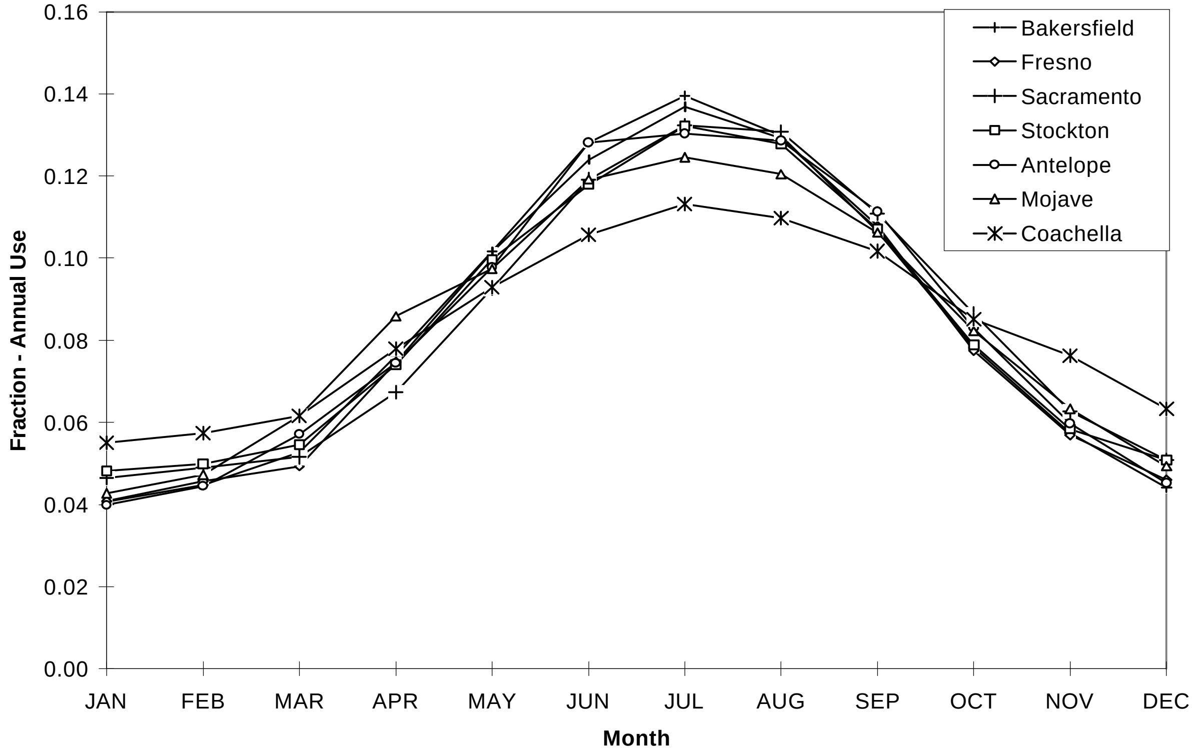

Figure 3. Inland Monthly Urban Use Patterns

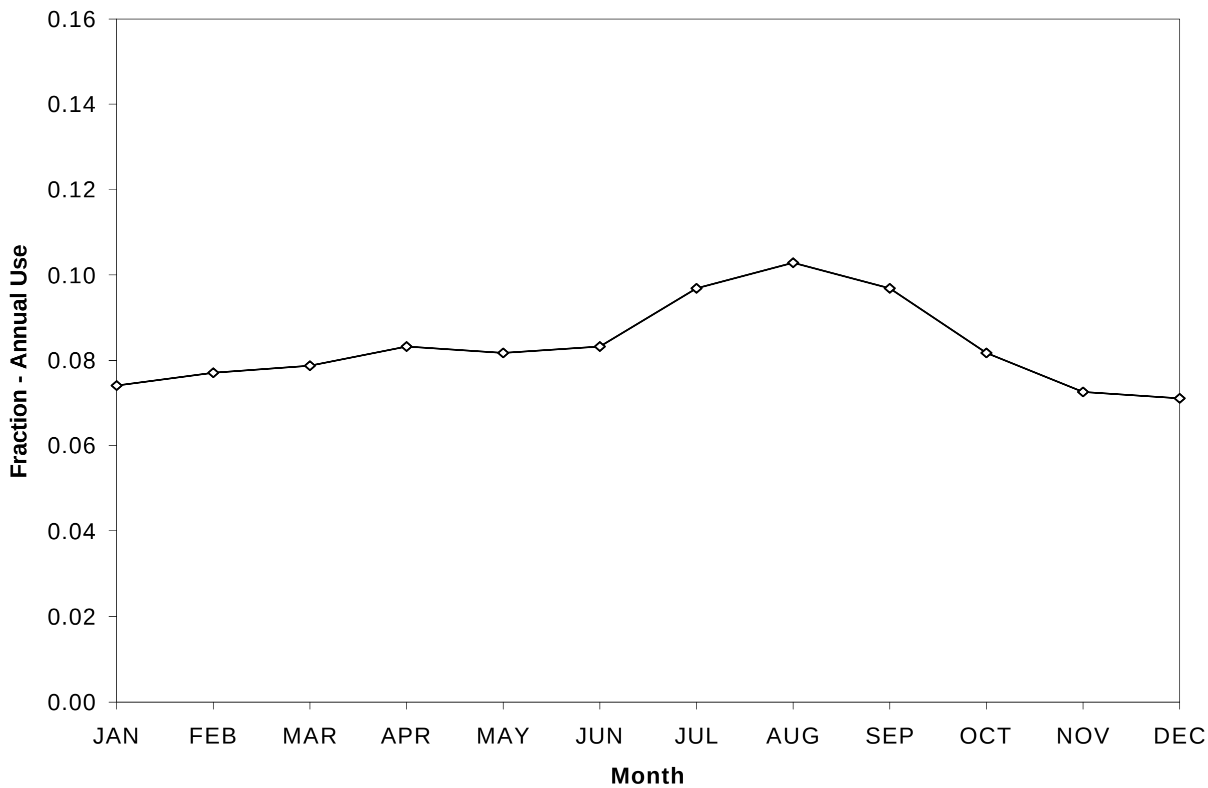

Figure 4. Statewide Average Monthly Industrial Use Pattern

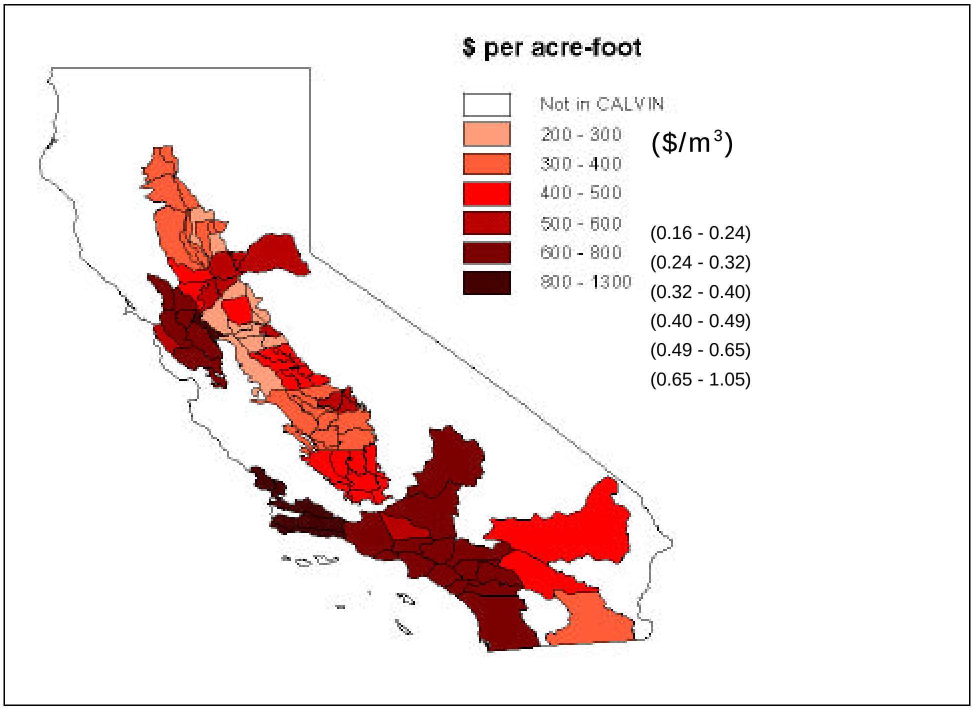

Figure 5. 1995 Urban Residential Water Prices in California

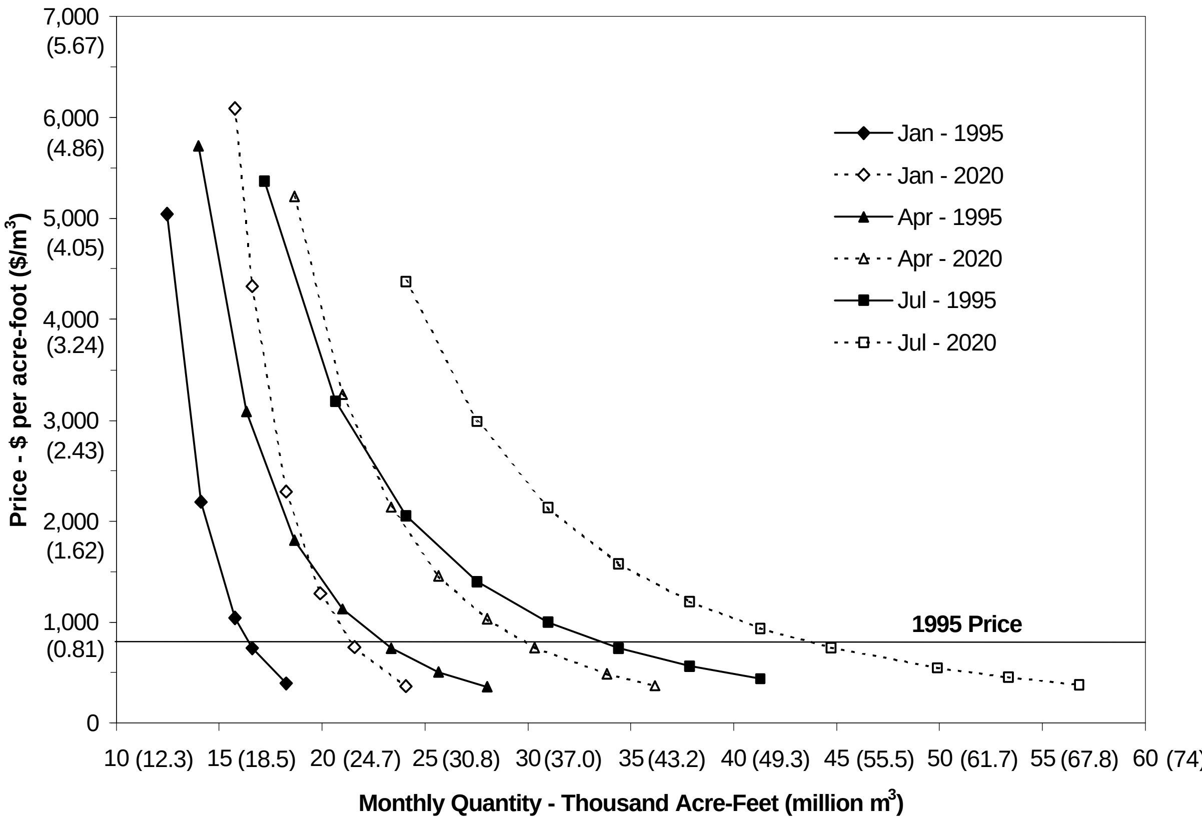

Figure 6. Example Monthly Residential Demand Functions for Aggregated Santa Clara Valley Area

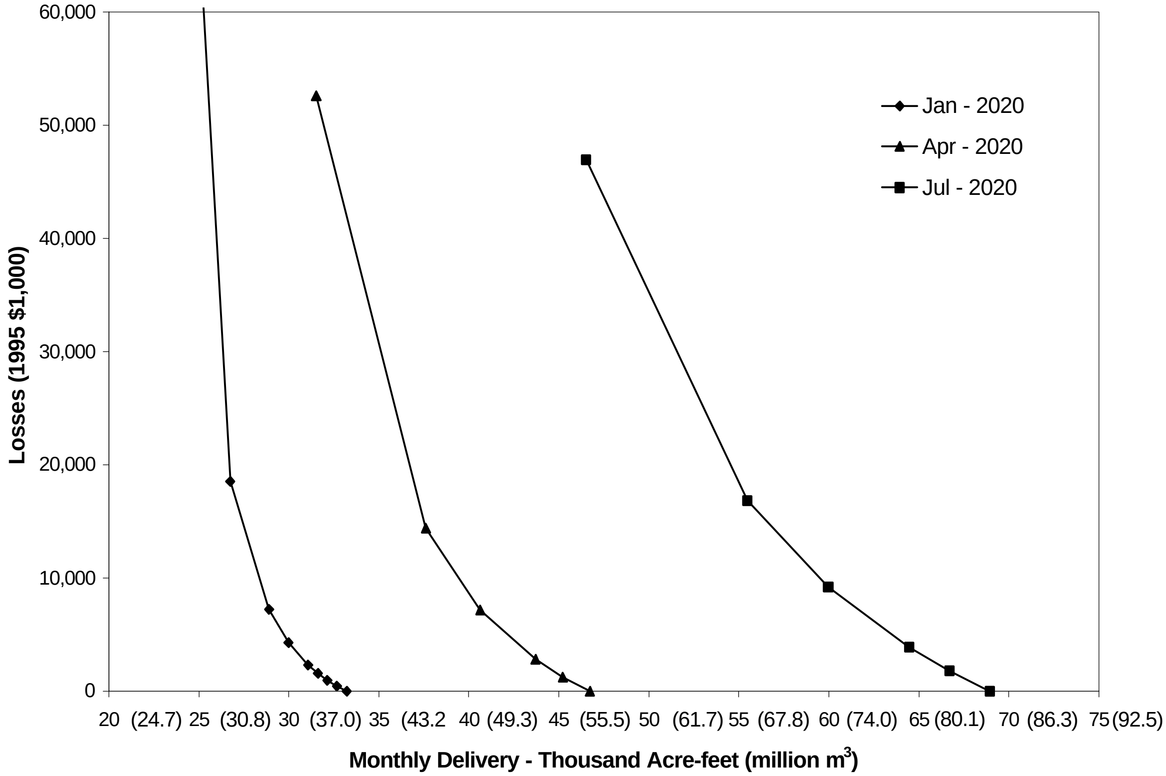

Figure 7. Example Residential, Commercial, and Government Monthly Loss Functions for Aggregated Santa Clara Valley Area

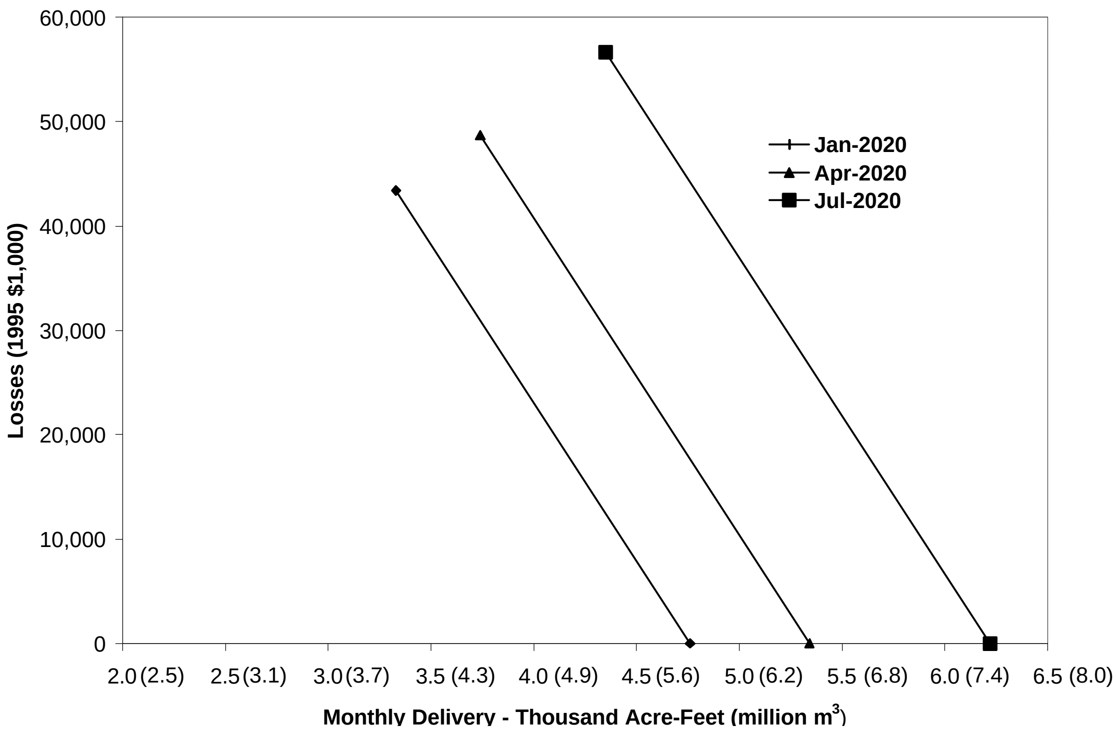

Figure 8. Example Monthly Industrial Loss Functions for Aggregated Santa Clara Valley

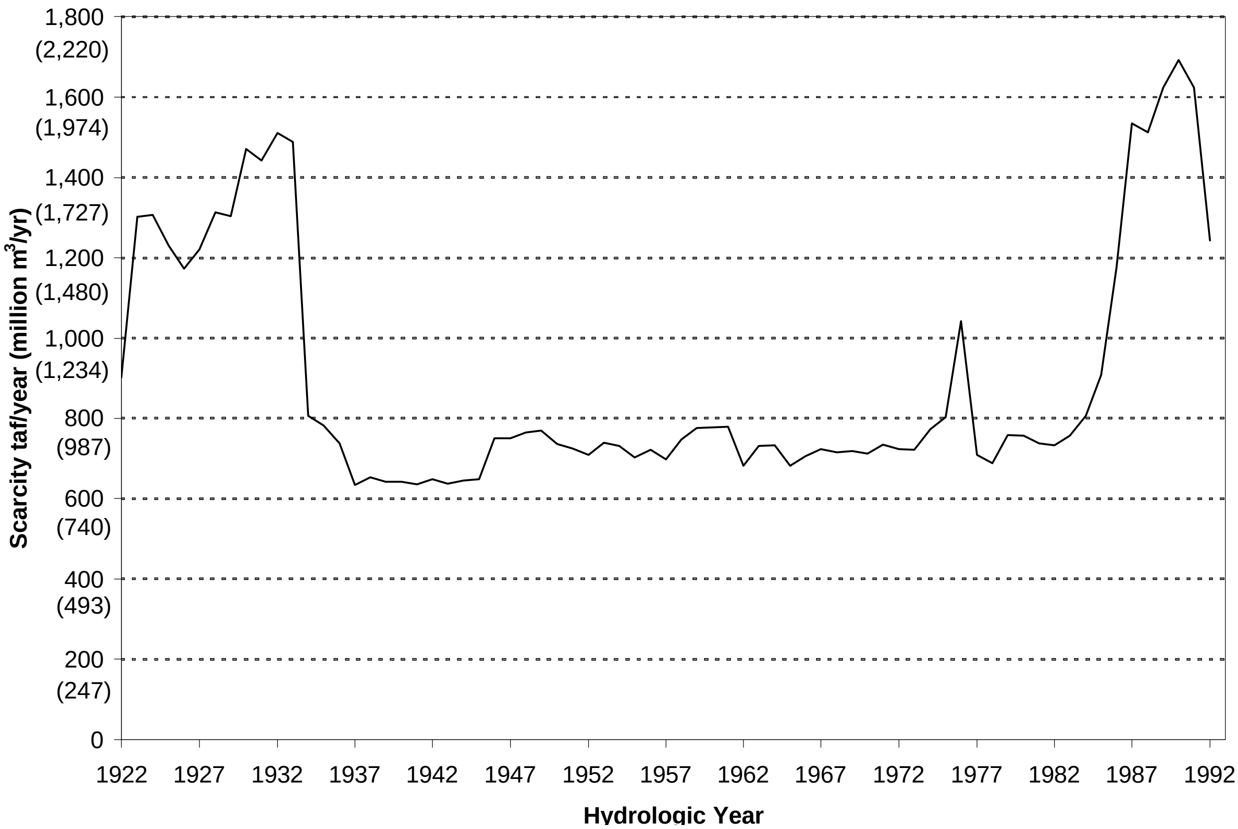

Figure 9. California Statewide 2020 Urban Scarcity for 1922-1993 Hydrologic Conditions

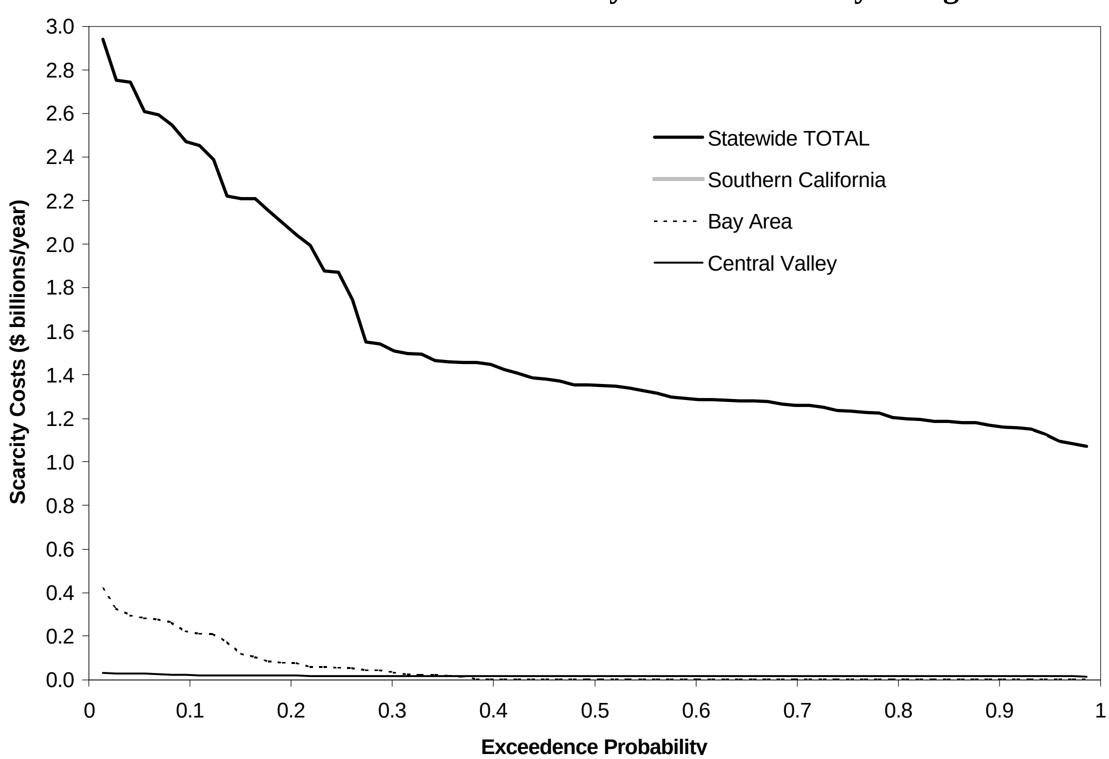

Figure 10. Exceedence Probability of 2020 Projected Annual Urban Scarcity Costs for California with Current Infrastructure and Management

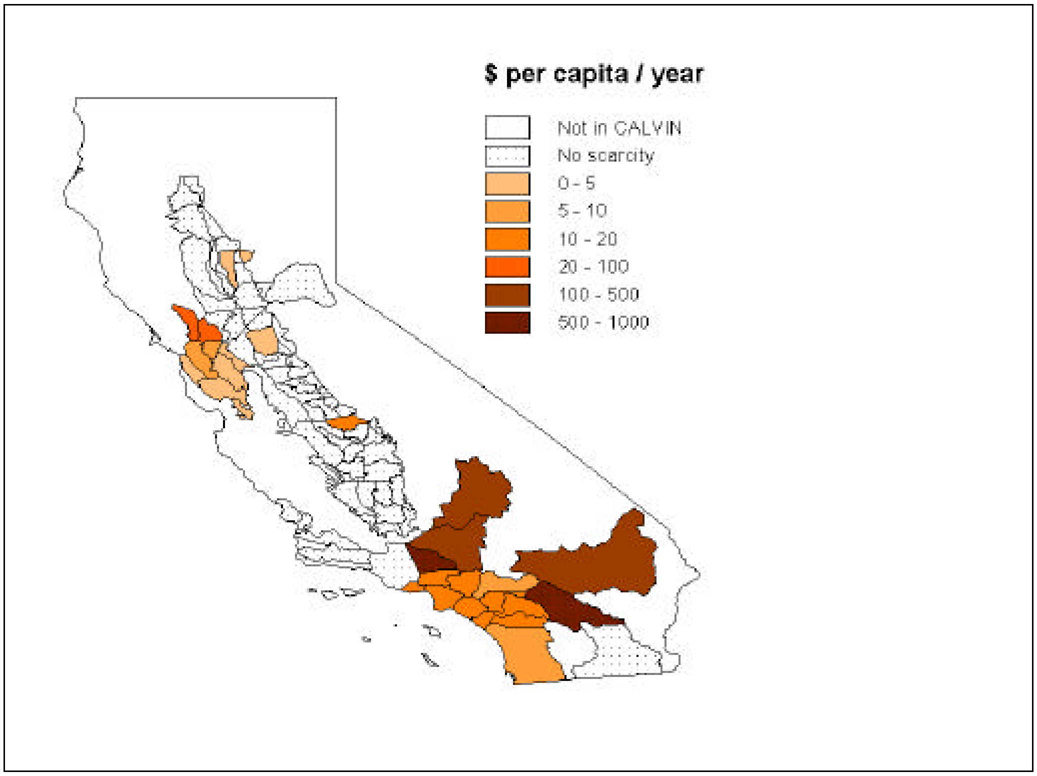

Figure 11. 2020 Urban Water Scarcity Costs