APPENDIX B2

URBAN VALUE FUNCTION DOCUMENTATION

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INTRODUCTION

This appendix presents the methods and assumptions used to develop economic values of urban water use in California in 2020 for CALVIN, a large-scale economic optimization model of state-wide water allocation. In general, the economic value of urban water use differs with use type, season, location, quantity, and over time as seen in econometric models of water demand (see review in Baumann et al. (1998) and Department of Water Resources (1998)). For example, industrial and commercial uses of water generally have higher value 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 the level of water shortage or the level of conservation increases, the value of water also increases. Differences across water agencies 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. Likewise, industrial water use and its value depend on the specific operations, size, water costs, and water efficiency of the mix of industries located in a given area.

Several methods, both direct and indirect, were considered in deciding how to estimate urban water values to drive the CALVIN model. These included:

- 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);
- using alternative costs of water shortage; and
- using contingent value studies of avoided water shortage.
- 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 on the water demand elasticities of other urban sectors such as commerce and industry (Baumann et al. 1998). However, evidence supports the assessment that commercial and industrial water demand is less elastic than residential demand (CUWA 1991; Bureau of

Reclamation 1997; Baumann et al. 1998). Estimated demand functions were recently applied to assess urban water values (consumer and producer surplus) in determining the urban economic impacts of the Central Valley Project Improvement Act (CVPIA) in California (Bureau of Reclamation 1997).

There have been many econometric studies of the residential demand for water in California, the most recent of which uses data from eight major urban water agencies representing 24% of the total population in California (Renwick et al. 1998). Table 1 lists elasticity values for California reported in this and other studies. There is one study of non-residential water use (Dziegielewski and Optiz 1991). No 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 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 of assessing the value of urban water have been proposed in the context of water shortages. These include using alternative costs of shortage and conducting contingent valuation surveys of willingness to pay to avoid shortage. Both methods have been rejected for this large-scale study because of data-related problems in their implementation.

Lund (1995) demonstrates the alternative cost method in developing a two-stage linear optimization model that selects the least-cost mix of residential water-saving alternatives applied to eliminate or manage water shortages. Unfortunately, data are lacking to characterize the full costs of alternatives and actions adopted by end-users of water in a shortage. Some of these water shortage costs concern the non-market costs of actions and alternatives, for example, those related to transaction, aesthetics, information, and so on associated with the implementation of most alternatives.

Two major surveys of California residents about the value of increased water supply reliability have applied contingent valuation methods to determine the willingness-to-pay to avoid shortages (Carson and Mitchell 1987; CUWA 1994). The results from both these surveys are questionable in that they suggest a decreasing average willingness-to-pay for water as shortage increases. Furthermore, both used a question format, called the referendum format, which has been shown to produce unreliable, usually overestimated, values (McFadden 1994).

For Southern Coastal California, the 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 water costs) are employed along with contingent valuation costs (Carson and Mitchell 1987) for rationing to the household sector.

The method using demand functions, based on estimated elasticities and observed prices and quantities, is preferred, given the shortcomings and severe data limitations in attempting to apply the indirect and mixed methods state-wide. 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 demand functions. This study, in following the work done in the CVPIA study, uses estimated demand functions to assess residential water values. However, assumptions and procedures in constructing 2020 demand functions are different in this study as are the assumptions and approaches for valuing commercial, government, and industrial water use.

The following sections of this appendix first describe how urban monthly residential demand functions are generated from the available data and converted into penalty functions to drive the optimization model. Major assumptions of the method are identified including how commercial and government water use is incorporated into these functions. The next section describes the approach, assumptions, and data used to estimate the values of industrial water use in California. The methods and data are then demonstrated with an example application to a specific urban demand area in the CALVIN model. Limitations of the methods are presented in the discussion section. A summary concludes the appendix.

Table B2-1. Reported 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	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	Average Summer	long long	-0.16 -0.20

[a] compiled from Dziegielewski and Optiz (1991), Bureau of Reclamation (1997) , Department of Water Resources (1991, 1998), and Baumann et al. (1998).
[b] Department of Water Resources, State of California
[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 the impacts of wastewater discharge requirements over analysis period

RESIDENTIAL WATER DEMAND FUNCTIONS: METHODS, ASSUMPTIONS, AND DATA

In constructing monthly residential demand functions to represent urban water values in 2020 for this project, several important assumptions have been made, largely because empirical data on elasticities are very limited. These include:

1. A constant price elasticity (η) of demand is assumed along the curve.
2. Seasonal effects on residential demand are included by using different 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 the 1995 demand functions by using 1995 observed residential retail water prices, 1995 observed residential water usage, and historic monthly use patterns of major water purveyors for each urban demand area represented in CALVIN.
4. Observed residential water use in 1995 for each urban demand area is the total applied water use for that area in 1995 multiplied by the residential fraction, based on 1990 estimates of urban water use by sector for each hydrologic region (Department of Water Resources 1994b). 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.
5. A 2020 residential monthly demand function for each urban demand area is projected outwards from the 1995 monthly demand function by scaling each ordinate value (water quantity) on the 1995 curve by the ratio of the population in 2020 to that of 1995 for that area. This approach avoids having to make assumptions about the retail price of water, the level of conservation, and the elasticity of demand in 2020. It also retains the present 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 penalty 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 1990 data, the most recent reported by the State of California, on the breakdown of urban water use by sector to 2020 conditions (Department of Water Resources 1994b).

While not accurate, in the price range over which elasticities in California have been empirically estimated in the studies reported in Table B2-1, constant elasticity is reasonable. Furthermore, although elasticity might be expected to change with increasing price along the water demand curve, adjustments to elasticity have no reliable basis in research. The other assumptions above are necessitated by lack of better data, particularly on a state-wide basis.

Data parameters used to compute residential urban values from derived 2020 demand functions for each economically modeled urban demand area in CALVIN are listed in Table B2-2. Most urban areas encompass several DAUs and/or more than one water purveyor. In such cases, the parameters are 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:

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

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

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

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:

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

In theory, 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, elasticities can only be reasonably estimated for residential water use in California by season and for long-run behavior. There are not enough empirical studies 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 computation of long-run 2020 demand functions for the residential portion of urban water use in each urban area in CALVIN in each month involves several steps using parameters defined in Table B2-2. First, the 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 elasticity estimate. P_{obs} is set equal to P_{1995} x 1000 to allow water quantities to be measured in thousands of acre-feet (KAF) and η is set equal to the appropriate seasonal value for the month. The monthly curve is then scaled by the 2020 population increase. An adjusted constant for the scaled 2020 monthly demand curve is calculated from the 1995 monthly constant and the 2020 to 1995 population ratio $PR_{(2020/1995)}$ as follows:

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

where $C_{1995\ i}$ and η_i are based on the values for month i.

In the last stage, the 2020 residential monthly demand functions are converted to penalty functions on water deliveries. Steps consist of:

1. defining a maximum level of residential demand in 2020 to which a zero penalty is assigned;
2. computing the residential water shortage penalty for any delivery less than the maximum use by integrating the demand curve from the 2020 residential maximum demand left-wards to incrementally smaller water delivery levels up to a 50% residential water shortage according to the penalty equation 5 below; and
3. adding the commercial and government target demand in 2020 to the residential water delivery level to shift the penalty function to the right for these required urban deliveries.

The monthly residential penalty function derived by analytically integrating equation 2 over the specified limits is:

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

where PEN($Q_{R\,i}$) is the penalty, expressed in 1995 dollars, for delivering $Q_{R\,i}$ KAF of water to the residential sector in month i of 2020, $C_{2020\,i}$ and η_i are the 2020 demand constant (see equation 4) and elasticity respectively for the month i, and $Q_{2020\,i}$ is the 2020 residential maximum demand for the month. $Q_{R\,i}$ must be less than or equal to $Q_{2020\,i}$ in equation 5. PEN($Q_{R\,i}$) is expressed in \$1000 by dividing by 1000 and paired with an adjusted delivery quantity equal to the sum of $Q_{R\,i}$ plus the combined commercial and government 2020 target demand for the month. For urban demand areas in CALVIN represented by a single value function (all sectors combined), in step three above, the industrial sector 2020 target demand is treated in the same way as the commercial and government sectors and added to $Q_{R\,i}$.

For the purposes of this project, the 2020 total target demand (all sectors combined) is simply the 1995 demand multiplied by the population ratio. No adjustments to the 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 target demand. A later section demonstrates the computations with an example.

INDUSTRIAL PRODUCTION LOSS FUNCTIONS: METHOD, ASSUMPTIONS, AND DATA

A recent survey of the cost of water shortages to industries in California provides empirical data to characterize simple linear loss functions from water shortages in some 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.

The steps and assumptions taken to develop 2020 monthly industrial penalty functions by county from these data are:

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

EXAMPLE APPLICATION

This section presents the calculations of water values for one urban demand area in CALVIN. The demand area (90) consists of detailed analysis units 44, 45, 62, and 30% of 47 representing the combined water districts of Santa Clara Valley, Alameda County, and Alameda County Zone 7. Table B2-2 lists the parameters and their values for the example calculations. Figure B2-1 shows the residential demand functions for three months in 1995 scaled up to 2020. These three months represent the seasonally varying elasticity values of winter (January), summer (July), and intermediate (April). Figure B2-2 shows monthly penalty functions for combined residential, commercial, and government sectors generated by integrating the 2020 residential demand functions in Figure B2-1 and then adding the commercial and government target demand to the residential delivery level. Figure B2-3 shows monthly penalty functions for industrial water use in Santa Clara County in 2020 computed from values in Table 2 according to the steps described above.

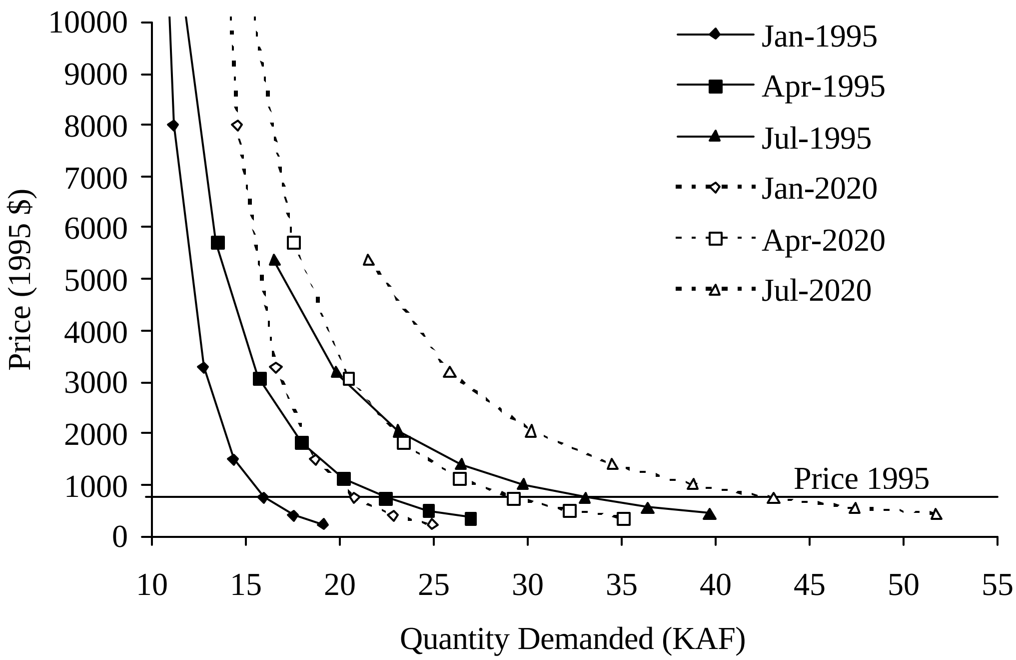

Figure 1. Residential Monthly Demand Functions - CALVIN Urban Node 90

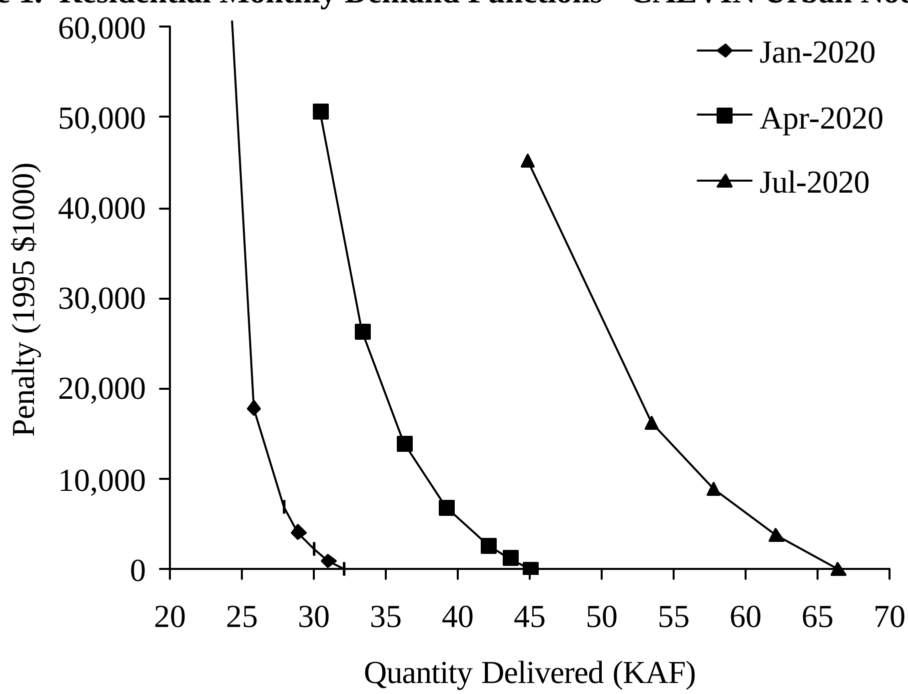

Figure 2. Combined Residential, Commercial and Government Monthly Penalty Functions - CALVIN Urban Node 90

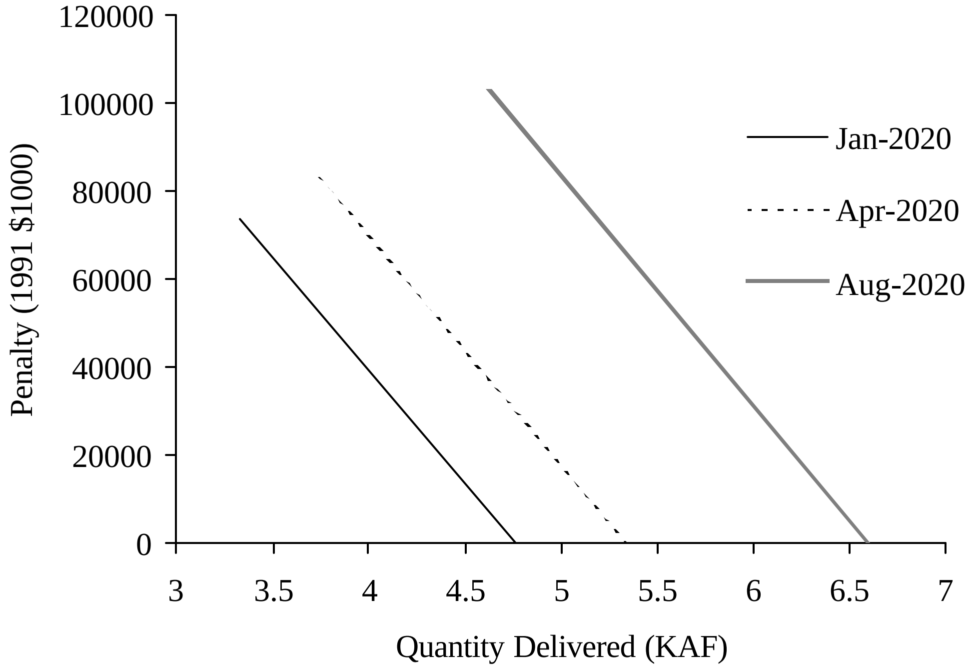

Figure 3. Industrial Monthly Penalty Functions - CALVIN Urban Node 90 (Santa Clara County)

Calculations for the residential penalty function for the month of January shown in Figure B2-2 include the following:

1. The 1995 and 2020 demand function constants for January are computed from equations 3 and 4 as follows:
   C_{1995} = ln ($741,000) – {ln (503.7 KAF x 0.59 x 0.054) / -0.15} = 32.02
   C_{2020} = 32.02 + {ln (1/ 1.303) / -0.15} = 33.78
2. The 2020 residential demand function (equation 2) for January is:
   P ($/KAF) = exp[{ ln (Q KAF) / -0.15} + 33.78]
3. The 2020 total target demand for January based on 1995 per capita use is:
   35.4 KAF = 2,971,513 x 197 gpcd x 365 days x 0.054 x 0.003068 KAF/10^6 gals
4. The 2020 residential penalty (equation 5) for January for a residential delivery of 15.7 KAF equivalent to a 25% shortage from the residential target demand of 20.9 KAF is computed as:
   PEN(15.7) = [exp(33.78)/{1+(1/-0.15)}] x [20.9^{1+(1/-0.15)}-15.7^{1+(1/-0.15)}]
   = $11,070,855
5. For the combined residential, commercial, and government penalty function, the adjusted delivery associated with the computed penalty in step 4 is:
   PEN($Q_{adjusted\ i}$ = 15.7+{35.4 x (0.24+0.07)}= PEN(26.7 KAF) = $11,070,855.

Steps 4 and 5 are repeated for different levels of reduced residential water delivery, $Q_{R\ i}$, to construct the piece-wise linear penalty functions. These calculations are then repeated for each month using appropriate monthly values.

Table B2-2. Urban Water Value Data Parameters and Example Data for Urban Area 90[a]

Data Parameter	Urban Area 90 Value	Explanation	Source
P_{1995}	$741/af[b]	weighted average residential water price in 1995 of major water purveyors within each represented 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 data by detailed analysis unit
PCU_{1995}	197 gpcd[c]	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 KAF[d]	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 projections by detailed analysis unit
PCU_{2020}	175 gpcd[c]	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 1994b
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 (1980-1990) of major water purveyors within each urban area	DWR 1994a
$m_{I,\,I}$	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] Urban Node 90 = Santa Clara Valley Water District, Alameda County Water District, and Alameda County Zone 7 comprising DAUs 44, 45, 62 and 30% of 47.
[b] acre-foot
[c] gallons per capita per day
[d] thousands of acre-feet
[e] 1991 dollars, Santa Clara County only

DISCUSSION

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

Limitations of the Demand Function Method

1. It is not possible to represent water demand functions for commercial and government sectors because empirical estimates of price elasticities are unavailable for these water users in California at this time. Thus, the way these water uses have been incorporated in the demand function will effectively prevent any shortages to their 2020 estimated use.
2. The residential 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. Those residential users who do not pay the retail price are insensitive to price changes. However, they have been aggregated with all residential water users. The value of urban water for spot market water transfers and purchases in a drought situation should be based on the short-run elasticity of demand. In the CALVIN model both long-term water allocations and short-term drought transfers are represented such that both long-run and short-run values of urban water are important to the analysis. By using long-run values, the urban economic benefits derived from water marketing and infrastructure alternatives examined with CALVIN will be lower bound estimates.
3. The difficulty of projecting elasticities and water prices in 2020 has obliged using the 1995 demand function as the basis for residential water values in 2020. With projected increases in the level of conservation, demand is likely to be more inelastic in 2020. Prices may also be higher in 2020 if water agencies are forced to pay higher costs for their water supplies. A higher price leads to a reduced demand in 2020 than projected from 1995 prices and demand.
4. The present (1990) portions of urban use by sector are assumed in 2020 because better information is unavailable at this time. While changes will occur specific to each area of California, there is currently no way to predict these changes.
5. Urban target demands in 2020 represent the average condition. However, demand actually varies with the hydrologic year-type, 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

1. 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.
2. The 2020 industrial target demand for an urban demand area in CALVIN is based on the portion of urban water used by industries in 1990 projected onto the total 2020 estimated water demand for this area. No better data is available to project changes in industrial water use state-wide in 2020. The computed 2020 industrial target demand is then associated with the CUWA (1991) production lost data for the county that overlaps most closely with the urban demand area. In some cases, counties and urban demand areas do not fully coincide.

However, it was not possible to partition out production by DAU from the CUWA county-level industrial data.

3. It is not possible at this time to construct a more realistic non-linear industrial penalty function because no production loss data were available for smaller magnitude shortages.

Clearly, there are many limitations to the methods. However, most do not bias the results in an obviously systematic way. The 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, as mentioned above, the urban economic benefits will be underestimated. In the latter instance, urban water allocations will be higher than they might be if commercial and government water values could be represented.

SUMMARY

This appendix has presented the methods, assumptions, and data used to generate economic values of urban water use for large-scale economic-based optimization of California's state-wide water system in CALVIN. Combined residential, commercial, and government sector estimated demand functions and industrial production losses from water shortages form the basis of the valuation methods. Limitations in the methods, assumptions, and data are examined. Most of these arise from lack of better comprehensive data across the state for such a large-scale model.

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