California Urban Water Demands for 2100

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January 2002

1. Introduction

The CALVIN urban economic value preprocessor model (see Appendix B, Jenkins et al., 2001) has been used to develop urban water demand functions across California to drive the optimization by the CALVIN model. These value functions are developed from current and projected estimates of population, per capita water use, sector water use breakdowns (residential, commercial/public, and industrial), industrial water production values, and monthly use patterns for each urban area, as well as from estimates of the seasonal residential price elasticities of demand and current retail water price for each urban area represented in CALVIN.

Population estimates are based on a spatially disaggregated projection of population for the year 2100 (Landis and Reilly, 2002). These spatial data, at county and California Department of Water Resources (DWR) detailed analysis units (DAU) scales, have been aggregated into the different CALVIN urban nodes.

Per capita water use has been estimated using a California DWR 2020 projection of per capita urban water use as a baseline (DWR, 1998a). The change in population density has been translated into a change in per capita water use (pcu) using linear regressions of cross-sectional data on observed population density and pcu for distinct climatic regions in California.

Projections of land use conversion from agriculture to urban and likely location of new housing developments allow urban projections to be consistent with agricultural land use assumptions.

After analyzing the new urban demand projections, new economic urban water demand areas have been added to the CALVIN network, mainly in the Central Valley and in some parts of southern California.

2. 2100 Projections of California’s Urban Demands

The projected population and spatial distribution of urbanized land are taken from Landis and Reilly’s study (2002) on California’s urban population and footprint projections through the year 2100.

In this study, we project the annual county-level population growth through 2100. A cross-sectional regression model relating county infill shares to remaining “greenfield” land is then used to project future infill and greenfield shares. Projected greenfield population growth is allocated to undeveloped sites in each region in order of development probability. These probabilities are taken from four regional spatial/statistical growth pattern models calibrated to historical development, and estimated for individual 1 ha sites. The four regional models cover the lower Sacramento Valley, the San Joaquin Valley, the Bay Area and Central Coast, and southern California. Using a geographic information system (GIS) allows representation of these spatial patterns of growth in new urban areas, which is aggregated at the DAU and county level.

As a result of Landis and Reilly’s study, projected population and urban land are available at the DAU level in 2100 for a “high” and “low” scenario. By further aggregation of DAU data, we obtain 2100 population and urban area for each CALVIN urban node. Figure B-1 compares the 2020 DWR population projections (currently used for estimating urban water demands in CALVIN for 2020) and the new 2100 “high”scenario projection. The largest percent increases in population, Table 1, take place in Mojave, Coachella, Blythe and El Centro in Southern California, and in several urban nodes within the Central Valley (CVPM 4, 8, 13, 17, 20). The urban areas´ aggregation in the Central Valley is derived from the urban water demands associated to each of the CVPM (or Central Valley Production Model) agricultural areas (USDI and USBR 1997).

3. Urban Water Demands Representation in CALVIN

The representation of California’s urban water demands in CALVIN can be categorized in three groups according to their size and the way in which their water supply sources are modeled (see Appendix B, Jenkins et al., 2001, for a detailed explanation of the three categories):

1. Demands excluded from CALVIN analysis. These demands are supplied by sources outside the intertied water system modeled in CALVIN.

2. Demands included in CALVIN as fixed diversions (type “TS,” for time series). Usually these are small demands represented as a fixed time series of deliveries.

3. Demands included in CALVIN as economic value functions. The model uses two approaches to represent these economic functions. The first approach combines all urban water use sectors and develops a single economic value function (type "CF," or combined demand function). The second approach separates industrial water use from residential and other water uses and develops two separate value functions (type "SF," or split demand function). See Appendix B, Jenkins et al., 2001, for a detail description of the methods, assumptions, and data used to develop the economic value functions, as well as file "*URBAN3 v4.xls*" in the Software and Data Appendices of Jenkins et al., 2001.

For this 2100 study, the third category includes not only the original 19 urban demand areas economically represented in CALVIN for 2020 but also 11 additional areas. These 11 areas have been added to this category because of their expected high growth in water demand for year 2100.

Per Capita Water Use Projections

Per capita water use has been estimated using the DWR 2020 projection of pcu by county as a baseline (DWR 1998a, DWR 1998b). That work assumed that urban water conservation options (BMPs, or best management practices) would be put into effect by 2020. The differences between the DWR 1995 baseline pcu (DWR 1998a, DWR 1998b), previously used in CALVIN, and the 2020 base levels reflects the influence of the saving assumptions for BMPs, socioeconomic change, and differential population growth on pcu in each region, according to DWR projections.

In this work, the 2020 pcu baseline has been adjusted for 2100 to consider the population density effect on pcu. The change in population density from 2020 to 2100 has been translated into a change in pcu by using linear regressions between observed population density and current pcu. Two regression equations have been calibrated: one for inland DAUs and the other for coastal DAUs (Figures 2 and 3). As noted in these figures, the population density effect is higher for inland DAUs; climatic differences are expected to result in higher outdoor water use in inland areas (higher landscape irrigation requirements, sometimes as much as 60% of annual residential water use) compared with coastal regions in California. This would make inland pcu more sensitive to changes in population density, because higher density implies a smaller landscaped area per person. Figure 4 displays the per capita water use for the different CALVIN urban nodes, obtained from the 2100 population (high scenario)-weighted average densities at the DAU level, under different pcu assumptions—the 1995 DWR pcus, the 2020 DWR pcus, and the regression-adjusted pcus, which are the values finally adopted for this study.

Other important factors affecting pcu are income effect, evolution of economic activities, and water pricing (for a discussion on the influence of these factors, see, for example, Baumann et al.

1998). Because it is difficult to make any type of extrapolation of these factors to the year 2100, we have found it more realistic to consider only the density effect over the 2020 pcu baseline.

4. Method for Generating 2100 Urban Penalty Functions

Urban monthly residential demand functions are generated from the available data and converted into penalty functions to drive the optimization model. The main steps in the generation of urban value functions are

1. Determination of year 2100 urbanized area and population at the DAU scale from Landis and Reilly's (2002) urbanized spatial footprint projections and population growth forecasts.

2. Grouping and mapping of DAUs into CALVIN urban nodes.

3. Projection of 2100 populations and urbanized land for DAUs outside Landis and Reilly's spatial footprint projection boundaries using the county-level population and urbanized land growth estimates (see details in *Filling_Gaps.xls* file). This approach has been applied to DAUs corresponding to CALVIN's economically represented urban nodes of Redding (DAUs 141 and 143) and Yuba (to DAU 167), and to DAUs in several other Central Valley urban demand areas in CALVIN (CVPM2, CVPM4, CVPM 5, and CVPM8).

4. Aggregation of the DAU's projected population and per capita water use data into CALVIN urban nodes. Per capita water use in each CALVIN node is obtained from the population-weighted average of the pcu of the DAUs composing that node.

5. Correction of data for DAUs that are split across CALVIN nodes.

6. Calculation of the annual water demand based on population and pcu.

7. Breakdown of demands by months and sectors. The demands are split into three sectors (residential, industrial, and others) according to statewide information available from DWR (1993). For each urban area, annual demand is disaggregated into monthly demands according to a monthly use pattern, derived from 1980-1990 statewide agency monthly municipal and industrial production data published in Bulletin 166-4 (DWR 1994). In urban demand areas with separate industrial value functions, an industrial average monthly use pattern (California Urban Water Agencies [CUWA], 1991) is applied to the industrial portion of the demand.

8. Using 1995 observed retail water prices and estimated seasonal price elasticity of water demand, the monthly penalty functions on water deliveries for each demand were generated for projected conditions. Prices for urban water are based on the 1995 California survey of residential water prices (Black and Vetch, 1995). Different long-term elasticity values are considered for winter, summer, and intermediate months (see references in Appendix B, Jenkins et al., 2001). No attempt has been made to adjust residential prices, elasticities or sector breakdown, and monthly use patterns from 2020 to 2100.

The penalty for any delivery less than the maximum demand equals the forgone benefit caused by water scarcity, equivalent to the area (integral) under the demand curve from the maximum demand (maximum = projected population times projected pcu) left-ward to the water delivery level. Commercial and governmental demands are assumed to be price insensitive. Therefore, the commercial and governmental target demand is added to the residential water delivery level to shift the penalty function to the right for each urban demand. The penalty function for industrial water demand is represented as a simple linear function of water shortages, using data for production losses for a 30% cutback in 1991 (CUWA, 1991). Figure 5 summarizes the information that the processor uses to generate the urban water penalty functions.

5. California’s Urban Water Demands for 2100 “High” Scenario

To compute 2100 urban water demand for each DAU, the adjusted 2100 pcu was multiplied by the 2100 population forecast. The DAU results have been aggregated at the CALVIN urban node level and a set of monthly penalty functions has been generated for each of the urban demands, following the steps described in the last section.

After analyzing the 2100 results, 11 more economically represented urban demands (that were represented previously as fixed diversions) have been added to the 19 original ones at the 2020 level of development, based on expected growth in water demand and the likely need for new water supplies to meet high growth. Figure 6 displays the projected 2100 “high” water demand for each CALVIN urban node compared to the 2020 urban water demands previously used in CALVIN (see Appendix B, Jenkins et al., 2001).

Tables 2 and 3 list the existing and new economically represented urban demand areas in CALVIN, respectively. Table 4 provides the DAU-level data for the urban demands newly represented with economic value functions for 2100. Table 5 lists the demands that remain as fixed diversions (all are small demands in the Central Valley), their aggregated DAUs, and their 2020 and 2100 urban water demand. Finally, Figure 6 displays the previous CALVIN urban water demands (year 2020 projection) and the final 2100 urban water demands for each urban CALVIN demand area.

For the three Metropolitan Water District (MWD) areas modeled in CALVIN (Central MWD, East and West MWD, and San Diego), the representation of the demands in the 2020 CALVIN model have been changed from the hydrologically varying representation used over the 72 year period (from October 1921 to September 1993) to average year representation for 2100 urban demands. The monthly use patterns for an average year are obtained from the historical average monthly pattern provided by MWD.

CALVIN urban demands for Antelope, Castaic Lake, Napa-Solano, Yuba, and Redding, which were previously represented as net demands in the CALVIN 2020 model (local supplies not modeled in CALVIN were deducted from these full target demand; see Appendix B, Jenkins et al., 2001), are now represented by their total target demand. These local supplies are explicitly represented as a fixed inflow time series.

A new demand has been created, Blythe, made up of Colorado River Hydrologic Region Planning Sub-Areas 02 and 03 (CR2 + CR3), given the high expected population growth in this area bordering the Colorado River. Likewise, Colorado Hydrologic Region Planning Sub-Area 05 (CR5) has been added to the original CALVIN 2020 San Diego urban node (DAU 120) for the year 2100.

Table 6 shows the total population and urban water demand values from the previous 2020 CALVIN study and from the 2100 projection.

6. Limitations

A number of limitations are contained in the 2100 urban water value functions estimated here for use in CALVIN. Most result from the difficulty in predicting changes in water use characteristics, patterns, and costs and values that could occur in the state by 2100. The most apparent limitations include:

1. CALVIN water demands functions for 2100 are developed assuming current seasonal estimates of the price elasticity of demand and the current retail water price; no adjustment is made for possible changes in either the price elasticity or the water prices.

2. No further BMPs in urban water conservation beyond those expected to be in place by 2020 (projections in DWR, 1998a) are added for 2100.

3. Bulk pcu projections for 2100 from 2020 estimates consider only the effect of increased population density on outdoor water use and ignore income effects that might occur as well as possible changes in the level of industrial, commercial, and public water use in different parts of the state.

4. The monthly pattern and amount of outdoor landscape water use in each urban demand area across the state in 2100 ignores the effects of climate change, holding these at the same values used in 2020.

5. The 2020 CALVIN scaled values for industrial water shortages at the county level (taken from 1991 surveys) are used unchanged in 2100. These values are given as dollar of production lost per fractional cutback in water availability from desired levels. Other estimates would require predicted changes in the level and type of industrial activity as well as changes in industrial water use practices by 2100.

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Table 1. Percent population increase from DWR 2020 projection to 2100 projection

Urban name	DWR 2020 population	2100 population	% population increment
Redding area	231,495	421,786	82
Yuba and others	210,450	442,266	110
Sacramento area	2,181,605	4,201,943	93
Napa-Solano	711,324	1,334,834	88
Contra Costa	565,353	896,486	59
East Bay Municipal Utility District (EBMUD)	1,326,460	1,961,825	48
San Francisco Public Utilities Commission (SFPUC)	1,501,900	1,987,120	32
Santa Clara Valley (SCV)	2,971,513	5,690,081	91
Santa Barbara–San Luis Obispo (SB-SLO)	713,675	1,534,167	115
Ventura	1,022,850	1,956,007	91
Castaic	688,500	1,156,443	68
San Bernardino Valley Water District (SBV)	878,944	1,016,582	16
Central MWD	15,645,756	25,321,581	62
East/West MWD	2,251,030	5,381,640	139
Antelope Valley	1,079,650	1,821,155	69
Mojave River	1,075,775	4,395,538	309
Coachella	628,820	2,477,594	294
San Diego	3,839,800	8,078,707	110
Stockton	421,575	904,601	115
Fresno	1,142,125	1,429,670	25
Bakersfield	612,100	987,108	61
El Centro and others	214,250	977,078	356
Blythe	58,800	889,500	1,413
CVPM 2	190,110	461,137	143
CVPM 3	42,275	125,008	196
CVPM 4	17,565	121,927	594
CVPM 5	358,800	371,47[a]	4
CVPM 6	894,299	368,680[a]	-59
CVPM 8	92,445	514,633	457

CVPM 9	391,700	753,932	92
CVPM 10	150,580	350,271	133
CVPM 11	653,980	1,277,364	95

Table 1. Percent population increase from DWR 2020 projection to 2100 projection (cont.).

Urban name	**DWR 2020 population**	**2100 population**	**% population increment**
CVPM 12	297,770	727,016	144
CVPM 13	422,150	1,263,670	199
CVPM 14	69,375	97,531	41
CVPM 15	216,200	349,507	62
CVPM 17	294,210	1,060,199	260
CVPM 18	534,140	1,369,290	156
CVPM 19	41,100	95,210	132
CVPM 20	156,675	823,226	425
CVPM 21	84,150	166,539	98
Subtotal	44,881,273	85,560,323	91
Total California	47,507,399	92,081,030	94

a. Changed with regard to CALVIN 2020 model (DAU originally shared with Yuba and Napa-Solano are transferred fully from CVPM 5 and CVPM 6 demands to Yuba and Napa-Solano, respectively).

Table 2. Existing economically represented urban demand areas in CALVIN.

#	CALVIN node name	DAUs included	2020 demand TAF/year	2100 demand TAF/year	Description of major cities, agencies, or associations
20	Yuba City and others	159, 168	63.83	116.33	Oroville, Yuba City
30	Sacramento Area	172, 173, 158, 161, 186	678.51	1,061	Sacramento Water Forum, Isleton, Rio Vista, PCWA, EID, W. Sacramento, N. Auburn
50	Napa-Solano	191, 40, 41	148.8	260.50	Cities of Napa and Solano Counties
60	Contra Costa WD	192, 70% of 46	134.80	145.60	Contra Costa Water District
70	EBMUD	70% of 47, 30% of 46	297.30	352.30	East Bay Municipal Utility District
80	SFPUC	43	238.01	264.50	San Francisco PUC City and County and San Mateo County service areas not in node 90
90	SCV	44, 45, 62, 30% of 47	657.70	927.90	Santa Clara Valley, Alameda County and Alameda Zone 7 WD
110	Santa Barbara-San Luis Obispo	67, 68, 71, 74, 75	139.20	268.70	Central Coast Water Authority
130	Castaic Lake	83	176.58	263.40	Castaic Lake Water Agency
140	SBV	44% of 100	282.52	285.10	San Bernardino Valley Water District
150	Central MWD	87, 89, 90, 92, 96, 114, 56% of 100	3,730.70	3,898.8	Mainly Los Angeles and Orange County portions of Metropolitan Water District of Southern California (MWD)
170	Eastern & Western MWD	98, 104, 110	740.04	1,245.7	Mainly Riverside County portion of MWD
190	Antelope Valley Area	SL3, SL4	283.30	420.4	AVEKWA, Palmdale, Littlerock Creek
200	Mojave River	SL5, CR1	354.90	1,396.97	Mojave Water Agency and Hi Desert Water Agency
210	Coachella Valley	CR4 (348, 349)	600.73	2,078.54	Dessert Water Agency, Coachella Valley Water Agency
230	San Diego MWD[a]	120 + CR5	988.12	1,660.04	all of San Diego County
240	Stockton	182	94.90	176.40	City of Stockton
250	Fresno	233	383.74	446.80	Cities of Fresno and Clovis
260	Bakersfield	254	260.50	382.20	City of Bakersfield
	Total		10,254	15,535	

a. Area expanded from 2020 CALVIN representation to include CR5.

Table 3. New 2100 economically represented urban demand areas in CALVIN.

#	CALVIN node name	DAUs included	2020 demand TAF/year	2100 demand TAF/year	Description of major cities, agencies, or associations
10	Redding	141, 143	79.4	145.6	Redding
120	Ventura	81	218.8	367.5	Oxnard (Camarillo, Ventura)
270	El Centro and others	all CR6	51.8	205.5	El Centro, Calexico, Brawley
280	Blythe and others[a]	CR2, CR3	-	239.9	Blythe, Needles
308	CVPM 8 Urban	180, 181,184	26.4	134.3	Galt
311	CVPM 11 Urban	205,206,207	231.7	379.19	Modesto, Manteca
312	CVPM 12 Urban	208, 209	109.6	292.3	Turlock, Ceres
313	CVPM 13 Urban	210-215	160.8	411.9	Merced, Madera
317	CVPM 17 Urban	236, 239,240	85.0	255.5	Sanger, Selma, Reedley, Dinuba
318	CVPM 18 Urban	242, 243	147.1	347.4	Visalia, Tulare
320	CVPM 20 Urban	256, 257	53.9	269.7	Delano, Wasco
	Total		1,164.5	3,048.8	

a. Excluded urban demand in 2020 CALVIN model.

Table 4. Data for demands with added economic function.

Calvin node no.	Calvin node name	DAUs	Population 1997	Population 2100	Change in population 1998-2100	Main growth center (city)	Current supply[a]	Increase in urban land 2020-2100 (ha)	Reduction in agricultural land 2020-2100 (hectares)	Reduction in agricultural water (TAF/y)	Possible new sources
10	Redding[a]	141	62,775	146,581	83,806	Redding	70% SW-30% GW	Not available	-	-	
10	Redding	143	83,930	275,205	191,275	Redding		Not available	-	-	
120	Ventura	81	716,176	1,956,007	1,239,830	Oxnard (Camarillo, Ventura)	71% SW; 21% GW	34,272	-	-	
270	El Centro	CR6	139,332	977,078	837,746	El Centro, Calexico, Brawley	100% SW	38,733	-	-	
280	Blythe	CR2	198	307,704	307,506	Blythe		16,246	-	-	
280	Blythe	CR3	29,677	611,671	581,994			24,255	-	-	
308	Urban CVPM 8	180	37,102	485,388	448,286	Galt	100% GW	7,504	-	194	
308	Urban CVPM 8	181	10,850	28,741	17,891			Not available	-		
308	Urban CVPM 8	184	361	504	143			0	-		
311	Urban CVPM 11	205	94,511	528,849	434,338	Manteca	100% GW	13,498	21,173	180	
311	Urban CVPM 11	206	229,925	743,501	513,576	Modesto	100% GW	11,119			
311	Urban CVPM 11	207	2,721	5,014	2,293			6			
312	Urban CVPM 12	208	203,822	723,559	519,737	Turlock, Ceres	100% GW	12,731	11,131	86	
312	Urban CVPM 12	209	2,257	3,457	1,200			0			
313	Urban CVPM 13	210	130,333	557,475	427,142	Merced	100% GW	16,671	34,671	270	
313	Urban CVPM 13	211	6,584	20,705	14,121			695			
313	Urban CVPM 13	212	5,542	110,506	104,964			5,122			

Table 4. Data for demands with added economic function (cont.)

Calvin node no.	Calvin node name	DAUs	Population 1997	Population 2100	Change in population 1998-2100	Main growth center (city)	Current supply[a]	Increase in urban land 2020-2100 (ha)	Reduction in agricultural land 2020-2100 (hectares)	Reduction in agricultural water (TAF/y)	Possible new sources
313	GW CVP13	213	48,647	415,809	367,162	Madera	50% SW, 50% GW	15,039	34,671	270	
313	GW CVP13	214	21,158	147,074	125,916			5,212			
313	GW CVP13	215	1,496	12,101	10,605			391			
317	GW CVP17	236	88,580	784,570	695,989	Sanger, Selma	100% GW	33,705	37,443	270	
317	GW CVP17	239	53,991	259,800	205,809	Reedley, Dinuba	100% GW	10,268			
317	GW CVP17	240	9,165	15,829	6,664			128			
318	GW CVP18	242	222,435	913,651	691,216	Viaslia, Tulare	100% GW	27,905	3,076	24	
318	GW CVP18	243	100,536	455,639	355,103			15,512			
320	GW CVP20	256	70,973	617,378	546,405	Delano, Wasco	100% GW	25,701	24,012	177	
320	GW CVP20	257	11,270	205,848	194,578			6,579			

a. SW = surface water supply; GW = ground water supply.

Table 5. Fixed diversion urban demand areas in CALVIN.

CALVIN node name	DAUs	2020 demand TAF/year	21000 demand TAF/year
Urban CVPM 2	142, 144	63.8	145.42
Urban CVPM 3	163	15.7	38.09
Urban CVPM 4	164, 165, 167	5.24	29.75
Urban CVPM 5	166, 170, 171[a]	112.1	77.33
Urban CVPM 6	162[a]	200.9	92.28
Urban CVPM 9	185	77.1	127.97
Urban CVPM 10	216	41.9	90.28
Urban CVPM 14	244, 245	17.4	22.48
Urban CVPM 15	235, 241, 246, 237-8	63.3	89.80
Urban CVPM 19	255, 259, 260	23.4	34.18
Urban CVPM 21	258, 261	25.8	48.99
Total		646.6	796.6

a. Changed with regard to CALVIN 2020 model (DAU originally shared with Yuba and Napa-Solano are transferred fully from CVPM 5 and CVPM 6 demands to Yuba and Napa-Solano, respectively).

Table 6. Total CALVIN 2020 and 2100 population and urban water demands.

	2020 projection	2100 projection	% increase
Population CALVIN	44,881,273	85,560,323	91
Population California	47,507,399	92,081,030	94
CALVIN urban water demand (maf/yr)	12.061	19.380	61

Figure 1. 2020 DWR and 2100 Population Projections.

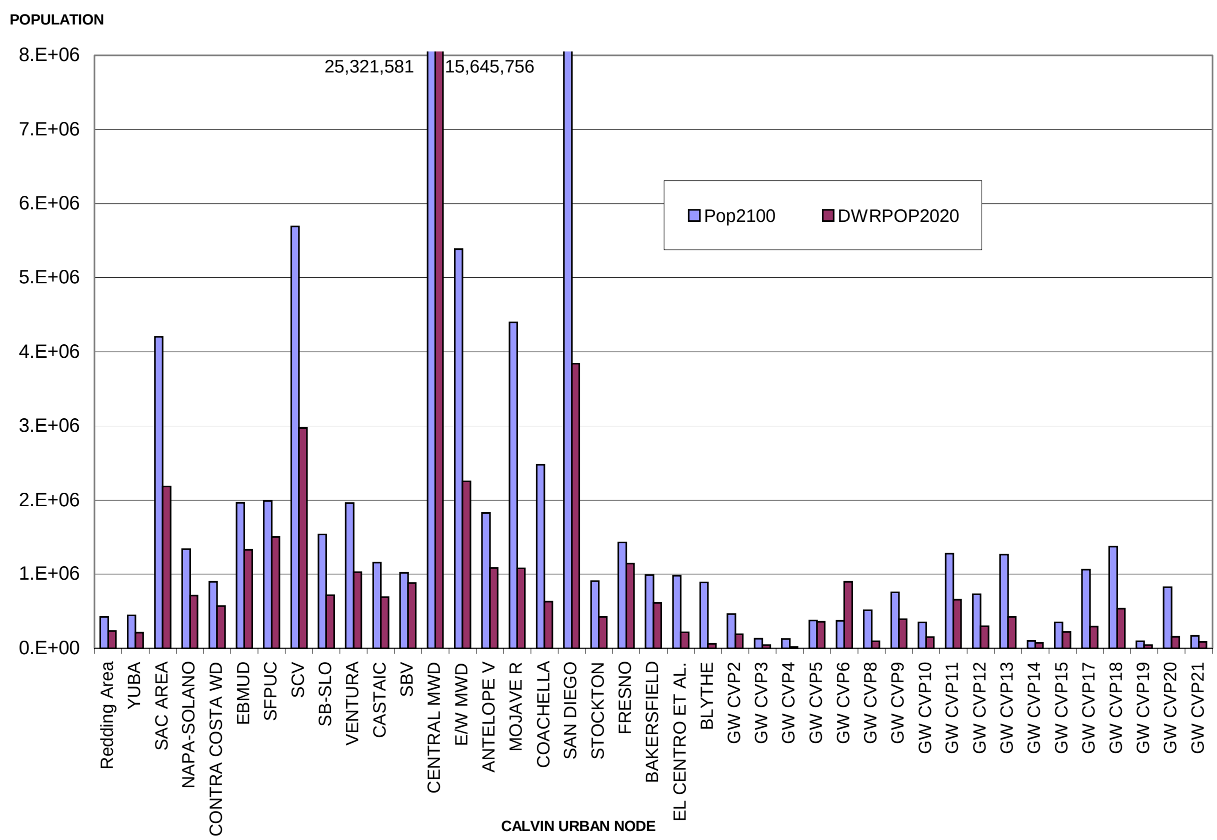

Figure 2. PCU versus Population Density Regression for DAU's in Coastal Areas.

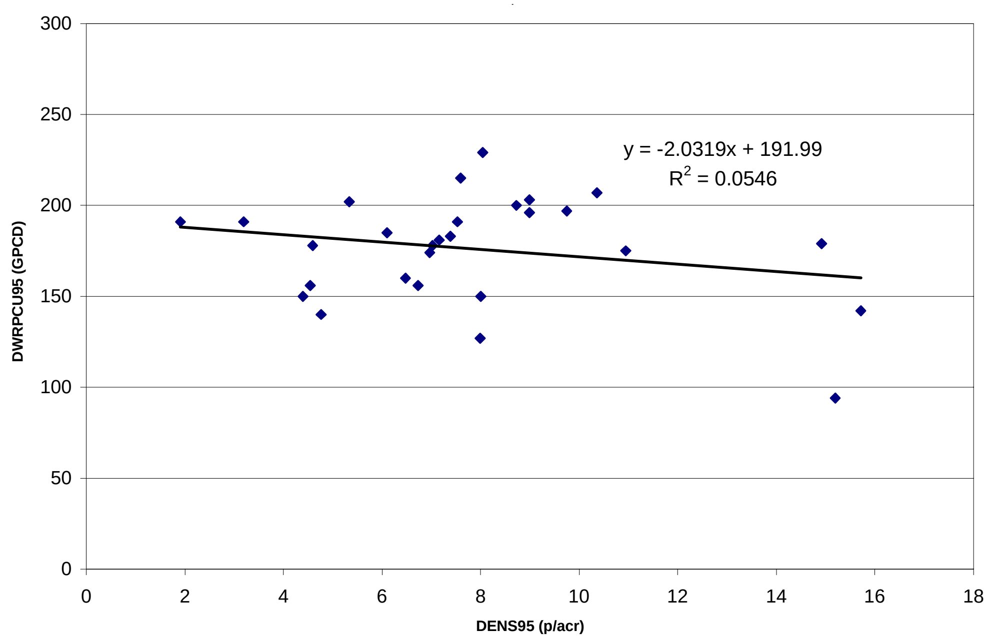

Figure 3. PCU versus Population Density Regression for DAU's in Inland Areas.

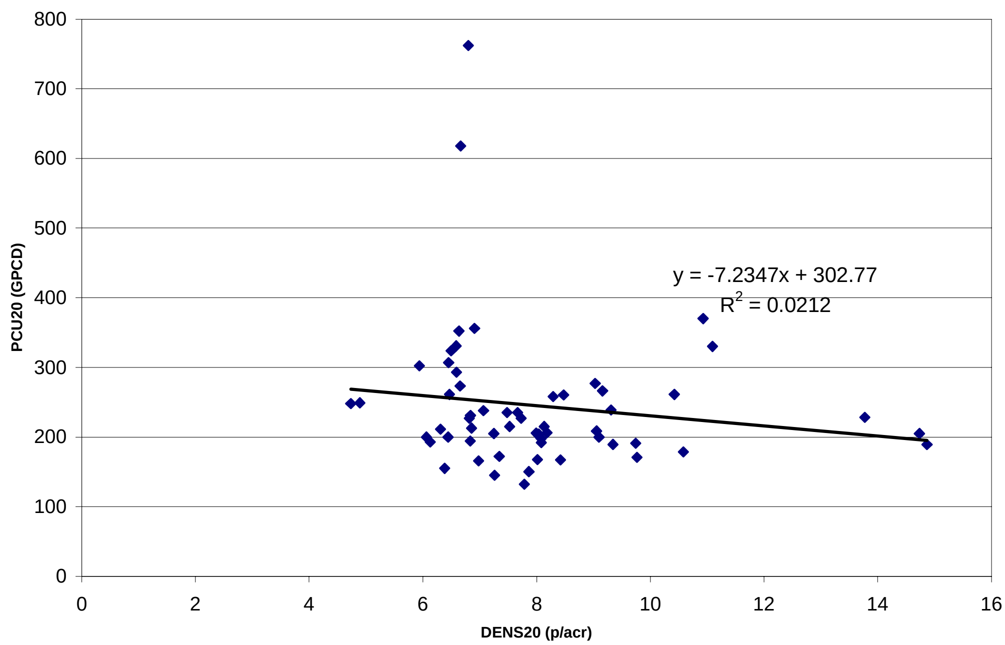

Figure 4. Per Capita Water Use comparison.

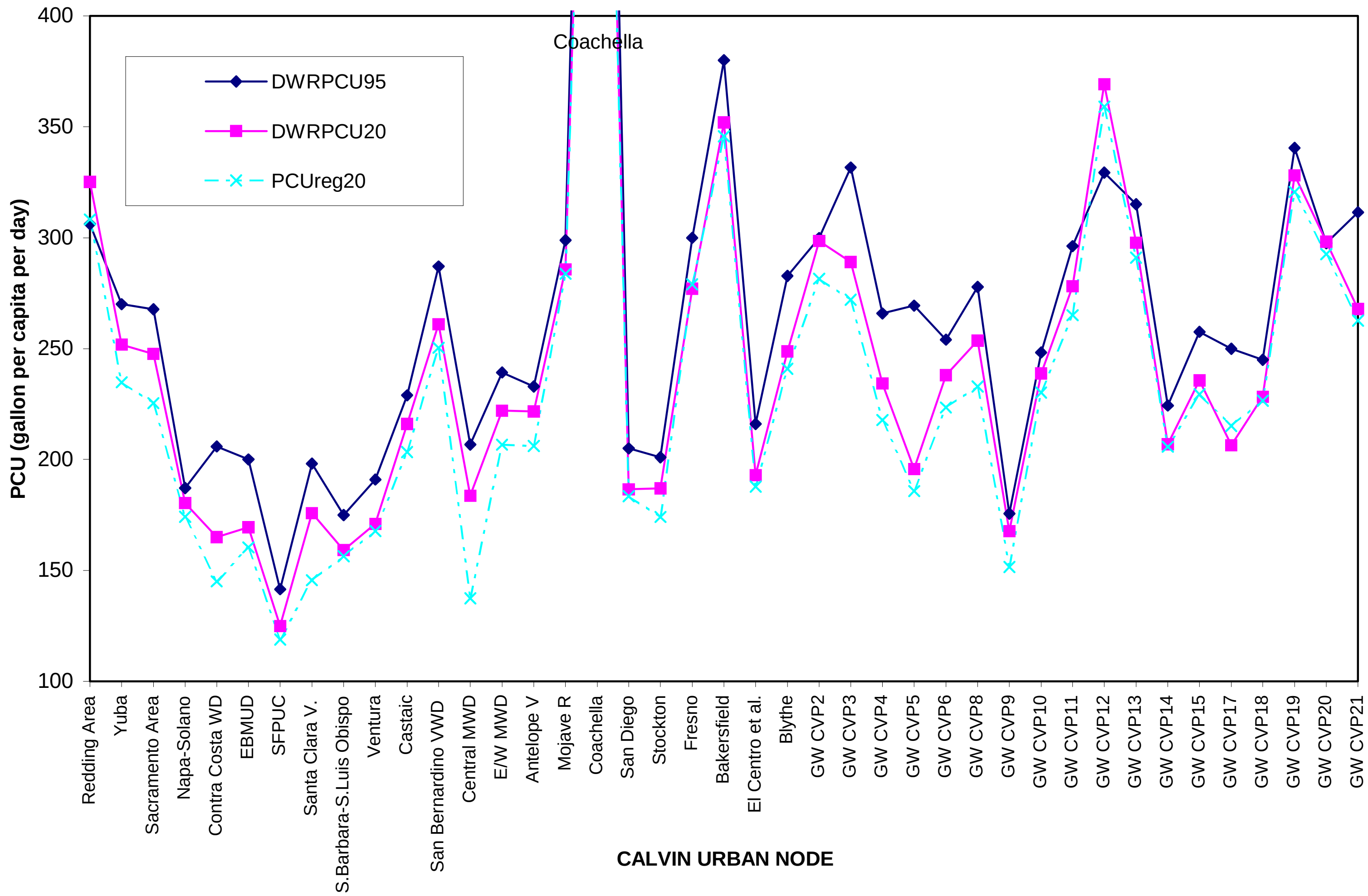

Figure 5. Generation of Urban Water Value Functions for CALVIN.

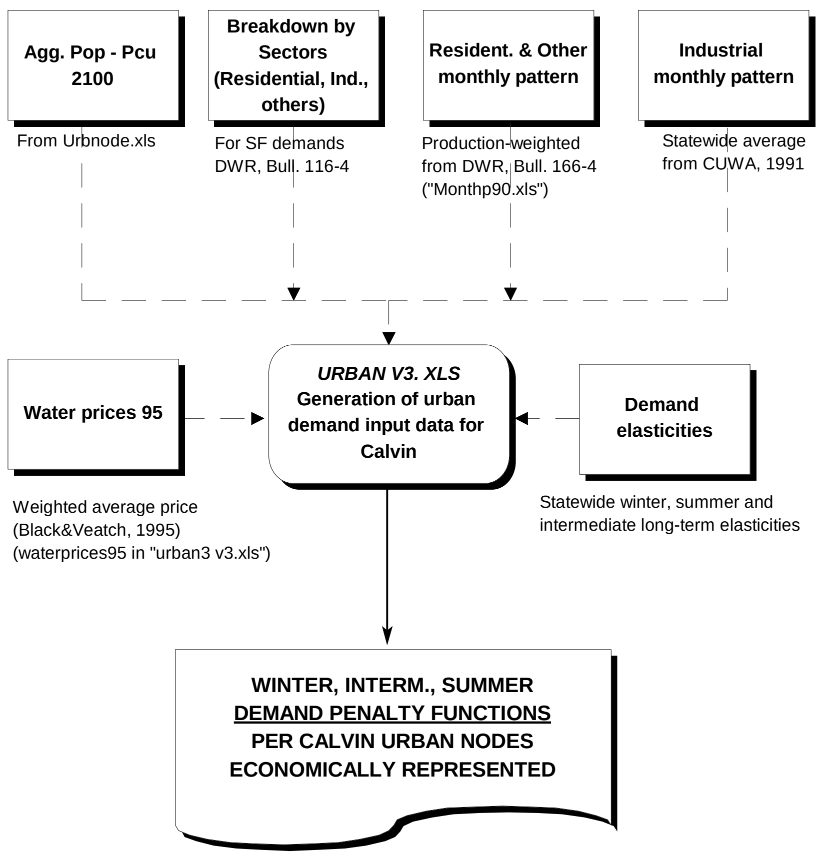

Figure 6 CALVIN 2020 and 2100 Urban Water Demands.