

Lawns and Water Demand in California

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SUMMARY

Over the next 25 years, California's population is expected to grow by some 11 million residents, with over half of this growth occurring in the hotter inland counties. This shift raises the prospect of substantial increases in urban water demand, especially for outdoor uses, because landscaping typically accounts for at least half of all residential water use in inland areas. Because water demand growth poses both financial and environmental challenges, many water utilities are now launching conservation programs to curb water use outdoors. In this issue of CEP, we examine the role of residential land use in the demand for water outdoors, with a focus on the water needs of cool-season turf grass lawns. We also explore the savings potential of some key water conservation tools.

Drawing on detailed residential housing data, we find that outdoor water needs for typical residential lots are likely to be more than two to three times higher in inland areas than along the coast. Although climate plays a role in this difference, residential land use patterns are far more important. Single-family homes, which typically use about twice as much landscaping water as multifamily units, make up a much larger share of inland housing. Inland areas also generally have larger lots, including a higher proportion of "ranchettes" (i.e., lots between one and 20 acres). Recent housing trends suggest some attenuation of these differences, with the rise of denser single-family tract developments in the Central Valley and the Inland Empire. But in contrast to the coast, where there has been a surge in multifamily housing since 2000, the inland region has seen multifamily homes continue to fall as a share of total housing.

Recent conservation efforts have aimed to lower outdoor water use by improving the efficiency of landscape irrigation and replacing some lawns with less thirsty plants. Field studies suggest that both strategies offer considerable potential for saving water. At the state level, there has also been renewed attention to the role of water rates, which often fail to provide residents with correct signals about the scarcity of water resources. Conservation-oriented water rates can play an important role in both new and existing neighborhoods. Our analysis also suggests that improved irrigation technologies may be cost effective in many parts of the state, even when water rates are relatively low. By contrast, "cash for grass" programs, which give homeowners rebates for replacing turf with drought-tolerant plants, are likely to pay off only if the new landscapes also

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Lawns and Water Demand in California

lead to substantial savings in garden supplies and labor. Promotional strategies to implement conservation include public education and outreach, customer rebates, and regulatory restrictions on landscaping options. Whether education and outreach will be sufficient to encourage new development to be “water smart,” or whether regulatory solutions are required, is still an open question.

Introduction

Without efforts to reduce per capita water use, California faces significant increases in urban water demand over the coming decades—a prospect that poses both environmental and financial challenges. Lawns are one of the biggest culprits. Outdoor water use often accounts for half or more of all residential water demand, especially in the hotter inland areas where population growth is now fastest. California’s inland counties are expected to accommodate over half of the 11.3 million new California residents anticipated over the next 25 years. In addition, an increasing share of growth is occurring in warmer inland areas of coastal counties.¹

Recognizing the water demand that this population growth will bring, water utilities are paying more attention to urban water conservation than ever before. Whereas conservation efforts during the 1990s focused mainly on indoor uses, the focus is now shifting to the outdoors. The policy toolkit includes a host of incentives and technological fixes to encourage residents to water their yards more efficiently and to landscape with low-water plants. To help spearhead these efforts, the legislature recently called for the creation of a Landscape Task Force, composed of stakeholders from the water and landscaping sectors, to evaluate and recommend proposals for improving the efficiency of water use in new and existing urban irrigated landscapes in California.

Landscape choices are considered key because Californians—like their neighbors in other semi-arid western states—have tended to use plants more suited to humid climates. The typical California lawn, a cool-season turf grass, can require several times more water than native plants. Inefficient watering systems, such as incorrectly timed automatic sprinklers, can significantly compound the problem, creating overwatered lawns and excess water spillage.² In addition to the resource costs associated with water waste, overwatering generates polluted run-off, which damages rivers, lakes, and coastal waters.

Lawns and Water Demand in California

Land use patterns also matter. Denser development—with more multifamily homes and smaller single-family lots—is typically also more water smart. On a per household basis, multifamily homes use half as much water outdoors as do single-family homes. Among single-family homes, those with larger lots typically use more water for landscaping.

This edition of CEP looks at a range of issues related to residential outdoor water use. Drawing on detailed residential housing data, we first assess whether housing patterns are reinforcing or extenuating the pressures posed by California's demographic shift inland. To determine patterns in outdoor water use, we examine differences across regions and over time in the composition of the housing stock (in particular, the share of multifamily homes) and in the size of single-family lots. We use the reference evapotranspiration rate—a measure of the amount of water required to maintain turf grass in different climatic zones—to estimate the water needs of typical yards across regions. Finally, we assess the potential for key elements in the conservation policy toolkit—including water pricing and various programs to improve irrigation efficiency and encourage the use of low-water plants—to reduce outdoor water use in different parts of the state.

human water use in the state in 2000.

The urban share has been growing over time; in 1980, it accounted for only 14 percent of the total (Department of Water Resources, 1983). This increase is not simply the result of population growth. Per capita use rose steadily throughout the latter half of the 20th century, with declines setting in only during the 1990s (Figure 1). Average urban per capita use was 185 gallons per day in 1960, 20 percent lower than in 2000.

The growth in per capita use probably reflects several factors. One is rising incomes, which tend to increase water demand, in part because of greater demand for water-using appliances (Baumann, Boland, and Hanemann, 1997). A second is residential lot sizes, which, as we shall see, increased over much of this period. A third is the faster rate of population growth in hotter inland areas, where water use is considerably higher. In 2000, inland water use averaged 355 gpcd compared to 195 gpcd along the coast.

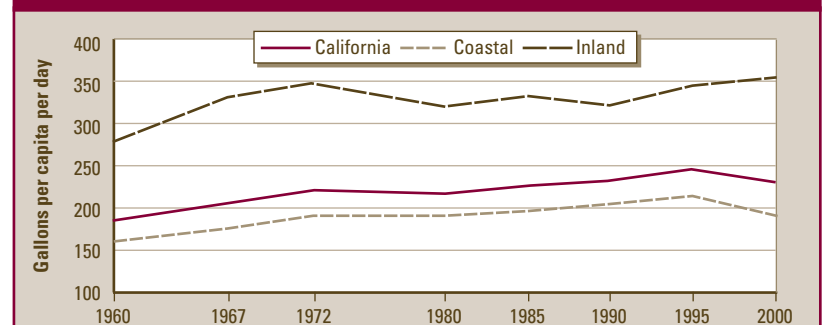
Even with continued efforts in conservation, total urban water use could grow significantly over

California's cities and suburbs used approximately 8.9 million acre-feet of water in 2000, or about 232 gallons per person per day.

Water Use and Population Growth in California

According to the Department of Water Resources (DWR) 2005 update of the *California Water Plan*, California's cities and suburbs used approximately 8.9 million acre-feet (maf) of water in 2000, or about 232 gallons per capita per day (gpcd).³ This total—often known as the “urban” water demand—includes all residential, commercial, governmental, and industrial uses, with residential uses constituting about two-thirds of the whole, or 5.8 maf. In the same year, California's farmers irrigated an estimated 9.6 million acres of cropland with 34.2 maf of water. Thus, urban uses accounted for 20 percent of total

Figure 1. Urban Water Use in California, 1960 to 2000 (gpcd)



Sources: Department of Water Resources (1966, 1970, 1974, 1983, 1987, 1994b, 1998, 2005).

Notes: “Coastal” includes the North Coast, San Francisco Bay, Central Coast, and South Coast hydrologic regions. “Inland” includes the Sacramento River, San Joaquin River, Tulare Basin, North Lahontan, South Lahontan, and Colorado River hydrologic regions. Although the individual regional classifications varied somewhat in earlier periods, the broad distinction between coastal and inland is fairly consistent over time.

the coming decades. The *California Water Plan's* “current trends” scenario anticipates demand growth by 3.0 maf between 2000 and 2030, despite a projected modest decrease in per capita use, from 232 to 221 gpcd. Southern California’s urban utilities will face additional needs because of requirements to reduce their use of Colorado River water by 0.8 maf.

Such levels of demand growth pose considerable challenges for California’s urban water utilities. Most new sources of water are relatively costly, and many options pose risks to the environment because of their effects on wildlife habitat. In principle, a good deal of urban demand growth could be accommodated by transfers of agricultural water rights to urban users, because agricultural water use

is expected to decline as a result of various market forces, including land development (Department of Water Resources, 2005). In practice, transfers are likely to account for only a portion of urban needs because of institutional and logistical constraints (Hanak, 2003). Among other alternatives, the *Plan* highlights urban conservation as one of the single largest sources of cost-effective “new” water to support growth.⁴

The *Plan's* estimates for outdoor residential use may be on the low side. One study of a cross-section of 12 U.S. cities found an average outdoor rate of 58 percent (Mayer et al., 1999). California’s Landscape Task Force concluded that outdoor use constitutes about half of residential demand in the state (California Urban Water Conservation Council, 2005). This share can be much lower in milder coastal zones and much higher in hot, dry, desert areas. The water provider for the Las Vegas Valley, located in the Mojave Desert, estimates that roughly 70 percent of residential demand goes to outdoor irrigation.⁶ Officials in Riverside County estimate that 80 percent of residential water in the Coachella Valley—an area with a similar climate—is used outdoors (Bowles, 2005).

Although a majority of California’s population still lives in the two main metropolitan coastal regions—the Los Angeles Basin and the San Francisco Bay Area—forecasts suggest that some of the biggest growth pressures in the coming decades will be in hotter inland areas (Table 1). California’s population is projected to grow by 11.3 million people between 2005 and 2030, and over half of that growth will occur inland—the Sacramento Metro region, the San Joaquin Valley, and the Inland Empire.

Residential Lot and Yard Sizes

Outdoor water use tends to rise with single-family lot sizes, because larger properties have larger yards. County assessor records make it possible to measure lot sizes for single-family homes in most of the counties in our main metropolitan regions (for details, see the web-only appendix, http://www.ppic.org/content/other/706EHEP_web_only_appendix.pdf). We define “yards” as lot size minus the building footprint. Because it is likely that residents with very large lots water a smaller portion of their yards, we have broken these data into small lots (one acre or less) and large lots (between one and 20 acres). Figure 2 presents the cumulative average lot sizes by region for single-family residences

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Growth Patterns and Outdoor Water Use

Because water meters do not generally track indoor and outdoor uses separately, the share of urban water used outdoors can only be estimated. The 2005 *California Water Plan* estimates that the residential sector used roughly 2.3 maf outdoors in 2000, or 42 percent of total residential demand. Parks, golf courses, and other “large landscapes” used another 0.7 maf.⁵ (The *Plan* did not separately estimate outdoor uses for commercial and industrial customers.)

Lawns and Water Demand in California

Table 1. Projected Population Growth in California Regions, 2005–2030 (millions)

Region	Counties	Population, 2005	Projected Growth, 2005–2030	Percent of Projected Growth
San Francisco Bay Area	Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, Sonoma	7.10	2.08	18.4
South Coast	Los Angeles, Orange, San Diego, Ventura	17.15	2.74	24.3
Sacramento Metro region	El Dorado, Placer, Sacramento, Yolo	2.04	1.37	12.1
San Joaquin Valley	Merced, San Joaquin, Stanislaus, Fresno, Kern, Kings, Madera, Tulare	3.73	2.19	19.4
Inland Empire	Riverside, San Bernardino	3.82	2.12	18.8
Rest of state	Alpine, Amador, Butte, Calaveras, Colusa, Del Norte, Glenn, Humboldt, Imperial, Inyo, Lake, Lassen, Mariposa, Mendocino, Modoc, Mono, Monterey, Nevada, Plumas, San Benito, San Luis Obispo, Santa Barbara, Santa Cruz, Shasta, Sierra, Siskiyou, Sutter, Tehama, Trinity, Tuolumne, Yuba	2.98	0.80	7.1
California		36.81	11.30	100

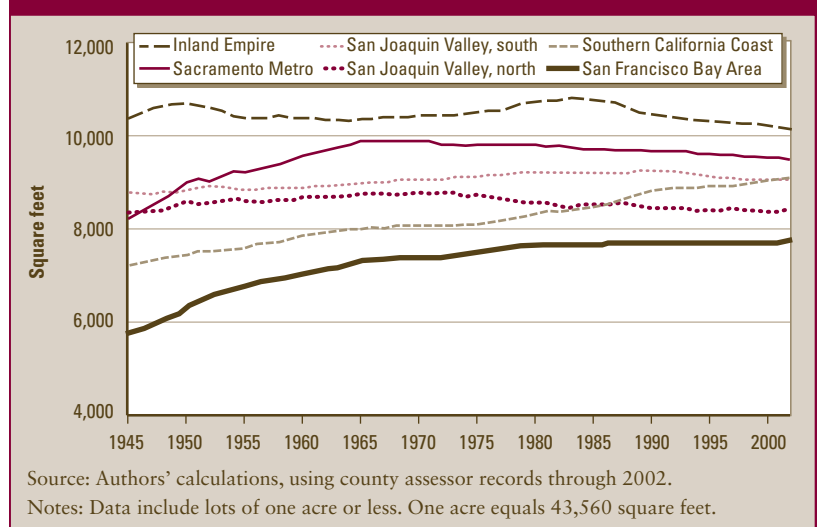
Sources: Department of Finance (2004, 2005).

on small lots.⁷ The San Joaquin Valley is split into two regions to isolate the effects of growth pressures that link its northern end to the Bay Area and its southern end to the population centers in Southern California.

As expected, lot sizes are smallest in the region with the highest land prices, the San Francisco Bay Area (7,697 square feet), and they are generally largest in the inland regions, notably the Inland Empire (10,176 square feet) and the Sacramento Metro region (9,515 square feet). What is surprising, however, is the steady upward trend in coastal lot sizes, particularly in Los Angeles and San Diego Counties. Lots in the South Coast (9,076 square feet) are now larger, on average, than those in the northern San Joaquin Valley (8,416 square feet) and nearly as large as those in the southern San Joaquin Valley (9,056 square feet).

Because the proportion of homes with more than one story has been on the rise, there has been

Figure 2. Cumulative Average Small Single-Family Lot Sizes by Region



Despite the recent policy attention to denser land use—often known as “smart growth”—California actually built many more multifamily homes in the 1960s and 1970s than it does today.

relatively little increase in average building footprints (estimated as the building size divided by the number of stories), even though home sizes have been steadily increasing.⁸ Thus, the general patterns for yard sizes are similar to those shown in Figure 2.

Meanwhile, lots between one and 20 acres, often called ranchettes, remain an important component of California’s

residential landscape (Figure 3). The shares of these lots are lowest in the two coastal regions and also relatively low in the northern San Joaquin Valley, which appears increasingly influenced by Bay Area housing patterns. Ranchettes average around three acres in size but somewhat higher in the Sacramento region (4.7 acres). They are particularly prominent in some counties—Napa and Sonoma in the Bay Area, El Dorado and Placer in the Sacramento Metro region, Kern in the southern San Joaquin Valley, and San Diego in the South Coast.⁹

The share of multifamily housing is another important factor in the outdoor water use equation. Because they share common outdoor space,

multifamily homes use considerably less water outdoors than do single-family residences. Despite the recent policy attention to denser land use—often known as “smart growth”—California actually built many more multifamily homes in the 1960s and 1970s than it does today (Figure 4). Although the share of multifamily housing has increased since 2000, this is mainly a coastal phenomenon. In the hotter inland regions, the overall shares are much lower (Figure 5). As we shall see, these housing trends have a marked effect on outdoor water needs in different parts of the state.

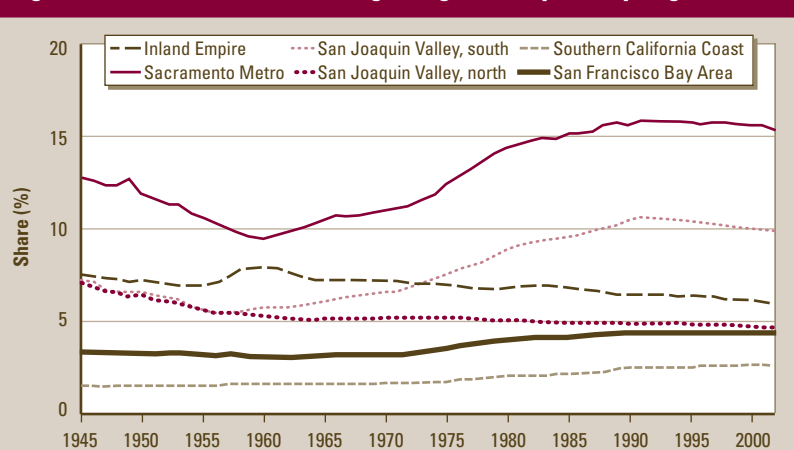
Climate Zones and Housing Trends

Because hotter climates increase water needs for any given lot size, we reclassified the housing data by climatic zone. These zones are based on evapotranspiration rates for the typical California lawn. Evapotranspiration (ET) is the rate at which plants lose water through evaporation from soil and plant surfaces and transpiration through plant canopies. “Reference evapotranspiration” (ET_0) rates provide a measure of the water needed by cool-season turf grass. Thus, ET_0 rates give a measure of the baseline water needs of a typical California lawn in different parts of the state. We assigned each Census tract to one of 18 ET_0 zones, using maps provided by DWR. For purposes of presentation, we consolidated the 18 zones into four “superzones”: Coastal, Inner Coastal, Central, and Desert (Figure 6).¹⁰

The differences across zones are significant. In the Coastal zone, a square foot of cool-season turf grass will require 28 gallons of water or less per year. In the Desert zone, the same patch of grass will need 37 gallons of water or more. The differences are even more pronounced during the dry summer months, when irrigation needs are highest (Figure 6).

These evapotranspiration zones provide a much finer breakdown of climatic differences than do regional and county boundaries. Whereas climates

Figure 3. Cumulative Share of Large Single-Family Lots by Region



Source: Authors’ calculations, using county assessor records through 2002.

Note: Data include lots between one and 20 acres.

Lawns and Water Demand in California

in some regions appear relatively homogeneous (for instance, the Sacramento Metro region and the northern San Joaquin Valley fall entirely within the Central zone), other areas display a great deal of variation. Los Angeles County, for example, spans the entire spectrum from mild coastal to harsh desert climates (for details on individual counties, see the web-only appendix, http://www.ppic.org/content/other/706EHEP_web_only_appendix.pdf).

As of the 2000 Census, 33 percent of the state’s population resided in the Coastal zone, 43 percent in the Inner Coastal zone, 19 percent in the Central zone, and 4 percent in the Desert zone. However, housing production in the Central and Desert zones is growing fast (Figure 7). Nearly 39 percent of the units built in the 1990s were in these two zones, up from 32 percent in the 1980s and just 26 percent in the 1970s. Housing production in the Central zone has now eclipsed production in the Coastal zone. Single-family lots are 60 percent larger in the Desert zone than in the Coastal zone, and large lots are still far more preponderant in the hot inland zones. In addition, the share of multifamily homes recorded by the 2000 Census reads, in inverse order of climate conditions: Coastal (40.1%), Inner Coastal (33.6%), Central (21.1%), and Desert (20.4%).

Implications for Outdoor Water Demand

Clearly, land use differences across climatic zones appear to be reinforcing the pressures of the demographic shift inland. Despite some signs of inland densification—declines both in lot sizes and in the share of ranchettes—inland areas have lower shares of multifamily homes, higher shares of ranchettes, and higher average lot sizes than does the coast. What do these land use trends mean for outdoor water use?

Theoretical Water Needs

To get a sense for outdoor water demand, we estimated the average water requirements for cool-

Figure 4. Statewide Trends in Multifamily Construction, 1940–2004

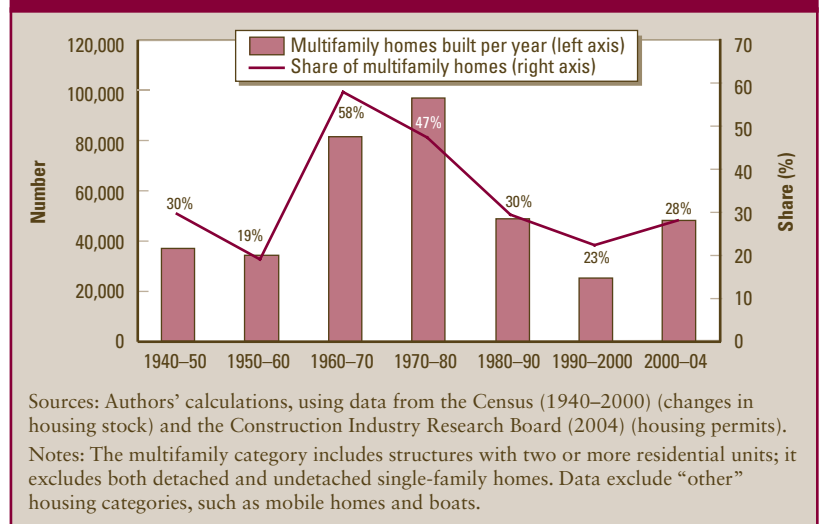
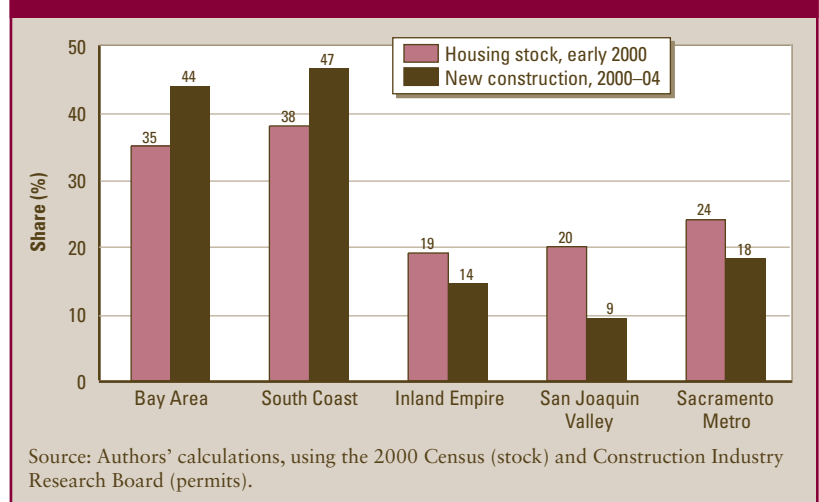


Figure 5. Regional Shares of Multifamily Homes in Housing Stock and New Construction



season turf grass, our ET_0 crop. Table 2 provides these estimates for small single-family lots by region and by ET_0 superzone. We assume that households irrigate 35 percent of their yard, with the remainder covered either in hardscape or in non-irrigated landscape.¹¹ Across regions, this amounts to an average irrigated area in the range of 2,000 to 3,600 square feet. Average water requirements are obtained by multiplying this area by average ET_0 rates.¹²

Lawns and Water Demand in California

Figure 6. Evapotranspiration “Superzones”

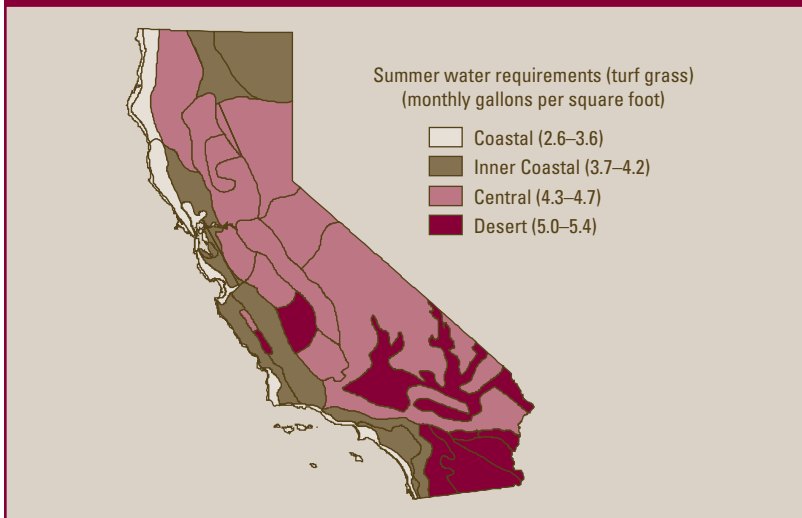
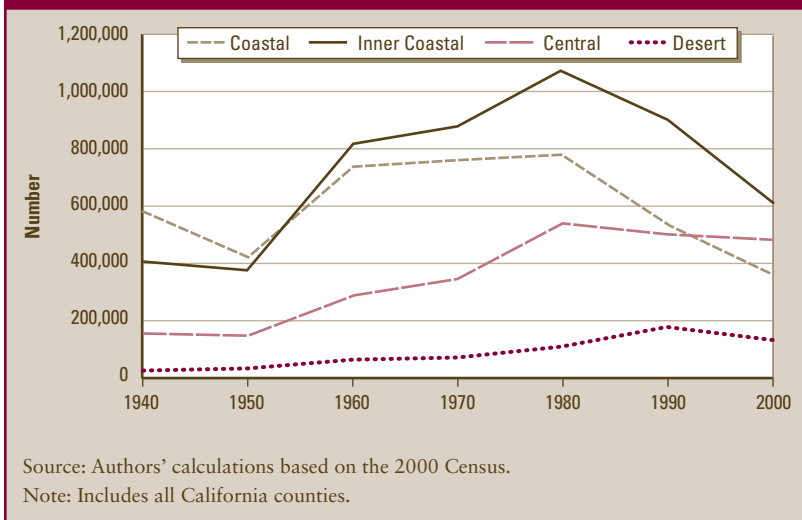


Figure 7. Units Built by Decade by ET₀ Superzone



Because of larger lot sizes and drier climates, the amount of water lost through evapotranspiration from a typical grass lawn is much greater in California's inland areas. In the Coastal zone, a typical single-family lawn requires 0.17 acre-feet per year, whereas its Desert zone counterpart needs nearly three times as much.

With some additional assumptions, we can apply this same framework to the entire housing stock, incorporating ranchettes and multifamily

lots (Table 3). For ranchettes, we assume only 10 percent irrigated landscaping, corresponding to an average area of roughly one-quarter of an acre.¹³ For multifamily homes, we assume that outdoor water use is half the single-family average.¹⁴ These estimates imply that California households irrigated a total of just under 633,000 acres in 2000.¹⁵

For the most part, incorporating these additional housing stock characteristics exacerbates the differences in regional water needs described in Table 2. Water needs decrease in the Bay Area and the South Coast and in the corresponding climatic zones (Coastal and Inner Coastal)—a benefit of the high share of multifamily homes. Elsewhere, the effect of large lots dominates. This effect is most striking for the Sacramento Metro region, where ranchettes are most common: The average household's outdoor water needs increase by 60 percent. For the Central and Desert zones as a whole, these needs increase by 20 to 30 percent. Water requirements in these zones are more than two to three times greater than on the coast.

Because climate and land use are working in the same direction, it is useful to see how much each factor contributes to these regional differences. Figure 8 compares estimated water needs in inland zones with the water needs these zones would face if they shared the more compact housing patterns of the coast. Actual land use patterns account for a substantially greater share of the additional water needs than climate does. In the Central and Desert zones, land use—not climate—is the clear driver, accounting for four-fifths of the total increase relative to the Coastal zone.

Recent changes in land use may be shifting outdoor water needs. To track this trend, we compared the water needs of homes built between 1991 and 2000 with the needs of the 1990 housing stock. Figure 9 shows these comparisons, with new housing needs expressed as a percentage of the needs of homes already built by 1990. To isolate the effects of lot size and composition, we applied the ET₀ rates for older homes to the new housing.

For single-family homes of one acre or less, denser tract development in the four inland regions

Lawns and Water Demand in California

Table 2. Average Water Requirements of Turf Grass for Small Single-Family Lots

Region	Yard Size (square feet)	Weighted Average ET ₀ (inches/year)	Annual Water Requirements (acre-feet)	% Increase over Region with Lowest Need
San Francisco Bay Area	6,308	45.9	0.19	—
South Coast	7,623	49.8	0.25	31
San Joaquin Valley, north	7,060	54.4	0.26	33
San Joaquin Valley, south	7,711	56.2	0.29	50
Sacramento Metro region	8,129	56.8	0.31	59
Inland Empire	8,858	56.2	0.33	72
ET₀ zone				
Coastal	6,019	42.6	0.17	—
Inner Coastal	7,930	51.9	0.28	60
Central	7,687	56.0	0.29	68
Desert	10,349	66.7	0.46	169

Table 3. Average Water Requirements of Turf Grass for Residential Lots

Region	Small Single-Family Lots		Large Single-Family Lots		Multifamily Lots	Average Annual Water Requirements	
	% of All Lots	Average Yard Size (square feet)	% of All Lots	Average Yard Size (square feet)	% of All Lots	Acre-Feet per Household	% Increase over Region with Lowest Need
San Francisco Bay Area	61.2	6,308	2.8	139,855	36.0	0.19	—
South Coast	59.1	7,623	1.6	119,824	39.3	0.22	16
San Joaquin Valley, north	76.1	7,060	3.7	134,766	20.2	0.27	46
San Joaquin Valley, south	67.8	7,711	7.4	152,849	24.8	0.36	89
Sacramento Metro region	63.8	8,129	11.5	203,920	24.7	0.50	165
Inland Empire	74.6	8,858	4.7	127,035	20.7	0.35	85
ET₀ zone							
Coastal	58.7	6,019	1.1	127,382	40.1	0.15	—
Inner Coastal	64.4	7,930	2.0	111,147	33.6	0.25	67
Central	71.4	7,687	7.5	175,058	21.1	0.38	158
Desert	70.0	10,349	9.6	144,556	20.4	0.55	276

Figure 8. Effects of Climate and Land Use on Outdoor Water Needs of Turf Grass

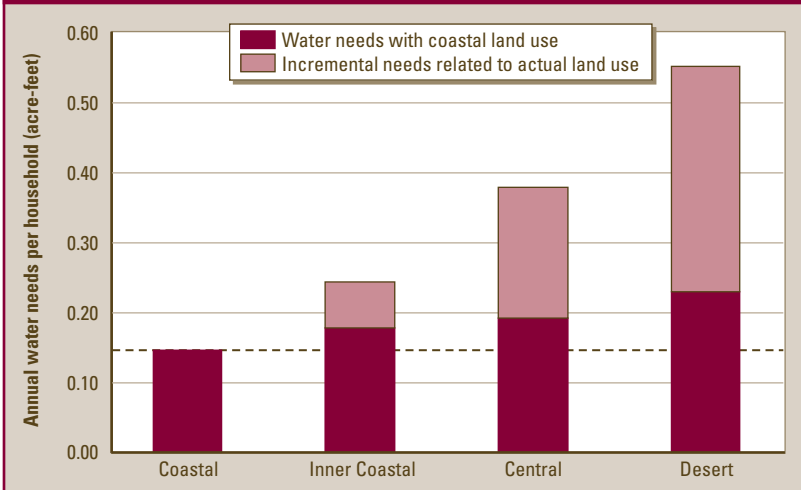
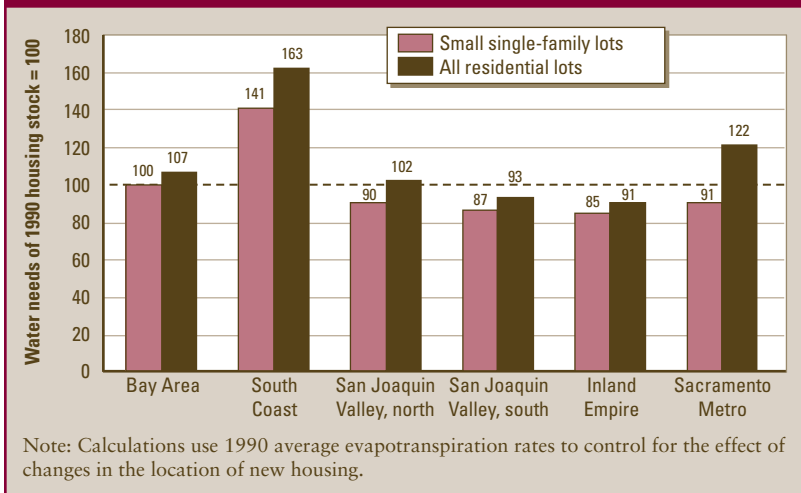


Figure 9. Comparison of Outdoor Water Needs for Homes Built During the 1990s and Older Homes



has reduced landscape water needs for new homes by 9 to 15 percent compared to the older housing stock. The opposite is true in the South Coast, where single-family lots have been getting larger.

The picture changes somewhat when we take into account all types of new housing combined. Some of the inland savings disappear, and water needs increase substantially in the South Coast and in the Sacramento Metro region. One factor is the declining share in new construction of multifam-

ily housing in the 1990s, which occurred in every region. But an even bigger factor is the growing role of large lots. They rose slightly as a share of all housing in three regions (Sacramento Metro, South Coast, and the Bay Area), and they increased in average size everywhere. For the South Coast, the overall result is a profile of new housing with potential landscape water needs over 60 percent above the level in 1990. In the Bay Area and the South Coast, these needs have also increased somewhat because newer housing has located in warmer areas.¹⁶ These trends have reduced some of the differences in water needs between coastal and inland regions.

Actual Water Needs

Of course, these figures provide only a “guesstimate” of households’ actual outdoor water use. In practice, there is considerable variation in the proportion of yards that are watered, and not everyone plants only cool-season turf grass, our baseline crop.¹⁷ Moreover, irrigation practices can differ widely. The ET_0 rates for turf grass allow for a lush, thick lawn, several inches high. In practice, experts assume that residential lawns can get by with about 80 percent of the ET_0 requirements.¹⁸ However, the ET_0 rates also assume that no water is wasted, either in making the ground soggy or in spilling onto sidewalks and streets. Such waste results in a level of irrigation efficiency—the share of water actually used by the plant—below 100 percent. Many residences and businesses still fall well below the existing statewide standard for landscape irrigation efficiency of 62.5 percent.

The amount of water a plant actually needs (sometimes known as the “ET adjustment factor”) can be summarized in this fashion:

$$\text{ET adjustment factor} = \frac{\text{plant's ET requirement}}{\text{irrigation efficiency rate}}$$

Thus, a residential lawn with an 80 percent ET requirement, irrigated at 80 percent efficiency, needs 100 percent of its baseline water needs (the ET_0). If irrigation efficiency is lower, the actual water

Table 4. Landscape Water Needs with Different Plant Types and Irrigation Efficiencies

Irrigation Efficiency	Average Plant ET Requirement				
	High Water (80%)	Medium Water (50%)	Low Water (20%)	50% High 50% Medium (65%)	1/3:1/3:1/3 ^a (50%)
50%	160	100	40	130	100
62%	129	81	32	105	80
70%	114	71	29	93	71
80%	100	63	25	81	62

Note: Numbers are expressed as a percentage of reference evapotranspiration.
^a1/3:1/3:1/3 denotes a mix of one-third each high-, medium-, and low-water-using plants.

needed is greater than 100 percent. If it is higher, or if the plant mix is less thirsty, the actual water needed falls below 100 percent. Table 4 summarizes this relationship for some benchmark plant types and irrigation efficiency rates.

Cool-season turf is a typical high-water-using plant. (Warm-season turf grass, still not very common in California, has an ET requirement of 60 percent.) Various landscape alternatives, including shrubs and trees, fall into the medium category, and many native species are low water users. A conventional residential mix might be half cool-season grass and half trees and shrubs, for an overall ET requirement of 65 percent.¹⁹ Using California’s irrigation efficiency standard of 62.5 percent, such a yard would require 105 percent of the ET₀ shown in Tables 2 and 3. We estimate that the average for California yards in 2000 was in the range of 106 to 127 percent of the ET₀.²⁰

In a normal year, rainfall during the cooler winter months can generally cover about a quarter of these needs, and the balance must be made up with irrigation. In dry years, which are no stranger to California, landscape water needs are typically higher. Because supplies are also scarcer in such times, droughts often lead utilities to impose outdoor watering restrictions.

Looking ahead, there is a strong possibility that climate warming will increase plant water needs in California—particularly in the hotter inland areas,

where average temperatures are predicted to rise considerably (Hayhoe et al., 2004). Climate change is also expected to put greater pressures on water supplies by reducing the amount of water stored in the Sierra Nevada snowpack.²¹ These shifts will raise the importance of efforts to curb outdoor water use.

Conservation Strategies

As the preceding analysis makes clear, land use patterns can have a tremendous effect on the potential outdoor water needs of the residential sector. Smart growth land use mixes that achieve higher density can truly be water smart. However, most approaches to outdoor conservation focus on ways to reduce water use with existing land use patterns. The following four strategies provide different paths toward water-smart yard maintenance and greater outdoor water conservation.

Water Pricing

One overarching tool that is gaining renewed attention is water pricing. There are four general kinds of rate structures: flat, declining block, uniform, and

Smart growth land use mixes that achieve higher density can truly be water smart. However, most approaches to outdoor conservation focus on ways to reduce water use with existing land use patterns.

Lawns and Water Demand in California

increasing block. Flat water rates—which do not vary by the amount of water used—are still common in the Central Valley, much of which remains unmetered. Declining block rates, which essentially offer a bulk discount to heavy water users, are now rare. Most residential lots in California are subject to uniform rates—which charge the same amount for every gallon—or increasing block rates—which charge more per gallon for higher levels of use (Hanak, 2005). (Seasonal pricing, under which rates are increased during the summer months of peak demand, is rarely used in California.) Since 1991, the California Urban Water Conservation Council has encouraged the adoption of “conservation pricing”—with rates set as close as possible to the utility’s own long-run marginal cost of water, using either uniform or increasing block rates.²²

Although water is a relatively “inelastic” commodity, recent evidence suggests that consumers are more sensitive to water prices than previously thought.²³ It appears that price sensitivity is higher when customers face increasing block rates rather than uniform rates.²⁴ Customers also appear to be more sensitive to prices for outdoor than indoor uses (Mansur and Olmstead, 2006). These findings suggest that increasing block rate structures may be better than uniform rates at encouraging conservation—and that pricing can be an especially important outdoor conservation tool. (Flat rates, in contrast, offer no incentive to conserve.) Increasing block rate structures also have a built-in equity component, given that larger lots and higher water use within an area are generally associated with higher-income households.

To see how water rate structures interact with residential land use patterns, we matched our single-family lot data with water rate data for the four-fifths of our sample residing within the service areas of large utilities (Table 5).²⁵ As the table makes clear, water rates are least conducive to

conservation in some of the state’s hottest areas. However, flat and declining rate structures do not appear to be encouraging larger average lot sizes; lots are actually largest in the Central and Desert zone communities with increasing block rates.²⁶

Increasing block rate structures are most prevalent in the Coastal and Inner Coastal zones, where water authorities have been more active in state-wide conservation programs. Many utilities adopted these rate structures following the early 1990s drought. However, there has been little progress in shifting to increasing block rate structures or away from flat rate structures since the mid-1990s (Hanak, 2005).

Recent efforts to put conservation pricing back on the front burner come from two quarters. One is the Landscape Task Force, which developed new conservation pricing guidelines to encourage utilities to send more accurate price signals to customers.²⁷ The other is the California legislature, which has been pushing utilities with flat rates to convert to metering. After more than a decade of political wrangling, the legislature passed AB 2572 in 2004, which requires that all utilities with 3,000 or more customers install meters over the next two decades and begin using installed meters for billing by 2010. (Since 1992, builders have been required to install meters in new homes, but utilities have not been required to read them.) Some communities are starting to see the potential conservation benefits of this change: For instance, the fast-growing town of Lodi aims to finish installing meters long before the 2024 deadline, to realize conservation savings sooner (Hood, 2005).

Smart Sprinklers

Automatic sprinkling systems are popular because they are more convenient than manually operated hoses or sprinklers. The problem is that they often operate for too long or at times when watering is not needed. (As a rule of thumb, these systems operate with an irrigation efficiency rate of 50 percent or less.²⁸) Rather than encourage people to go back to manual systems, many utilities are looking to address this problem by promoting “ET” or

Although water is a relatively “inelastic” commodity, recent evidence suggests that consumers are more sensitive to water prices than previously thought.

Table 5. Average Small Single-Family Lot Sizes by Water Rate Type

ET ₀ Superzone	Flat		Declining Block		Uniform		Increasing Block	
	Average (square feet)	% of Lots	Average (square feet)	% of Lots	Average (square feet)	% of Lots	Average (square feet)	% of Lots
Coastal	7,617	0	16,711	0	7,202	43	7,327	57
Inner Coastal	n/a	0	10,913	0	8,905	44	9,351	56
Central	8,306	49	8,266	6	8,051	29	10,083	16
Desert	9,429	2	n/a	0	10,929	62	11,709	37
Total	8,308	7	8,324	1	8,396	42	8,727	50

Source: Authors' calculations, using county assessor records through 2002.

Notes: Percentages show the share of homes in each climatic zone with each type of rate structure. Data include lots of one acre or less.

“smart” irrigation controllers, which automatically adjust watering times based on plant cover and weather conditions. Smart controllers can operate either with on-site weather sensors or with communication links to a centralized weather-monitoring system.²⁹ Previously limited to large commercial or public landscapes, smart controllers are now available to residential customers through rebate programs in several water districts.

Field studies have shown that smart controllers can reduce residential water use considerably. In 2000, the Irvine Ranch Water District (IRWD) retrofitted 33 high-water-using homes with ET controllers.³⁰ After two years, these homes had reduced their total water consumption by 41 gallons per household per day—approximately 18 percent of outdoor water use. In 2002, several water districts targeted high residential water users in Santa Barbara County. By 2003, 62 customers had switched to ET controllers, and preliminary results indicate that their average total water use has gone down by 26 percent.³¹ The Metropolitan Water District of Southern California (MWDSC), the large wholesale utility serving much of Southern California, estimates that smart controllers, in conjunction with highly efficient spray nozzles, could reduce outdoor residential water use by 28 percent within its service area.³²

If ET controllers can save this much water, are they a good investment? To find out, we calculated

the cost of saving water in different regions, using the savings rates obtained in field trials. Table 6 presents consumer and utility costs under some different scenarios. The calculations assume the use of a new, smart controller in a typical small lot in each of the four climatic zones, currently planted half turf and half shrubs and trees and being watered at 50 percent irrigation efficiency.³³

The top panel of the table shows scenarios for water savings and customer costs. For the cost of the ET controller itself, the “low” alternative is for purchase and professional installation of an on-site sensor system and the “high” alternative is for a satellite system, which has a higher up-front cost and a monthly subscription fee.³⁴ These costs are shown spread out over 15 years (the estimated life of the controller), both with and without utility rebates of \$180 to \$220 per system.³⁵ The table’s bottom panel shows the water costs to utilities and the potential water bill savings for customers. Utility costs are expressed as the investment costs of procuring this “new” water through the rebate program, again on the assumption that the savings are available for only 15 years. We include an allowance for administrative costs.³⁶

For consumers, the best bet is likely to be controllers with on-site sensors. With the utility subsidy, these systems generate enough savings on the water bill to more than cover the \$9 in annualized costs, even with lower efficiency gains and in places with

Table 6. Smart Controller Costs and Savings

ET Superzone	Inputs					
	Water Savings (gallons per day per household)			Annual Cost to Customer (per controller)		
	Low (15%)	High (25%)			Low (on-site)	High (satellite)
Coastal	22	37		Full cost	\$26	\$95
Inner Coastal	36	60	After rebate	\$9	\$79	
Central	38	63				
Desert	60	101				
ET Superzone	Outputs					
	Costs to Utility (\$/acre-foot)		Annual Savings to Customer (per controller)			
	Low Water Savings	High Water Savings	Low Water Price (\$242/acre-foot)		High Water Price (\$678/acre-foot)	
			Low Water Savings	High Water Savings	Low Water Savings	High Water Savings
Coastal	584	350	6	17	10	28
Inner Coastal	397	238	10	27	16	46
Central	379	228	10	29	17	48
Desert	256	154	16	46	27	76

Notes: Assumes that 25 percent of water needs is met by rainfall. Both utility and customer investments are amortized at a rate of 4 percent.

low water prices (the sole exception is low prices and low savings in the Coastal zone).³⁷ Meanwhile, it is hard to break even with the satellite-linked systems, which cost \$79 after rebate, mainly because it is harder to cover the on-going subscription costs (now \$48 per year) through water bill savings.

For utilities, the calculus involves comparing the costs of water procured through the rebate program with the costs of alternative sources. By this yardstick, these rebate programs have the potential to be cost effective. As a point of comparison, desalinated water has estimated annual costs in the range of \$800 to \$1,500 per acre foot, and average costs for recycled wastewater are estimated at \$600 (Department of Water Resources, 2003a, 2003b).³⁸

For both customers and utilities, savings would improve under rebate programs targeting high water users—those with particularly low irrigation efficiency, larger yards, and a higher share of turf in their overall yard mix. For customers, the sav-

ings would also improve if ET controllers reduce other costs (e.g., less wastage of fertilizers and pesticides from overwatering).³⁹ To the extent that ET controllers also help curb urban run-off, these programs can bring additional local benefits in pollution control.⁴⁰ However, smart controllers do not address other sprinkler system problems, such as incorrectly set valves or sprinkler heads or other inefficiencies in the layout of the system. For this reason, consumer education needs to accompany these programs.

Water-Wise Landscapes

Water consumption can also be greatly reduced through the use of drought-tolerant plants. Throughout the American West, utilities have promoted “water-wise” landscaping since the mid-1990s. Outreach efforts have focused not only on educating people about the water savings potential but also on the attractiveness of these landscapes, which

Lawns and Water Demand in California

include many beautiful, flowering plants, not just prickly cacti and rocks. Because plant availability can be a problem, utilities have begun locating their demonstration gardens at home and garden stores. The hope is that this will encourage major retailers like Home Depot to stock native plants, which they have begun doing only recently. Consumer education can be a major undertaking. Since 2002, MWDSC has spent more than \$6 million on advertisements to promote “California friendly” landscaping, designed to reduce overwatering and encourage the use of native plants.⁴¹

To add teeth to these efforts, some water districts have launched turf buy-back programs, or so-called “cash-for-grass” initiatives. Through these programs, utilities pay customers to replace turf with less water-intensive plants and to install drip irrigation. Rebates range from \$0.40 per square foot in Victorville, California, to \$1 per square foot in Las Vegas, Nevada. These rebates cover only a portion of the cost to the consumer to replace turf. The Southern Nevada Water Authority (SNWA), which runs the Las Vegas program, estimates that customers pay from \$2 to \$5 per square foot to convert their landscapes.⁴²

The potential water savings come from the combined effect of lower plant needs and higher irrigation efficiency, and they are truly spectacular. Well-installed drip irrigation can attain efficiency levels approaching 90 to 95 percent, and low-water plants need only 20 percent of the ET_0 rate (compared to 80 percent for lawns). A conversion of a cool-season turf lawn using a “dumb” automatic sprinkler system to a “smart” drip-irrigated garden with drought-tolerant plants could move overall plant needs from 160 percent to as low as 21 percent (Table 4).

Although the savings in practice are more modest, they are nevertheless considerable. Drawing on detailed field surveys, SNWA estimates that conversion from turf to low-water landscaping brought water use down from 73.0 gallons of water per square foot to just 17.2 gallons per square foot, a 76 percent savings.⁴³ The agency has encouraged residential customers to go for varied landscapes,

keeping turf grass in places where they actually use it. Between 2001 and 2005, SNWA bought back over 1,500 acres of turf, or over 11,300 acre-feet of water. Purchases went up dramatically in 2003, when the rebate was raised from \$0.40 to \$1.00 per square foot.

How might such a program fare in California? Table 7 compares the costs to utilities and customers of turf buy-back programs across California’s climate zones, assuming water savings similar to that in Las Vegas (76%). To calculate these savings, we assume lower irrigation efficiency than in the smart controller example above (37.5% versus 50%).⁴⁴ Water savings and costs are shown per square foot, so that the only variation across zones is due to climate. Utility costs assume 15 years of savings, as above. For customers, costs are shown in terms of the number of years needed to recoup the net investment, assuming a total conversion cost ranging between \$2 and \$2.60 per square foot. The three payback scenarios reflect different assumptions about the savings from conversions: (1) savings on the water bill only, (2) additional savings from lower expenditures on garden supplies, and (3) additional savings from lower labor expenditures on garden maintenance. These “non-water” savings are drawn from a survey in the Las Vegas area, which found that homes with a greater proportion of lawns had higher labor and supply costs for mowing and other aspects of lawn maintenance.⁴⁵ It must be stressed that these results may not be representative.

For consumers, the water savings alone are unlikely to be a significant draw, even with a generous utility rebate. The picture changes dramatically, however, if homeowners reap additional savings in terms of lower garden supply and labor costs. These savings even make conversion a potentially attractive proposition in coastal areas and with higher net costs. These very different results underscore the importance of improving our understanding of

In Las Vegas, conversion from turf to low-water landscaping brought water use down from 73.0 gallons of water per square foot to just 17.2 gallons per square foot, a 76 percent savings.

Table 7. Turf Conversion Costs and Savings

			Customer Years to Recoup Investment			
			Low Net Conversion Costs (\$1.00/square foot)			
ET ₀ Superzone	Water Savings (gallons/square foot)		I	II	III	
Coastal	32		23	6	3	
Inner Coastal	39		17	6	2	
Central	42		15	5	2	
Desert	51		12	5	2	
		Costs to Utility (\$/acre-foot)	High Net Conversion Costs (\$1.60/square foot)			
		Low Rebate (\$0.40/square foot)	High Rebate (\$1.00/square foot)	I	II	III
Coastal	363	907	76	10	4	
Inner Coastal	298	745	38	10	4	
Central	276	690	32	9	4	
Desert	232	580	23	8	4	

Notes: Assumes a retail water price of \$678 per acre-foot. Scenario I includes only water savings, scenario II also includes garden supply savings, and scenario III includes labor cost savings. Both utility and customer investments are amortized at a rate of 4 percent. Baseline irrigation efficiency is 37.5 percent, with 25 percent of plant water needs met by rainfall (or alternatively, 50% irrigation efficiency with no rainfall contribution).

the total costs of landscape alternatives to households, not just the water savings.

For utilities, purchasing water through a cash-for-grass program appears to be a considerably more expensive proposition than the rebate program for smart controllers, particularly at the price of \$1 per square foot and in the milder climate zones. Actual costs may be higher, as we have not included the costs of program administration and we have assumed very high rates of water savings. If, on the other hand, the program creates a permanent shift in landscaping habits, rather than the 15 years assumed here, this would lower costs by about a third. As with smart controllers, there are additional benefits in control of polluted run-off.

Regulating Landscapes

In addition to public education and rebate programs, which aim to change tastes and behavior through voluntary means, some localities are

emphasizing regulations. Such policies typically take the form of local ordinances, and they target landscaping practices in public, commercial, and residential areas. In California, the initial push for landscape regulations came from the state legislature, during the early 1990s drought. In 1990, the Water Conservation in Landscaping Act (AB 325) required that DWR draft a model water-efficient landscape ordinance. The model ordinance contained a number of stipulations involving irrigation design and efficiency and the use of native plants.⁴⁶ It applied to large commercial and public landscapes and to residential landscapes installed by developers. Local agencies were required to adopt the model ordinance, adopt their own ordinance, or issue legal findings that they did not need an ordinance. Although most cities and counties complied with the statute, actual implementation of the local ordinances has been inconsistent, and program monitoring has been minimal (Bamezai, Perry, and Pryor, 2001).

Lawns and Water Demand in California

Some of the most enthusiastic local adopters are in fast-growing inland areas of Southern California. Many towns now require that developers use “California friendly” plants in all road medians and other public spaces. The City of Lancaster, for example, located in a hot area of eastern Los Angeles County, requires that all public landscaping be drought-tolerant. Several desert cities and utilities have adopted more widely applicable landscape ordinances. The Coachella Valley Water District (2003) recently adopted an ordinance requiring that new and refurbished landscaping feature vegetation that uses 25 percent less water than that required by the model ordinance. Other localities are taking the lead from cities in neighboring southwestern states, where landscaping restrictions have become increasingly common.

In weighing the pros and cons of landscape regulation, it is important to consider the value of lawns to households and communities. To the extent that lawns provide recreational space, low-water plants, no matter how beautiful, are not a good substitute. Even though common area lawns may be a more efficient way to provide this space, many households may prefer to have their own lawns for privacy and safety reasons. These considerations suggest that cost savings alone will not be enough to motivate all residents to make the switch. Encouraging people to cut back on turf in places where they do not use it—such as front yards and median strips—may be a more effective strategy than encouraging wholesale lawn removal.⁴⁷

What Role for State Policy?

Many outdoor conservation policies stem from local and regional initiatives, but the state has not been absent from the scene. Various rebate programs are supported by state grants, state legislation provided the impetus for landscape ordinances, and legislation now requires that utilities start using meters to bill for water use. The recommendations of the Landscape Task Force, presented to the governor and the legislature in December 2005, call for the state to play a greater role in the future. The report contains 43 recommendations

covering a wide range of actions (California Urban Water Conservation Council, 2005). In addition to stressing the importance of rate structure reform and more education and training, the recommendations focus on regulatory approaches: requiring smart irrigation controllers and dedicated landscape meters, adopting and enforcing statewide prohibitions on overspray and runoff, and strengthening and enforcing compliance with landscape ordinances. They also call for improvements in the knowledge base on irrigation requirements and plant water needs in different parts of the state. This includes extending the California Irrigation Management Information System (CIMIS)—a network of weather stations designed to gauge irrigation needs—to more urban areas.

The emphasis on regulation parallels the established approach to indoor conservation; state and federal regulations on plumbing fixtures and appliances are widely viewed as central to the successes achieved to date. For the outdoor environment, where there is considerably more variability in the potential for water savings, it will be especially important to weigh the costs and benefits to households and to society before imposing regulatory solutions. As with indoor appliances, regulations focusing on new construction may have the greatest potential to achieve a beneficial outcome.

Conclusion

The magnitude and geographical distribution of population growth in California are poised to exert significant pressure on the state’s water delivery systems over the coming decades. Outdoor water conservation will need to be an important policy focus in many parts of the state, both to limit increases in water demand and to free up water supplies to accommodate new

Outdoor water conservation will need to be an important policy focus in many parts of the state, both to limit increases in water demand and to free up water supplies to accommodate new residents.

Lawns and Water Demand in California

residents. Key elements of the policy toolkit include water rate reform; the use of new, “smart” watering methods; and landscaping changes that reduce water use.

Many utilities are focusing on education and outreach to provide households with information on alternatives and to make low-water plants more readily available at nurseries. Some are proposing rebates. Regulatory restrictions on landscaping of new homes—restricting lawns to a fraction of the yard—are still rare in California but increasingly common in neighboring states. Our analysis suggests that rebates to homeowners may be a cost-effective way to improve irrigation systems, particularly in the hotter, dryer regions and when water prices are higher. The savings from replacing turf with low-water plants are less obvious. For new homes, it may be easier (and more cost-effective) to build “water smart” from the ground up. Whether education and outreach (particularly with builders) is sufficient to encourage this goal, or whether regulatory solutions are required, is still an open question. Conservation-oriented water rates, which signal water scarcity to households, should be a part of any conservation package. ❖

Notes

¹ An analysis of 2000 Census housing data by tract reveals that the average “reference evapotranspiration rate”—a measure of plant water needs resulting from climate—increased significantly in both the San Francisco Bay Area and the South Coast region for housing built since 1980. See the discussion on evapotranspiration zones. For trends in individual counties, see the web-only data box, http://www.ppic.org/content/other/706EHEP_web_only_appendix.pdf.

² For a sample of 1,129 households with sprinklers, Madaus and Mayer (2001) found that the addition of an automatic sprinkler increased outdoor use by 55 to 60 percent. In the hotter zones, 57 percent of surveyed homes used these systems compared to 20 percent in the cooler, wetter climates.

³ An acre-foot of water is equivalent to 325,851 gallons, the amount of water it takes to cover an acre of land one foot deep. One acre-foot is the amount of water used annually by five to eight people.

⁴ The *Plan* cites several studies suggesting the potential for significant, cost-effective savings. A Pacific Institute study (Gleick et al., 2003) estimated that urban water use could be reduced by roughly 12 percent at a cost of \$100 per acre-foot or less and by as much as a third at less than \$600 per acre-foot (the benchmark price used by the study authors for alternative sources). The California Urban Water Agencies (2001, 2004) estimate that implementation of quantifiable “best management practices” (a narrower set of goals) would generate just over one million acre-feet cost-effectively by 2030. A study for the California Bay Delta Authority (2005) estimates a savings potential of up to 3.1 million acre-feet, although the last million might not be cost-effective.

⁵ Measurement of water use in the “large landscape” category is more precise, thanks to separate meters.

⁶ See http://www.snwa.com/html/cons_waterfacts.html.

⁷ Although the graph only shows trends back to 1945, the cumulative average extends back to the earliest records, as early as 1803 in the South Coast.

⁸ Single-family home sizes in California grew from an average of 1,277 square feet in the mid 1940s to nearly 2,600 square feet by the early 2000s. Building footprints increased from roughly 1,200 square feet to 1,900 square feet over this interval. It is possible that the total amount of hardscape—including garage area and pavement, in addition to the home’s footprint—has increased by a greater amount, but we have no way to measure this.

⁹ Because the data on lot sizes are less precise for some of these counties, it is possible that our analysis overstates the importance of these lots in the overall picture. Also, some of these ranchettes may be hobby farms or vineyards, for which water use would fall within agricultural demand.

Lawns and Water Demand in California

¹⁰ The Coastal superzone includes ET₀ zones 1 through 5, the Inner Coastal superzone includes ET₀ zones 6 through 10, the Central superzone includes ET₀ zones 11 through 15, and the Desert superzone includes ET₀ zones 16 through 18.

¹¹ This percentage is in line with recent field studies by the East Bay Municipal Utility District (EBMUD). In a 1995 survey, an average of 2,513 square feet, or 26 percent of the total lot, was irrigated—corresponding to roughly 31 percent of our definition of yard (Opitz and Hauer, 1995). In a 2001 survey, average irrigated area was estimated as roughly the same (2,510 square feet), but no total lot size was given (Water Resources Engineering, Inc., 2002). Our estimates from county assessor records suggest that this corresponds to roughly 36 percent of total lot size.

¹² The weighted average ET₀ for each region and superzone is calculated based on the number of lots in each of the 18 detailed ET zones. The numbers shown here reflect regional and zonal ET₀ using the distribution of single-family homes in the county assessor records. The results are nearly identical when we use the rates calculated from the distribution of homes in the 2000 Census.

¹³ We also evaluated higher percentages, but these implied far too much aggregate outdoor residential water demand relative to DWR's estimates of total residential use.

¹⁴ This estimate is derived using the 2000 Census estimate of the share of multifamily units in the total (32.9%) and DWR's estimate that multifamily units accounted for 26.8 percent of residential water use in that year (see Department of Water Resources, 2004). For that same year, DWR (2005) estimates average indoor residential use at 3,233,000 acre-feet, or 0.28 acre-feet per household, and average outdoor use at 2,328,000 acre-feet. If average multifamily and single-family indoor use is the same, this implies an average single-family outdoor use of 0.24 acre-feet and average multifamily outdoor use of 0.11 acre-feet, 46 percent of the single-family value. We apply a rate of 50 percent, because it is also likely that multifamily homes have somewhat lower indoor use. Note that these ratios are similar to those found by Dziegilewski et al. (1990) in a study conducted in Southern California (Department of Water Resources, 1994a).

¹⁵ The estimates are obtained by multiplying the average lot sizes in each ET₀ superzone by the volume of single and multifamily housing reported in the 2000 Census.

¹⁶ The additional effect of shifts in the average ET₀ rate was a 7 percent increase in the Bay Area and a 3 percent increase in the South Coast. In the inland regions, the increases are under 1 percent.

¹⁷ A recent survey of single-family homes in the EBMUD service area found, for instance, that roughly a quarter of all households had no irrigated landscape in the front or back yard (Water Resources Engineering, Inc., 2002).

¹⁸ This is the standard for cool-season turf grass embodied in California's Model Landscape Ordinance, for instance.

¹⁹ In the EBMUD studies, lawns accounted for about 40 percent of the irrigated landscape (Opitz and Hauer, 1995; Water Resources Engineering, Inc., 2002). The Metropolitan Water District of Southern California's outdoor water conservation programs assume that a conventional landscape consists of 60 percent lawn and 40 percent shrubs and trees.

²⁰ We obtained these figures by comparing outdoor water use estimates in the inland and coastal areas with our estimates of irrigated acreage and assuming that 25 percent of plant water needs are covered by rainfall. With DWR's estimate of outdoor residential water use (2.3 million acre-feet, or 42 percent of all residential use), we obtain an ET factor of 106. If outdoor use instead made up half of the residential total, the ET factor jumps to 127. Rates are higher in the inland regions in both scenarios.

²¹ Hayhoe et al. (2004); Lund et al. (2003); Department of Water Resources (2005).

²² The long-run marginal cost is the incremental per unit cost of expanding water supply, taking into account both investment and operational costs.

²³ In part, this new view stems from improved estimation techniques, which better capture the effect of fixed fees and jumps in prices associated with increasing block rates. See Hanemann and Hewitt (1995).

²⁴ In a study based on a climatically and geographically diverse dataset, Olmstead, Hanemann, and Stavins (2005) find that households subject to increasing block rate water prices exhibit nearly double the price elasticity of houses subject to uniform pricing structures. The study found a price elasticity of -0.64 for increasing block rate households versus -0.33 for uniform pricing households. In a meta-analysis incorporating over 300 estimates of water price elasticity, Dalhuisen et al. (2003) also found greater price sensitivity under increasing block rate systems.

²⁵ The data on rate structures are from Black and Veatch (2001, 2003) and phone surveys. The sample included 348 utilities meeting the size threshold for the Urban Water Management Plans Act (at least 3,000 customers or 3,000 acre-feet of annual water sales).

²⁶ In particular, this group includes water districts in the Sacramento Metro region, the Inland Empire, and Los Angeles County. Most switched from uniform to increasing block rates in the early to mid-1990s.

²⁷ In practice, this is proposed through benchmark shares of volumetric pricing in total revenues. To qualify as conservation pricing, 60 percent of total revenue through a tiered rate structure must come from volumetric revenue (as opposed to revenue from fixed charges). For uniform rate structures, volumetric revenue must constitute at least 75 of total revenue. See California Urban Water Conservation Council (2005).

²⁸ This is the rate the Metropolitan Water District of Southern California is assuming in its estimates of potential water savings from improved irrigation efficiency, for

Lawns and Water Demand in California

instance. Maddaus and Mayer (2001) estimate that these rates could be even lower, within the range of 30 to 50 percent.

²⁹ On-site systems rely on either a solar sensor or a temperature sensor, in both cases combined with a rain sensor.

³⁰ Bamezai (2001); Hunt, et al. (2001); Municipal Water District of Orange County and Irvine Ranch Water District (2004). IRWD did not adjust the controllers after installation to simulate the minimal consumer adjustment that they expected would happen under normal circumstances.

³¹ Santa Barbara County Water Agency (2003).

³² Interview with Lynn Lipinski, John Wiedman, and Tim Blair, MWDSC, October 28, 2005; Kissinger and Solomon (2005). With these technologies, irrigation efficiency would jump from 50 to 69 percent.

³³ For a typical home in the Coastal zone, our estimates generate slightly lower per household savings from ET controllers than the 41 gallons per day found in the Irvine Ranch Water District (Bamezai, 2001). That pilot study targeted water users in the top 20 percent of households, who likely had either larger lawns, lower irrigation efficiency, or a combination of these factors.

³⁴ See <http://www.mwdoc.com/SmartTimer/ETControllers.htm> for a list of products eligible for rebates under a joint program by the Municipal Water District of Orange County and the Irvine Ranch Water District. One system listed has a starting price of \$1,400, but it is mainly directed at commercial clients. The price of on-site sensor-based controllers ranges from \$140 to \$260 for an eight-valve system, and the price of satellite-linked systems starts in the range \$560 to \$650. After year two, a monthly subscription fee of \$4 is charged. Installation costs range from \$75 to \$130 (the higher price includes rooftop installation of solar sensors).

³⁵ Utility rebates are assumed to be \$20 per valve. For the Coastal zone, we assume an average of nine valves (the current practice in Orange County); for the Inner Coastal and Central zones, an average of ten valves; and for the Desert zone, an average of 11 valves, to take into account larger lot sizes.

³⁶ We assume a cost per controller of \$40, in line with current programs in Orange County.

³⁷ These rates are calculated for a sample of 251 utilities with uniform rates using data in Black and Veatch (2003). The “low” price (\$242/acre-foot) is the average rate charged in 2003 in the San Joaquin Valley, and the “high” price (\$678/acre-foot) is the comparable rate for the South Coast region. Average rates were higher in the Bay Area (\$827) and the Central Coast (\$711) and lower in the Inland Empire (\$453) and the Sacramento Valley (\$265). Marginal rates may be higher in some increasing block rate systems, which are not included in these calculations.

³⁸ Some urban utilities have access to lower-cost sources, notably through purchases of farm water and underground storage, which can cost as little as \$100 to \$200 per acre-foot in some locations (Hanak, 2005).

³⁹ For instance, Gleick et al. (2003) have argued that the non-water cost savings from more efficient irrigation practices could be substantial.

⁴⁰ The Irvine studies mentioned above found that run-off was reduced by 50 percent for homes retrofitted with ET controllers (Municipal Water District of Orange County and Irvine Ranch Water District, 2004).

⁴¹ Interview with Lynn Lipinski, John Wiedmann, and Tim Blair (MWDSC), October 28, 2005.

⁴² Information provided by Tracy Bower, SNWA, February 2005 and Kent Sovocool, SNWA, January 2006. These estimates cover turf removal and installation of the new landscape, including a drip irrigation system. During the SNWA’s field study in the late 1990s (Sovocool, 2005), the average costs were on the order of \$2 per square foot. These costs have been rising in recent years, in part because more people are using contractors to do the conversion and in part because of a loss of scale economies as people convert smaller plots.

⁴³ Using irrigation submeters, SNWA monitored over 300 single-family homes that had converted at least 500 square feet of turf grass to “xeric” (low-water) landscapes (Sovocool, 2005).

⁴⁴ This assumes, as above, that 25 percent of water needs are met by rainfall. Alternatively, the same ET adjustment factor (160%) could be attained with 50 percent irrigation efficiency and no allocation of rainfall to cover plant needs.

⁴⁵ The maintenance survey was conducted by mail in the summer of 2000, drawing from a sample of participants in SNWA’s turf conversion program. Respondents were asked to record their time and capital costs (lawnmowers, fertilizers, etc.) for their residential landscapes. Usable records on costs were available for 216 cases, of which 50 had at least 60 percent turf in their gardens and 166 had at least 60 percent xeriscape landscape, with an average landscaped area of 1,750 square feet. The annual capital costs were \$214 lower for the yards with more xeriscape (yielding a savings of \$0.12/square foot), and these residences used 2.3 fewer hours of labor per month (yielding a savings of \$0.23/square foot if valued at \$14.50 per hour, a price assumed for unskilled landscaping work). See Hessling (2001) and Sovocool (2005).

⁴⁶ Notably, it set a standard for irrigation efficiency of at least 62.5 percent, and it advocated a 1/3:1/3:1/3 crop mix (see Table 4). For details, see California Urban Water Conservation Council (2005).

⁴⁷ For an overview of flexible, water-smart landscaping approaches, see Department of Water Resources (2002).

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