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MUNICIPAL WATER USE AND WATER RATES DRIVEN BY SEVERE DROUGHT: A CASE STUDY[1]

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ABSTRACT: This paper synthesizes and interprets data pertaining to the evolution of average water revenue, water use, and the average cost of water supply in the City of Santa Barbara, California, from 1986 to 1996, a period which included one of the most devastating droughts in California this century. The 1987-1992 drought hit the study area particularly hard. The City of Santa Barbara was dependent exclusively on local sources for its water supply. That made it vulnerable as the regional climate is prone to extreme variability and recurrent droughts. The 1986-1992 drought provided a rare opportunity to assess the sensitivity of municipal water use to pricing, conservation, and other water management measures under extreme drought conditions. Our analysis indicates that the average cost of water rose more than three-fold in real terms from 1986 to 1996, while the gap between the average cost of supply and the average revenue per unit of water (= 100 cubic feet) rose in real terms from $0.14 in 1986 to $ 0.75 in 1996. The rise of $3.08 in the average cost of supplying one unit of water between 1986 and 1996 measures the cost of hedging drought risk in the study area. Water use dropped 46 percent at the height of the drought relative to pre-drought water use, and remains at 61 percent of the pre-drought level. The data derived from the 1987-1992 California drought are unique and valuable insofar as shedding light on drought/water demand adaptive interactions. The experience garnered on drought management during that unique period points to the possibilities available for future water management in the Arid West where dwindling water supplies and burgeoning populations are facts that we must deal with.
(KEY TERMS: water management; water conservation; water demand; economics; water policy; decision making; water law; water development.)

INTRODUCTION

During the water years 1986-1987 through 1991-1992 (with water years elapsing from October 1 of any calendar year through September 30 of the following calendar year), California endured one of the most severe droughts of the 20th century (Loaiciga *et al.*, 1993; Loaiciga and Leipnik, 1996). Of the ten hydrologic regions in which the State of California is divided (see page 50 of California Department of Water Resources, 1994), the Central Coast hydrologic region suffered particularly strong hydrologic, economic, and environmental impacts from the 1986-1992 drought. The Central Coast region roughly includes the counties of Monterey, San Benito, Santa Barbara, Santa Cruz, and San Luis Obispo. Within the Central Coast region of California, annual streamflow was below average for the duration of the 1986-1992 drought. For water years 1986-1987 to 1991-1992 annual streamflow in the Central Coast was equal to 19 percent, 20 percent, 19 percent, 9 percent, 43 percent, and 53 percent of the annual average, respectively (California Department of Water Resources, 1993). To compound matters, the Central Coast region received only a nominal annual delivery of 32,000 acre feet (32,000 AF = 39.456 x 10^6 m^3) from the California State Water Project, a vast system for inter-regional water transfers. None of this water, however, was allocated to Santa Barbara County, which includes the study area of this work. The County of Santa Barbara, thus, relied completely on local surface water and ground water supplies in a region subject to substantial climatic variability (Loaiciga *et al.*, 1993; Turner, 1996).

This article analyzes the evolution of water use, average water revenue, and average water cost of water supply in the City of Santa Barbara, California, from 1986 to 1996; i.e., from pre-drought to post-drought conditions. The drought of 1986-1992 presented hydrologists and water planners with a truly

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exceptional opportunity to observe the evolution of municipal water use, average water revenue, and average water cost in a mid-sized community (approximately 94,000 inhabitants at present) solely dependent on local water sources (Lawrence *et al.*, 1994). The remainder of this article presents an account and interpretation of related hydrologic/economic events associated with this remarkable natural event.

AN OVERVIEW OF CONDITIONS IN THE STUDY AREA

Climate, Surface Waters, and Ground Waters

The focus of this study is the water system of the City of Santa Barbara, California, throughout the 1986-1992 drought. The City of Santa Barbara is located within Santa Barbara County, at the southern end of the Central Coast hydrologic region of California (see Figure 1). It is a coastal community of some 90,000 plus residents which boasts a service-oriented economy whose pillars are tourism, higher education, high-technology industry, retail trade, finance, and real estate. In 1986, prior to the 1986-1992 drought, the City of Santa Barbara derived its municipal water supplies from its local aquifer and from the Santa Ynez river, whose yield it shares with several neighboring agencies of Santa Barbara County, and for which the focal point was, and is, the Cachuma reservoir. The Cachuma reservoir, with a current storage capacity of about 190,000 AF (234.27×10^6 m^3) dams the Santa Ynez river, capturing median annual runoff of about 23,000 AF (28.359×10^6 m^3) generated over a drainage area of approximately 400 sq. mi. (1,035 km^2).

The climate of the Santa Barbara region shows high inter-annual variability (Loaiciga *et al.*, 1992; Turner, 1996). Its sources of precipitation are almost exclusively westerly cold fronts moving land wards from the Pacific Ocean and southwesterly, subtropical, flow originating also in the Pacific Ocean. Occasionally, polar fronts descending from arctic regions generate rainfall in the area as well. Figure 2 shows a time series of annual rainfall recorded in the City of Santa Barbara since 1868. Median annual rainfall is 15.77 in. (40.05 cm) and inter-annual variability in rainfall is high. For example, the historical record shows an all-time low rainfall of slightly below 5 in. (12.7 cm) in 1879, and a maximum of about 45 in. (114.3 cm) in 1940, for a range of nearly 40 in. (101.6 cm) in annual rainfall. Streamflow fluctuations in the Santa Ynez River are also extreme, with a runoff regime characterized by negligible flow during the summer months (July-September) and concentrated floods in winter and spring (typically from February to April) following heavy rainfall. Turner (1996) has documented the persistence of dry streamflow conditions in the Santa Ynez river, emphasizing the challenges of water supply under such variable, and drought prone, climatic conditions.

Figure 1. Generalized Location Map of the Study Area.

Ground water, the second source of water to the City of Santa Barbara, has been extensively studied by Martin (1984), Martin and Berenbrock (1986), and McFadden *et al.* (1991). The estimated total ground storage capacity of the City's aquifers is estimated at about 108,800 AF (134.2×10^6 m^3), of which only about 5,550 AF (6.843×10^6 m^3) is extractable in any one year (EIP Associates, 1994). The estimated perennial safe yield is on the order of 1,400 AFY (1.726×10^6 m^3/yr) according to the City's Long-Term Water Supply Program. Ground water recharge to the productive, confined, aquifer is highly dependent on percolating rainfall through heavily fractured bedrock aquifers (McFadden *et al.*, 1991).

Prior to the drought, the City of Santa Barbara was diverting a total of about 14,000 AF/year (17.262×10^6 m^3 /year) from the Santa Ynez river. Between

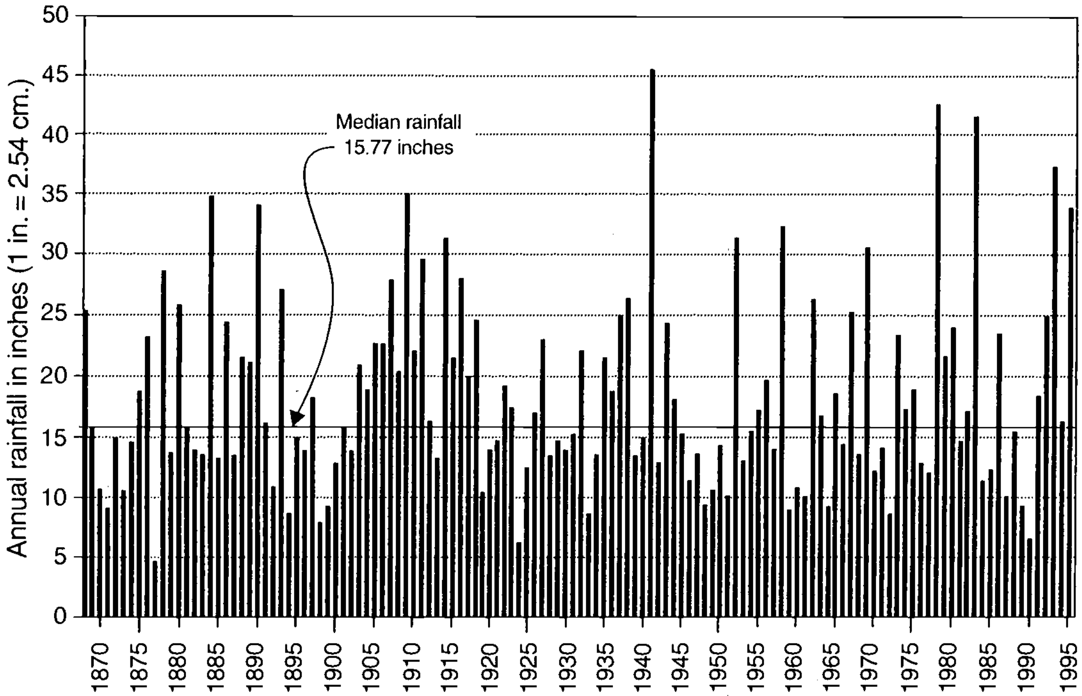

Figure 2. Annual Rainfall Totals for the City of Santa Barbara, Water Years 1868 to 1995. (Source: Public Work Department of the City of Santa Barbara) (1 in. = 2.54 cm)

1,000 and 2,000 AF (1.233×10^6 and 2.466×10^6 m^3) of ground water was added annually to surface water supplies to meet pre-drought water use on the order of 15,000 to 16,000 AF/year (18.495×10^6 m^3 to 19.728×10^6 m^3/year).

Water Use in the Pre-Drought Era

The City of Santa Barbara records annual water use in terms of total potable production and total metered sales. Total potable production refers to the total amount of water produced and sent into the distribution system for delivery to all customers. Total potable production includes water which cannot be accounted for due to leaks in the delivery system, water meter error, fire fighting, customer theft, etc. Total metered sales, on the other hand, refers to water that is actually delivered and recorded on the customer's water meter. The metered sales ratio is the total metered sales divided by the total potable production. From the pre-drought through the post-drought era in Santa Barbara, this ratio has ranged from 91 percent to 96 percent (Source: Public Works Department of the City of Santa Barbara).

Prior to the 1986-1992 drought, water use had been relatively stable for several years. Table 1 shows the annual total potable production by water year going back to 1969. From water year 1968-1969 to water year 1982-1983, total production varied between 12,636 AFY (15.580×10^6 m^3/year) in water year 1977-1978 and 15,141 AFY (18.669×10^6 m^3/year) in water year 1971-972, with a median total production of 13,874 AFY (17.106×10^6 m^3/year). By the pre-drought water year 1985-1986, total potable production had been close to or above 16,000 AFY (19.728×10^6 m^3/year) for three consecutive years. Water year 1986-1987 was the first one in the recent drought and people's attitude towards water consumption had not yet been influenced by protracted dry weather. With a population of 80,695 people and a total potable production of 16,641 AF (20.518×10^6 m^3), per capita water consumption in Santa Barbara in year 1986-1987 reached a level of 184 gallons per day (697 liter per day). The 1986-1987 per capita daily consumption in Santa Barbara was slightly above the national average of 158 gallons per day (600 liters per day) (Tchobanoglous and Schroeder, 1987).

Water Supply Implications of the 1986-1992 Drought

In order to better understand the implications of the 1986-1992 drought from the perspective of water supply in Santa Barbara, one must consider primarily the amount of streamflow generated in the Santa

Ynez River and the evolution of water storage in Cachuma reservoir during that period. Figure 3 shows unimpaired streamflow (i.e., measured streamflow augmented to account for upstream diversions) of the Santa Ynez River at Cachuma reservoir for water years 1918 through 1992. Runs of below-median annual streamflow are frequent in the Santa Ynez River (Figure 3). Drought conditions, as defined by persistent below-median annual streamflow (see Loaiciga and Leipnik, 1996), interspersed by an occasional above-median streamflow year, existed between 1919 and 1925, 1928 and 1934, 1947 and 1951, and from water year 1986-87 to water year 1991-92. The Bradbury Dam at Cachuma reservoir was completed in 1959 with a total storage capacity of 200,000 AF (246.6×10^6 m^3), and developed an annual target draft of about 45,000 AF (55.485×10^6 m^3) (Turner, 1996). The purpose of developing Cachuma reservoir was to smooth the extreme streamflow variability and associated uncertainties in water supply in the service region of the Santa Ynez river. Thus the 1986-1992 drought was the first to be experienced in Santa Barbara during full utilization of Cachuma reservoir yield.

Figure 4 shows the time series of monthly unimpaired flows at Cachuma reservoir from October of 1984 through September of 1992. The winter of 1986

TABLE 1. Total Potable Water Production for the City of Santa Barbara, Water Years 1968-69 to 1994-95 (Source: Public Works Department of the City of Santa Barbara).

Water Year	Total Potable Water Production (AF*)	Water Year	Total Potable Water Production (AF)
1968-69	12,683	1982-83	14,216
1969-70	14,565	1983-84	16,621
1970-71	14,232	1984-85	16,169
1971-72	15,141	1985-86	15,958
1972-73	13,577	1986-87	16,641
1973-74	13,796	1987-88	16,228
1974-75	14,189	1988-89	15,287
1975-76	14,916	1989-90	10,518
1976-77	12,791	1990-91	9,149
1977-78	12,636	1991-92	10,184
1978-79	13,525	1992-93	10,587
1979-80	13,952	1993-94	11,337
1980-81	14,663	1994-95	11,724
1981-82	13,529		

*1 AF = 1,233 m^3.

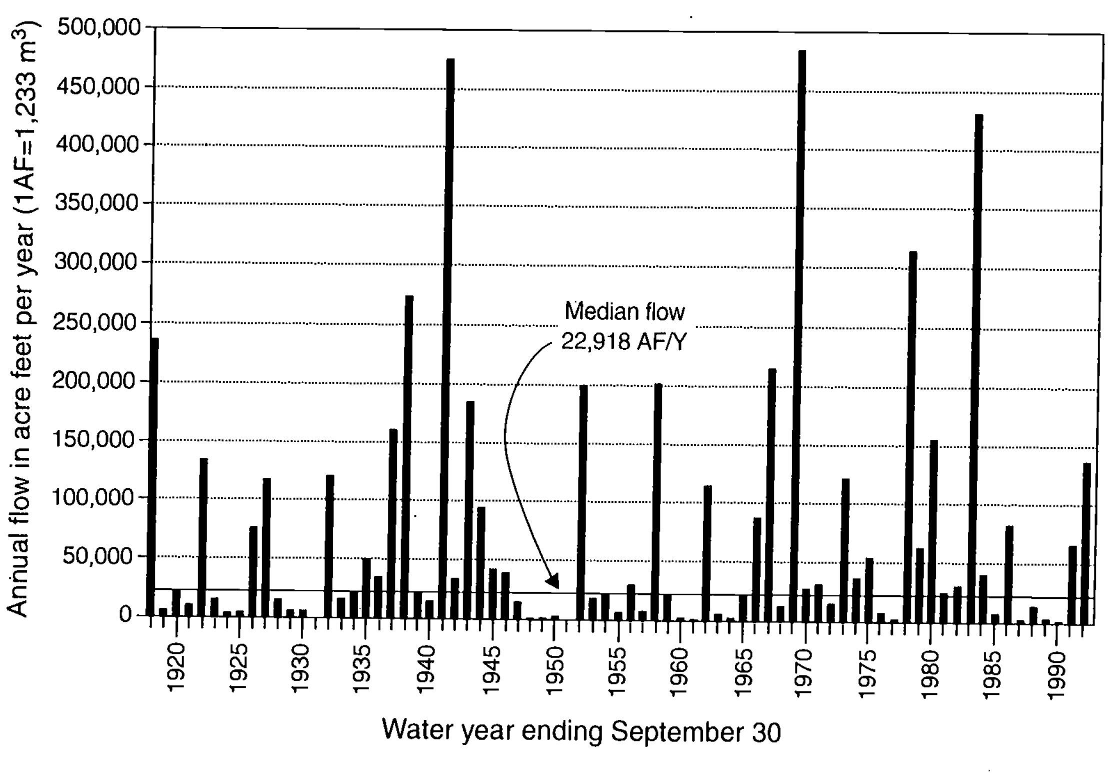

Figure 3. Unimpaired Flows of the Santa Ynez River at Cachuma Reservoir, Water Years 1918-1992. (Source: Santa Barbara County Flood Control and Water Conservation District) (1 AF = 1,233 m^3)

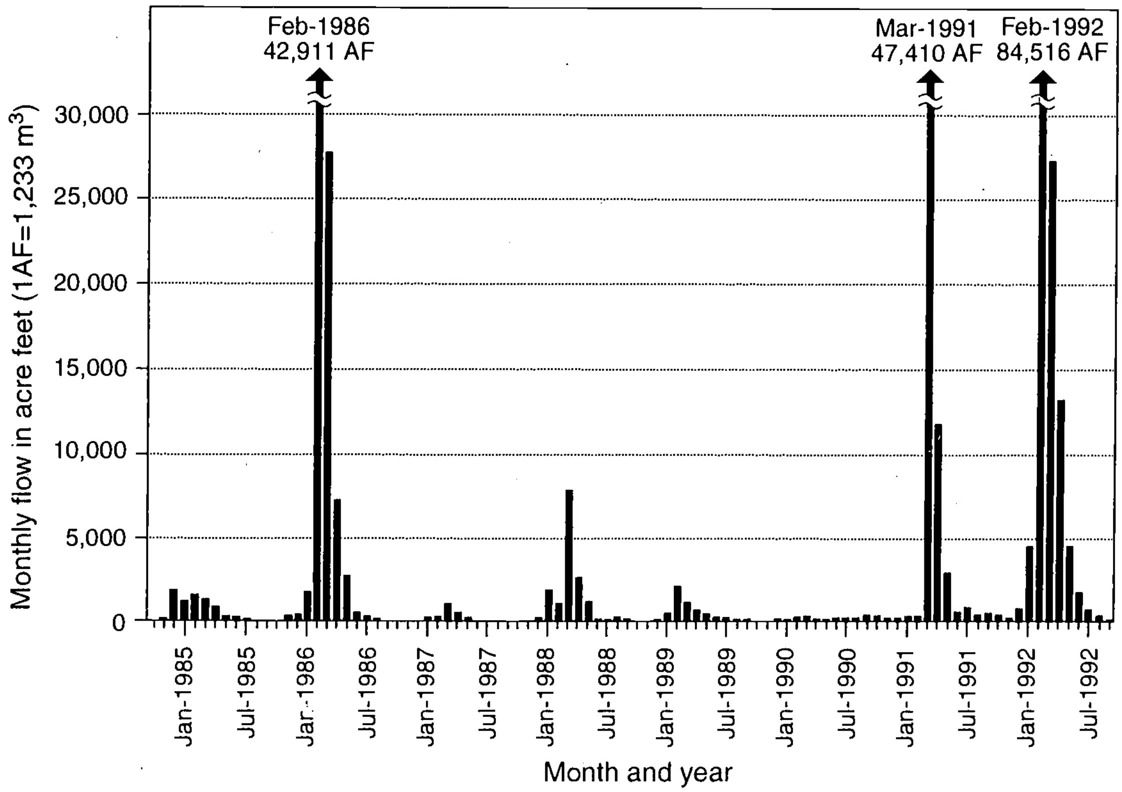

Figure 4. Unimpaired Flows of the Santa Ynez River at Cachuma Reservoir, Water Years 1985-1992. (Source: Santa Barbara County Flood and Water Conservation District) (1 AF = 1,233 m^3)

was indeed a very wet one (Figure 4). Thereafter, and except for a wet period in February/March of 1991, significant streamflow did not occur until the winter of 1992. The water supply impact of the observed streamflow regime shown in Figure 4 is put in clear perspective by analyzing Cachuma reservoir storage in the period 1986-1992 (Figure 5). The wet winter of 1986 filled the reservoir to capacity. Beginning in March of 1986, Cachuma storage started to decline until March of 1991, when the trend was temporarily reversed by heavy storms. By March of 1991, Cachuma reservoir storage had declined to about 25,000 AF (30.825 x 10^6 m^3). This storage was sufficient to meet water demand for a few more months only in the service area of the Cachuma Project member units.

With reservoir storage dangerously low and local aquifers nearly depleted, the end to water supplies in Santa Barbara became a real possibility in the very short term. The communal anxiety and hardship inflicted by dwindling water supplies were well publicized by the media locally and nationally. Unorthodox schemes to pre-empt total depletion of available water supplies were put forward in 1990 and early 1991, including a proposal to tanker water from the Canadian west coast in large ships. From this social upheaval and brainstorming emerged funding for the construction of an ocean desalination plant, in 1991, with a capital cost of $35 million and a production capacity of 7,500 AF/year (9.248 x 10^6 m^3/year). In addition, Santa Barbara residents voted to approve the permanent importation of State Water Project water at a price tag of close to $500 million, to be shared with several neighboring water agencies in Santa Barbara County and San Luis Obispo County as well. Up to 1986, Santa Barbara County residents had declined to import northern California water. This reflected the hegemony of antigrowth political forces which equated water importation with runaway population growth. By 1992, the drought had turned the tables around and water importation had become a reality.

As events unfolded, the Santa Ynez River received some large flows from heavy rain in March of 1991. Cachuma storage rebounded to about 65,000 AF (80.145 x 10^6 m^3) in April of 1991 (Figure 5). The rains of March 1991 provided a much needed, though partial, drought relief, and they were considered by many Santa Barbarans as a benevolent act of God – a miracle, in the words of many locals. In spite of the temporary respite brought about by the March 1991 rains, Figure 5 shows that the Cachuma storage began to decline again until March of 1992, when

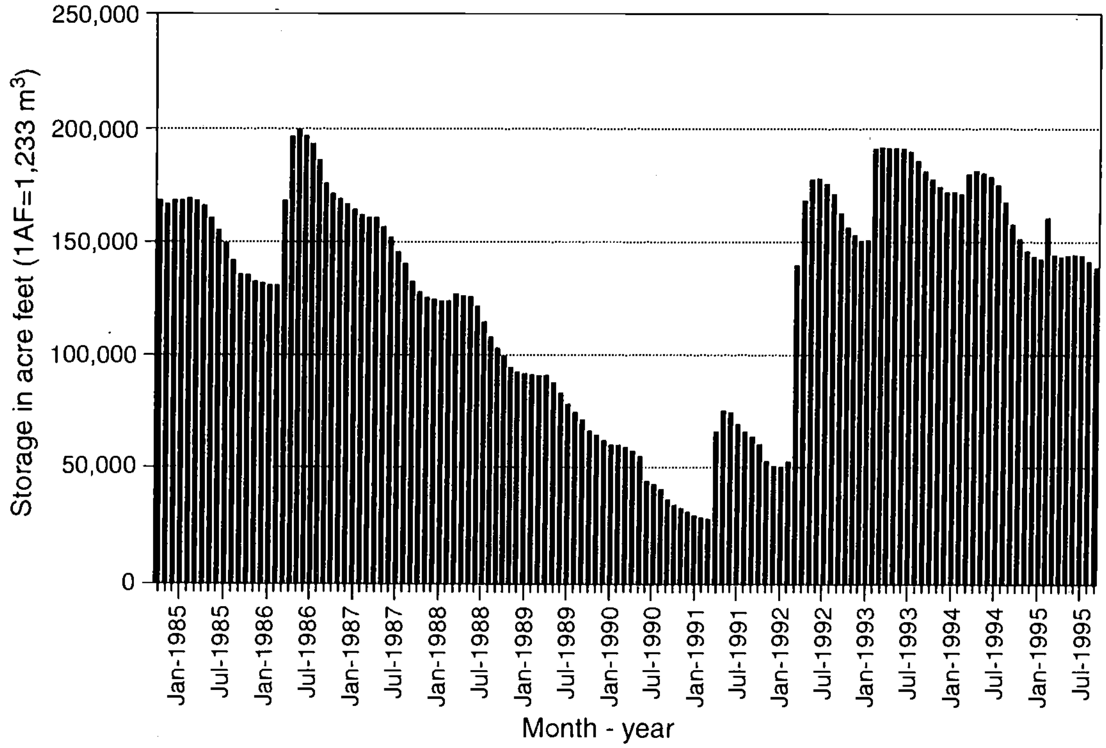

Figure 5. Monthly Distribution of Storage Capacity for Cachuma Reservoir, Water Years 1984-1995. (Source: Cachuma Operations and Maintenance Board) (1 AF = 1,233 m^3)

heavy springtime rains that year filled the reservoir to near capacity. The reservoir spilled for the first time since 1986 in February, 1993, now at a reduced capacity of 190,000 AF (234.27 x 10^6 m^3), some 10,000 AF (12.33 x 10^6 m^3) below the original 200,000 AF capacity. (The 10,000 AF loss in reservoir storage was caused by large sediment fluxes since the inception of the project.)

EVOLUTION OF WATER USE, REVENUE, AND COST

Water Pricing by Water Purveyors

The Water Code of the State of California prescribes that municipalities, such as Santa Barbara, may price water so as to cover all operating costs (fixed and variable) associated with supplying water to customers (State of California Legislature, 1977). This is what we refer to herein as "average-cost" pricing; i.e., when the average cost per unit of water equals the unit average revenue. In actuality, it is common for cities and public water purveyors in California to price water at less than its average cost. The shortfall in revenue from water sales needed to cover all water-supply related operating costs is made up through a variety of financial instruments available to public water purveyors. These include, among others, allocation of interest generated from water-related investment accounts to the water budget, revenue raised from "utility" taxes, or the allocation of moneys directly from the "general" fund (which accrues mainly from property and other city taxes, plus returns on investment portfolios) to pay for the cost of water supply.

Water-rate structures vary widely among municipalities in California. In some cases, water supply and garbage collection charges are lumped into a single, and fixed, monthly or bimonthly bill to households. In most cases, such as in the City of Santa Barbara, water customers pay, on a monthly or bimonthly basis, a fixed "service" or "meter" charge plus a variable charge which depends on the amount of metered water use during the billing period. The schemes used to assess the variable charge varies widely across California, but they generally fall in three categories. The first is the so-called uniform rate, whereby the price per unit of water is constant regardless of the amount of water used during the billing period. [The most common water unit used to measure deliveries to municipal water customers in California is the HCF or 100 cubic feet (= 2.83 m^3).] The second category takes the form of an increasing block-rate structure, in which the unit price of water is assigned increasingly larger values as water use rises. This is the rate structure which is currently in place in the City of Santa Barbara, and will be discussed in greater detail below. The third category consists of a declining block-rate structure, whereby the unit price of water is assigned increasingly smaller values as water use rises. To complicate matters, it is common to have different water-rate structures within the same municipality for different customers categories. Thus, for example, the City of Santa Barbara has different water-rate structures for residential, commercial, agricultural, and governmental (e.g., schools, public parks, etc.) customers. The differences in water rates among customer categories are explained by differentials in the cost of service to each customer category (Kennedy/Jenks Consultants, Inc., 1995), but they are also a reflection of the internal political process.

It is worth pointing out that about 20 percent of residential metered water connections in California are now operated by private water purveyors (Floyd Wicks, CEO, Southern California Water Company, Personal Communication, 1996), a growing industry. The Public Utilities Commission (PUC), a State regulating agency, oversees and authorizes water rates implemented by private purveyors. Their water rates are set so as to cover all operating cost and yield a reasonable rate of return on investment. As many local governments streamline and downsize their operations, the private water supply market has gained ground in California. In this respect, the total privatization of urban water supply in England is exemplary. Completed in the early 1990s, the transition to private hands has been accomplished remarkably well there. Under privatization, households in England may choose to pay water bills determined from either the assessed market value of the property or the metered volume of water consumption. Customers are allowed to pay the water bills in a lump sum or in installments, but due within each fiscal year (Philip J. Aldous, Thames Water Utilities, U.K., Personal Communication, 1996).

Causes of Water Use Decline During the Drought

The first three years of drought (water years, 1986-1987, 1987-1988, and 1988-1989) engendered uneasiness in the study area but, at the same time, were generally perceived by Santa Barbara residents as yet another temporary oddity of the climate, soon to be reversed. The high water production for water years 1986-1987, 1987-1988, and 1988-1989 (see Table 1) lend support to this assertion. Water prices rose moderately (see Figure 7 for data on water rates during the drought) and water use was likewise moderately depressed. During the 1986-1988 period, it seems reasonable to hypothesize that water use changes were mainly driven by water price increases. The decline in water use during water year 1988-1989 may be partly attributed to a water conservation program instituted by the City of Santa Barbara in 1988. Unfortunately, there are no empirical data to allow us ascertain the relative contributions of water price changes and conservation to water use decline during the drought.

As the drought entered its fourth year (1989-1990) customers began to modify their water consumption behavior noticeably, most likely the result of a well-publicized "drought watch" campaign to promote water conservation. Customers cut down on their personal, recreational, and landscaping water use. In addition, they improved their water systems by repairing leaks and by retrofitting irrigation and household water delivery systems with water efficient devices. Some 22,000 low-flow toilets have been installed by Santa Barbara households since 1988 as part of the City's water conservation program. The City issues customers an $80 rebate for each standard toilet which is replaced by a low-flow toilet. This rebate program has lowered residential water use by about 314 AFY (387,100 m^3/yr).

By March of 1990, water scarcity became critically acute. Customers, in particular residential customers, were using water sparingly. Water prices had become punitive, specially for water used over and above that needed to satisfy basic needs (see discussion about Figure 7 below). A drought emergency was declared by the City of Santa Barbara in February of 1990, under which government agencies were directed to cut their anticipated water use by 20 percent. In addition, landscape irrigation, car washing, and filling of pools were prohibited within City limits. More "drought officers" were hired to patrol the City and enforce the drought emergency measures. They were authorized to issue $250 citations to violators for each offense. Water flow restrictors were installed in the water connections of two-time offenders. It is reasonable to hypothesize that by the end of 1990 water demand had become more sensitive to additional price increases relative to the pattern of 1986-1987 to 1988-1989. As drought conditions subsided in 1991 and vanished in 1992, customers began modifying their water use behavior again but this time in an opposite direction. Water prices remained relatively high and constant compared to pre-drought years, but water use increased as customers moved to regain some of the amenities brought about by a freer use of water.

The variations in water use observed during water years 1986-1987 to 1991-1992 in Santa Barbara were caused by a complex and dynamic interaction among water rates, changing patterns of customer behavior towards water use induced by the conservation campaign, and water supply system management during the study period. The data to be presented next quantify the magnitudes of water use changes caused by the drought.

The Single-Family Residential Sector

Prior to considering average water revenue and total water use variations in the study area, it is instructive to consider the evolution of water rates in the single-family residential sector of customers. The single-family sector represents the largest block of customers both in terms of its share of total water use (about 44 percent of total metered water sales) and of revenues accruing from metered water sales. Table 2 shows total and single-family metered water sales data for the City of Santa Barbara by water year (which during the drought went from May 1 of any given year to April 30 of the following year). Water consumption figures are expressed in units of hundred cubic feet (HCF = 2.83 m^3). It is seen in Table 2 that water consumption dropped from 6,676,890 HCF (18,895,598 m^3) in water year 1986-1987 to 3,602,345 HCF (10,194,636 m^3) in water year 1990-1991, an astonishing decline of 46 percent in total metered water consumption. By the end of water year 1994-1995, three years after the end of the drought, total water metered sales were only 68 percent of the 1986-1987 level. Similar percentage drops in single-family residential water consumption can be derived from Table 2. Table 2 also indicates that single-family residential water consumption, expressed as a percentage of total metered water sales, has remained fairly stable from pre-drought to post-drought years, hovering at about 45 percent.

Figure 6 shows monthly water consumption distribution curves for the single-family residential sector in the City of Santa Barbara calculated for five selected time intervals. The greatest discrepancy between water consumption distribution curves corresponds to those calculated in 1986 and 1991. In pre-drought 1986, 50 percent of the single-family residential customers used no more than 9 HCF/ month (25.5 m^3/month). In contrast, in 1991, 50 percent of the single-family residential customers used no more than 6.3 HCF/month (17.8 m^3/month). Monthly water consumption in 1991 was spread out over a much narrower range (1 HCF to 30 HCF, 2.83 m^3 to 85 m^3) than that of 1986 (1 HCF to 250 HCF, 2.83 m^3 to 708 m^3) in the single-family residential sector (Figure 6). Compared to the 1986 consumption distribution curve, the distribution curves calculated during the drought period became steeper and shifted to the left of the 1986 curve. This implied a reduction of water use at the high end (say, over 10 HCF = 28.3 m^3) and concentrated water use in the 1 HCF to 10 HCF (2.83 m^3 to 28.3 m^3) range during the drought years.

The complex evolution of water rates in Santa Barbara between 1986 and 1995 is best illustrated by Figure 7. There we show, for the single-family residential sector, (1) the monthly service (or meter) charge (which does not depend on the level of a customer's monthly water use), (2) the unit price for water as a function of a customer's level of monthly use, and (3) the month and year in which a given rate was instituted and the month and year of its

TABLE 2. Total Metered and Single-Family Residential Water Consumption Data for the City of Santa Barbara, Water Years 1986-1987 to 1994-1995. Water consumption is reported in hundred cubic feet (HCF) units, where 1 HCF = 2.83 m^3. (Source: Adapted from data by the Public Works Department of the City of Santa Barbara)

Water Year	Total Metered Water Sales (HCF)	Population	Single Family Metered Sales (HCF)	Single Family as Percentage of Total Metered Sales
1986-87	6,676,890	80,695	2,804,293	42.0
1987-88	6,526,009	81,995	2,936,704	45.0
1988-89	6,056,649	83,295	2,950,972	48.7
1989-90	4,239,116	84,672	1,734,392	40.9
1990-91	3,602,345	87,014	1,511,630	42.0
1991-92	4,145,724	90,006	1,768,448	42.7
1992-93	4,350,638	91,711	1,899,778	43.7
1993-93	4,625,222	92,756	2,073,034	44.8
1994-95	4,559,419	93,957	2,014,420	44.2

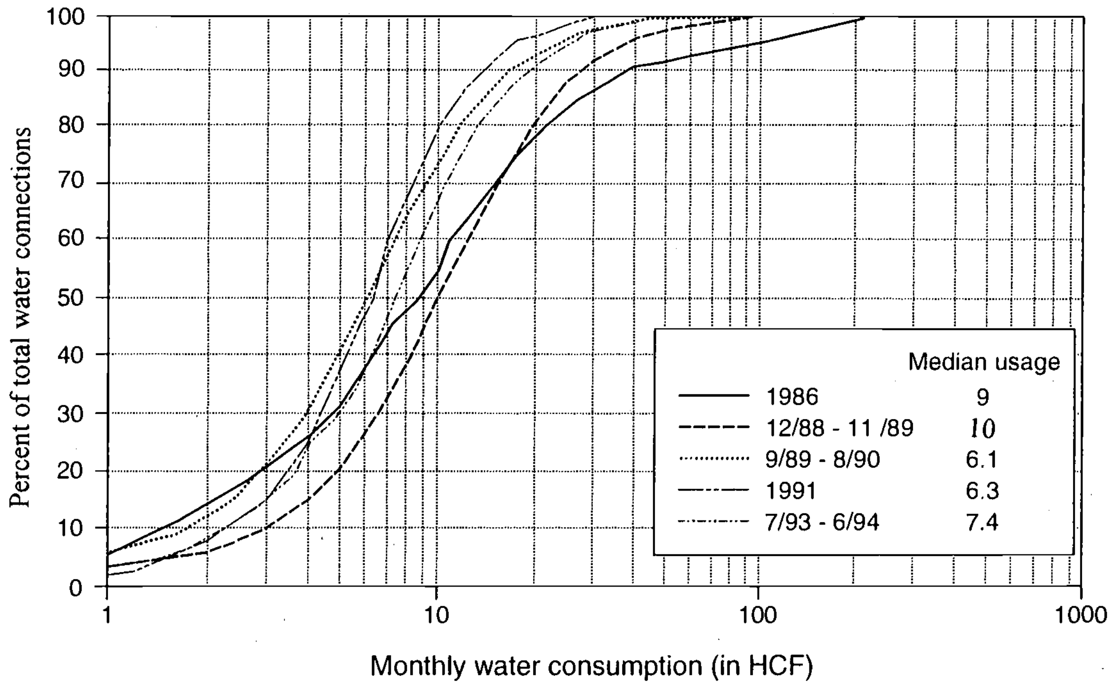

Figure 6. Single-Family Residential Consumption Distribution Curves for the City of Santa Barbara, 1986-1994. (Source: Public Works Department of the City of Santa Barbara, and Kennedy/Jenks Consultants, 1995) (1 HCF = 100 cubic feet = 2.83 m^3)

abolition. In the period June 1986 to June 1988, Santa Barbara had a uniform rate structure. Single-family residential customers paid a unit price of $0.89/HCF regardless of the level of monthly water use, plus a monthly service charge of $4.10. Thus, someone using, say, 20 HCF/month (56.6 m^3/month) received a monthly water bill of 20 x 0.89 + 4.10 = $21.9. Beginning in July 1989, Santa Barbara switched to an increasing block rate structure, whereby the first 8 HCF (22.6 m^3, i.e., the first "block") of water in any month were priced at $1.09/HCF; between 8 and 20 HCF (22.6 and 56.6 m^3, the second block) water was priced at $1.58/HCF; in the third block, between 20 and 40 HCF (56.6 and 113.2 m^3), the price of water was $1.97/HCF; the last block, over 40 HCF (113.2 m^3), was priced at $3.01/HCF. The monthly service charge was set at $1.47 in July 1989 (Figure 7). In March 1990, the block rate structure became much steeper. According to Figure 7, in the period March 1990 to October 1990 a single-family residential customer using 20 HCF/month (56.6 m^3/month) was paying 1.09 x 4 + 3.27 x 4 + 9.81 x 6 + 29.43 x 6 + 1.47 = $253.35/month. The later is almost 12 times the monthly bill that would have applied in 1986 for the same amount of water used by a single-family residential customer. As of this writing, the monthly bill to a single-family residential customer using 20 HCF/month (56.6 m^3/month) is readily calculated from the water rate established in August 1995, which is written in the last row of Figure 7, as being equal to $69.90.

Variations in Total Metered Water Sales and Average Water Revenue

Table 3 presents water use and revenue data for fiscal years 1986-1987 to 1995-1996 in Santa Barbara (the fiscal year begins July 1 of any calendar year and ends on June 30 of the following calendar year). Columns 2 and 3 present the actual total revenue from water sales and metered water sales, respectively. Column 4 shows the average water revenue calculated by dividing the total revenue from water sales by the metered water sales. Column 5 shows the adjusted total revenue, which is the actual revenue of Column 2 expressed in 1994-1995 dollars after the effect of inflation (at 2.5 percent during the study period) is removed. Column 6 contains the adjusted metered sales, which are equal to the metered water sales of Column 3 normalized to a common 1994-1995 population consumption level (the 1994-1995 population was 93,957). The adjusted metered sales compare water use over time once the effect of population growth has been removed. Column 7 in Table 3 lists the adjusted average water revenue, which is obtained by dividing the total revenue in Column 5 by the metered sales in column 6. The adjusted average water revenue provides a yardstick for comparison standardized to 1994-1995 conditions. The adjusted average water revenue went from \$1.18/HCF in 1986-1987 to \$3.65/HCF in 1995-1996, a threefold increase from the pre-drought era to the post-drought era (Table 3).

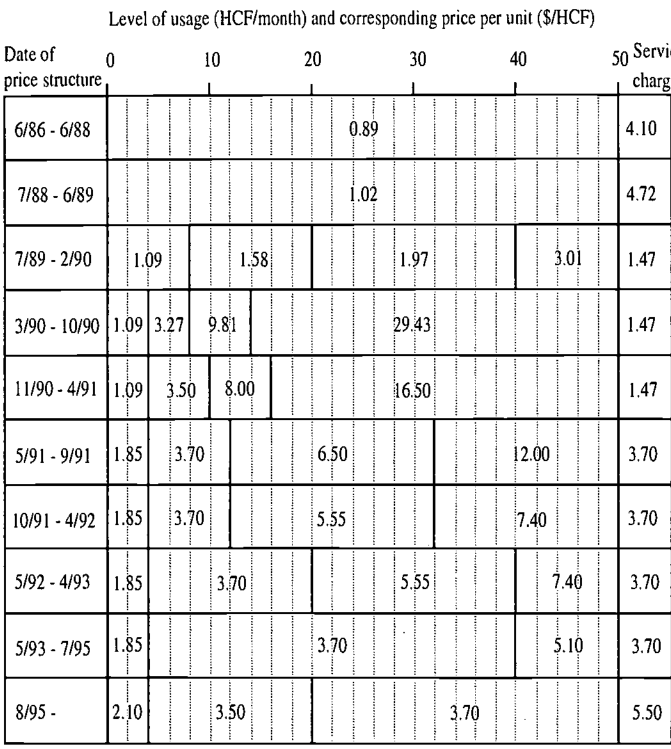

Figure 7. Water Rate Structures for Single-Family Residential Units Which Were in Effect Before, During, and After the Drought in the City of Santa Barbara. (Source: Public Works Department of the City of Santa Barbara)
(1 HCF = 100 cubic feet = 2.83 m^3)

Figure 8 is a plot of the adjusted average water revenues and their corresponding adjusted total metered sales during the period 1986-1996. It was hypothesized in a previous section that in the period 1986-1987 to 1987-1988 changes in water use were largely driven by changes in water prices. Thus, the section of the curve in Figure 8 comprised between years 1986-1987 and 1987-1988 may be viewed as an approximate demand curve for water. On the other hand, the points in Figure 8 corresponding to years 1988-1989, 1989-1990, and 1990-1991 imply large changes in water use caused by the combined effect of increased water rates and water conservation measures. Thus, the 1988-1989/1990-1991 data points were arrived at from the 1987-1988 point in the graph of Figure 8 by large shifts of the demand curve, rather than by water use-average revenue displacements along a demand curve.

The mathematical equation of the straight line between 1986-1987 and 1987-1988 in Figure 8 was determined to be:

$$P = 3.56 - 0.000000306Q \quad (1986\text{-}1987/1987\text{-}1988) \quad (1)$$

in which the (adjusted average) revenue P is given in \$/HCF and the (adjusted total metered) water demand (or sales) Q is given in HCF. Under the assumption that Equation (1) is an approximation to the pre-drought demand curve for water, the pre-drought sensitivity, S_D, of water demand to average revenue changes can be approximated from it. S_D is defined as minus the percentage change in water demand divided by the percentage change in the average revenue of water. Notice that we are not equating sensitivity, as defined herein, with the classical definition of price elasticity under monopolistic water supply (i.e., there is a single water supplier in the water industry for the area under study). Price elasticity presupposes demand variations driven by price changes alone, while all other demand-influencing factors are held constant. With these important caveats in mind, and based on Equation (1), the pre-drought water sensitivity to average revenue fluctuations is given by:

$$S_D = 3,265,035\frac{P}{Q} \quad (1986\text{-}1987/1987\text{-}1988) \quad (2)$$

in which the average revenue P is in \$/HCF, and the total water demand (or sales) Q is in HCF. Using the adjusted average revenue and adjusted total metered sales figures in Table 3, the reader can readily verify that the sensitivity of water demand fluctuated between 0.50 (in 1986-87, for P = \$ 1.18/HCF and Q = 7,770,298 HCF) and 0.52 (in 1987-88, with P = \$1.22/HCF and Q = 7,629,609 HCF).

The section of the curve in Figure 8 comprised between 1987-1988 and 1989-1990 represents a transitional stage, wherein water use changes are not due to changes in water price alone. Instead, those changes in water use arose from the confluence of price changes, changes in consumers' behavior towards water use, water system modifications, and tighter management of the water system. Between water years 1989-1990 and 1990-1991 there was another sharp shift in water use spearheaded by higher water rates and heightened water conservation measures that culminated with the state of emergency declared in February of 1990. Notice that the curve in Figure 8 became steeper in the period 1989-1990 to 1990-1991. Once customers had adopted most available water saving measures prior to 1989-1990,

TABLE 3. Water Sales and Average Revenue Data for the City of Santa Barbara, Fiscal Years 1986-1987 to 1996-1996. (Source: Public Works Department of the City of Santa Barbara) (1 HCF = 100 ft³ = 2.83 m³)

Fiscal Year (1)	Total Revenue ($) (2)	Total Metered Sales (HCF) (3)	Average Price[a] ($/HCF) (4)	Adjusted Total Revenue[b] ($) (5)	Adjusted Total Metered Sales[c] (HCF) (6)	Adjusted Average Price[d] ($/HCF) (7)
1986-87	7,514,899	6,646,257	1.13	9,156,175	7,770,298	1.18
1987-88	7,849,727	6,631,474	1.18	9,330,859	7,629,609	1.22
1988-89	8,516,467	6,284,645	1.36	9,876,490	7,117,291	1.38
1989-90	9,854,983	4,943,011	1.99	11,150,009	5,540,215	2.01
1990-91	12,328,522	3,566,380	3.46	13,608,382	3,896,726	3.49
1991-92	13,883,662	3,806,591	3.65	14,951,185	4,009,619	3.73
1992-93	15,701,997	4,376,425	3.59	16,496,911	4,505,255	3.66
1993-94	15,771,912	4,470,600	3.53	16,166,210	4,516,454	3.58
1994-95	17,200,000	4,600,635	3.74	17,200,000	4,600,635	3.74
1995-96	17,800,00	5,227,200	3.41	17,365,854	4,761,393	3.65

[a]Obtained by dividing total revenues in Column 2 by total metered sales in Column 3.
[b]Obtained by adjusting total revenue in Column 2 to 1994-1995 dollars using a 2.5 percent annual inflation rate.
[c]Obtained by adjusting total metered sales in Column 3 to a common 1994-1995 population consumption level.
[d]Obtained by dividing the adjusted total revenue in Column 5 by the adjusted total metered sales in Column 6.

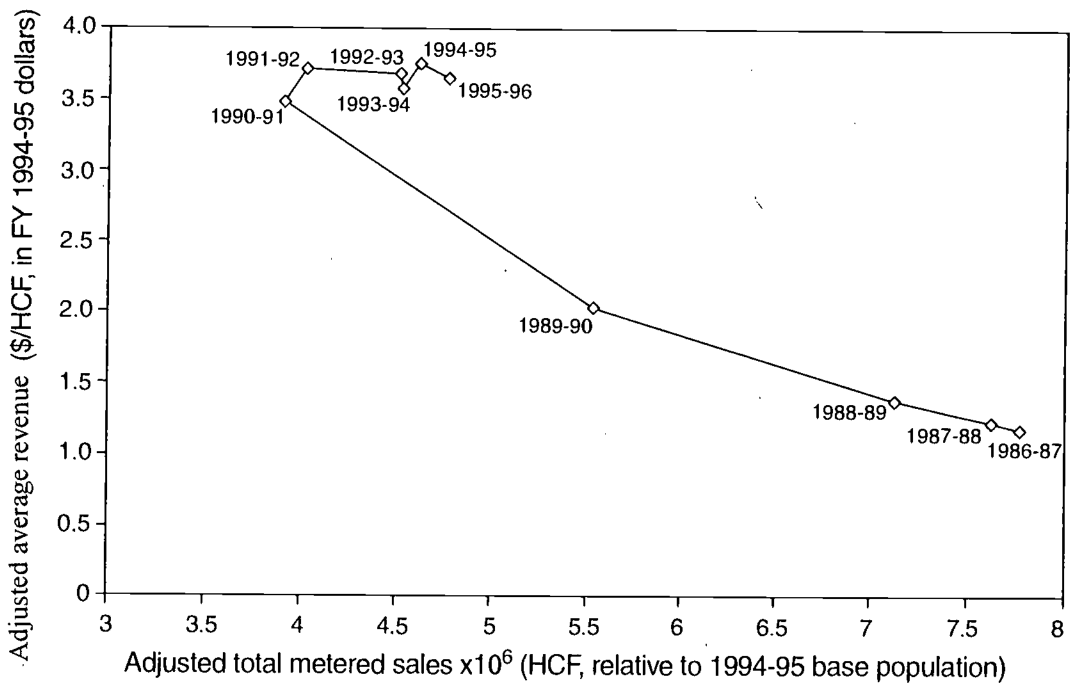

Figure 8. Average Revenue and Total Metered Sales for Water in the City of Santa Barbara, Fiscal Years 1986-1987 to 1995-1996. (Source: Public Works Department of the City of Santa Barbara) (1 HCF = 100 cubic feet = 2.83 m³)

it became more difficult to achieve incremental water savings. Thus, larger price increases were required between 1989-1991 to achieve the same level of marginal water savings that were observed prior to 1989.

Figure 8 shows an interesting evolution of the water use-average revenue relationship in the post 1990-1991 era. Water rates have remained relatively stable till present, while the metered water sales have steadily, *albeit* slowly, increased. As of this writing, adjusted metered sales in 1995-1996 (4,761,393 HCF = 13.475 x 10^6 m^3) are 61 percent of what they used to be in 1986-1987 (7,770,298 HCF = 21.990 x 10^6 m^3).

Variations in the Cost of Water Supply

Table 4 presents data on the cost of water supply from fiscal year 1986-1987 to fiscal year 1995-1996 in Santa Barbara. Columns 2 and 3 of Table 4 contain the total operating cost (fixed plus variable costs) and the total metered water sales respectively for years 1986-1987 to 1995-1996. Column 4 shows the average cost of water supply, obtained by dividing the total operating cost of each fiscal year by its total metered sales. Column 5 shows the total operating cost expressed for each year in terms of 1994-1995 dollars. Column 6 contains the total metered water sales normalized to the 1994-1995 population consumption level. Lastly, Column 7 shows the adjusted average cost of supplying water, which is calculated by dividing the adjusted total operating cost by the adjusted total metered water sales.

The average cost of water supply went from \$1.32/HCF in 1986-1987 to \$4.40/HCF in 1995-1996, implying more than a three-fold increase in the cost of water supply from pre-drought years to post-drought years (Table 4). The rise in the average cost of supply from 1986-1987 to 1995-1996 may be attributed largely to investments made during that period to mitigate future drought impacts. Those investments consisted of an ocean desalination plant and the importation of State Water Project water (see above for their total costs). The difference in average cost of water supply between 1995-1996 and 1986-1987 is \$4.40 - 1.32 = \$3.08/HCF. This difference can be considered as a premium paid for hedging drought risk by water supply augmentation, which involves long-term capital investments (desalination plant and State Water transfers to Santa Barbara), as well as capital replacement investments (reduction of water system leakage by pipe replacement). The Santa Barbara data have provided a rare opportunity to estimate of the average cost of hedging drought risk.

Figure 9 contains plots of the average revenue and average cost of water as a function of time for the period 1986-1987 to 1995-1996. It is seen how in 1986-1987 the average cost of water supply was almost matched by the average price of water, except for a small deficit of \$1.32 - \$1.18 = \$0.14/HCF (from data in Tables 3 and 4). The pricing scheme in 1986-1987 was, therefore, very close to average-cost pricing. The gap between the average cost of water supply and the average price of water widened through the drought years, reaching a peak of \$1.03/HCF in 1993, and at present, in 1996, is equal to (from data in Tables 3 and 4) a deficit of \$4.40 - \$3.65 = \$0.75/HCF. The City of Santa Barbara supplements metered water sales with revenues that accrue from a utility user's tax and from income generated from interest earned on an investment "water" account. Even

TABLE 4. Total Operating Cost and Average Cost Data for the City of Santa Barbara, Fiscal Years 1986-1987 to 1995-1996. (Source: Public Works Department of the City of Santa Barbara) (1 HCF = 100 ft^3= 2.83 m^3)

Fiscal Year (1)	Total Operating Cost (\$) (2)	Total Metered Sales (HCF) (3)	Average Cost[a] (\$/HCF) (4)	Adjusted Total Operating Cost[b] (\$) (5)	Adjusted Total Metered Sales[c] (HCF) (6)	Adjusted Average Cost[d] (\$/HCF) (7)
1986-87	8,400,000	6,646,257	1.26	10,234,584	7,770,298	1.32
1987-88	8,600,000	6,631,474	1.30	10,222,697	7,629,609	1.34
1988-89	13,719,748	6,284,645	2.18	15,910,701	7,117,291	2.24
1989-90	13,279,446	4,943,011	2.69	15,024,474	5,540,215	2.71
1990-91	13,361,575	3,566,380	3.75	14,748,679	3,896,726	3.78
1991-92	16,385,575	3,806,591	4.30	17,645,409	4,009,619	4.40
1992-93	20,106,575	4,376,425	4.59	21,124,470	4,505,255	4.69
1993-94	19,767,753	4,470,600	4.42	20,261,361	4,516,454	4.49
1994-95	19,212,361	4,600,635	4.18	19,212,361	4,600,635	4.18
1995-96	21,488,889	5,227,000	4.11	20,964,770	4,761,393	4.40

[a]Obtained by dividing total operating cost in Column 2 by total metered sales in Column 3.
[b]Obtained by adjusting total operating cost in Column 2 to 1994-1995 dollars using an annual inflation rate of 2.5 percent.
[c]Obtained by adjusting total metered sales in Column 3 to the 1994-1995 population consumption level.
[d]Obtained by dividing the adjusted total operating cost in Column 5 by the adjusted total metered sales in Column 6.

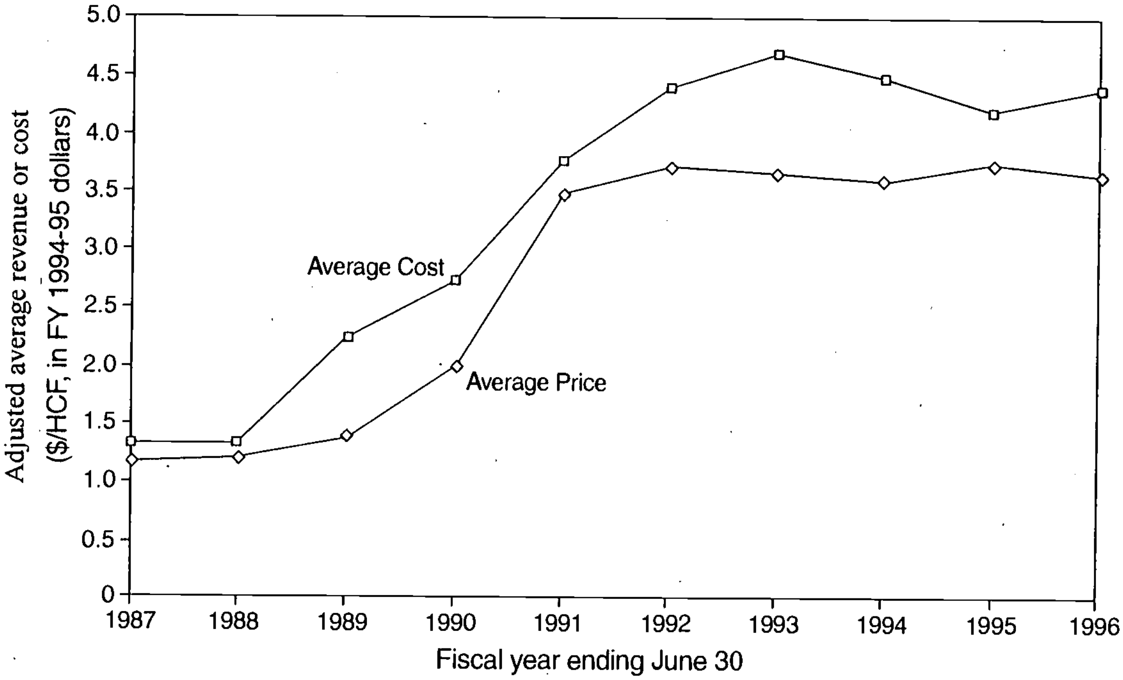

Figure 9. Average Revenue and Average Cost for Water in the City of Santa Barbara, Fiscal Years 1986-1987 to 1995-1996. (Source: Public Works Department of the City of Santa Barbara) (1 HCF = 100 cubic feet = 2.83 m^3)

though these two additional sources of revenue offset any shortfalls in total revenue needed to cover total costs, one must realize that the greater the gap between metered sales and operating costs, the greater the percentage of water-investment revenues that needs to be dedicated to cover operating costs. This has potential detrimental effects, such as reducing the ability to develop a healthy investment fund to help cover catastrophic losses in the water system that may arise from wild-fires or earthquakes, both common in the study area.

CONCLUSIONS

This paper has presented a synthesis and interpretation of data pertinent to the evolution of water use, water rates, average water revenue, and average cost of water supply from 1986 to 1996, a period which included one of the most devastating droughts in California. The 1986-1992 drought hit the City of Santa Barbara, California, the case study area, particularly hard. The City of Santa Barbara was dependent exclusively on local sources for its water supply. That made it quite vulnerable as the regional climate is prone to extreme variability and recurrent droughts. The 1986-1992 drought provided a rare and valuable opportunity to observe the sensitivity of water demand to pricing, water conservation measures, and a public education campaign. In the early phase of the drought, water demand was depressed slightly by relatively mild water price increases. Subsequently, water price increases, water conservation, and public education commingled to reduce water use to about 50 percent of the pre-drought level. In the post-drought era, water rates have remained stable and high compared to pre-drought levels, while water use remains at about 61 percent of the pre-drought consumption.

The Santa Barbara data yielded estimates of the variation in the cost of water supply triggered by severe drought. That cost rose more than three-fold in real terms from 1986 to 1996. The rise in the average cost of water supply is attributable to large capital investments aimed at supply augmentation and conservation to mitigate future drought. In this sense, the rise of $3.08 in the cost of supplying one unit of water between 1986 and 1996 can be equated with the cost of hedging drought risk in the study area.

The gap between the average cost of supply and the average revenue generated per unit of water rose in real terms from $0.14 in 1986 to $0.75 in 1996, in spite of the fact that the average price of water more than tripled from 1986 to 1996. The widened gap between water sales and operating costs in the post-drought era hints to a greater reliance of investment-fund generated income. This may hinder the ability to develop a healthy future water fund which could serve as valuable insurance against other likely natural hazards.

The main conclusion learned from this study is that it is possible to depress water use significantly through a combination of water-rate manipulation, consumer behavior adaptation to drought, and water conservation measures supported by strict enforcement. Although it was not possible to separate how much of the water use decline is attributable to either water conservation or water pricing, it was learned how useful these tools are in diminishing water use while new water supplies are developed to weather out protracted drought. The data derived from the 1987-1992 California drought are unique and valuable insofar as shedding light on drought/water demand adaptive interactions. The experience garnered on drought management during that unique period points to the possibilities available for future water management in the Arid West, where dwindling water supplies and burgeoning populations are facts that we must deal with.

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