LOOKING AHEAD FOR WATER

Can southern California keep growing indefinitely without fear of a water shortage? Here's what engineers and scientists are doing to meet the inevitable problem.

by JACK E. McKEE

WATER, OR RATHER THE SHORTAGE thereof, is a problem of continuing and growing importance in the western states and especially in southern California. Next to air, water is the most critical substance for man's existence and development. And, next to smog, water shortages present the most serious challenge to the ultimate growth of this region.

Do we have enough water for the next decade or two? Can southern California continue to grow indefinitely without fear of a water shortage? Will there be enough water for industry, or must the economy remain predominantly agricultural? If more water is needed, where can it be obtained and at what cost? What needs to be done now? These are questions that this paper attempts to answer, with the aid of a crystal ball and data from many sources.

The history of water supply for southern California is a long and fascinating story, ably told by Remi Nadeau (1) and by Vincent Ostrom (2). This article, however, is concerned not with the past nor even the present, but with the future and ultimate problem.

In any discussion of water-supply problems in arid regions, it is important to recognize the distinction between water "use" and water "consumption." Water is considered to be "consumed" when it is irretrievably lost by transpiration from plants, by natural or man-made evaporation, by percolation into aquifers too deep for recovery, or even by mixing with ocean or other saline waters. Water is "used" but not consumed when it drives a power turbine, when it floats logs down a flume or sluices minerals from a hill, when it passes through cooling coils and returns to a stream, and even when it serves domestic purposes and flows to a cesspool or an inland sewage treatment plant. In general, water is "consumed" by agriculture but merely "used" by municipalities and industry unless they discharge to the ocean. This distinction is important when one is considering the transition of southern California from a rural to an urban economy.

It is common in waterworks practice to assume that water requirements will be a function of population growth, with per capita demands remaining constant or increasing only slightly with time. For many eastern cities this assumption has been relatively valid; but where industry or irrigation is a dominant influence, water requirements may far outstrip, or even run counter to, population growth. In Los Angeles, for example, the per capita use was 200 gpd (gallons per day) in 1905 when the supply was unmetered, but it dropped to 128 gpd by 1928 as a result of metering and to 110 gpd by 1935 because of economic depression. It has been rising steadily since 1935 to about 150 gpd now. An an example of high per capita requirements, the nearby industrial community of Vernon uses 14,000 gpd per resident, and the number of residents decreased by about 50% during the last census decade! In contrast, troops on desert maneuvers have subsisted on as little as one gpd per man for all purposes. It is difficult, therefore, to try to base the future and ultimate water requirements of southern California on population.

A better yardstick in regions of mixed demands by cities, industries, and irrigated agriculture is based on area to be served and the "duty" of water—duty being defined as the water supplied in acre ft.(AF) per acre per year (or ft. per year)—because the duty tends to approach a predictable asymptote for each type of use, and the number of habitable and irrigable acres is limited. Moreover, duties for agricultural and domestic purposes are quite comparable in magnitude. When an orange grove in the San Gabriel Valley, for example, is replaced by a subdevelopment of five or six houses per acre, the total annual water requirement per acre is not increased and, what is more important, the consumptive use by vegetation is replaced partly by non-consumptive domestic use.

Typical duties of water requirements on an areal basis for southern California are shown in the table below, along with some of the reasons for the variability of the figures. The requirements for irrigation and for single-family dwellings are comparable, but in apartment-house zones and crowded business districts the areal use may reach or even exceed 100 ft. per year. Most industries, on the other hand, are generally quite moderate in their demands for water. At the Kaiser Steel Co. in Fontana, for example, the demand is only 2.8 ft. per year. At eastern mills, 65,000 gallons of water are used to make one ton of steel, but at Fontana this figure has been reduced to 1100 gallons per ton by conservation and the reutilization of waste water. When faced with the necessity of reducing water use and preventing pollution of streams or groundwater basins, most other industries can adapt their operations to a rigid economy that will not greatly exceed municipal or irrigation requirements on an areal basis.

The South Coastal Basin of California, (roughly the Ventura-San Bernardino-San Diego triangle) represents a geographical subdivision that can be considered as a unit in planning for water supply. The total area in this basin suitable for municipal, industrial, and agricultural use is approximately 2,800,000 acres. For a mixed economy it is probable that the ultimate mean annual water requirement will approach 2.0 ft. and hence the total ultimate water requirement is estimated at 5,600,000 AF per year.

How well can the existing sources of water meet this requirement and where can additional fresh water be developed? Local supplies have their origin in the limited precipitation on the valley floors and in the heavier rainfall of the nearby mountains. The mean seasonal precipitation on valley and mesa lands in the South Coastal Basin is 2,084,000 AF, but very little of this water is available for water supply, either as surface run-off or as groundwater replenishment. Most of it is consumed by evaporation and transpiration, over and above the water requirement by irrigation. Approximately 400,000 AF per year (as a mean figure) escapes to the ocean during floods or heavy storms, but very little of this amount is recoverable.

TYPICAL WATER REQUIREMENTS IN SOUTHERN CALIFORNIA

(in feet per year or acre-ft. per acre per year)

USE	MIN.	MEAN	MAX.	VARIATION DEPENDS ON
1. Agricultural	0.5	1.5	3.0	Total Annual Rainfall Rainfall Distribution Type of Crop Type of Soil
2. Residential	0.5	2.0	3.5-5.0	Population Density Standard of Living Economic Conditions
3. Business-Commercial	0.1	5.0	100	Type of Use Size and Occupancy of Bldgs.
4. Industrial	0.5	2.5	5-10	Type of Industry Measures for Conservation Cost and Availability of Water and Sewers
5. A Probable Mixed Economy	1.0	2.0	3.0	

PRESENT SOURCES OF WATER SUPPLY FOR SOUTH COASTAL BASIN

(in acre feet per year)

	PRESENT USE	ULTIMATE
Safe Yield of Local Supplies	1,000,000	1,000,000
Overdraft of Local Ground Water	400,000	....
Owens Aqueduct (L.A. City)	300,000	300,000
Colorado River Aqueduct (M.W.D.)	200,000	1,200,000
TOTALS	1,900,000	2,500,000

Area Utilized at Present	= 1,200,00 ACRES
Water Used at Present	= 1.58 Ac. Ft. /ACRE/YEAR
Ultimate Habitable Area	= 2,800,000 ACRES
Ultimate Water Requirement	= 5,500,000 Ac. Ft./YEAR
Anticipated Ultimate Deficit	= 3,100,000 Ac. Ft./YEAR

More useful for water supply is the surface run-off from local mountains, for which the long-time mean is 1,227,000 AF per year. This is only 1.7% of the total for the state, yet the basin constitutes 6.9% of the state's area and contains about 55% of the population. Although this surface run-off is sporadic and subject to prolonged wet and dry periods, the extensive groundwater basins of this region provide tremendous underground reservoirs to store heavy run-off during wet years. In a depth of 50 ft. above and below normal water tables, these groundwater basins can store more than 7,000,000 AF of withdrawable water.

With allowances for losses during floods and for some augmentation by valley-floor precipitation, it is estimated that the mean safe yield of local supplies is only 1,000,000 AF per year. At present, however, the draft on these supplies is about 1,400,000 AF per year, representing an annual overdraft of 400,000 AF from local groundwater basins. This is analogous to withdrawing from a savings account each year more money than is deposited, a procedure that obviously cannot be continued indefinitely.

Thanks to the far-sighted planning of waterworks engineers of the City of Los Angeles and the Metropolitan Water District many decades ago, imported water is now available from the High Sierras and the Colorado River to overcome present deficiencies in local supplies. As shown in the table above, the Owens Aqueduct of the City of Los Angeles is operated up to its capacity of 307,000 AF per year; but the Colorado River Aqueduct, which has a capacity of 1,200,000 AF per year, has been used only as a standby supplement. In recent years, however, the demand for MWD water has been increasing rapidly. The total safe yield of local and imported supplies, listed in the table above, is only 2,500,000 AF per year—or less than half of the estimated ultimate requirement.

To meet the shortage that is sure to occur ultimately, and probably before 1990, consideration is being given to several new sources of water supply; viz, desalting of sea water, augmentation of rainfall by cloud seeding, sewage reclamation, and further importation from distant rivers. Each of these plans is described briefly below and compared with the others as to probable cost.

Sea water

The tremendous volume of water at the doorstep of coastal cities has always stirred the imagination of man, but to date the cost of converting sea water to fresh water has been prohibitive. Some attempts have been made to use saline water directly; indeed, industry in southern California is already using about 750,000 AF per year for cooling, sluicing, and other purposes. Dual distribution systems for cities, analogous to those of ocean vessels, have been proposed to provide fresh water for cooking, washing, or irrigation, and salt water for flushing toilets. Two important factors militate against this proposal: first, it is not economically feasible inasmuch as 60-70% of the total cost of any waterworks is attributable to the distribution system; and second, the drainage would cause saline pollution of groundwater basins.

How much does it cost to convert sea water to fresh water? The minimum free energy required to separate one AF of fresh water from sea water has been computed to be about 850 kilowatt hours. This is based on an "ideal" process, infinitely slow, with a fraction of fresh water from a huge volume of sea water, and no inefficiencies. When one AF of fresh water is taken from 2 AF of sea water, the figure rises to 1150 kwh, and with 50% overall efficiency (which is optimistic) the energy cost would be 2300 kwh per AF. Since other changes (amortization, labor, etc.) run about twice the power cost for this type of operation, and with power at ½ cent per kwh, the minimum cost under optimum conditions would be about $35 per AF. This value is not prohibitive, but how close can it be approached by known processes?

There are two general ways to convert sea water to fresh water: remove the water from the brine, or remove the salt from the brine. The first category comprises: (a) simple distillation, (b) multiple-effect distillation, (c) vapor-compression distillation, (d) solar distillation, (e) temperature-difference evaporators (Claude process); and (f) freezing. Included in the second group are: (a) straight chemical precipitation, (b) ion exchange by means of synthetic resins, (c) simple electrolysis, and (d) electro-dialysis with ion-permeable membranes. These ten processes are described and discussed ably by Aultman (3), DeHaven et al. of the RAND Corporation (4), Ellis (5), and Sherwood (6). The table below is a summary of their cost estimates, including allowances for amortization, power, and labor. The most promising methods appear to be vapor-compression distillation, the Claude process, and electro-dialysis with ion-permeable membranes; but it is highly improbable that any of these methods will ever produce fresh water from the ocean at less than $125 or $150 per AF at sea level.

Cloud seeding

Among meteorologists and hydrologists there does not appear to be much unanimity as to the effectiveness of cloud seeding for rainfall augmentation. If it works as well as its proponents claim, cloud seeding is certainly the cheapest source of additional water for any region. Its application to the South Coastal Basin, however, is restricted by the rapid run-off from mountain areas and by the danger of floods in areas of high property value.

The best application of cloud seeding appears to be for increasing the snow packs of the High Sierras and the Rocky Mountain watershed of the Colorado River. If winter precipitation can be augmented by 20%, the run-off will be increased by 30 to 60%, thereby improving the reliability and quality of the present imported supplies. Indeed, southern California can claim a part of any excess flow in the Colorado River.

Sewage reclamation

With the progress of urbanization and industrialization in southern California, there is a steady shift in the ultimate destination of water from evapotranspiration by vegetation to waste water in sewers. This waste water, or sewage, is still fresh water, containing less than 1000

ESTIMATED COSTS FOR LARGE-SCALE SALT WATER CONVERSION PROCESSES

(in dollars per acre foot)

PROCESS	T. K. SHERWOOD (M.I.T.)	ELLIS	AULTMAN	RAND REPORT PRESENT	RAND REPORT POSSIBLE FUTURE
Simple Distillation	1600-3200	......	820*	......	......
Multiple-Effect Distillation	1200	220	340*	1200	900
Vapor-Compression Distillation	540	220	400	700	200
Temperature Diff. (Claude)	......	......	......	150	100
Solar Evaporation	900	......	......	350	100
Freezing	235-400	220	......	......	400
Ion Exchange	6300	......	8000*	......	8000*
Chemical Precipitation	9500	......	......		......
Ion-Permeable Membranes	235-315	100	......	500	130

* = partial costs, for fuel or chemicals only

parts per million by weight of solids, in contrast with sea water, which has about 35,000 ppm of solids. Indeed, sewage is over 99.90 percent pure, which is purer than a well-advertised brand of soap. When discharged to the ocean and diluted in sea water, however, sewage is lost forever as a source of fresh water.

Sewage from most of the City and County of Los Angeles is now treated and discharged to the ocean at a total rate of about 550,000 AF per year. Including similar discharges from Ventura, Orange, and San Diego Counties, the total is about 700,000 AF per year, or about 35% of the water supplied. Ultimately, this proportion may reach 50%, or as much as 2,800,000 AF per year. Herein lies a potential source of fresh water to help meet the anticipated ultimate deficiency.

There is nothing new about the reclamation of waste waters. It occurs locally when drainage from thousands of cesspools helps to replenish the groundwater basins, or as inland sewage plants discharge to dry river beds or to percolation basins. It occurs along eastern rivers where each city in turn takes its water from the river and returns its sewage to be used by downstream communities. It occurs at the federal installation at Grand Canyon National Park where treated and reclaimed sewage is used for toilet flushing and at plush hotels in Las Vegas where treated sewage is used to irrigate the decorative vegetation. It occurs in Baltimore where the Bethlehem Steel Co. purchases much of the effluent from the city's Back River sewage treatment plant. It will continue to occur whenever reclaimed sewage is the cheapest source of additional fresh water.

Reclamation costs

The cost of water reclaimed from sewage is difficult to assess. Part of the cost is rightfully chargeable to waste disposal, for the sewage must be treated to a certain degree before it can be discharged inland or even to the ocean. The cost of additional treatment to render the sewage suitable for direct use by industry or agriculture, or to recharge ground-water basins, is chargeable to water supply. This additional cost will vary from about $10 per AF at large installations to $100 per AF at small installations, with median values of $20-35 per AF.

There are several obstacles to the early reclamation of sewage in southern California. At present, extensive reclamation is neither necessary nor economically advisable inasmuch as the Colorado River Aqueduct is not being used to capacity. Second, there are health hazards involved in the direct use of improperly treated sewage for irrigation. Until these hazards are overcome by effective procedures for disinfection, the State Health Department will continue to enforce rigid rules of precaution. Third, there is a natural reluctance on the part of the public knowingly to use reclaimed sewage, unless the merits of such use are carefully explained in a public-relations program. For this latter reason, it is probable that most reclamation will involve groundwater recharge rather than direct use, so that the sewage will lose its identity.

Even if sewage reclamation is carried to the utmost extent, it will still not provide sufficient additional water for the South Coastal Basin. Outfall sewers to the ocean will always be needed to discharge some sewage and much of the industrial wastes which are not amenable to treatment and reuse. These outfall sewers will be needed also as "bleed" valves to prevent an excessive build-up of salts from the recycling of groundwater. Consequently, additional water will be needed to augment present sources even with the reclamation of sewage.

Imported water

Twice before in its phenomenal growth, southern California has reached out to distant sources for supplemental water. It appears now that a third major aqueduct will be needed to bring more imported water to this region. Fortunately, California will not have to seek water from the Columbia River or other remote streams, for there are sufficient water resources within the state boundaries. Recent reports from the State Division of Water Resources indicate that the mean total run-off of California streams is about 70,000,000 AF per year. If only half of it is recovered and used, this annual volume will support 30 million people and three times the present irrigated agriculture. The problem, however, is to transfer water from northern regions of excess to southern areas of deficiency.

A plan for accomplishing this transfer has been developed by the State Engineer as part of a comprehensive California Water Plan. Known as the Feather River Project, it comprises (a) a dam and power plant on the Feather River near Oroville for flood control, low flow regulation, and power supply, (b) diversion and pumping of Sacramento River water from the delta region near Tracy, (c) a main canal along the west side of the San Joaquin Valley, through the San Bernardino Mountains, and past Hemet to the headwaters of the San Diego River, and (d) diversions to Santa Clara Co., Ventura Co., and Santa Barbara Co. Alternate routes are still being considered, but the most likely plan involves about 567 miles of aqueduct and a total lift of about 3500 ft., with some power recovery on this side of the mountains.

This plan will provide 1,773,000 AF per year of additional water of high quality to the regions south of the Tehachapi Mountains. The initial and ultimate costs of this water per AF have not been determined definitely as yet. Depending on methods of financing and periods of amortization, it appears that the cost will be $40 to $60 per AF.

There is no danger of an acute overall water shortage in southern California during the next 20-30 years, owing to the far-sightedness of the engineers who conceived the Metropolitan Water District. Ultimately, however, the total water requirements for the South Coastal Basin will

APPROXIMATE COSTS OF WATER SUPPLIES FOR SOUTH COASTAL BASIN (in dollars per acre foot, including amortization)	
Local Runoff and Ground Water	$ 3.00 - 10.00
Owens Aqueduct	19.00
Colorado River Aqueduct	35.00 - 45.00
Reclaimed Water (estimated)	20.00 - 35.00
Feather River Project (estimated)	40.00 - 60.00
Salt Water Conversion (estimated)	125.00 - 200.00

be more than twice the available supply from local resources and present aqueducts. Part of this deficiency can be met by the reclamation and reutilization of waste waters, but an additional source of new fresh water is needed. The cost data shown in the table above indicate that the Feather River Project is the logical answer to this problem. The desalting of sea water does not appear to be economically feasible for this region, barring a miracle of thermodynamics or a cheap source of power.

Although no critical water shortage looms for the next few decades, engineers and scientists cannot neglect planning and research to meet the inevitable problem. About 20 years were required from the initiation of the MWD until the first Colorado River water reached southern California. A similar period or longer may be necessary to secure additional water from the Sacramento Basin. In the meantime, the active program of research and development to improve methods of salt water conversion should be encouraged. More important, perhaps, investigations must be accelerated to find cheaper, safer and more efficient ways to reclaim and reutilize sewage and other wastes.

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