POTENTIAL EFFECT ON WATER PROJECT YIELD OF CHANGED SNOWMELT RUNOFF PATTERNS

by
Maurice Roos[1]

ABSTRACT

One of the potential changes of global warming would be a shift in runoff patterns in temperate zone mountains with less spring snowmelt and more direct winter rain runoff. The Mokelumne River, located in the central Sierra Nevada range of California, was examined to see how this shift in runoff pattern would affect water supply yield. The shift reduced April through July runoff by an average of 28 percent with a corresponding increase in winter runoff, some of which had to be released for flood control purposes. However, the loss in water project dependable urban supply was only 1 to 3 percent. Part of the reason for the small change was the fact that total reservoir storage capacity exceeds average annual runoff of the basin. Another factor was the relatively uniform monthly demand, which generates a smaller dry season draft than an equivalent annual agricultural demand. The level of demand also has an influence; water systems operating beyond their firm yield limit will be more stressed by changing runoff.

INTRODUCTION

In an earlier paper at the 1990 Western Snow Conference, the author presented an estimate of the potential reduction of spring snowmelt runoff in California if a 3°C rise in average temperature occurred. The result was a substantial shift in runoff away from the snowmelt season into the winter months. Spring snowmelt, defined as April through July runoff, could drop about one-third, with an offsetting increase during winter months. The change was greater in the northern Sierra than in the higher elevation southern Sierra. That paper went on to estimate that the shift in runoff pattern could reduce water supply drought period yield about 7 percent.

The purpose of this paper was to examine in more detail, in monthly operation studies, what the impact would be for the Mokelumne River system. The Mokelumne River was chosen because it is fairly central in the Sierra, and has quite a bit of reservoir capacity. In the original study, which was based on average conditions, the estimated reduction in spring runoff was 30 percent, fairly close to the average regional impact of the assumed climate

---

Presented at the Western Snow Conference, April 1994, in Santa Fe, New Mexico.

[1] Chief Hydrologist, California Department of Water Resources, 1416 9th Street, P. O. Box 942836, Sacramento, CA 94236-0001.

change. A very basic assumption was that precipitation patterns would remain the same; therefore the effect is that of more precipitation being in liquid instead of frozen form. The average snow line elevation on April 1 would rise from 1640 to 1980 meters (5000 to 6500 feet) with an estimated decrease of 36 percent in snow covered area above the stream gage near Mokelumne Hill (essentially the inflow to Pardee Reservoir). The average April through July reduction for the 50 years of this study turned out to be 28 percent, approximately 160 million cubic meters (130,000 AF) per year.

THE SETTING

Figure 1 shows the location of the Mokelumne River watershed. The 50 year (1941-90) average natural runoff at the Mokelumne Hill gage is 923 million cubic meters (748,000 AF), with 574 million cubic meters (465,000 AF), some 62 percent, during the April through July snowmelt season. The 50 year period, 1944-93, of the yield studies was slightly drier with an average runoff of 894 million cubic meters (724,000 AF). The wettest water year of record since 1906 was 2222 million cubic meters (1,800,000 AF) in 1983. The driest was just six years earlier in 1977 with only 159 million cubic meters (129,000 AF). The six year average during the 1987-92 drought was about 395 million cubic meters (320,000 AF). The earlier 1929-34 drought average was around 506 million cubic meters (410,000 AF), eased somewhat by an average year in 1932 in the middle of the drought period.

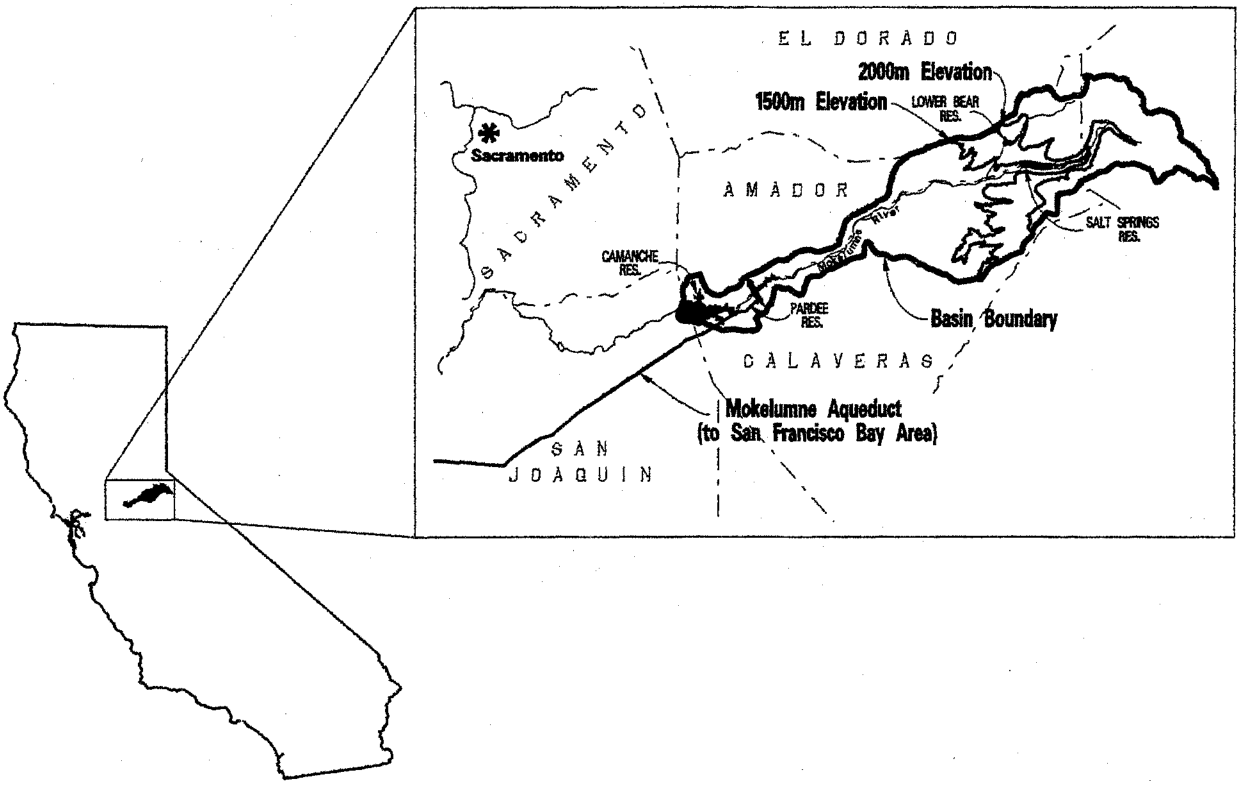

Figure 1. Location of Mokelumne River Basin

Most of the water supply for the large East Bay Municipal Utility District serving Oakland, Berkeley, Walnut Creek and other cities on the eastern side of San Francisco Bay is drawn from the Mokelumne River. The Mokelumne Aqueduct consists of three pipeline barrels 140 kilometers (90 miles) long with a capacity of 17 cubic meters per second (590 cfs), starting at Pardee Reservoir. Diversions began in 1929. The current level of diversion is about 310 million cubic meters (250,000 AF) per year. There is over 180 million cubic meters (150,000 AF) of terminal reservoir storage in the East Bay area to regulate supplies and to provide some insurance against supply interruptions.

Total reservoir storage in the Mokelumne River basin is about 1,040 million cubic meters (840,000 AF), a little more than average annual runoff. The four major reservoirs are as follows:

Reservoir	Capacity			
	Million Cubic Meters	Thousand Acre-Feet	Owner	Year Completed
Camanche	514	417	EBMUD	1963
Pardee	259	210	EBMUD	1929
Salt Springs	175	142	PG&E	1931
Lower Bear	60	49	PG&E	1952

Winter season storage is limited by the need to maintain up to 247 million cubic meters (200,000 AF) of flood control space. Flood control needs are gradually reduced after mid-March, with no constraints at the end of May. The full flood control space is required again on November 5. Dead storage of the reservoir system is probably about 60 million cubic meters (50,000 AF).

WATER YIELD

In addition to EBMUD, Mokelumne River water supplies downstream prior right irrigators mostly near the City of Lodi, fishery flow into the Delta, and some of the local mountain communities in the Sierra foothills. In addition, there are substantial seepage losses as the river flows across the valley and reservoir evaporation. In a normal year requirements downstream of Camanche Reservoir are about 330 million cubic meters (270,000 AF). Amounts are reduced in dry and critical years when irrigation diversions and downstream fishery amounts are curtailed.

Historically, firm water yield of a water project has been determined as the annual amount delivered over the worst drought of record, with the understanding that some reductions are applied during the driest of years. In the case of EBMUD, reductions should not exceed 25 percent. Originally when the Pardee and later Camanche Dam was built, the historical critical period for the Mokelumne River Project was the severe drought of 1929-34. Later, in 1976 and 1977, the two driest pair of years in the record caused a lowering of the dependable firm yield for EBMUD. Now, it appears that the more recent 1987-92 drought was a more severe test.

For these studies, which are illustrative, the 50-year period 1944-1993 was used for model operation studies. Downstream river demands at Camanche Reservoir were based on three patterns: a normal and wet year pattern of 336 million cubic meters (272,000 AF) per year, a dry year pattern of 233 million cubic meters (189,000 AF) per year, and a critical year pattern with 165 million cubic meters (134,000 AF) per year. In the 50-year base period, 5 years were critical, 16 dry, and the remainder were normal to wet. The same classification was used for the modified runoff. (In actual operations, the projected November 1 storage is a parameter which enters into the water year classification for fishery flow. That recomputation was ignored in the study so that the total change in water supply would show up in the project yield figure.)

YIELD COMPARISONS

The modified runoff for the Mokelumne river was estimated from regression equations similar to those used now for forecasting spring runoff, except to reduce the snow term by 36 percent to reflect reduced snow covered area. This gave a reduction in April through July volume which was deducted proportionately from May through July amounts. A similar amount was added to the November through March runoff to account for the increase in direct rain runoff from presumably higher snow levels. Figure 2 shows the monthly percentages of runoff for the base study and the modified runoff estimated for 3 degree C warmer conditions.

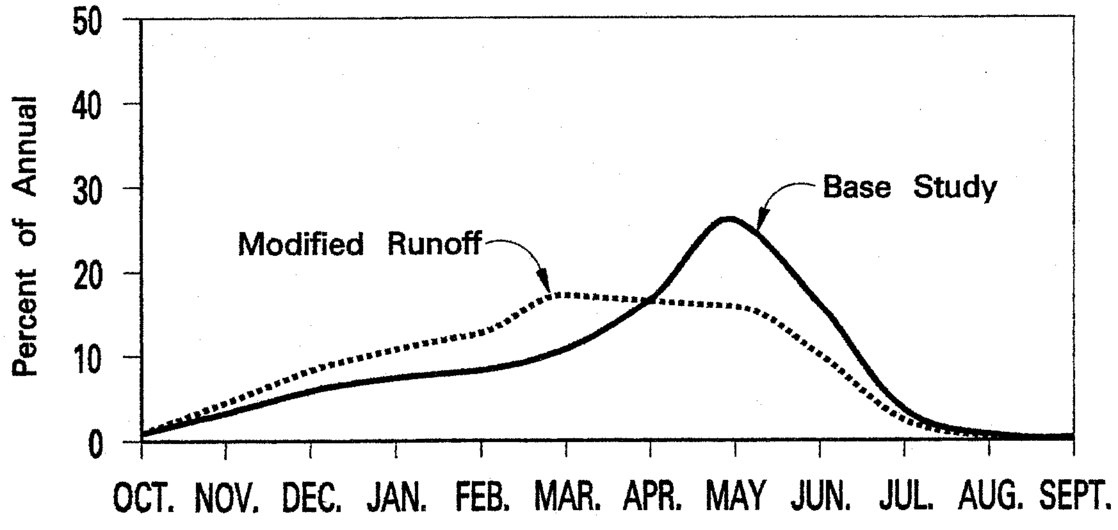

Figure 2. Comparison of Runoff Patterns

Several simplified reservoir operation (simulation) studies were made to examine the effect of modifying runoff patterns. The system was tested at project demands of 370 million cubic meters (300,000 AF) per year (approximately the current level of use), 430 and 490 million cubic meters (350,000 and 400,000 AF). The estimated dependable dry period supply, allowing up to 25 percent critical year curtailment, was about 390 million cubic meters (318,000 AF)for historical conditions and was determined by the 1987-92 drought. Repeating the run with inflows modified for warmer temperatures only reduced the dependable supply by about 6 million cubic meters (5,000 AF) per year. The original study showed shortages in 6 years of 50; the same 6 years gave trouble in the modified pattern scenario with similar deficits. However, when one looks the remaining reserve at the end of the drought, there is a difference which would translate into the small yield reduction.

Figure 3 shows the change in reservoir storage for the first comparison. Note that late winter water levels are higher and summer levels are lower with runoff modified for global warming.

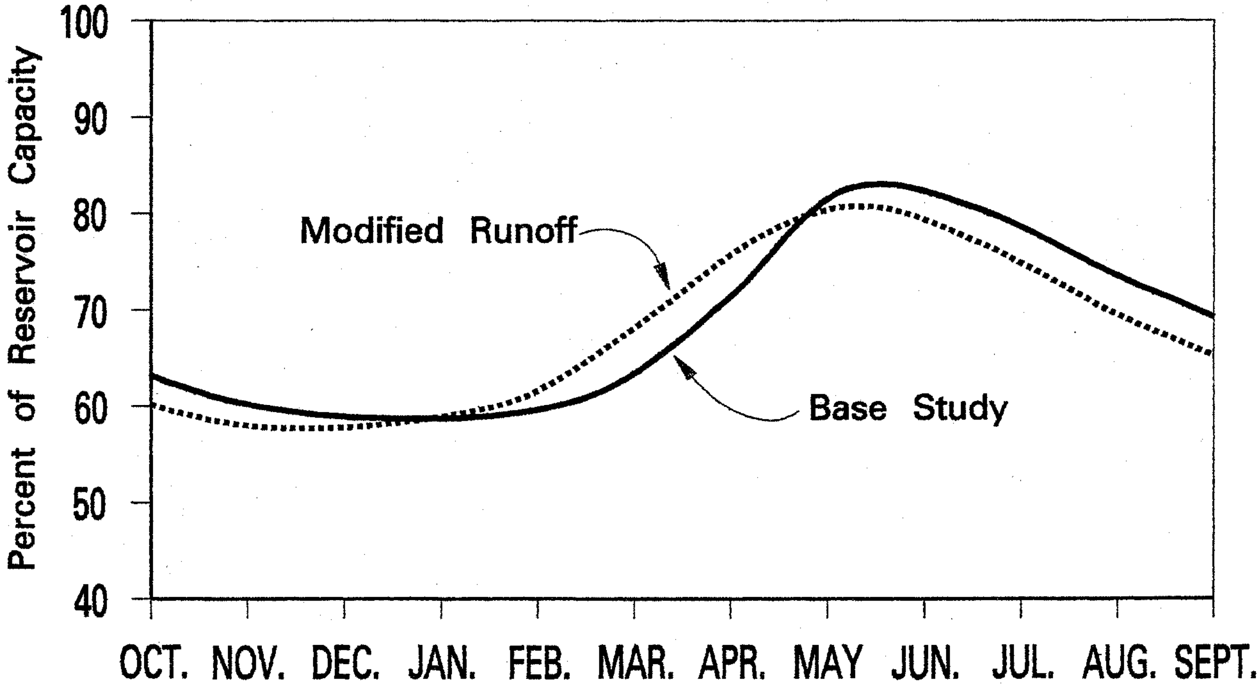

Figure 3. Comparison of Reservoir Storage

Increasing project demand to 430 million cubic meters (350,000 AF) placed more stress on the system. Total shortages for the base study condition were 860,000 million cubic meters (700,000 AF), with deficits in 7 years of the 50 years. Under the modified runoff, these dry year shortages increased 11 million cubic meters (9,000 AF) per year with supply problems during 8 of the years.

A third test at 490 million cubic meters (400,000 AF) per year of project demand was made. As expected, this run resulted in shortages more often in 12 of the 50 years. Modifying the runoff pattern increased the shortages and caused supply problems in 14 of the 50 years in the study and increased the dry period deficits about 2.5 percent.

The last test was to go back to the initial study demand of 370 million cubic meters (300,000 AF) per year, but to place it on an agricultural pattern (See Figure 4). This means a much greater portion of need during the summer season. The result was a much larger impact of the modified runoff pattern, about a 6 percent reduction in dependable supply.

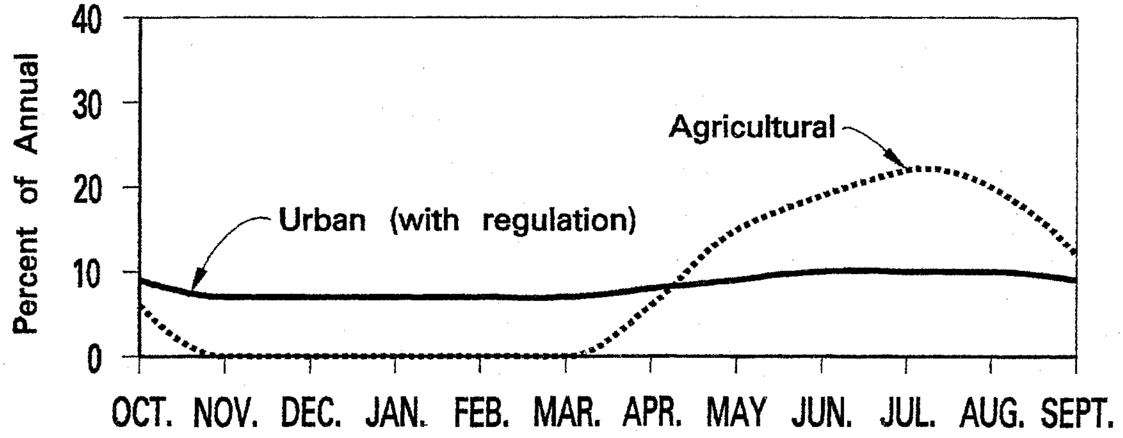

Figure 4. Comparison of Demand Patterns

SUMMARY

Results of the several studies are summarized below. Shortages include 25 percent allowable curtailment in critically dry years.

Loss in Water Supply with Modified Runoff Pattern

Demand Level	Dry Period Yield	Number of Years with Shortages	
		Base	Modified
Urban:			
370 MCM (300 TAF)	1. 6 percent	6	6
430 MCM (350 TAF)	2.6	7	7
490 MCM (400 TAF)	2.5	12	14
Agricultural:			
370 MCM (300 TAF)	5.7	6	8

Comparison of Shortages
50 Year Total, in Percent of Annual Demand

Demand Level Urban:	Base Condition	Modified
370 MCM (300 TAF)	139	140
430 MCM (350 TAF)	200	238
490 MCM (400 TAF)	373	401
Agricultural:		
370 MCM (300 TAF)	145	195

In conclusion, several observations can be made:

1. It is risky to make generalized yield change estimates; detailed studies can show much variation from regional conditions in each basin. Effects of warming on basins north of the Mokelumne River would probably be considerably more.

2. Even though the total runoff is essentially the same, the shift in runoff patterns due to possible global warming would cause some loss in usable water supply.

3. The impact is greater when reservoir systems are operated beyond the firm dry period yield.

4. The pattern of demand makes a difference; in this case, the use of an agricultural demand pattern worsens the impact because of higher summer water needs.

5. The Mokelumne River system, if one counts terminal storage in the East Bay area, has storage capacity over 1.3 times annual runoff. This is a relatively high ratio for California rivers. The storage does a lot to cushion the impact of the runoff pattern shift.

6. Based on inspection of results, it would be possible for a 2 to 3 year drought impact to approach 10 percent if the first year's spring runoff was early; however, that combination of adverse events did not occur during the 50-year period of analysis.

ACKNOWLEDGEMENTS

The author wishes to thank Matthew Colwell, California Cooperative Snow Surveys Program forecaster, for his help in performing a series of computer operation studies for this paper.

REFERENCES:

California Energy Commission, The Impacts of Global Warming on California, Interim Report, August 1989, Sacramento, CA.

California Energy Commission, Global Climate Changes, Potential Impacts and Policy Recommendations. Volume I and II, December 1991, Sacramento, CA

Climate Change and U.S. Water Resources. Report of the AAAS Panel on Climate Variability, Climate Change and the Planning and Management of U. S. Water Resources, edited by Paul E. Waggoner, 1990. Climate Project, American Association for the Advancement of Science, John Wiley, New York, NY.

Dennis, A. S., Initial Climate Change Scenario for the Western United States, US Bureau of Reclamation, September 1991, Denver, Colorado.

Dettinger, Michael D. and Cayan, Daniel R., Large-Scale Atmospheric Forcing of Recent Trends Toward Early Snowmelt Runoff in California. Journal of Climate, Submitted March 1994.

EDAW, Inc. December 1992. Draft EIS/EIR for the Updated Water Supply Management Program, prepared for East Bay Municipal Utility District, Oakland, CA.

Gleick, Peter H., editor, The Colorado River Basin and the Greenhouse Effect: Water Resources and Management, Workshop Proceedings, May 1990, Pacific Institute, Oakland, CA.

Intergovernmental Panel on Climate Change (IPCC), WMO/UNEP, Climate Change, the IPCC Scientific Assessment, July 1990, Cambridge, UK.

IPCC, WMO/UNEP, Climate Change, the IPCC Impacts Assessment, Working Group II, 1990, Canberra, Australia.

IPCC, WMO/UNEP, Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment, 1992, Cambridge, UK.

Roos, Maurice, Possible Climate Change and Its Impact on Snowmelt Supply in California, Pages 130-136, Proceedings of 58th Annual Western Snow Conference, April 1990, Sacramento, CA.

US Congress, Office of Technology Assessment, Changing by Degree, Steps to Reduce Greenhouse Gases, OTA-O-482, February 1991, Washington D.C.

U S Congress, Office of Technology Assessment, Preparing for an Uncertain Climate, October 1993, Washington D.C.

US Environmental Protection Agency, The Potential Effects of Global Climate Change on the United States, Report to Congress, December 1989, Washington D.C.

University of California, Research Needs and Recommendations, Global Climate Change and Its Effects on California, Executive Summary of U.C. Workshop, July 1989, Davis, CA