A TREND OF DECREASING SNOWMELT RUNOFF IN NORTHERN CALIFORNIA

by

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INTRODUCTION

The California Department of Water Resources, in its Cooperative Snow Surveys Program, has computed the unimpaired or natural runoff for major Sierra Nevada-Cascade rivers as far back as records were collected. Unimpaired runoff represents the runoff from a basin that would have occurred had not human activities altered the flow by upstream diversions, storage, and by export or import of water to or from other watersheds.

The Sacramento River Index is widely used as a measure of natural water supply available in that large northern California hydrologic basin. (See location map, Figure 1.) The Index is computed by adding the flows of the four major rivers:

Sacramento River above Bend Bridge, near Red Bluff
Feather River at Oroville Reservoir
Yuba River at Smartville
American River at Fair Oaks (Folsom Reservoir)

The average runoff of the four rivers comprising the Sacramento River Index during the 1906-90 period of record was about 22 cubic kilometers, (18 million acre-feet). This represents over 80 percent of the total Sacramento basin runoff of around 27 cubic kilometers (22 MAF) and includes almost all of the snowmelt runoff. Forecasts of snowmelt (April through July runoff) have been made for more than 50 years by the Snow Surveys Program staff.

Because of the concern about possible climate change, this long record of unimpaired runoff was examined for signs of change in runoff patterns.

EFFECT OF CLIMATE CHANGE ON WATER SUPPLY

Global general circulation computer models of the atmosphere have been used to predict possible climate change from increased CO_2 and other trace gases. Model predictions of warming generally range from 2° to 5°C for an effective doubling of CO_2 (when increased CO_2 plus the other trace gases such as methane and chlorofluorocarbons equal the greenhouse effect of doubled CO_2). That time is expected to be about the middle of the next century, unless current rates of increase in fossil fuel burning are scaled back.

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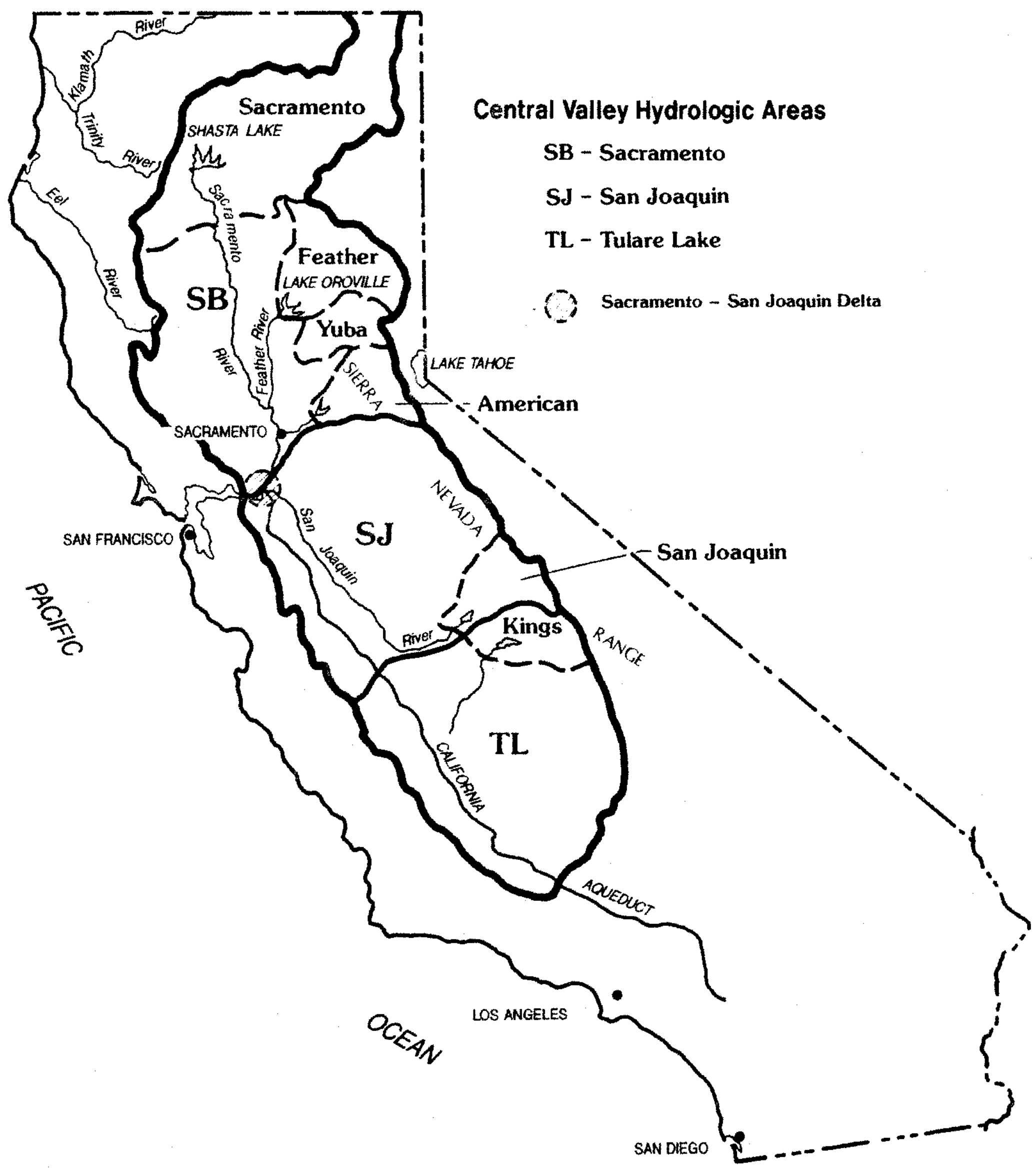
Figure 1. Location Map



The increase in atmospheric CO_2 since the industrial age began is already about 25 percent. Currently atmospheric CO_2 concentration, as measured by Professor C. D. Keeling of Scripps Institution of Oceanography, is about 355 ppm, up from an estimated level of around 280 ppm in the middle of the 1800s. Much of the increase has taken place during the last 30 years; the 1960 atmospheric CO_2 concentration was about 315 ppm. When the greenhouse effect of increases in methane, CFCs, and other pollutants is added in, the world is not far from being halfway to an effective doubling from the pre-industrial age base. Perhaps some effects can be noticed on hydrologic variables, especially snow, which is temperature sensitive.

A global temperature increase would definitely affect the amount of snow accumulation and spring snowmelt from mountain watersheds throughout the west, especially in California where substantial watershed area is in the transition zone between snow and rain.

The term "white gold" is not without merit in California. The average April through July snowmelt of major western slope Sierra Nevada and Cascade Range rivers is about 17 cubic kilometers (nearly 14 MAF), about 40 percent of the estimated total statewide net water use of 42 cubic kilometers. It has been estimated by the author that a 3°C rise in average temperature could reduce spring snowmelt runoff by about 1/3, assuming no change in rainfall patterns.

TREND ANALYSIS

The Sacramento River is California's largest stream and is of primary importance to the State's water users and to anadromous fisheries. In view of global model predictions, Sacramento River Index flows were examined for signs of changed runoff patterns. Especially of concern were possible changes in snowmelt runoff patterns in this large river system. Results of the trend analysis are presented on Figure 2. This chart shows April through July runoff volumes as a percentage of total water year runoff. Looking at the chart more carefully, a rather pronounced decreasing trend shows up after 1950. The slope of the best fit linear regression line is about 0.13 percent per year. The correlation coefficient of the regression, r, was 0.39.

Streamflow in the Sacramento Basin is not predominantly snowmelt. During the period of record, about 38 percent of the annual runoff occurred during the April through July period. Median elevation of the Sacramento River Index watersheds drainage area is about 1400 meters (4500 feet) (See the area-elevation Table 1.)

TABLE 1. Approximate Area Elevation Data

	Sacramento Index Watersheds	Kings & San Joaquin River Watersheds
Total Area, Square Km	40,400	8,300
Elevation, (Meters)	Cumulative Percent	Cumulative Percent
500	11.1	4.3
1000	26.2	13.4
1500	59.6	22.1
2000	91.5	35.1
2500	98.9	53.4
3000	99.8	75.1
3500	99.9	92.3
4000	100.0	99.3

Figure 2. SACRAMENTO RIVER INDEX
April - July Runoff in percent of Water Year Runoff

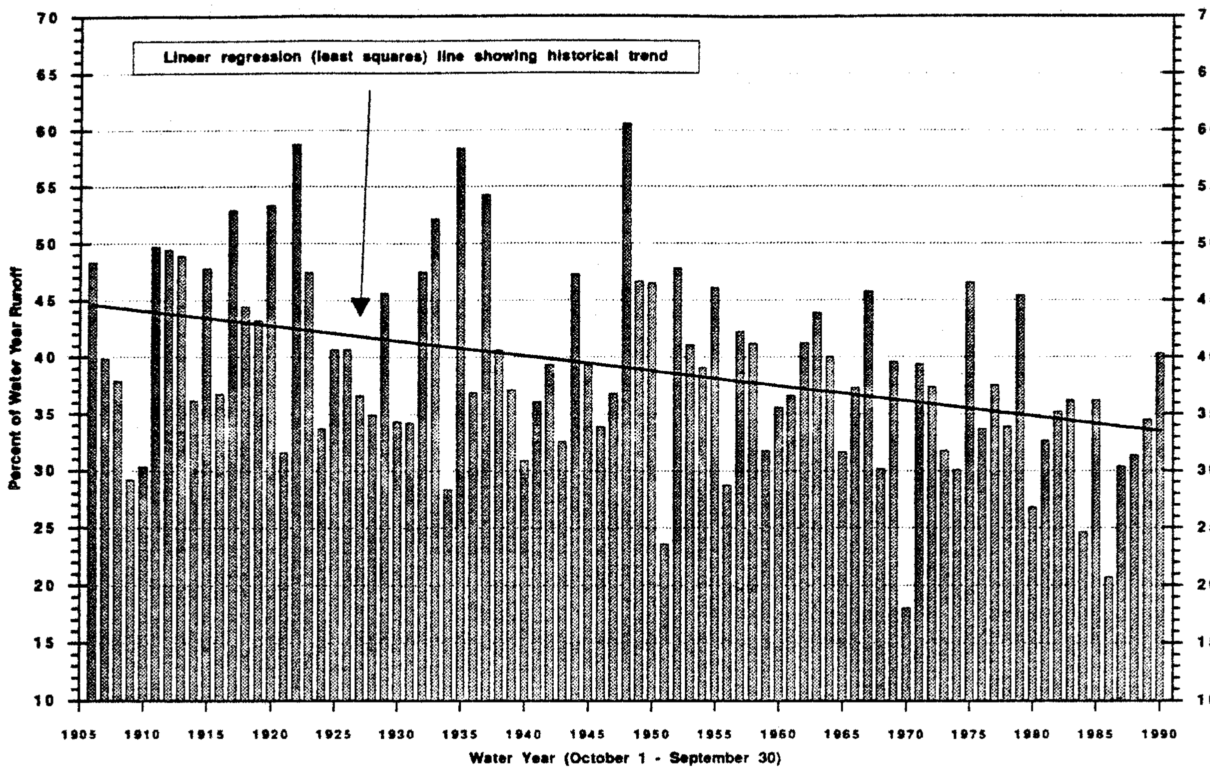
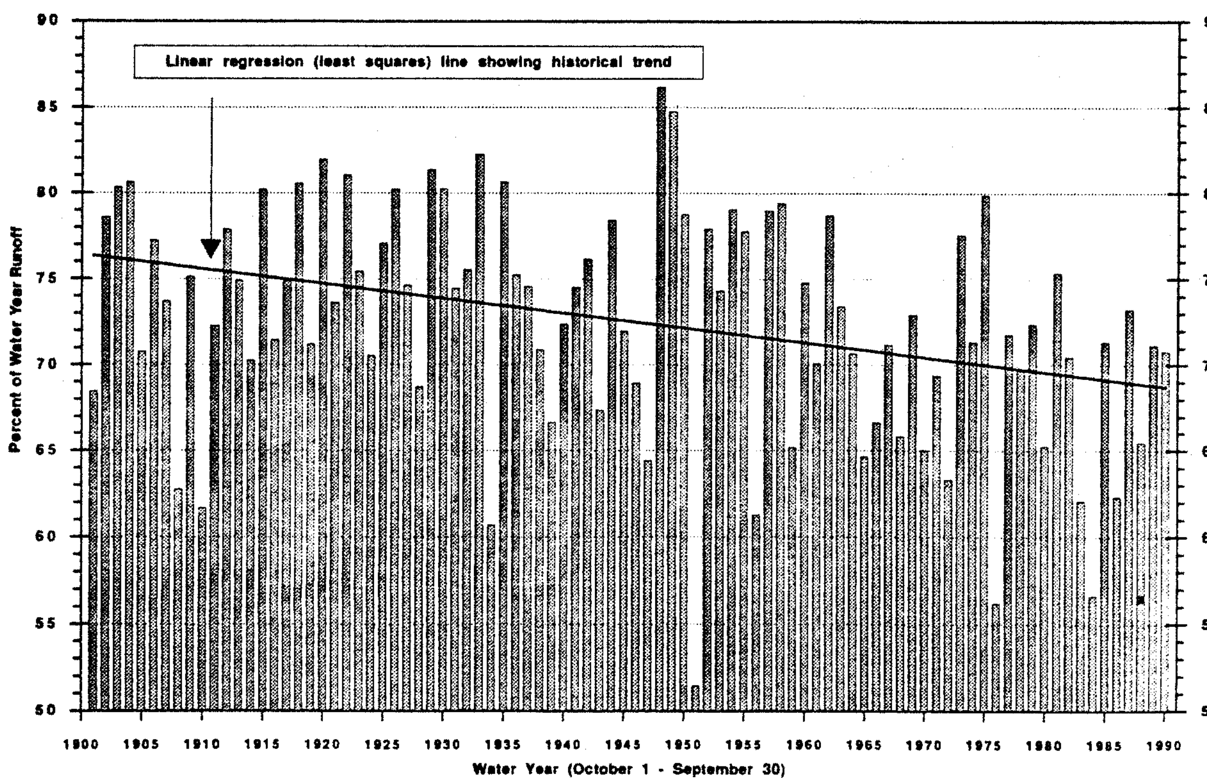


Figure 3. KINGS AND SAN JOAQUIN RIVERS
April - July Runoff in Percent of Water Year Runoff



The second chart (Figure 3) presents the same kind of information as before for the combined Kings and San Joaquin River runoff. These two southern Sierra rivers are much higher in elevation with a smaller fraction of the drainage area in the snow to rain transition zone. Median elevation is about 2400 meters (8000 feet). (See Table 1.) Results are similar to those of the Sacramento Basin but not as pronounced. The slope of the best-fit lines on the second chart is about 0.09 percent per year compared to 0.13 on the corresponding Sacramento Basin chart. So, if the cause is higher snow lines during winter storms, one would expect a smaller effect on the Kings and San Joaquin Rivers. Snow lines on April 1 probably average about 1800 meters (6,000 feet) in the Southern Sierra compared to around 1400 meters (4,500 feet) in the Northern Sierra. A 300 meter (1000 foot) elevation band centered on these levels accounts for 9 percent of the total area on the Kings and San Joaquin Rivers and about 27 percent on the Sacramento basin, including sizable areas of the drier Pit River basin.

POSSIBLE CAUSES

It is tempting to conclude that the decreasing fraction of snowmelt runoff is a signal of global warming. It is the kind of impact which would be expected. However, climatologists are still debating whether temperature records actually show that global warming has begun. At least the amount of warming seems to be rather small, so far, and not enough to account for the changes in runoff observed. James Goodridge has shown that California rural temperatures have not shown noticeable warming during the past three decades.

One possibility is that there is some difference in the way unimpaired runoff has been computed. The methodology is the same. However, the 1950s and 1960s were an era of large dam building in California. It has been suggested that winter flood flows are being measured better now as regulated flows below the large dams instead of the uncontrolled torrents which used to rush down into the Central Valley. A definitive answer to this question is difficult. But perhaps the fact that both the Feather and Sacramento River components of the Index runoff have a similar appearance is evidence enough to discount that possibility. The Sacramento River has been controlled by Shasta Dam since 1943 and the Feather River by Oroville Dam since 1967.

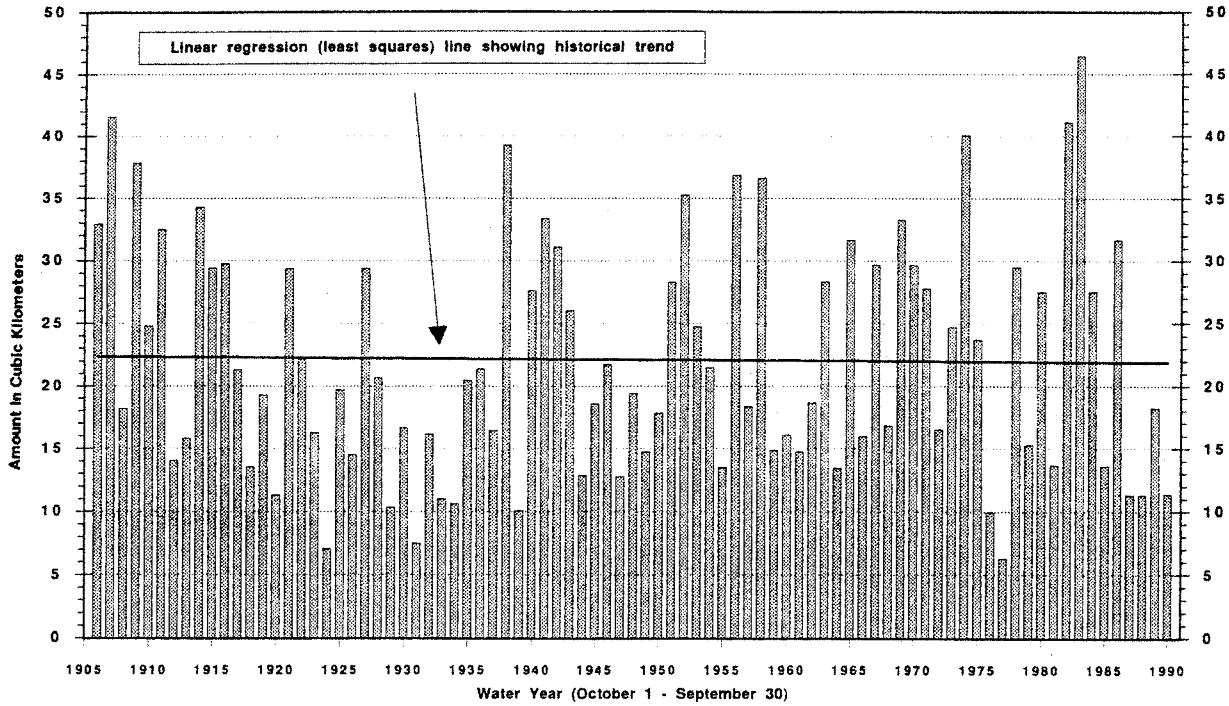
Total Sacramento River Index runoff for the water year shows no particular trend over the 85 years in Figure 4. In fact, if the last 4 years of drought were left out, there would be a slight increase during the past 60 years. On the other hand, the volume of April through July snowmelt runoff does appear to show a decreasing trend (bottom of Figure 4), confirming the trend noted in the snowmelt fraction of flow.

A similar pattern was noted in the Southern Sierra for the sum of Kings and San Joaquin River flows. However, in this case there was an apparent slight downward trend in water year runoff too, although not as much as the April through July decrease. It may be worth noting, at this point, that the average snowmelt runoff of these two southern rivers is 72 percent of annual runoff, compared to 38 percent for the Sacramento River Index.

More likely, the reduction is due to broad shifts in eastern Pacific Ocean and western North American weather patterns. To this end, precipitation patterns were examined for a group of 8 long-term stations which DWR uses as a Northern Sierra precipitation index corresponding to Sacramento River Index runoff. A reasonably adequate record was available from 1928 to 1990. A possible reason for the April through July runoff

Figure 4. Volume Trends in Sacramento River Index Natural Runoff

Water Year



April - July

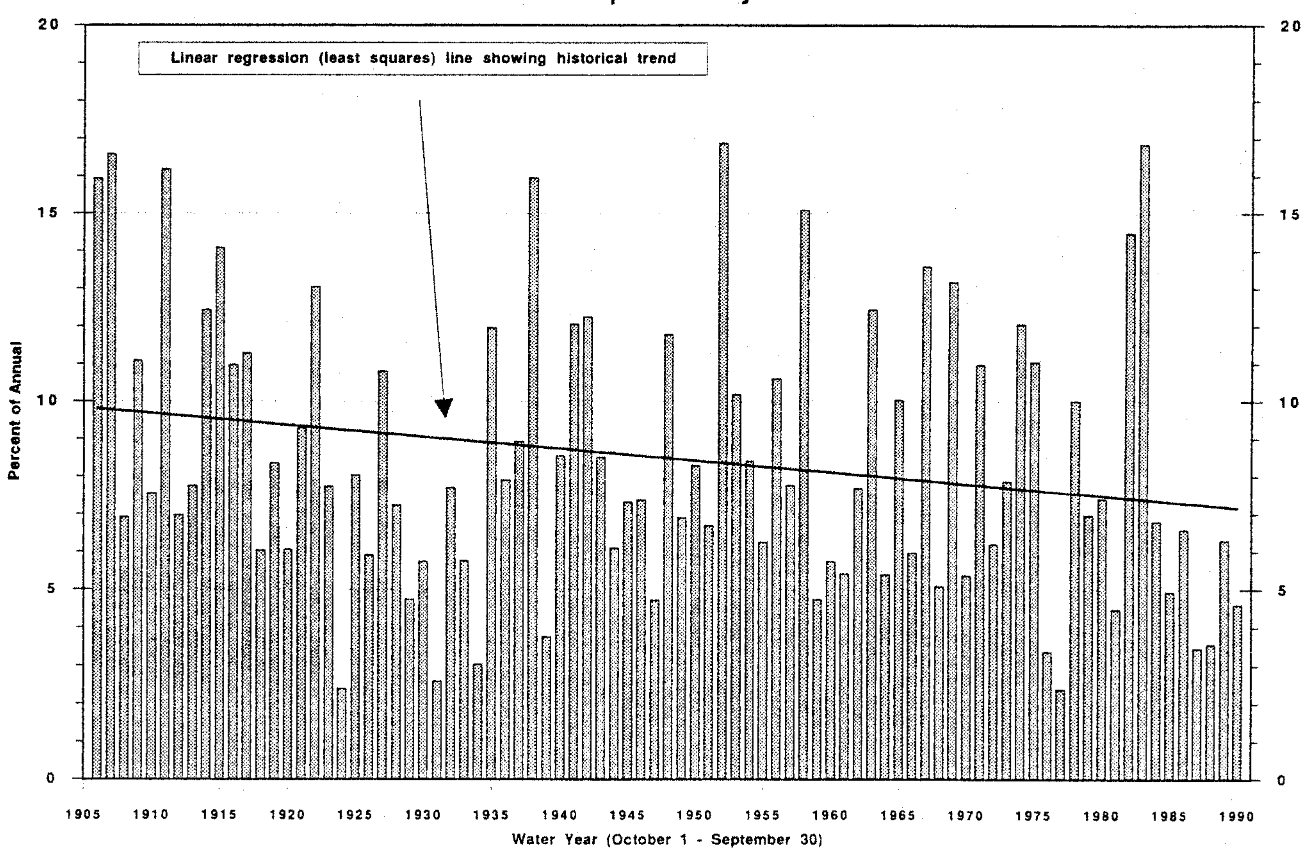
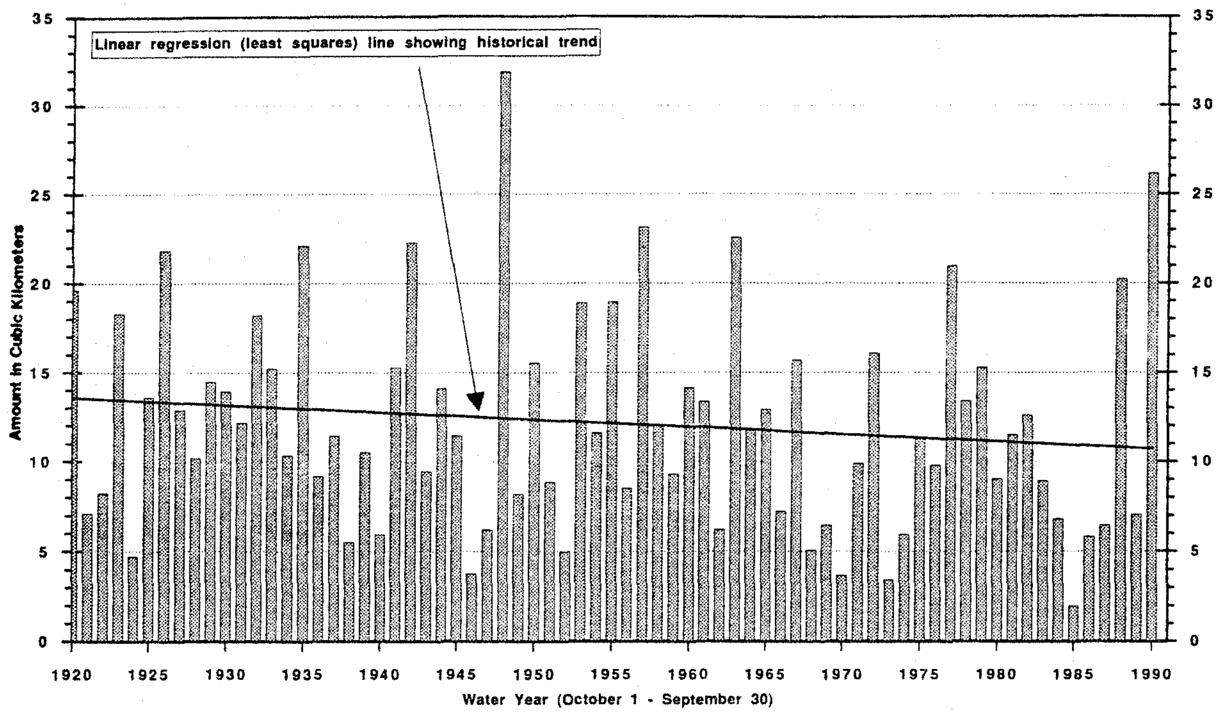
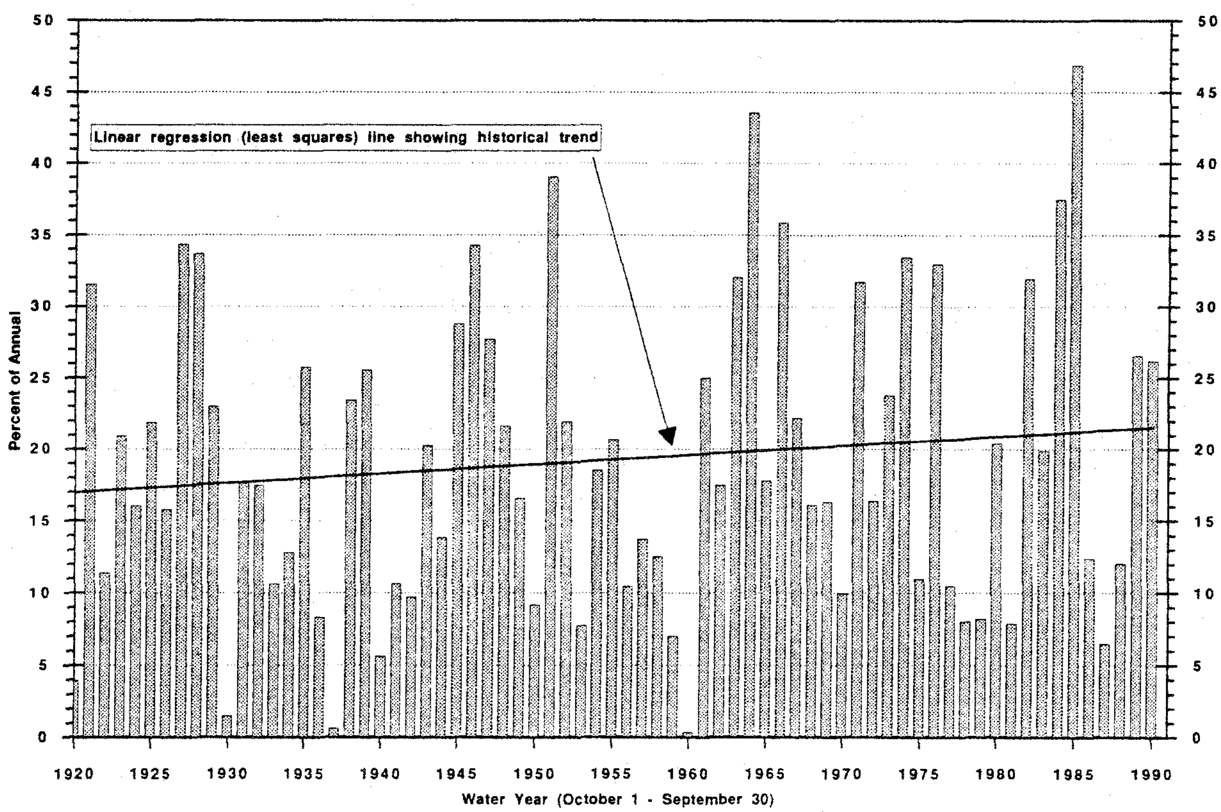


Figure 5. Comparison of the Fractions of Annual Water Year Precipitation during Spring and Fall. Northern Sierra Nevada

April and May



October and November



shift is simply less rain during the spring months after March, primarily April and May. (June and July rainfall is small and doesn't usually produce runoff.) Results are shown on Figure 5. The regression line shows a small decline of about 0.04 percent, but results are not significant (r= 0.14).

Next, fall precipitation in October and November was examined for trends. The weather is often warmer during those months; therefore, some direct runoff from transition zone areas or increased priming of the lower watersheds for winter runoff are possibilities. Results are also on Figure 5. A small rising trend with a slope of about 0.06 percent is evident. Again the correlation is low with r= 0.13.

It may also be that winter season temperatures are warmer now, with higher snow levels,during storms or more melting periods, even though annual temperatures (outside urban heat island areas) have not changed. Aguado, Cayan, and Riddle have recently compared the long record of Donner Summit snow course February 1 measurements to Nevada City seasonal precipitation from October through January. These researchers noted a decrease in the ratio of snowpack to seasonal precipitation which corroborates the runoff changes noted herein. They also observed a 1948-1986 widespread spring warming trend (February - April) in western North America coinciding with a cooling trend in the southeastern United States which appears to be part off a broad scale teleconnections pattern. Some researchers, notably Dr. Jerome Namias of Scripps, have said that there appears to be an approximate 50 year cycle in broad scale weather and North Pacific Ocean patterns. If so, a reversal in the decreasing spring snowmelt decline may be expected eventually. In fact, because winter season precipitation and runoff in water year 1991 was so very low, the spring runoff fraction will be relatively high even though it is a drought year.

CONCLUSION

There appears to be a definite trend toward a reduced snowmelt runoff in Northern California. No single cause is apparent. Most likely the cause is a combination of factors which include slight shifts in seasonal precipitation and broad scale temperature patterns. It might include a small global warming component. Part of the cause may be simply more frequent rain-on-snow winter season flood events. This phenomena is worthy of more research; hopefully others will look at their runoff data to see if the decreasing fraction of spring runoff is widespread or only peculiar to California.

ACKNOWLEDGEMENTS

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