Snowpack and Snowmelt Changes
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On average California's snowmelt runoff, much from the Sierra Nevada, has historically been around 15 million acre-feet (maf) per year. This meets about 35 percent of the total net agricultural and urban water demands of the State. In the future with global warming, this fraction is expected to decrease, with a 3 degrees Celsius rise likely to decrease snowpack runoff by about one third, assuming precipitation patterns don't change much. In legislative hearings in the early 1990s on the effect of climate change, the potential loss of snowpack was a graphic visual image of major changes for the Golden State.

My interest in the matter came about in a rather oblique way, out of the water year classification system for regulating Delta water quality requirements for the federal Central Valley Project and the State Water Project. In State Water Resources Control Board Decision 1485, issued in 1978, Sacramento-San Joaquin Delta quality and flow requirements to be maintained by the two water projects were keyed to the wetness of the water year. There were 5 classifications:

Wet,
Above normal,
Below normal,
Dry, and
Critical—

Two of these categories were above median runoff and three were below, based on the water year unimpaired flow volume of the four major rivers of the Sacramento River region. (The four rivers were: Sacramento River above Bend Bridge near Red Bluff, and the Feather, Yuba, and American Rivers.) There was also a new term based on April through July forecasted runoff. If that was forecasted to be under 5.9 maf in the May 1 edition of DWR Bulletin 120, Delta outflow requirements were relaxed in wet, above normal, and below normal years. This term was a recognition that higher flow requirements for the two big water projects would be more difficult to meet in years when snowmelt runoff was low, regardless of how wet the winter had been.

The source of the 5.9 maf number was the runoff in 1928, the first year of the most severe 6 year drought in the record at that time (subsequently matched by the 1987-1992 drought). The year classification was based on water year amounts for the Sacramento River system—the 4 river index. Relaxation of Delta outflow requirements in an "above normal" year (like 1928, which had a flood in March), could reduce the draft on project reservoirs by about 1 maf, which would boost dry period annual water supply by about 0.16 maf per year. Although the SWP supply was known to be inadequate for contractual needs, the assumption was that new water developments on the North Coast or Sacramento Valley would be built as needed to keep up with contract demands. The CVP, however, had to demonstrate that it had the dry period yield before contracting for water deliveries, so this subnormal snowmelt relief provision was very important.

In the early 1980s, I established a new office, the Hydrology Center within DWR. One of its primary goals was assisting the Cooperative Snow Surveys program in upgrading its snowmelt runoff forecasting procedures. In 1984 this office was merged with Flood Forecasting and Water

Supply Forecasting as a Hydrology office. One day, I believe it was in 1986, Jerry Cox, who was chief of the Water Operations Branch of the SWP and DWR's foremost Delta tide and flow expert, dropped in to talk about runoff and made the observation that we seemed to be getting more subnormal snowmelt years than we used to see. Both 1984 and 1986 (in spite of the February 1986 flood) were wet years but with subnormal snowmelt, a combination which had happened only once (in 1951) during the first 64 years of the runoff record until 1970. I had also had some casual conversations not long before with Bob Burnash, Hydrologist in Charge of the California-Nevada River Forecast Center, about an article he had read which forecasted global warming due to more and more global fossil fuel burning and the related increase in atmospheric carbon dioxide levels. To us, it seemed like the biggest effect on California water would be loss of winter snowpack and therefore spring snowmelt. But how was one to show such a trend, if it existed, in something so variable from one year to the next?

After pondering this question a while, I hit upon the idea of not comparing seasonal snowmelt amounts, but to use the percent of water year (October through September) flow occurring during the April through July snowmelt season. We started with the Sacramento River unimpaired flow amounts, the sum of the four major rivers of the region which are used as the water year classification yardstick. The water year classification, as noted before, was based on the unimpaired (natural) runoff as computed by the DWR Cooperative Snow Surveys group. The 1978 criteria were superseded by the 40-30-30 index in 1994 in the Bay Delta proceedings.

In 1987, with some help from Stein Buer, head of the Flood and Water Supply Forecasting Section at that time, I constructed charts of the ratio of April-July runoff to water year runoff (as percentages) for the Sacramento four river group and also the southern Sierra Kings River plus San Joaquin River runoff. Sure enough, there seemed to be a downward trend especially after about 1950. The regression best fit was a decrease of 14 percent per century rate on the Sacramento four river group runoff and a 9 percent decrease per century on the southern Sierra Kings River plus San Joaquin River runoff group. This finding seemed logical because the southern Sierra is at a higher elevation than the northern Sierra with incrementally less change per a 500 or1000 foot change in average winter snow levels. I reported these findings at the March, 1987, Pacific Climate Workshop in Asilomar in a paper titled: "Possible Changes in California Snowmelt Runoff Patterns", before an assembled group of largely academic and government researchers. There was interest but also considerable skepticism about the trend, its causes, and whether there was just some long range cycle at work. (Jerry Namias of Scripps, always outspoken at these meetings and highly respected, thought that perhaps some 50 year ocean pattern cycle was the primary influence.) We continued to look, as time permitted, at other rivers and noticed similar trends, although different rates, on all our major snow fed streams from the Trinity River in the north to the Kern River in the south and also on the Sierra eastside, with the Truckee and Feather showing more pronounced losses.

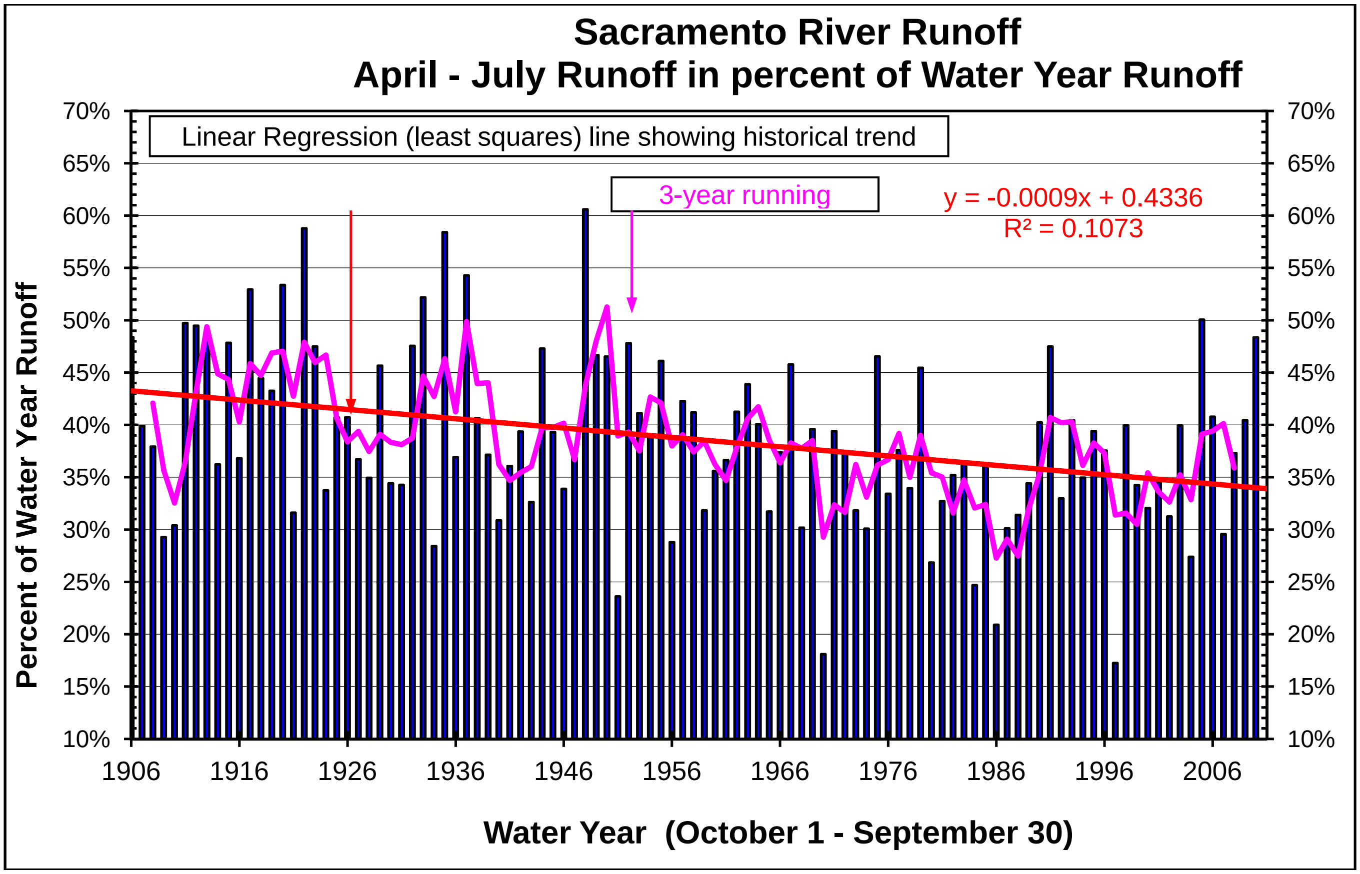
In 1989, the federal EPA issued a major report on the amount of global warming which could be expected with a doubling of carbon dioxide in the atmosphere. The report projected a likely average global temperature increase of 1.5 to 4.5 degree Celsius over the next 100 years if fossil fuel usage trends continued. We made some crude early estimates of what 3 degrees might do to California's April-July snowmelt runoff, based on an average rise of 1500 feet in elevation of historical snowlines during the winter. Overall, assuming no change in precipitation amounts, we estimated that spring snowmelt runoff would decrease by about one third. The northern Sierra would show a bigger impact than the higher- elevation southern Sierra. The California Energy Commission had embarked on a big global warming study in

1989 and 1990 and these findings were reported to it. Our findings were also the topic of a paper presented to a large Oceans Conference in September, 1989, in Seattle and an April 1990 presentation at the Western Snow Conference meeting which was in Sacramento that year. More information on the trends were presented in a second Western Snow Conference meeting in 1991. Both papers are in the WSC Proceedings of those respective years. Meantime, our Snow Survey Program cooperators were kept informed of both DWR and Energy Commission studies at the annual cooperators meeting, notably the one held in December 1989 in Oakhurst (Where Steve Lafond of Bakersfield gave the first of his many colorful musical reports on the Kern River). We were not sure how much of the apparent change was due to warmer world temperatures and how much due to other factors, such as changes in ocean patterns—which leaves quite a bit of uncertainty in what to project into the future.

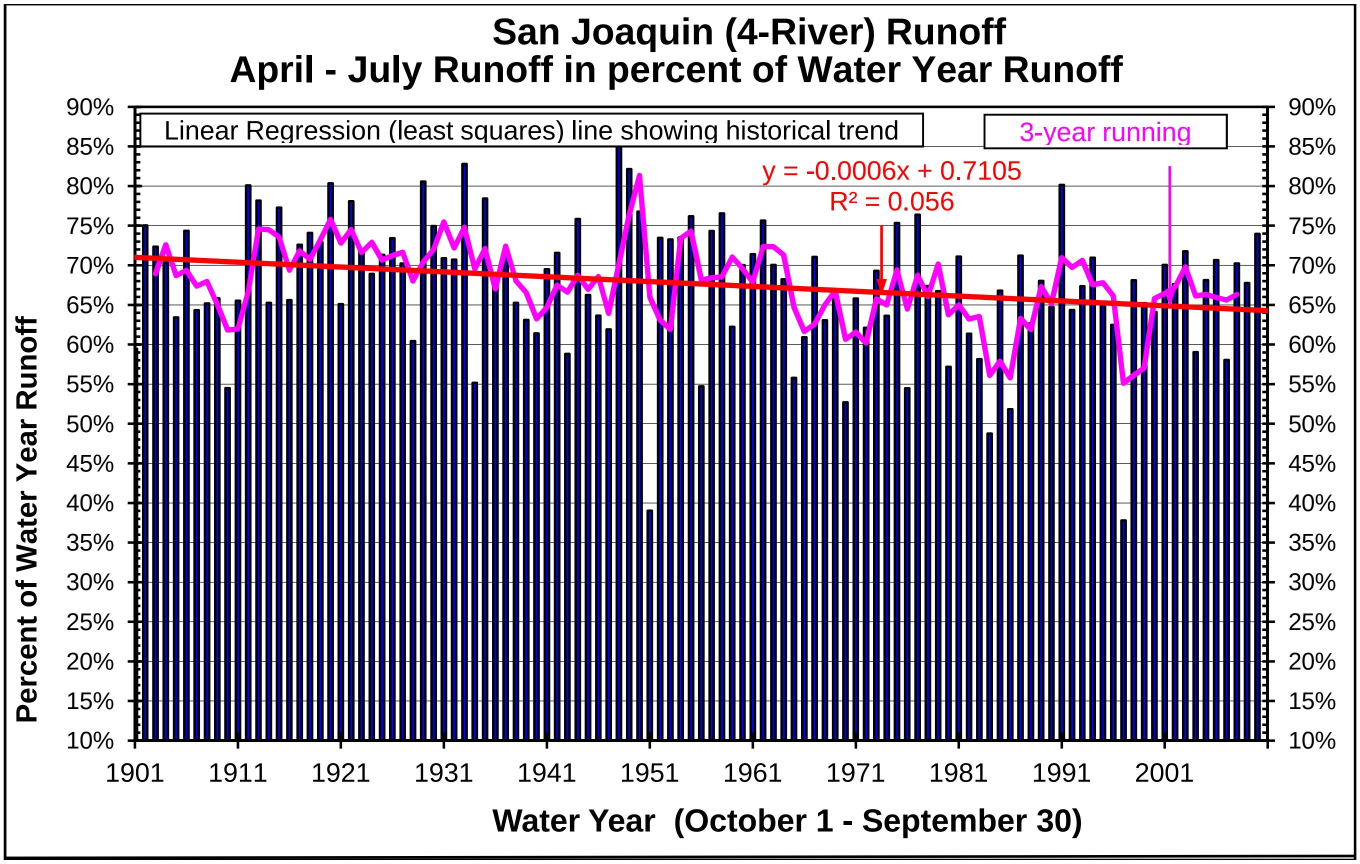
San Joaquin river systems was from about 1950 to 1990. During the last 2 decades, since 1990, the downward trend seems to have leveled out considerably. Originally the best fit slope was a decline of 14 percent on the Sacramento and 9 percent on the San Joaquin River group. However, extending the record through 2010 yields a flatter slope, 9 percent per century on the Sacramento and 6 percent on the San Joaquin 4 rivers (See the two charts on the last page of this blog). Possibly the flattening of the snowmelt fraction decline may be due to the Pacific Decadal Oscillation shifting into a negative phase. At some point, perhaps 10 or 20 years, the ocean pattern will probably reverse and we are likely to see a resumption of the percentage decline. The changes we have seen so far so support expected future losses in snowpack and snowmelt runoff, but the trend suggests that some of the large snowmelt loss projections may be slow to materialize. Extrapolating the observed trends beyond 2010 would show an estimated loss of snowpack runoff of near 9 percent now from historical 1950 levels, around 15 percent in 2050 and near 25 percent by year 2100. This would be assuming future precipitation was similar to historical precipitation. If loss rates from 2010 forward resume the slope calculated prior to 1990, we could lose about 35 percent of the historical mid 20th century snowpack by year 2100.

Link to January 1, 2012 Snow Survey

http://www.water.ca.gov/news/newsreleases/2012/010312snowsurvey.pdf



Sacramento River Runoff
April - July Runoff in percent of Water Year Runoff
Linear Regression (least squares) line showing historical trend
3-year running
y = -0.0009x + 0.4336
R² = 0.1073
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
1906
1916
1926
1936
1946
1956
1966
1976
1986
1996
2006
Percent of Water Year Runoff
Water Year (October 1 - September 30)


San Joaquin (4-River) Runoff
April - July Runoff in percent of Water Year Runoff
Linear Regression (least squares) line showing historical trend
3-year running
y = -0.0006x + 0.7105
R² = 0.056
Percent of Water Year Runoff
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
1901
1911
1921
1931
1941
1951
1961
1971
1981
1991
2001
Water Year (October 1 - September 30)