MONITORING MONTHLY SNOWMELT RUNOFF IN THE SIERRA NEVADA TO DETECT CLIMATE CHANGE

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ABSTRACT

Substantial changes in temperate zone mountain snowmelt water supply are projected to occur as a result of global warming. Water resources managers already collect extensive data to use in forecasting and in operations of water projects. If they are interested in climate change, they should look carefully at their long term records of operating projects to see if signs of change are apparent and what the rates of change are. Hydrologic records are inherently highly variable and long stable records and reconstructed natural stream flows are needed to assess systematic changes over time.

The author will present a couple of samples from northern California of the long term history of the fraction of mountain water year runoff occurring during the April through July period of snowmelt. The charts show a small declining trend during the past 50 years, but a decrease in the rate of change during the last 15 years. Reconstruction of natural flows will be briefly discussed as well as why the change in runoff patterns is so important to the large water projects in California.

A related potential effect is an increase in the size of flood events because of more watershed area contributing rain runoff during winter storms, possibly augmented by higher storm rainfall intensity. A 100-year sample of the flood record on a major Sierra river will be used to illustrate this problem.

INTRODUCTION

Mountain snowpack, mostly that of the Sierra Nevada, is an important element in California's water supply. The snow pack provides natural regulation of winter precipitation, carrying moisture over from the wet season into the first half of the dry season and, to some extent, even to mid summer. The April through July runoff, primarily from snowmelt, averages around 18 billion cubic meters (15 million acre-feet) which is about 35 percent of the usable annual supply for agricultural and urban needs. The two major river systems are the Sacramento River, draining the northern portion of the Central Valley basin and the San Joaquin River, which drains the south central part of the basin. The southern end of the basin, known as the Tulare Lake region, is an area of interior drainage with only small amounts from the northern fringe reaching the ocean in wet years. Figure 1 is a map showing the major terrain features of the state. Figure 2 shows the location of hydrologic regions.

From what we can tell there are five major potential effects on California water resources systems from global warming. These would be (1) a change in river runoff patterns, with more direct rain runoff during the winter and less snowmelt; (2) rising sea level which would affect the ability of the State's major water projects to divert water southward from the Delta; (3) larger floods which could affect the flood control operation of major multipurpose foothill reservoirs; (4) some increase in evapotranspiration, which could increase water consumption; and (5) more difficulty keeping major rivers cold enough for anadromous fish such as salmon and steelhead.

MEASURING TRENDS IN SNOWMELT RUNOFF

Water project operators and others routinely make measurements of flow, snow, stage, water use and water quality. The measurements are made to assist in operation of reservoirs and delivery systems and in making forecasts of runoff. Many of these are long term records and should be useful to look at for some of the trends expected with climate change. In our cooperative snow surveys program, long records of natural or unimpaired monthly flow, many 100 years in length, have been calculated for most of our major rivers, usually at the foothill line. Unimpaired flow is the natural water production of a river basin, that runoff which would have occurred without the effect of upstream diversions, reservoir storage or by exports or imports of water to and from other watersheds.

Paper presented Western Snow Conference 2006

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Figure 1. Major Terrain Features of California

One would expect if warming is occurring to see a change in the percentage of water year runoff during the snowmelt season, defined as April through July runoff. A rule of thumb is a snowline rise of about 150 meters (500 feet) for each degree C rise in temperature. We think we see such trends, more so in the lower elevation northern Sierra. Figure 3 shows the percentage trend in the Sacramento River basin. Figure 4 shows the April-July volume trend, which is less definite, and Figure 5 shows the 100-year trend for the water year volume. The April through July volume trend is also down. The water year trend shows little change over the century. Note the high variability from year to year which makes trends difficult to see on the volume charts. The Sacramento system rivers are the Sacramento above Bend Bridge near Red Bluff, and the Feather, Yuba and American Rivers.

Figure 6 shows the percentage trend for the four rivers of the San Joaquin River system, which are the Stanislaus, Tuolumne, Merced and Upper San Joaquin Rivers.

Figure 2. Location of Hydrologic Regions in California

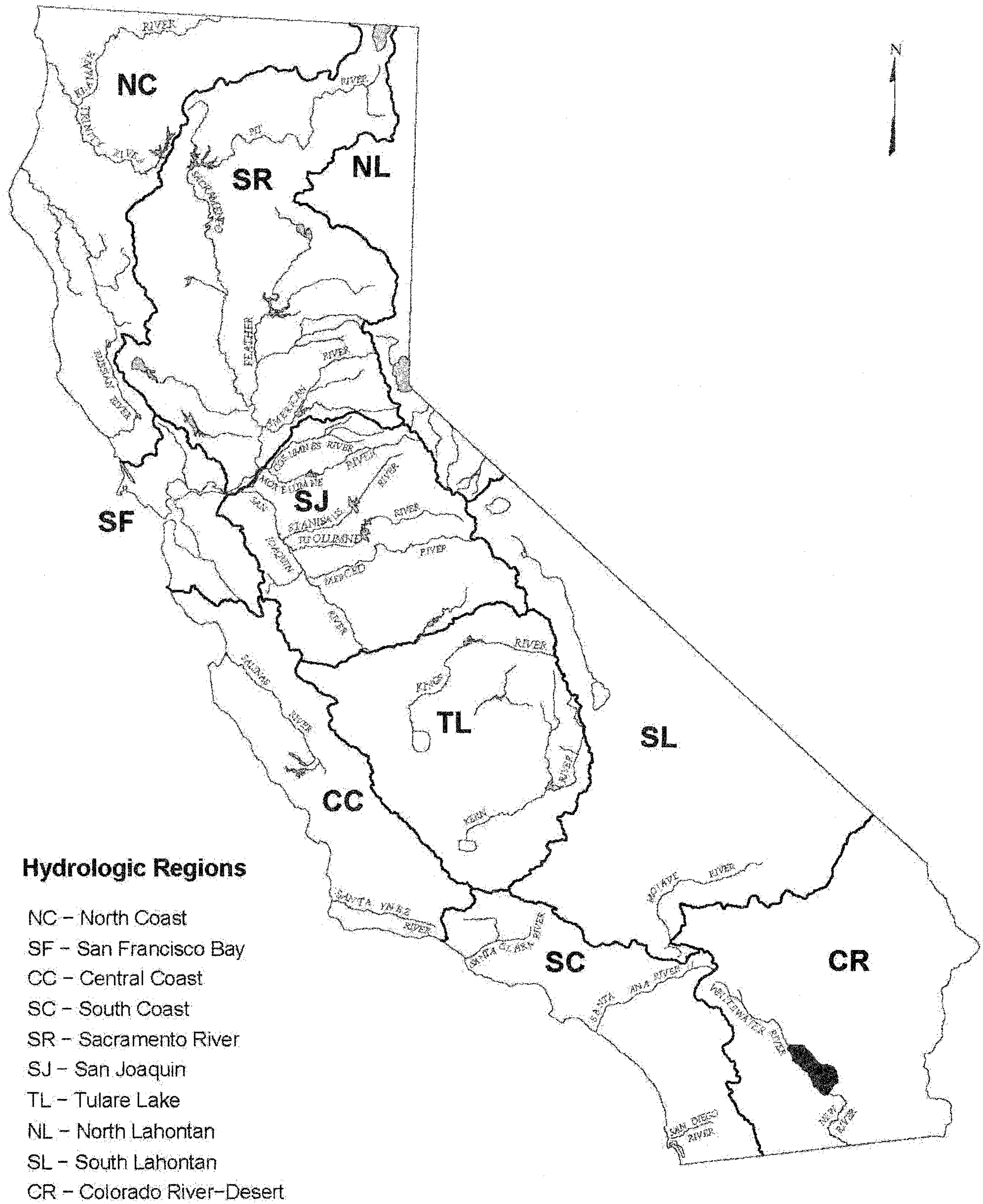
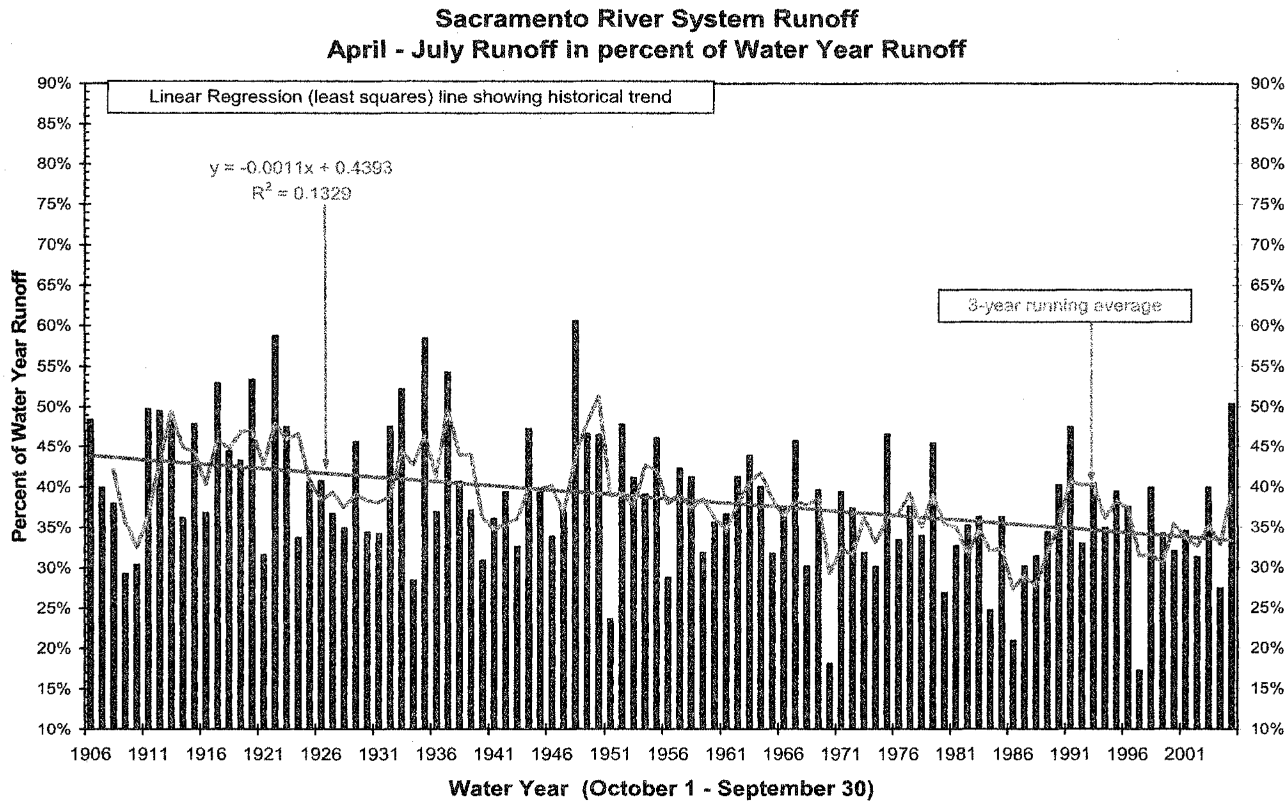


Figure 3.



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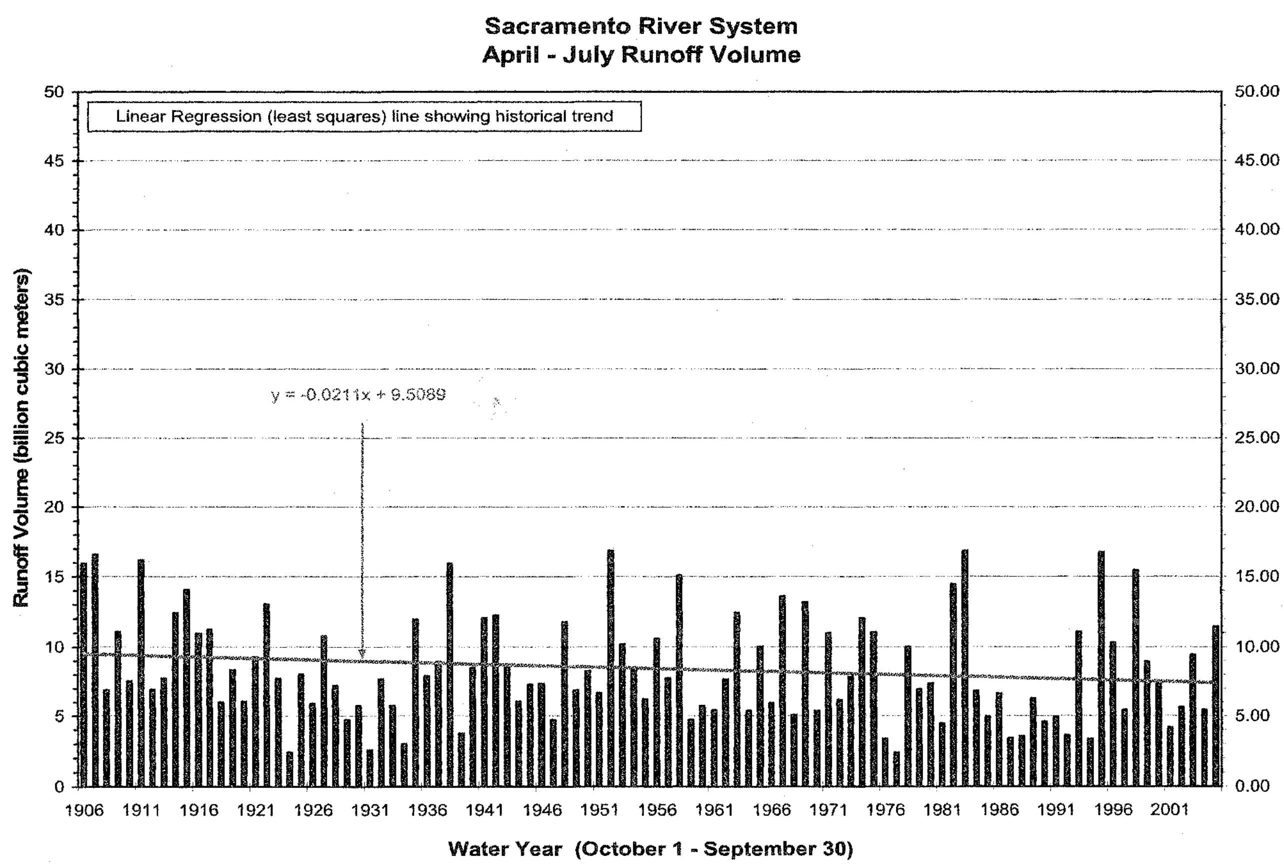

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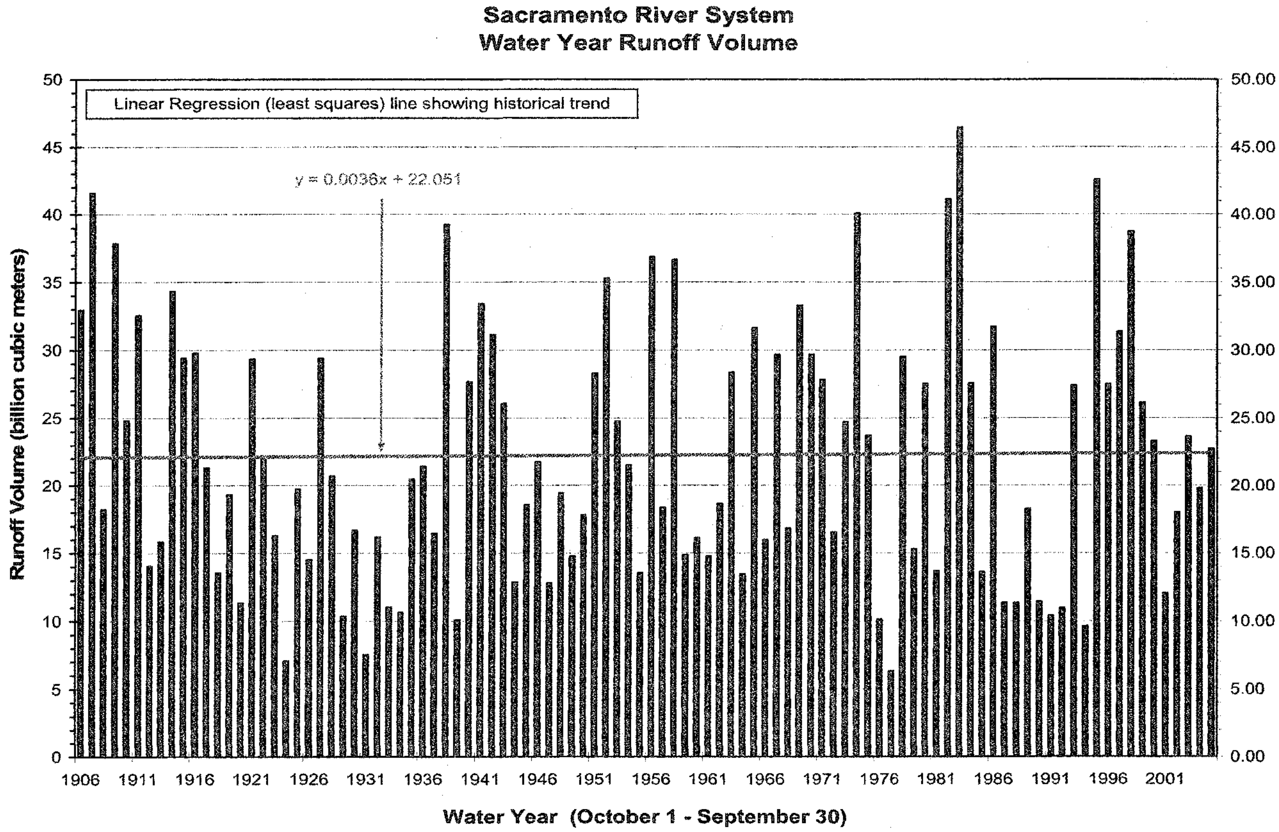

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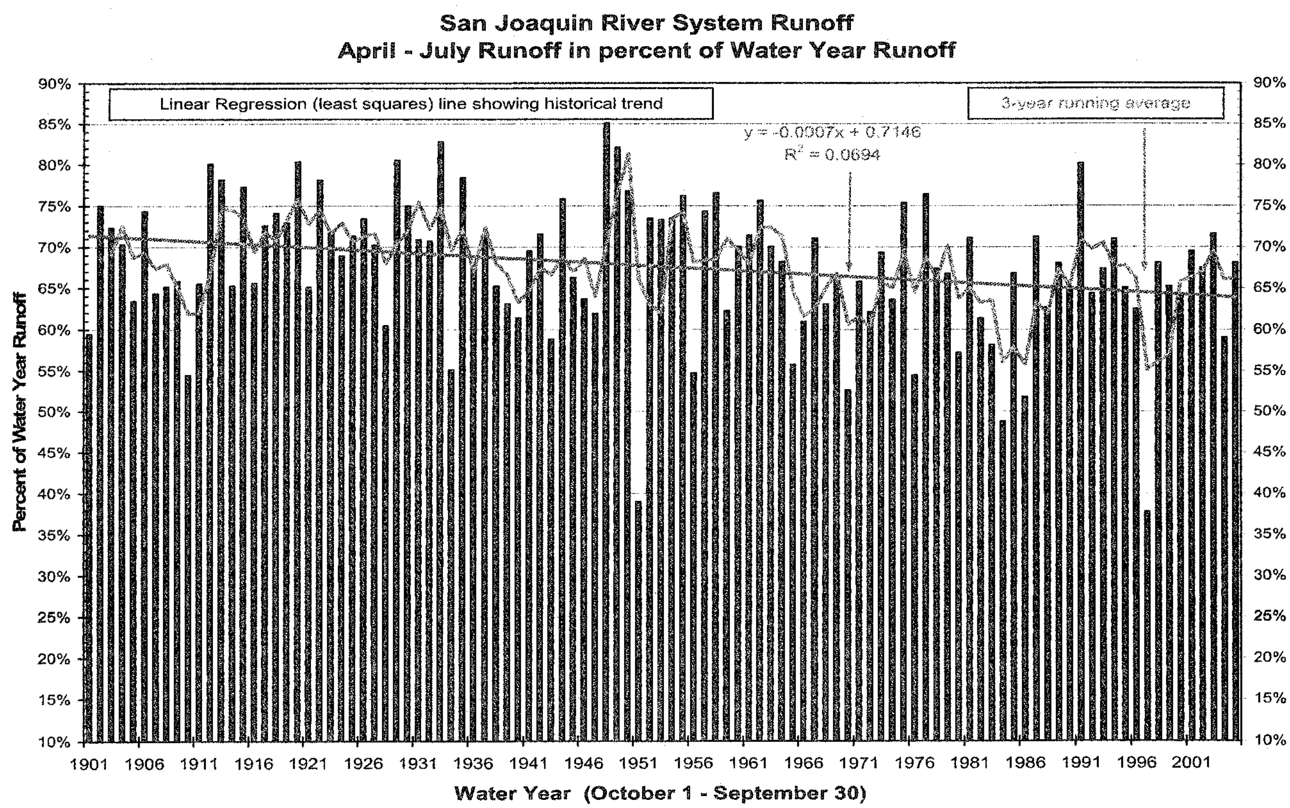
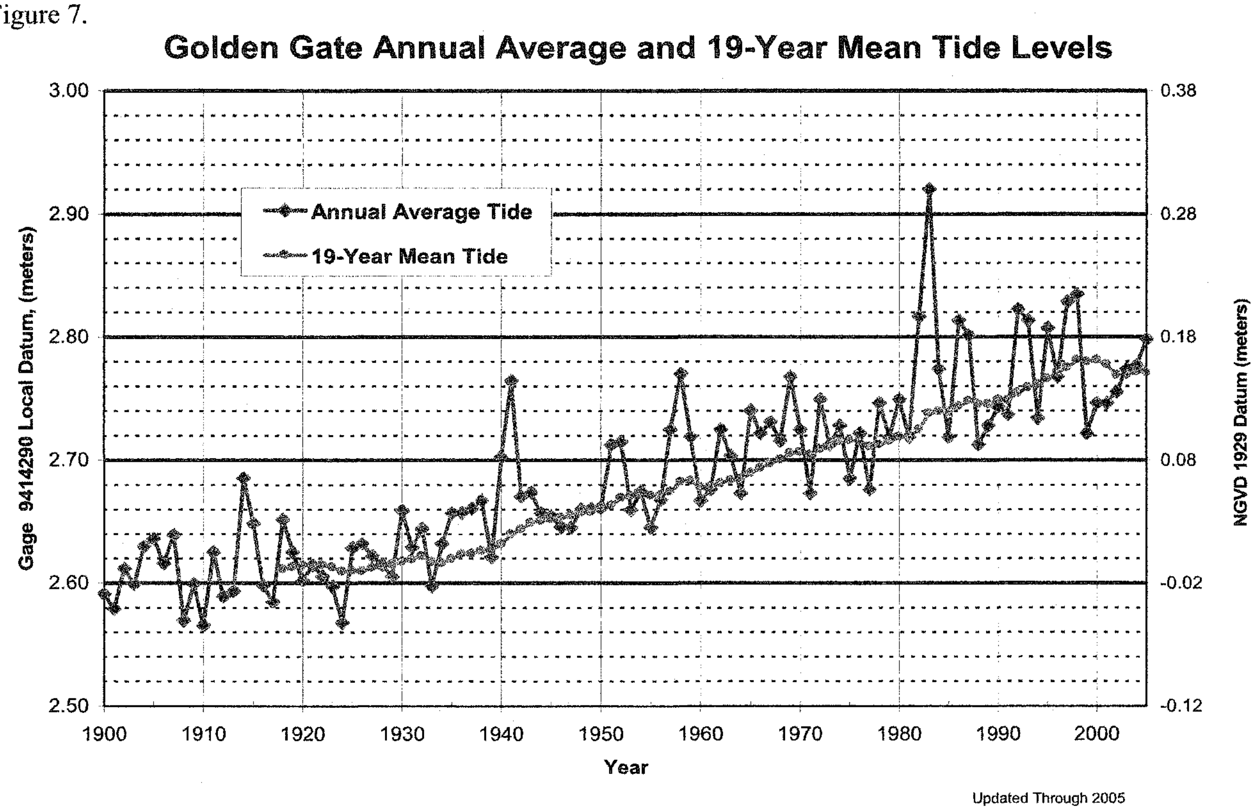


SEA LEVEL RISE

Higher sea level would affect the Sacramento San Joaquin River Delta, the hub of our water transfer system. A rise in sea level would mean more salinity intrusion from the ocean via San Francisco Bay which would affect the water quality of exports or require more fresh water to be released from upstream reservoirs to hold incoming salinity in check. Higher tide stages also create more stress on the weak Delta levee system, with a risk of more levee breaks. The islands of the Delta are well below sea level and a summer levee breach could cause an inrush of saline water, temporarily disrupting water transfer and exports.

The Golden Gate tide gage is the oldest in the country going back into the middle of the 19th century. Figure 7 shows the annual average sea level and the 19 year running average (19 years to encompass a complete lunar cycle of 18.6 years.) A slow rise in sea level seems to have started in the 1920's at a fairly regular rate of about 0.2m (0.7 feet) per century. Since California is tectonically active we can't be sure that this trend is of the sea itself; the land might be slowly moving too. But it seems to fit the worldwide means of tide gages. Interestingly, the rate of rise seems to have slowed in the last 15 years.

Figure 7.



Data from the National Ocean Service

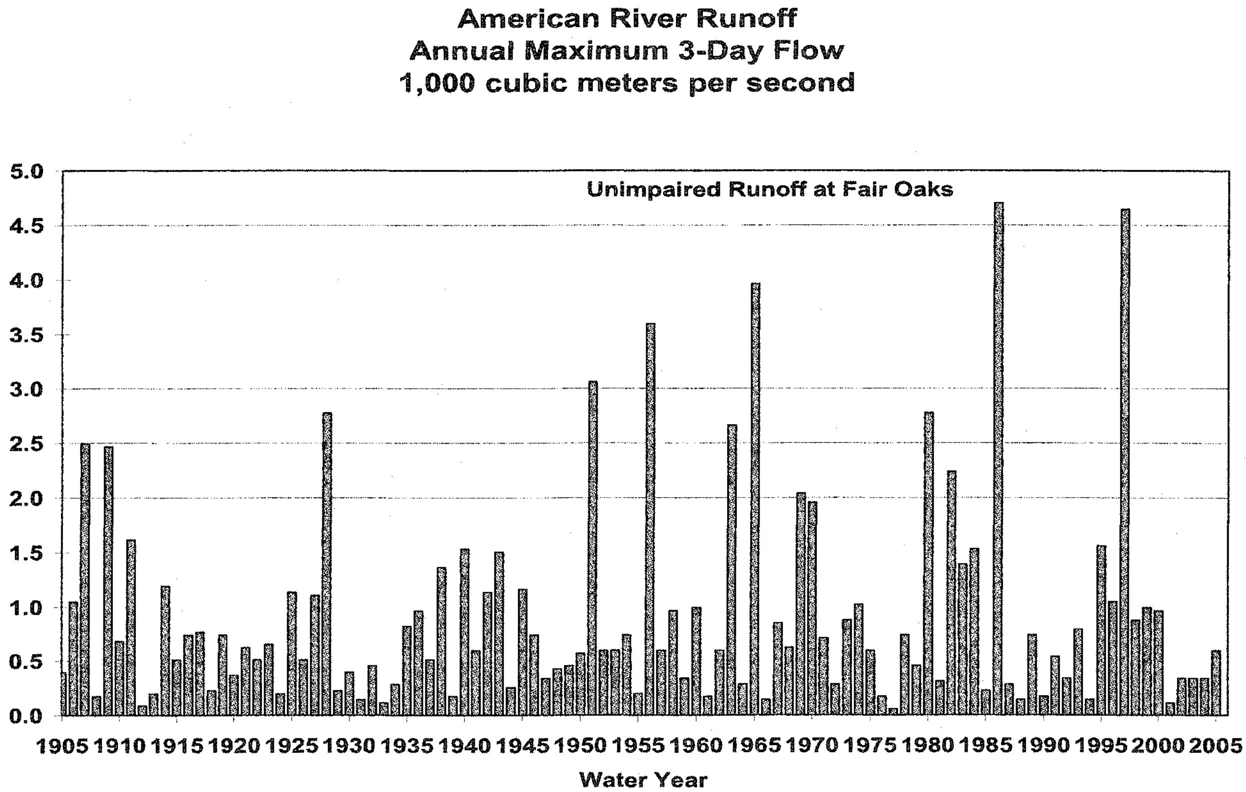
FLOOD FLOW

Global warming would likely cause some increase in the intensity of flood events. As a general rule, more extreme precipitation events go along with increasing temperatures. There are two reasons to expect bigger floods on major rivers. The first is that warmer air can hold more water vapor than cool air. For a given amount of lift of saturated air, more condensation will occur, around 10 percent more for 3 degrees at normal California winter storm temperatures. The second factor is that higher snow levels in the Sierra Nevada mean more watershed area contributing direct rain runoff during storms and less snow accumulation.

There appears to be a trend for larger floods during the last half of the 20th century. Unregulated flow of the American River at Folsom Dam exemplifies the trend. Figure 8 shows the annual 3-day peak rates. Three-day rates are probably the best measure of impact on a large flood control reservoir in northern California. Folsom

Dam was completed about 1956; since it was built, the floods are larger. The change is quite a bit more than can be explained by the minor amount of watershed warming which has occurred, on the order of 0.5 degree C. It may be that the first portion of the record represented an atypical mellow time.

Figure 8.



Data from Sacramento District, Corps of Engineers

WATER USE

It is not known whether changes in evapotranspiration can be detected from the 100 or so agro-climatic weather stations deployed around the State. Again, many years of record are needed to detect trends because of variation from month to month and year to year. The oldest stations date from the mid 1980's, but some lysimeter test plots measuring evapotranspiration of grass were operated in the 1960's. It may be more practical to measure plots in an urban area where background CO_2 is higher and the heat island effect of large urban areas produces elevated temperatures to see how potential evapotranspiration in an urban agro climatic station compares to more rural locations.

WATER TEMPERATURES

Rises in river temperature can cause problems for cold water fish. To some extent reservoir operators have been able to modify operations to save colder water for the warmer times of the year. With reduced snowmelt and higher ambient air temperatures, this may be more difficult to do. Temperature measurements in rivers which are not regulated or lightly regulated may give us a clue about how much warming has occurred. However, continuous temperature records are too short to place much confidence in trends yet. Tree cover adjacent to the streams is another influence.

SUMMARY

Trends from certain operational and forecasting records can provide much useful information on the effect of climate change on water resources systems. Trends are relatively modest so far but, if the global climate modelers are right, may be accelerating in the future. It is important to monitor these changes as a check on reliability of the models and to help water system operations adapt for future climate change.