

CLIMATE EFFECTS OF PACIFIC DECADAL OSCILLATION ON STREAMFLOW OF THE FEATHER RIVER, CALIFORNIA

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ABSTRACT

The timing of maximum monthly-mean streamflow for the Feather River in northern California has come earlier in the year in recent decades (since the 1950s), as have timings in most rivers throughout California and the western United States. Much of the timing shift in the Feather River basin appears to coincide with interdecadal changes in the North Pacific climate regime. The coincident timing changes are seen as a shift in the month of maximum streamflow from April-May during the cooler Pacific Decadal Oscillation (PDO) phase to March-April during the warmer phase. The change in streamflow timing in the Feather River basin became an issue during the testing of a new set of watershed models of inflow to Lake Oroville, because model performance degraded in simulations of recent years (1998-2001). The model calibration period (1971-97) was dominated by the warmer (1977-98) PDO phase. However, the 1998-2001 period mostly corresponds to a newly reestablished cool PDO (beginning late 1998). Simulations during 1998-2001 failed to reproduce streamflow as well as simulations of the calibration period, probably because some model parameters, like those associated with rain-snow mixes or temperature and precipitation distributions, are not calibrated for climatic conditions that occur during a cool PDO.

INTRODUCTION

The Feather River basin is a major contributor to the California State Water Project (DWR, 1998), and important for hydroelectric power production, flood management, water supply, water quality, and the health of fisheries downstream from Lake Oroville (as far as the Sacramento/San Joaquin River Delta). The State must manage its reservoirs for winter floods even as it plans for summer snowmelt-inflows to Lake Oroville (April-July 31). During this snowmelt season, large flood-generating storms are rare, but streamflow from snowmelt constitutes about 40 percent of the total annual average streamflow (DWR, 2000). Predicting spring and early-summer snowmelt is critical to understanding and managing the Feather River as a water resource. Improved understanding of streamflow variations and the basin's response to changing climate and land-management actions will aid in this effort.

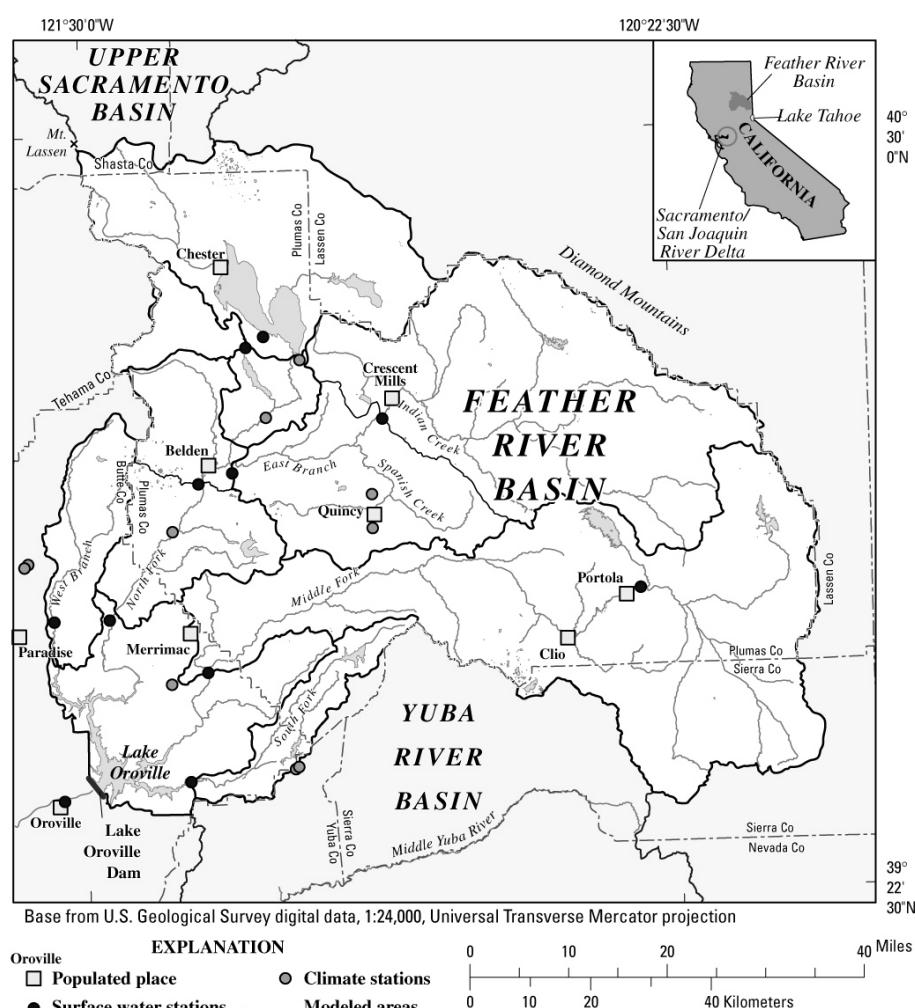


Figure 1. Feather River basin, model areas, major tributaries and reservoirs, climate and streamflow gaging (or reconstruction) stations used in models, larger towns, county lines, and selected peaks and valleys.

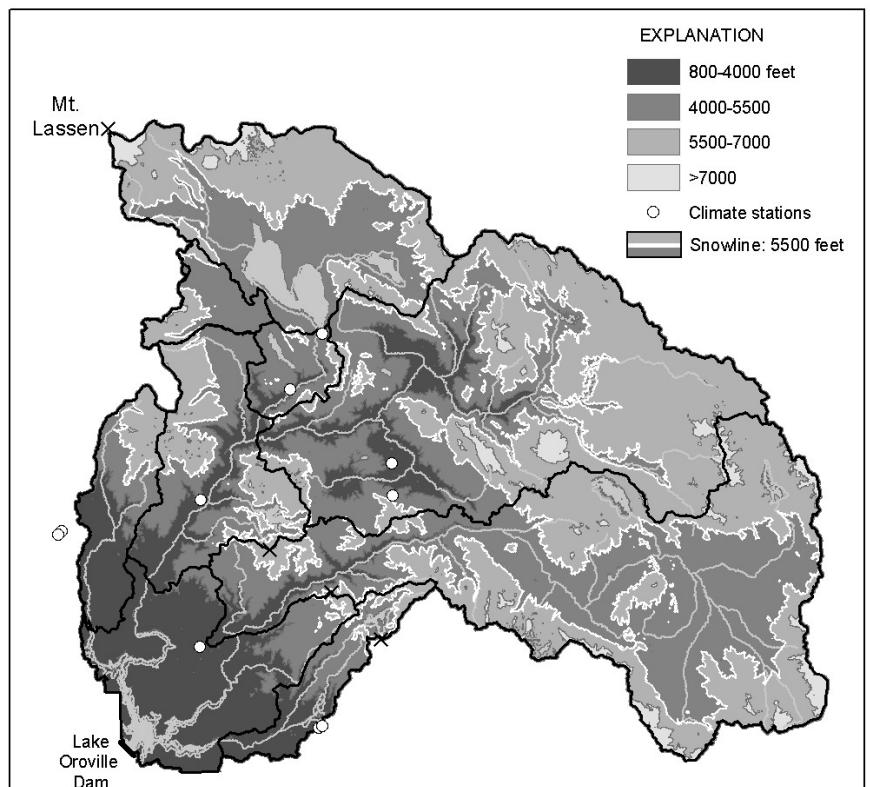
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PHYSICAL CHARACTERISTICS OF THE FEATHER RIVER BASIN

Basin Elevations

The basin encompasses 3,600 square miles (fig. 1) with altitudes ranging from 900 feet at Lake Oroville Dam to 9,500 feet near Mt. Lassen. The average snowline is about 5500 feet (fig. 2). Because fifty-five percent of the basin is between 2000 and 5500 feet, much of the basin is often warmer than freezing in winter, and very sensitive to slight temperature changes which affect the formation of a snowpack. Depending on the location and storm conditions, distributions of snow and rain are variable and difficult to estimate, yet crucial to streamflow simulation. Because of the low elevations and warmer than freezing temperatures in winter, predicting summertime snowmelt-fed streamflow in this basin is particularly challenging.

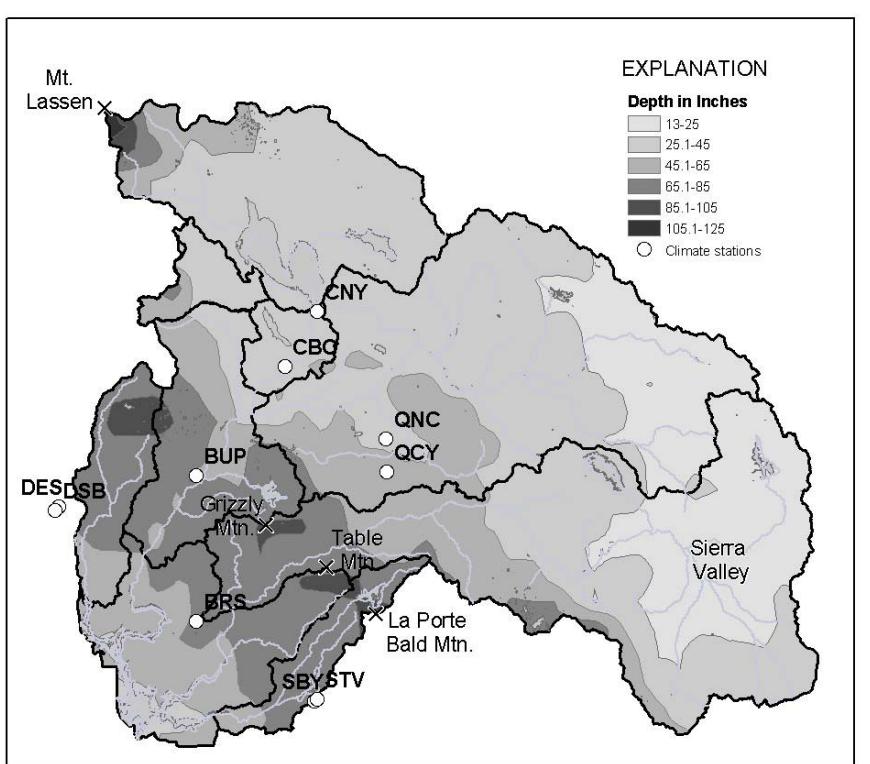


Modified from U.S. Geological Survey, 30 meter Digital Elevation Models.

Figure 2. Map of basin showing elevations above and below 5500 feet above sea level (snowline).

Climate

The basin receives about 45 inches of precipitation per year on average, and ranges from about 13 inches in the rain shadow of the Sierra Nevada to 125 inches at the highest points in the basin (fig. 3; Daly and others, 1994). The climate is Mediterranean with most precipitation occurring in the cool season (November-March). Mean monthly temperatures (measured at stations below 4600 feet) range from highs of 60-71 °F to lows of 33-46 °F. Much of the basin receives precipitation as snowfall during the winter. Because temperatures in most of the basin are at or above freezing at some time during most winter storms, rain and rain-on-snow are not uncommon. For example, at the Canyon Dam (CNY) weather station at 4650 feet elevation, temperatures during about 15 percent of winter storm days never rise above freezing and 15 percent never drop below freezing. Thus, 70 percent of storm days fluctuate above and below freezing in the broad middle-altitude band of the basin. As a consequence, streamflow fluctuations in the basin are almost as closely tied to temperatures as they are to precipitation. Both precipitation and temperature must be well represented in order to model the Feather River streamflows.



Modified from Parameter-Elevation Regressions on Independent Slopes Model (PRISM);
Daly and others, 1994.

Figure 3. Patterns of mean-annual precipitation from Parameter-elevation Regressions on Independent Slopes Model (PRISM) of Daly and others, (1994; 30 year mean-annual average, 1961-1990).

Reconstructed Streamflow

Because streamflow into Lake Oroville is heavily regulated upstream and no natural-flow data are available, monthly-reconstructions of full-natural flows from the California Department of Water Resources (DWR; reconstructed-streamflow station FTO; <http://cdec.water.ca.gov>) were used, in this study, to represent natural variations of streamflow in response to climate variations. Reconstructions were computed from measurements at the USGS gaging station (11407000) below the Lake, and include corrections for the regulation of the Oroville Complex facilities, exports, imports, diversions for hydropower and irrigation, and change in storage and evaporation in the larger reservoirs.

PACIFIC DECADAL OSCILLATION DEFINED

The Pacific Decadal Oscillation (PDO; fig. 4) is a long-term index of sea-surface temperature fluctuation of the North Pacific Ocean. Associated with this fluctuation, sea-surface temperatures become warmer and cooler every 20 to 30 years along the west coast of North America (Mantua and others, 1997). Between 1949-76, the North Pacific climate was influenced by a warm wedge of higher than normal sea-surface heights and temperatures in the central-to-western North Pacific and a horseshoe pattern of lower-than-normal sea-surface heights and temperatures along the west coast of North America (which together form a cool-PDO pattern). Between 1977 and 1998, the pattern was reversed, so that the central-to-western Pacific Ocean was cool while the west coast of North America was warm (a warm PDO pattern). These distributions of warm and cool water affect air temperatures along the west coast and reflect long-term changes (20-30 years) in the paths of storms and winds across the United States. In late 1998, the North Pacific climate returned to the cool-PDO pattern that dominated the 1949-76 period, and if this pattern persists interdecadally (every 20-30 years), the change can be expected to influence the hydroclimatology of the western United States for years to come (Cayan and others, 2001; Schmidt and Webb, 2001; McCabe and Dettinger, 2002).

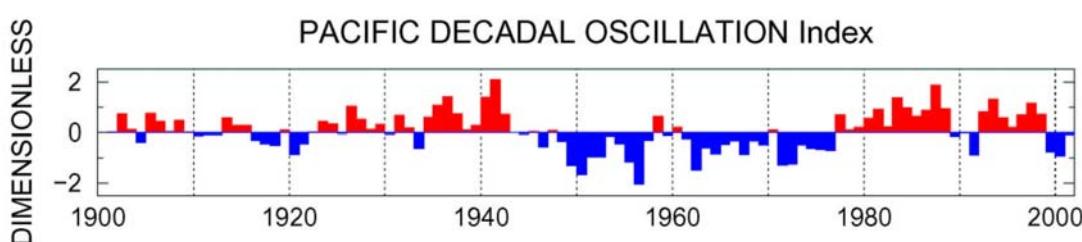


Figure 4. Index showing warm phase (above zero) and cool phase (below zero) Pacific Decadal Oscillation (Mantua and others, 1997; ftp://ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest).

EFFECTS OF PACIFIC DECADAL OSCILLATION

Streamflow timing in the Feather River, as in much of the West, varies from year to year, and from decade to decade, depending on the timing of precipitation and on temperatures during winter and spring (Dettinger and Cayan, 1995; Cayan and others, 2001). To understand some of the longer-term variations of the reconstructed streamflow into Lake Oroville (station FTO data series, 1906-1997), the timing of maximum monthly streamflows for each year was evaluated. The interdecadal long-term mean monthly flows for the period 1977-97 (fig. 5), show earlier peak flows characterized by a “warm PDO”, in response to warmer basin conditions, increased rainfall, and earlier snowmelt. Later peak flows characterize the “cool PDO” phase from 1949-76, in response to cooler basin conditions, more snow, and later snowmelt. During a warm-PDO phase from 1925-48, flows peaked in April, earlier than in the cool-PDO period (1949-76) that followed. The model calibration period (1971-97), straddles these PDO regimes, with most years from the recent warm (1977–98) PDO. Therefore, current model calibrations may be biased towards hydrologic conditions of the warm PDO phase. Early years of the calibration period (1971–76) were likely influenced by the cool (1949–76) PDO.

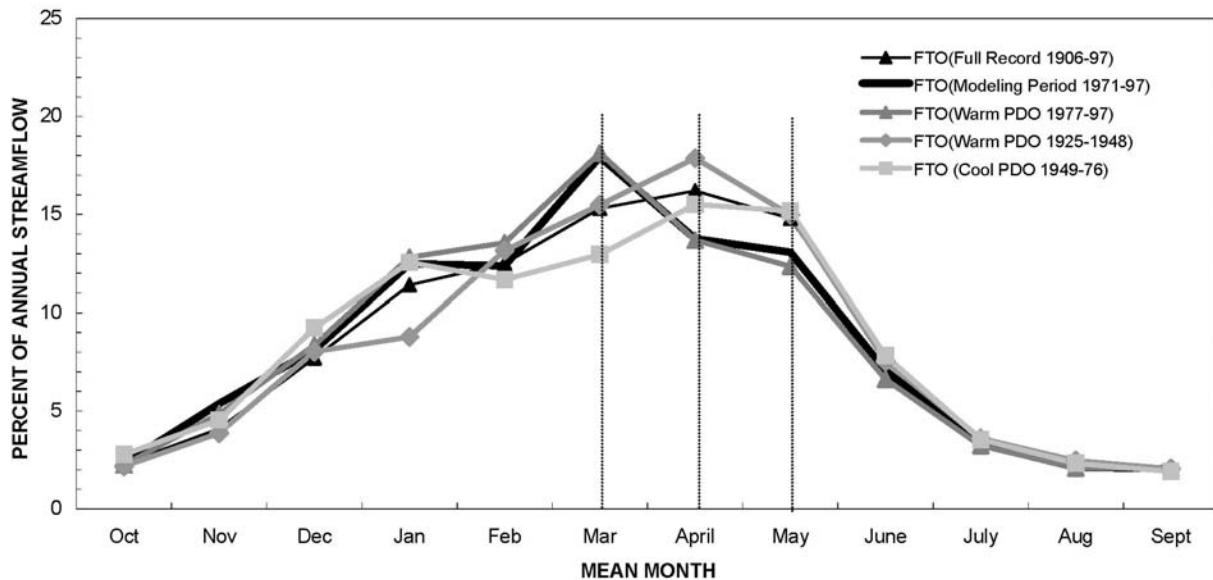


Figure 5. Historical mean-monthly variations in reconstructed streamflow (FTO) to Lake Oroville.

CONCLUSION

Peak monthly flows in the Feather River have come earlier in recent decades (1970s-90s), as they have in rivers all over the mountainous west (Dettinger and Cayan, 1995; Cayan and others, 2001). Streamflow timing is observed to vary in the Feather River on interdecadal time scales. Evaluation of reconstructed flows in the river for 1906-97 suggests that these timing variations may correspond to an influence of PDO. If so, watershed-model performance could be improved by a second calibration focusing on the historical cool-PDO periods. Parameters likely to change in a new calibration would be those that influence monthly-temperature lapse rates for areas in the basin, and thus effect evapotranspiration, sublimation rates, the formation of the snowpack, and the timing of snowmelt. Further research is required to confirm these findings.

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