

Looking for Recent Climatic Trends and Patterns in California's Central Sierra

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Introduction

Pacific Gas & Electric Company's (PG&E) water management team has historically assumed that future years, as a group of three or more successive years, were subject to the same level of climatic randomness characteristic of the past 25-50 years. There is increasing ongoing analysis that indicates that this may not always be the best assumption for future planning. With approximately 38% of its long term average annual hydroelectric generation derived from aquifer outflow, typical historic practice at PG&E, with regard to forecasting future seasonal runoff beyond the current year, has focused almost entirely on analyzing the current baseflow trend for the volcanic watersheds in northern California, such as in the Pit, McCloud, and upper North Fork Feather River watersheds. Historic climate randomness is then assumed for future seasonal precipitation and a multi-year baseflow forecast for a number of years forward is made for these northern watersheds. For the mid-to-high elevation headwaters, which overlay the central Sierra granites, the baseflow effect of prior years, is relatively minimal, and seasonal year-to-year randomness for historic precipitation has been assumed for input to multi-year runoff forecasts.

No attempts at PG&E have previously been made to utilize historic climate oscillation and trends as possible input to predict overall likelihood for precipitation in successive groups of upcoming years. Relatively recent analysis however, cautiously suggests that there may be relatively short precipitation cycles, which are approximately 14-16 years in length, and possibly longer term cycle and trend movements, which, while not necessarily helpful for defining wetness or dryness in the following year, may possibly provide helpful insight to better anticipate wetness for successive groups of years in terms of three or more years as a group. The apparent non-random subtle reflections of climatic cycling and trending was first noticed from the natural multi-year smoothing that accompanies baseflow trends and cycles of the large northern California volcanic springs that continuously contribute water as diminishing echoes of past wetness. Manga (1999) discusses timescales and groundwater discharge from the Cascade volcanics, which include those in northern California's Hat Creek drainage. A portion of the water, which is now emerging from underground storage to become surface runoff, may have come from seasonal precipitation that occurred many decades in the past. In this paper, an array of monthly and seasonal groupings of historic precipitation, snowpack and runoff are analyzed to reveal possible subtle signs of climatic oscillation and trending. While no attempt is made here to forecast future cycles of wetness based on observations of historic data, or being able to define the wetness for any given 1-2 years specifically, there may be potential for anticipating future wetness in terms of using successive groups of three or more years.

Repeating Climate Patterns in Wetness During the Past 100 Years

Recurring approximate 15-year oscillations in aquifer outflow rates from springs that contribute a large proportion of annual runoff into the Pit and McCloud rivers in northern California (Freeman 2001) provide possible clues that there may be multi-year periodicity to overall climate wetness and dryness as characterized by groups of successive years. This paper will illustrate some specific examples of precipitation, snowpack, and runoff that appear to support periodicity in wetness and dryness with amplitudes at about 7-8 years, and wetness and dryness, peaks and valleys respectively, utilizing three- and five-year grouped averages, each peak and valley being repeated approximately every 15 years. Some longer-term trends are also explored in this paper.

During either the wet or dry period, specific years were frequently observed to vary significantly from the three- or five-year average, but the group as a whole remained in relative harmony with the historic 15-year frequency. A review of aquifer outflow rates was utilized to identify the wet and dry amplitude peaks and valleys in terms of initially typing historic years. When applied to the 107-year, 1895 through 2001 Lake Spaulding precipitation record, grouping the year types into regular successive wet and dry three-year peaks and valleys according to rates of aquifer outflow, a relatively close matching relationship was found with the precipitation record. The apparent 15-year periodicity between successive recurring wet peaks and successive recurring dry valleys can be observed in Figure 1 for the 107-year period studied.

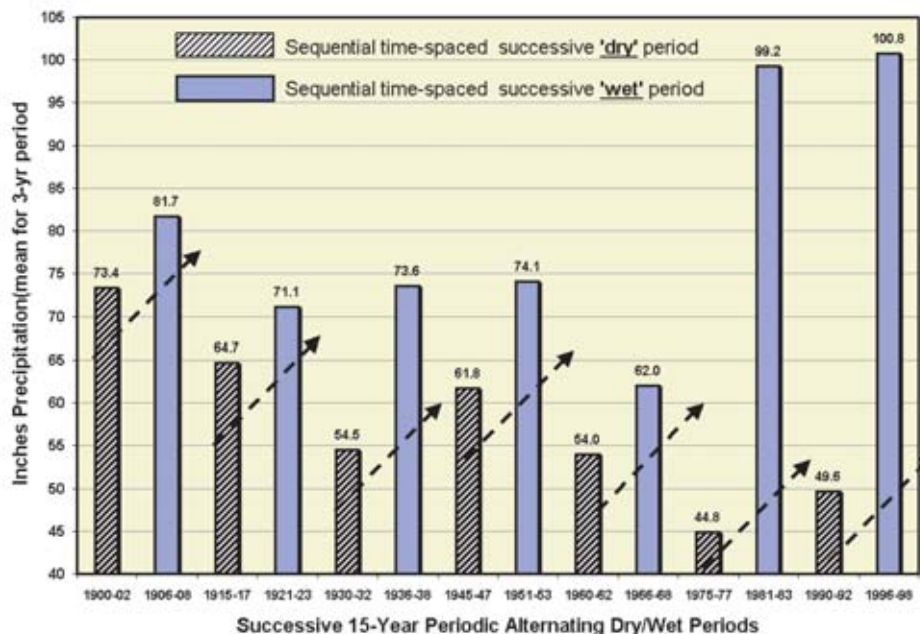


Figure 1 Lake Spaulding periodic oscillation of successive, sequential, time-spaced 3-year wet and dry groups of years. A sometimes subtle, but regular, oscillation appears to regularly repeat itself in terms of reaching a relative wetness maximum for the grouped years approximately every 15 years.

When other precipitation stations in both the central Sierra and southern Cascades near Mt. Shasta are combined and a five-year moving average smoother applied, the wet and dry oscillation again appears in a regular periodic manner, with some implied likelihood that the next dry valley for these three climate station will occur in or about 2005-2007 (Figure 2).

Spectral analysis can be applied to smoothed moving averages to reveal possible periodicity in wetness and dryness. This approach may reveal periodicity and show indication of the interval length, but in terms of prediction, this approach does not readily type the years into wet or dry groups such that the oscillation can be meaningfully extended forward in time from a specific year. Forecasts of periods, which reflect future periods of wetness and dryness based on past climate history, can be charted with possible implication that if the observed pattern continues, one may gain some skill for determining wet and dry groups of years forward of the present point in time. Such skill would be especially helpful for planning based on multiyear estimates of hydropower, water supply, and other longer-range hydro resource needs.

While individual years within the 3-5 year group are somewhat random in terms of being wet or dry, their moving average especially for the groupings reveals a somewhat regular oscillating pattern. A centered five-year moving average smoother was applied to the 1950 through 2001 Water Year flow for the east branch of the North Fork Feather River near Rich Bar, USGS 11403000 (Figure 3). This 52-year runoff record shows both the approximate 15-year periodicity in runoff and a possible longer-term trend toward increasing variance between high and low runoff periods.

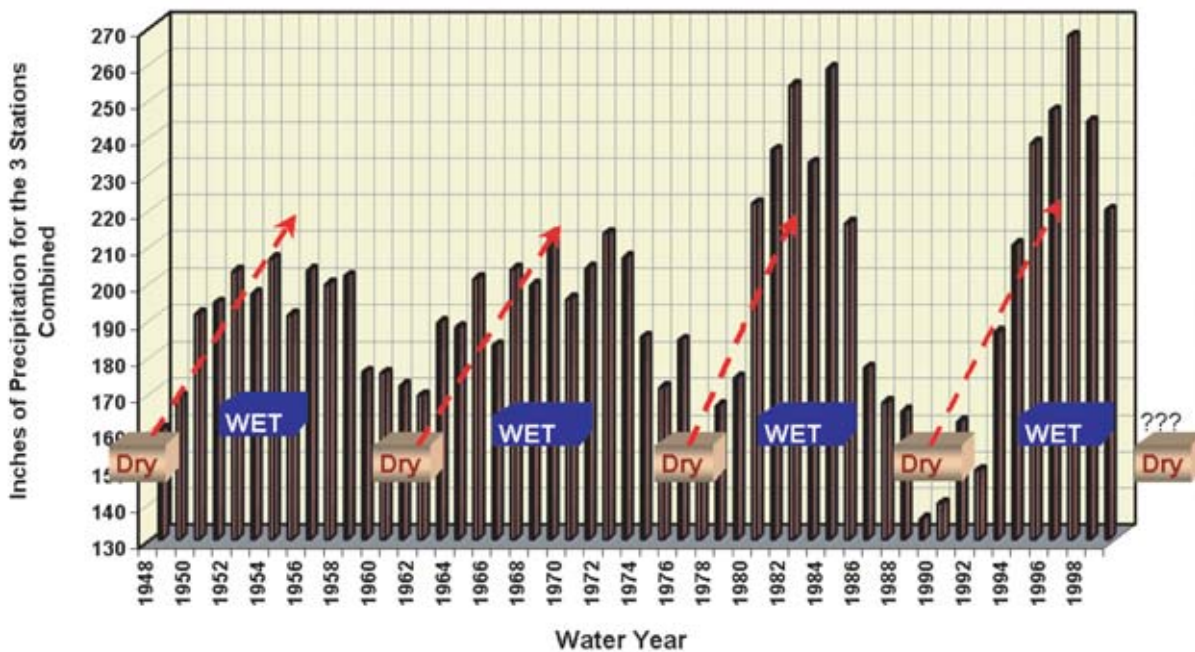


Figure 2 A five-year centered moving average smoother was applied to the combined water year precipitation of two central (Salt Springs, Lake Spaulding) and one northern California (Pit PH#5) climate stations. A regular periodic oscillation in wetness may provide some implied likelihood for predicting future wetness as a grouped set of years. In the past 30 years, two approximately 15-year oscillation periods, there appears to be increased difference between wetness and dryness amplitude compared with prior oscillations.

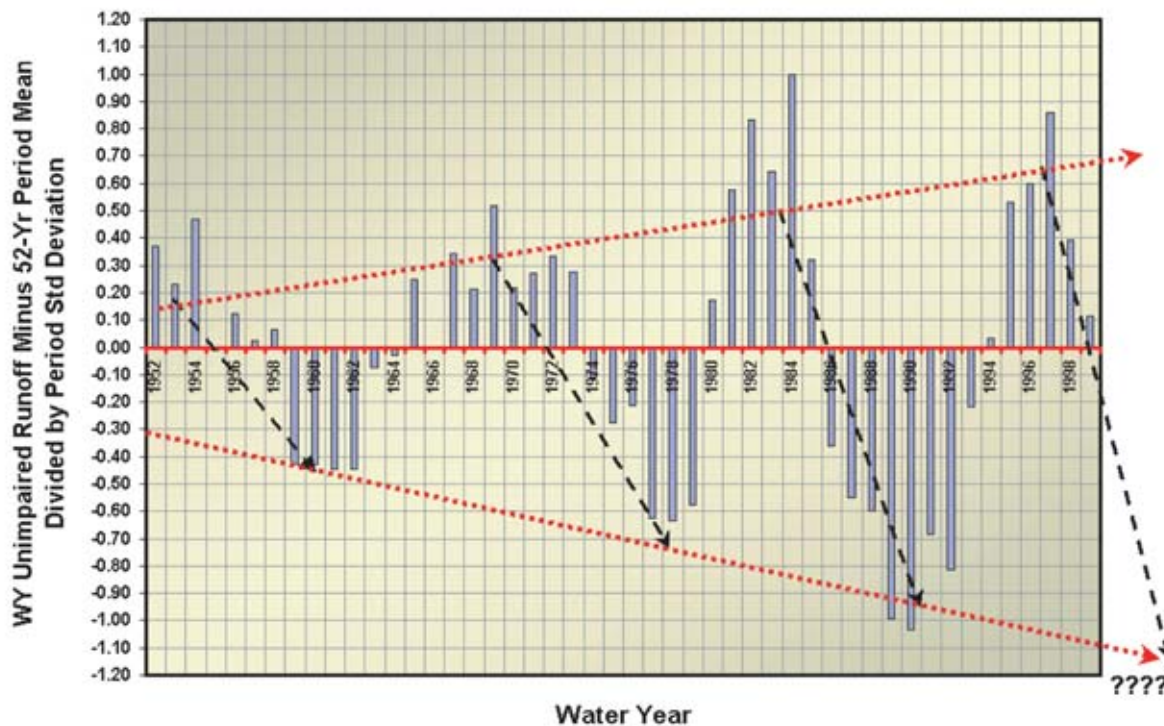


Figure 3 Recurring periods of greater and lesser-unimpaired runoff during the past 52 years on the east branch of North Fork Feather River. Increased period variability since about the mid-1970s, for the 52-year period, shows an increased variance in amplitude in recent years. Centered 5-year moving average applied.

Periods Within the Year also Show Recurring Runoff Patterns with Possible Long-Term Trends

In addition to the longer-term periodicity, there also appear to be trends and cycles (although less regular) that show up within the water year. The longer-term trend may possibly be due to earlier melt of the snowpack. The March runoff for the east branch of the North Fork Feather River (Figure 4) has increased while the May runoff (Figure 5) has decreased. Such trend change over the relatively brief span of approximately 50 years has potential to impact efficiently scheduling the water for hydroelectric production. The hydroelectric facilities were designed based on a runoff pattern for the Feather River typical of the early to mid-20th century. During the past 50 years the March runoff from the east branch of the North Fork Feather River, which represents about one-third the average annual runoff for the North Fork Feather River at Lake Oroville, has in recent years approximately doubled in quantity. In terms of hydroelectric scheduling, March flow releases from the large upstream storage reservoirs, Lake Almanor and Bucks Lake, have greatly decreased in recent years. This has in part resulted from an ongoing hydro scheduling practice to avoid when possible, the spill of upstream stored water from Lake Almanor past hydroelectric powerhouses along the lower reaches of the river that are already running at full capacity from the unimpaired east branch of the North Fork Feather River's March runoff. The approximate 15-year oscillation of grouped annual runoff observed in both the March and May months is most likely related to the similar wet/dry oscillation in annual precipitation. Seasonal precipitation amounts show an almost direct correlation with

snowpack amount and therefore snowmelt runoff, which will in turn likely affect March and May runoff amounts. This observed shift in runoff timing has in general within the past 15-20 years supported a relatively recent practice by water planners for reduced draft from both Lake Almanor and Bucks Lake during the January through March period, while the late winter and early spring uncontrolled sidewater flows from low elevation headwater areas, which have trended upward in recent years, are being increasingly utilized to run power houses downstream of these two lakes.

The November through February period was divided by the combined November through February period and the April through July period utilizing the monthly computed unimpaired flow for the Yuba River at Smartville, as computed by the California Department of Water Resources, for the 102-year period 1901 through 2002. The data was standardized with a centered five-year moving average smoother and is shown in Figure 6. Figure 6 reveals a positive upward drift in the November through February flows compared with the April through July snowmelt period.

Increased winter runoff is reflective of an increased proportion of precipitation falling as rainfall over the watershed during the November through February period. The record period used was 1901 through 2002 (102 years).

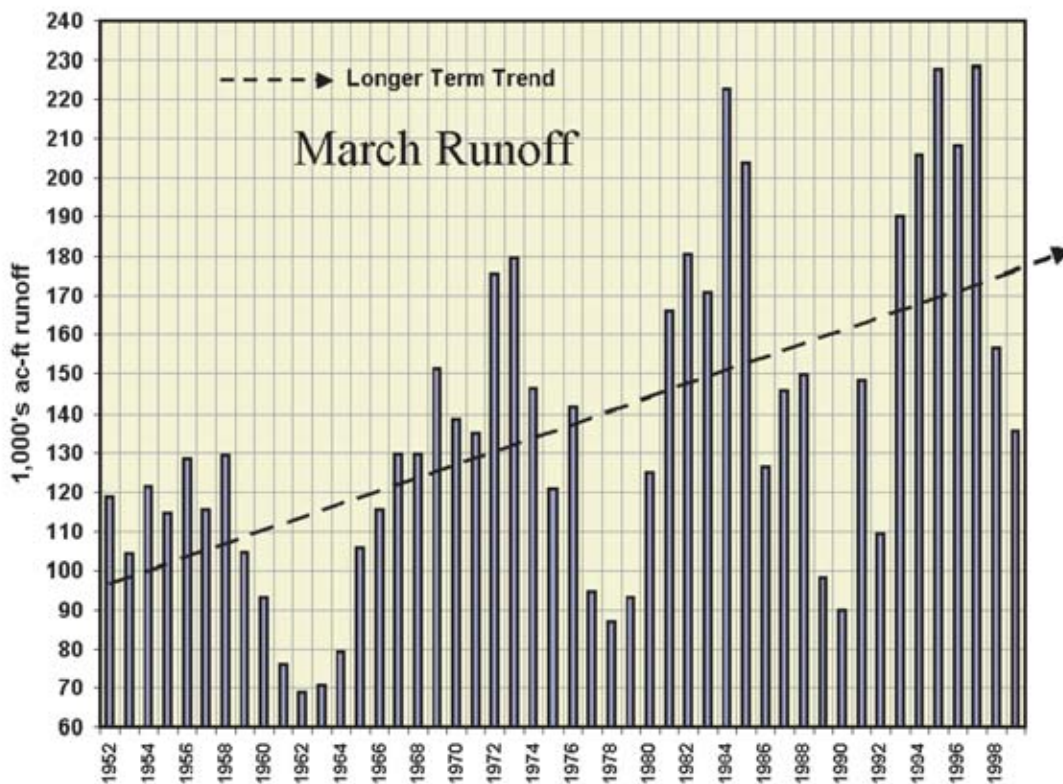


Figure 4 March unimpaired runoff for the east branch of the North Fork Feather River. Both a relatively short-term 14-16 year oscillation and longer-term trend toward increased March runoff in recent years appear on the chart. Centered 5-year moving average applied.

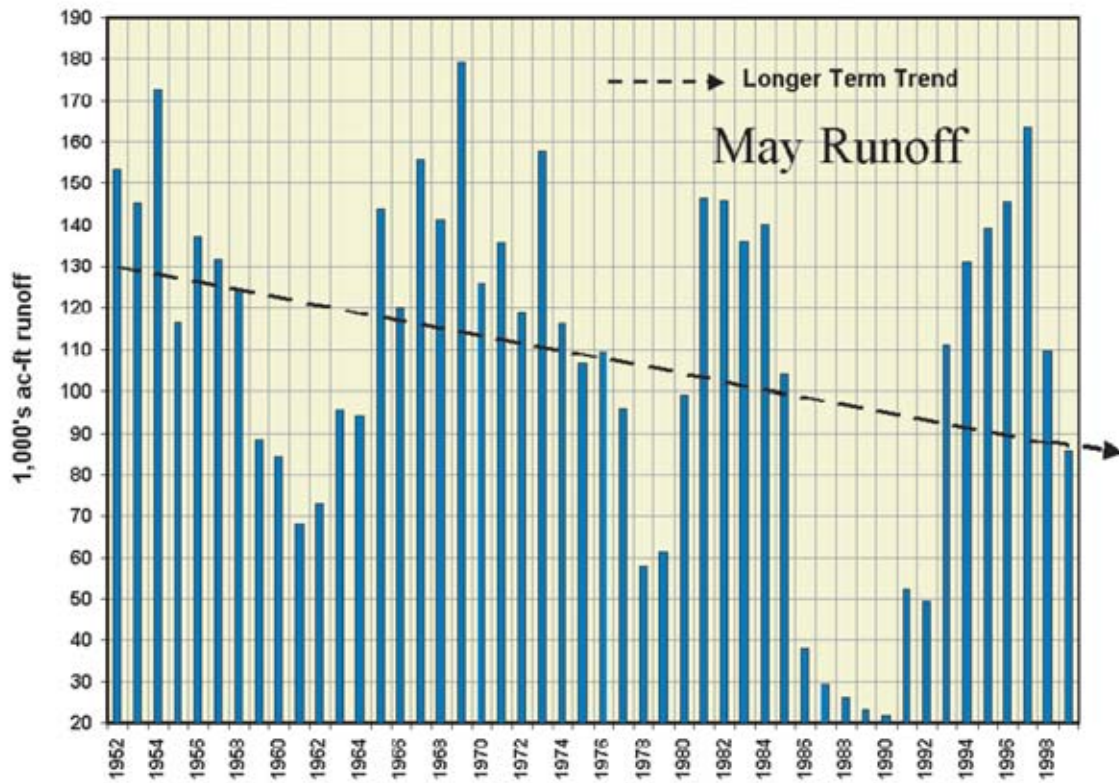


Figure 5 May unimpaired runoff for the east branch of the North Fork Feather River. Both relatively short-term 14-16 oscillation cycles and a longer-term trend toward decreased May runoff appear on the chart. Centered 5-year moving average applied.

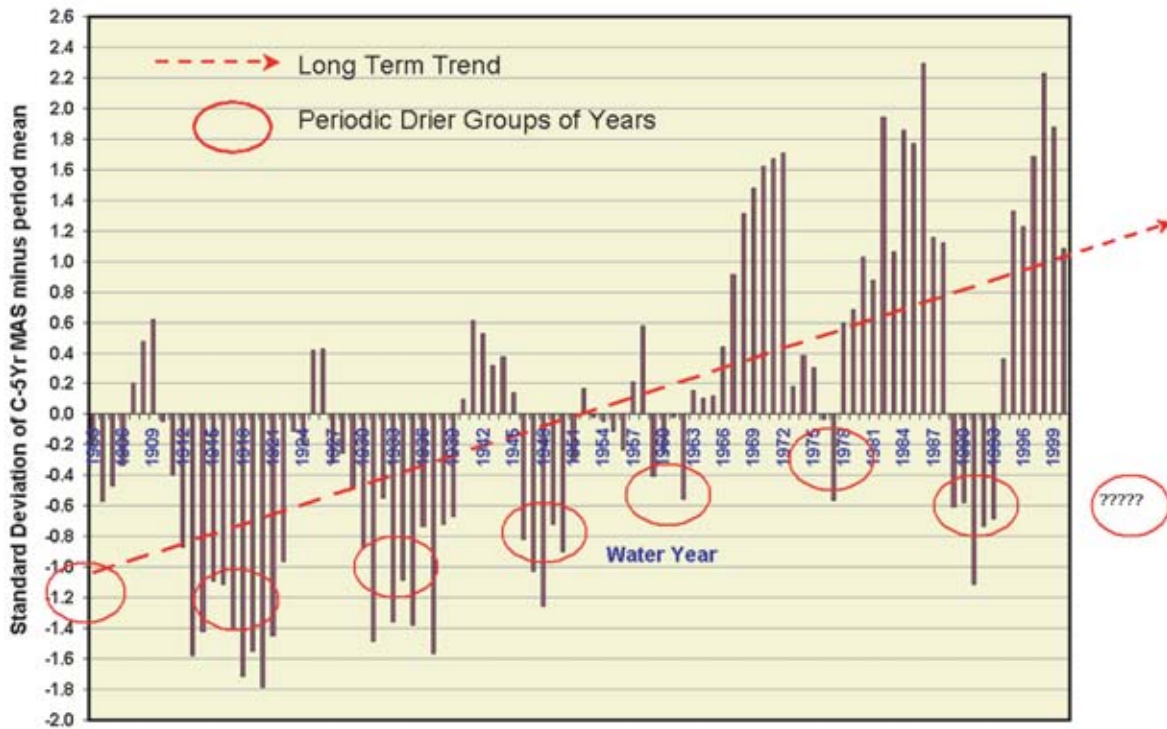


Figure 6 A drift in flow timing for the unimpaired runoff of the Yuba River at Smartville. Increased winter runoff in recent years appears reflective of an increased proportion of the annual precipitation falling as rainfall over the watershed during the November through February period. Record period used was 1901 through 2002 (102 years).

A continuous shift of the April through July runoff into the winter months November through February was observed from the data analyzed. With winter runoff in the Sierra largely produced from frontal type winter storms, the magnitude of winter runoff is mainly dependent upon quantity of winter rainfall produced runoff. If such is the case then it should reveal itself when charted over the past 102 years. Figure 7 illustrates an increased frequency of large rain-produced runoff events in the second half of the 20th century compared with earlier years. This appears consistent with recent research findings, which forecast a shift in spring snowmelt runoff to increased rainfall produced winter runoff (Cayan and others 2001). Figure 8 displays the November through February averages for the two periods. There was a 17% increase in the period averages for November through February runoff.

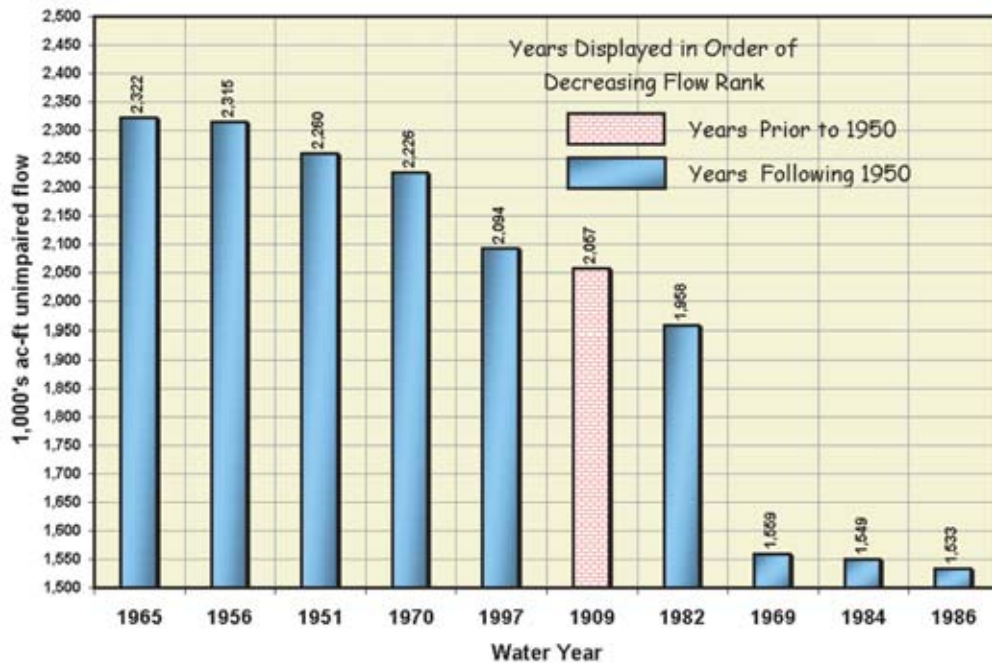


Figure 7 For the period 1901 through 2000, Yuba River at Smartville, only one year in the ten years of November through February unimpaired flows, which exceed 1,500,000 af, occurs prior to 1950. Recent years appear to have higher likelihood for more flow during the 4-month November through February winter period.

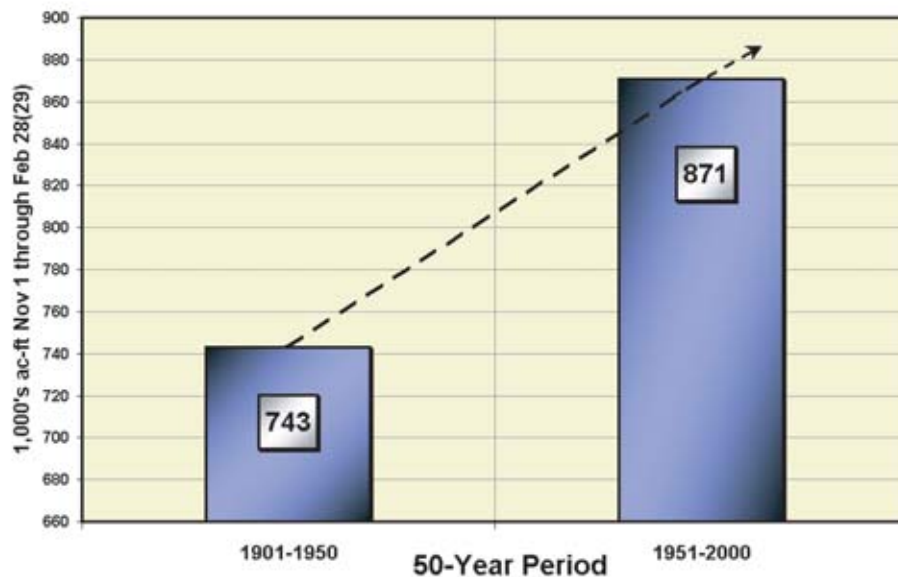


Figure 8 The mean flow of two successive November through February 50-year periods for the Yuba River at Smartville. There is a 17% increase in the more recent period.

The California Sierra Snowpack

California's snowpack likewise shows recurring patterns similar to that for both runoff and precipitation. A single snow course at Meadow Lake (#66) in the central Sierra at the 7,200 foot elevation readily reveals relative consistency in regular recurring oscillation between wet and dry groups of years as shown in Figure 9. While no attempt is made here to explain a cause for the observed recurring multiyear oscillation, a significant amount of the seasonal snowpack variability may be explainable with indices of Pacific Ocean Climate such as PDO (McCabe and Cayan 2001).

In order to test that the centered five-year moving average produced pattern was not simply a moving average "produced-aberration", regularly spaced discrete groups of years were also charted to verify alternating wet/dry periods. This is displayed in Figure 10. The regularly occurring highs and lows are readily identifiable, but in some cases are relatively subtle and could possibly be easily overlooked unless one was specifically looking at the appropriate successive regularly occurring time blocks.

Seasonal snowpack is closely related to both precipitation amount and freezing levels for winter and spring storms. The author found that for moderate to high elevation snow courses in the central Sierra, the April 1 snow water equivalent exhibit oscillation patterns closely resembling those of both precipitation and runoff.

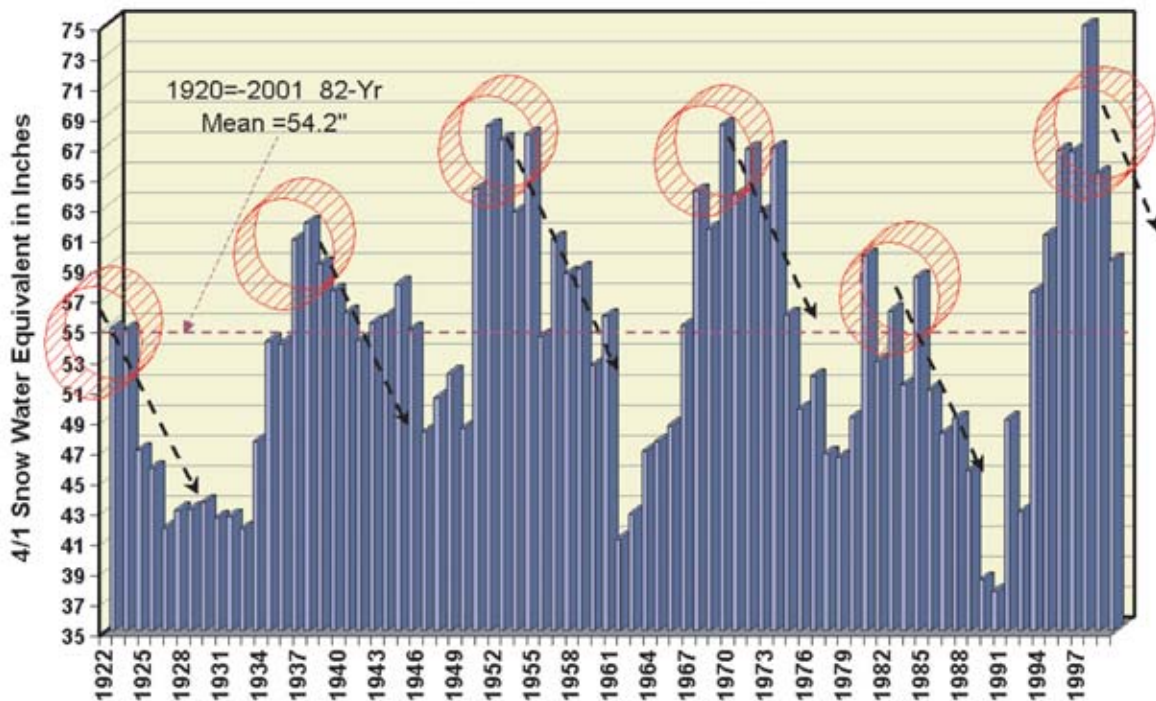


Figure 9 Meadow Lake snow course #66 in California's central Sierra Yuba River headwaters reveals a periodic oscillation in April 1 snow water equivalent (SWE) between periods of relative wetness and dryness. This snow course at the 7,200 foot elevation, unlike others at lower elevations, has not seen a reduction in snow water equivalent during the second half of the 20th century. Centered 5-year moving average applied.

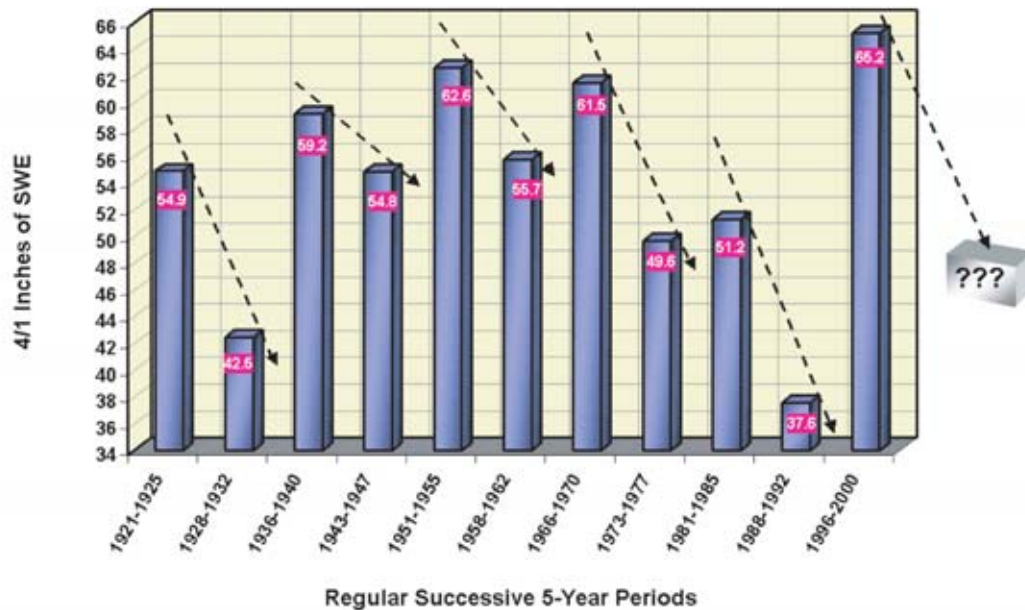


Figure 10 Meadow Lake #66 snow course — April 1 Snow Water Equivalent (*same original basic data set as used for Figure 10*). Discrete, successive 5-year groupings of regularly spaced years charted to show sometimes subtle, but regular, periods of wetness and dryness.

Comparison of the April 1 snow water equivalent for two snow courses on the south Yuba watershed for the period 1948 through 2002 — Lake Spaulding at the 5,200 foot elevation and Meadow Lake at the 7,200 foot elevation — reveals a downward trend for Lake Spaulding, the lower elevation snowpack (Figure 11). Meadow Lake, however, at the 2,000 foot higher elevation, approximately 10 miles northeast of Lake Spaulding, displays a near level trend line for the same 55-year period. The Lake Spaulding April 1 snow water equivalent is examined for a longer period (Figure 12). The April 1 snow water equivalent decreases from a mean of 24.4 inches for the 37-year period 1929 through 1965 to 19.8 inches for the 37-year period 1966 through 2002. This equates to a 19% drop in the mean for the more recent of the two periods (Figure 12). This long-term decreasing trend in low elevation snowpack and consequent decline in melt produced runoff appears consistent with that described elsewhere (Roos 1991).

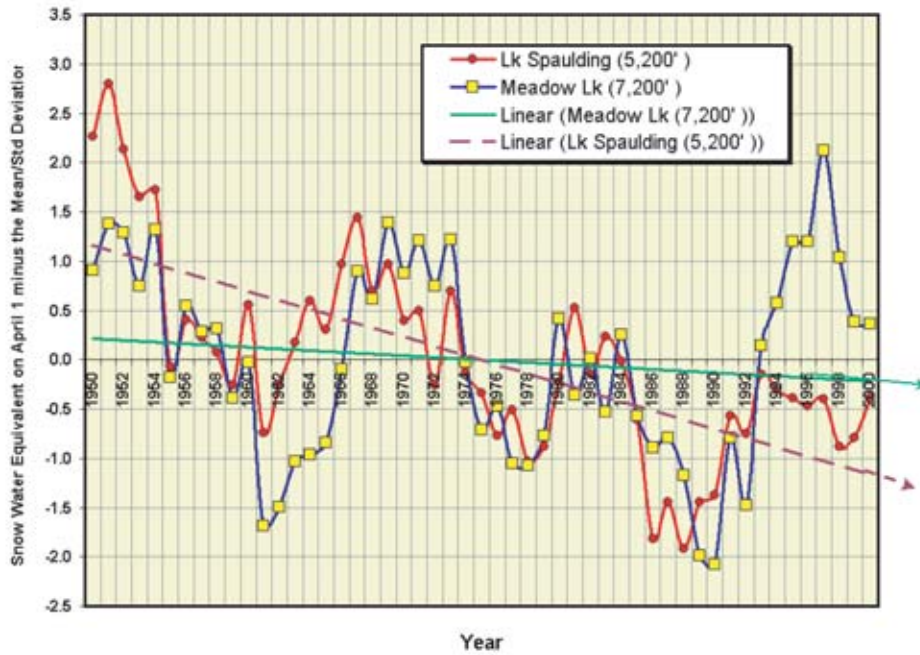


Figure 11 A comparison of the April 1 snow water equivalent for the two snow courses, Lake Spaulding #85 at the 5,200 foot elevation and Meadow Lake #66 at the 7,200 foot elevation in the headwaters in central California's Yuba River headwater drainage. Trend lines for each of the snow courses show a much steeper decline in recent years for the lower elevation Lake Spaulding snow course.

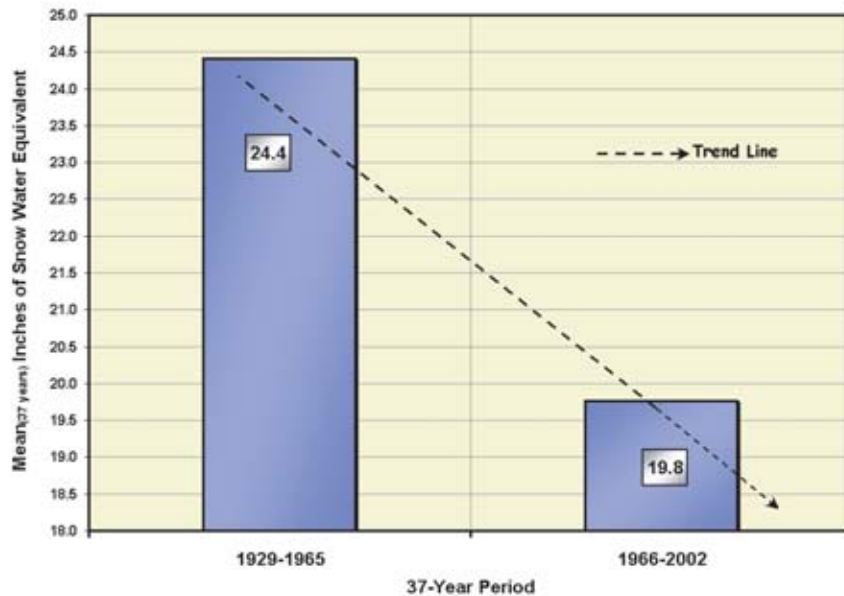


Figure 12 The April 1 snow water equivalent mean for two successive 37-year periods at the Lake Spaulding #85 snow course at the 5,200 foot elevation in California's central Sierra. This decrease in the April 1 SWE mean represents a 19% drop from the earlier period. No significant decline was observed to have occurred in the nearby snow course at Meadow Lake, which is 2,000 feet higher in elevation. The decline in low elevation snow in recent years may be indicative of a higher snowfall line with winter storm systems.

Conclusions

Analysis of historic hydrometeorological data reveals patterns that may have use in predicting future tendency toward wet or dry multiyear periods. If substantiated from additional research, such patterns may have potential use for long-range hydroelectric planning. Planning future outage schedules for hydroelectric facilities and reservoir carryover storage targets for multi-year storage reservoirs such as PG&E's Lake Almanor could benefit from increased skill in predicting upcoming years to have increased likelihood for more or less annual inflow. PG&E is already able to forecast approximately 40 % of its annual generation several years forward by making a baseflow forecast of anticipated relatively firm aquifer outflow from springs, which provide large relatively stable daily flows of the High Cascade and flood basalts of northern California. The apparent bimodal approximate 15-year oscillation pattern does not appear to provide much insight into predicting any given year's wetness in the future, but seems more useful for defining multi-year groupings as being in a wet or dry period as a grouping of three or more years. From the limited analysis presented here, precipitation, snowpack, and unimpaired runoff all appear to reflect this approximate 15-year oscillation in the central Sierra. The aquifer outflow of springs in northern California slightly lags these cycles and provides a natural moving average smoother of prior years annual precipitation variance.

Longer-term trends in apparent distribution shift of monthly runoff from the April through July snowmelt runoff period into the November through February period may be occurring from a trend toward reduced low elevation snowpack, possibly from an increased frequency of slightly warmer winter frontal storm cells during the second half of the 20th century. Since most of PG&E's hydroelectric system was designed based on historical flows prior to the mid-1960s, increased winter flows of higher magnitude are posing new challenges in monthly hydroelectric scheduling for reservoirs primarily designed to accommodate pre-1960s snowmelt quantities and annual year-to-year variance. Warmer conditions may shift reservoir filling from the late spring-early summer period toward holding additional water later into the winter-early spring period to increase assurance of filling from snowmelt. There is growing research that this trend is likely to continue (Knowles and others 2001; Snyder and others 2001). The reality of the limited observations discussed in this paper must await further, more thorough research, but the patterns and trends being observed tend to hint at possibility of a bimodal stochastic resonance effect. Regardless of the underlying forcing causes, the observed regularity of patterns appears helpful in making longer-range multiyear planning decisions.

References

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