THE 2014 CALIFORNIA DROUGHT – DEALING WITH EXTREME DRYNESS FROM A HYDROELECTRIC PLANNING PERSPECTIVE

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ABSTRACT

The 2013 calendar year was the driest year on record for California. For San Francisco based Pacific Gas and Electric Company (PG&E), which operates the largest investor owned hydroelectric system in the United States, the water management planning challenges, which were encountered during the first three months of 2014 and the twelve unusually dry months preceding 2014 were unlike those of earlier droughts. The acceptance of both the concept of climate change impacts as well as new paleo-climatological research findings about California and the southwest were for the first time being given serious consideration in the Company's water release planning. The prospect that the persistent high pressure region blocking the storm track into California from the Eastern Pacific and Gulf of Alaska could possibly remain "parked in place" became a principal scenario needed for effective planning. In terms of snow water equivalent (SWE), the February 2014 statewide snow surveys were less than 15% of the historical February 1 average. The demands on downstream water release requirements for maintaining biological flows, whitewater rafting, and other recreational opportunities have continued to increase in the past 38-39 years from the 1976-1977 drought, which were two successive very severe dry years. Conditions leading into the 2014 drought included 15-years of generally declining wetness over much of California causing the northern California's porous volcanic aquifer storage to decline significantly from the aquifer's relatively high mid-1990's storage state. Also water year runoff from rain-shadowed areas of the northern California's Sierra and southern Cascades have been in a state of trending decline since the 1976-1977 drought, a condition likely attributable to impacts from climate change. Utilizing the latest research findings available in 2014 on climate change and drought, the approach to reservoir and power production planning at PG&E changed from that utilized with prior droughts. Rather than assuming median likelihood or some low level of exceedances probability for remaining seasonal precipitation, the planning would take place as if the high pressure system pattern would continue to persist with no additional runoff expected. (Key words: drought, climate change, reservoirs, Sierra, hydroelectric).

INTRODUCTION

On January 17, 2014, following California's twelve driest months on record, the governor of California Edmund G. Brown Jr. declared a statewide drought. This declaration would start the needed processes for drought planning and providing federal aid to impacted businesses, communities, and other affected entities. For Pacific Gas and Electric Company based in San Francisco with the largest investor owned hydroelectric system in the United States, water management operational planning for its mountain reservoirs would require giving consideration to two relatively new concepts, not given serious consideration during earlier 20th century droughts. The first concept that needed planning consideration was some of the new paleoclimatological findings that indicated droughts which had occurred in California prior to the start of climate records in the mid-19th century were both more severe and longer lasting than droughts that occurred during the existing record. The second concept for consideration was to consider that ongoing climate change may have begun to impact the severity and persistence of earlier prerecorded droughts. For effective hydroelectric planning, with a long history of relying on historical time series of unimpaired flows, precipitation, and snowpack data, the concepts of climate change and new climate data becoming available about droughts that occurred prior to the record period would change the water management approach to water release planning. California is located in an area that uniquely defines the Mediterranean climate, having a long dry summer and wet winter and early spring period. The summer dryness is dependent on an area of high pressure

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shifting northward just west of the California coast deflecting the storm track northward. In the winter with the return of arctic ice and cooling, the blocking high pressure ridge shifts southward and storms can once again enter California from the eastern Pacific. For California, atmospheric rivers (AR's), which typically are relatively warm and semitropical in origin, and therefore have relatively high moisture content and are typically are a major contributor to winter precipitation. The majority of precipitation for California typically comes from 5-6 of these large AR's. On occasion a very large, relatively long duration AR event takes place, an event which has historically been called the 'Pineapple Express'. Some of the notable Pineapple Expresses occurred in February and March 1986, and in the winter of 1998, a year with a strong El Nino. PG&E's reservoir operational planning team gave strong consideration that the high pressure ridge was revealing a strong persistent pattern of "parking", resistant to moving, and consequently not allowing the storm track to enter into California. Beginning in early January, the lack of snowpack and increasing awareness of the persistent high pressure blocking prompted reservoir operators to quickly reduce water releases from most mountain reservoirs. In addition to reducing water releases for hydroelectric production, variances were quickly requested to reduce instream flow releases for biological, recreational, and downstream water use. The process of getting a variance in downstream water releases requires a lengthy review, therefore in order to be effective the variance request process needed to be initiated quickly. Some early February AR's entered into California as the Pacific High shifted slightly southward, however, much of the storm track continued to remain to the far northern part of California and Oregon. By mid-February, the lack of precipitation led to a very shallow snowpack covering the higher elevations in the Sierra and southern Cascades. As with earlier droughts, both the regression and conceptual modeling procedures utilized to forecast seasonal runoff did not consistently provide reasonable results. For PG&E, in which nearly 40% of its historical conventional hydroelectric production comes from northern California's large springs, the continued long term decline in aquifer outflow was best defined by utilizing trending rather than actual modeled prediction. Following 13 months of unprecedented dryness, soil moisture accounting became an important factor for consideration during the first significant precipitation, which occurred in early February. The early February 2014 storms were mostly from relatively warm AR's that brought rainfall rather than snowfall into the medium to higher elevations of the Sierra and southern Cascades. For northern California with its relatively low elevation Feather, Pit, and McCloud Rivers and the Eel River located in the coastal mountain range, soil moisture accounting was an important first step in runoff forecasting and water release planning for reservoir management.

THE YEARS PRECEDING 2014

The years leading up to the late 1900's, especially for northern California's Pit and McCloud Rivers were somewhat similar to the years leading into the 1928-1934 seven year drought. A number of years of below average water year precipitation beginning about 1908 and ending with 1934 resulted in a long term decline in aquifer outflow into the Pit River. The low state in northern California's aquifer storage fully restored itself and again reached a high storage state in 1976. A long term trend downwards from the 1976 'high aquifer outflow state' started in 1977. During the years leading up to 2014, there were three other high aquifer outflow periods, but each less than the earlier aquifer water year outflow. Beginning in in the mid-1970's a relatively steep downward trend in aquifer outflow rate was accompanied by a long term decline in precipitation. In terms of water year precipitation, only the 2006 and 2011 water years were significantly above normal. Hat Creek, a tributary that flows into the Pit River readily shows this long term decline in Figure 1. The aquifer outflow index component is calculated utilizing the minimum daily flows during the fall months of August and September for both the current and prior year. Because the aquifer outflows contain precipitation that had fallen several decades prior to the current year, the natural lag created a moving average of its own with long term trends that appears sensitive to the wet and dry cycles of the Pacific Decadal Oscillation (PDO) which lasts 20-30 years, the El Nino Southern Oscillation (ENSO) which lasts 2-7 years , and other types of recurrent cycles. Once the overall trend starts, the decline or rise is often multi-decadal and the direction that it's headed can be forecasted utilizing trending until a change takes place. Because the trend direction for the aquifer outflows is relatively long lasting, some idea as to what may lay ahead in terms of flows may be inferred. The gradualness of the rises and falls in the outflow rate of the large springs are helpful in predicting approximate flow rate going forward. Approximately 89% of Hat Creek's surface runoff comes from large springs, which provide water that had entered the headwater recharge area several decades earlier in the form of snow- or rain-fall. Once the aquifers in the headwaters have become sufficiently depleted, it may take several years, and possibly decades for the aquifer storage to fully recover depending on future wetness and snowpack which would provide sufficient recharge opportunity. With climate change and the continuing loss of the northern California snowpack (Freeman, 2011, 2012), the recharge opportunity for the aquifers are continuing to decline. Adequate recharge requires both sufficient wetness and precipitation in the form of snow to be effective in terms of slow melt allowing the maximum potential for recharge consistent with infiltration capacity of the soils. One of the concerns with warmer storms containing high moisture is that while they may reach sufficient cooling for producing precipitation through the orographic process when encountering high mountain barriers, there are many areas in northern California that are relatively low elevation and are located behind mountain barriers creating effective rain shadows.

RECENT RESEARCH AND TOOLS FOR DROUGHT PLANNING

Recent research findings for climate change, paleoclimatology, and atmospheric rivers have influenced water management planning at PG&E. Research findings by Ingram, 2013 provide numerous examples of past droughts that were more severe than those experienced in the record period and also examples of those that lasted decades and even centuries in California. Prior to 2013, the period of available record has the 1976 and 1977 water years as being the most severe dry years and the 1928-1934 and 1988-1992 as the two longest periods of consecutive

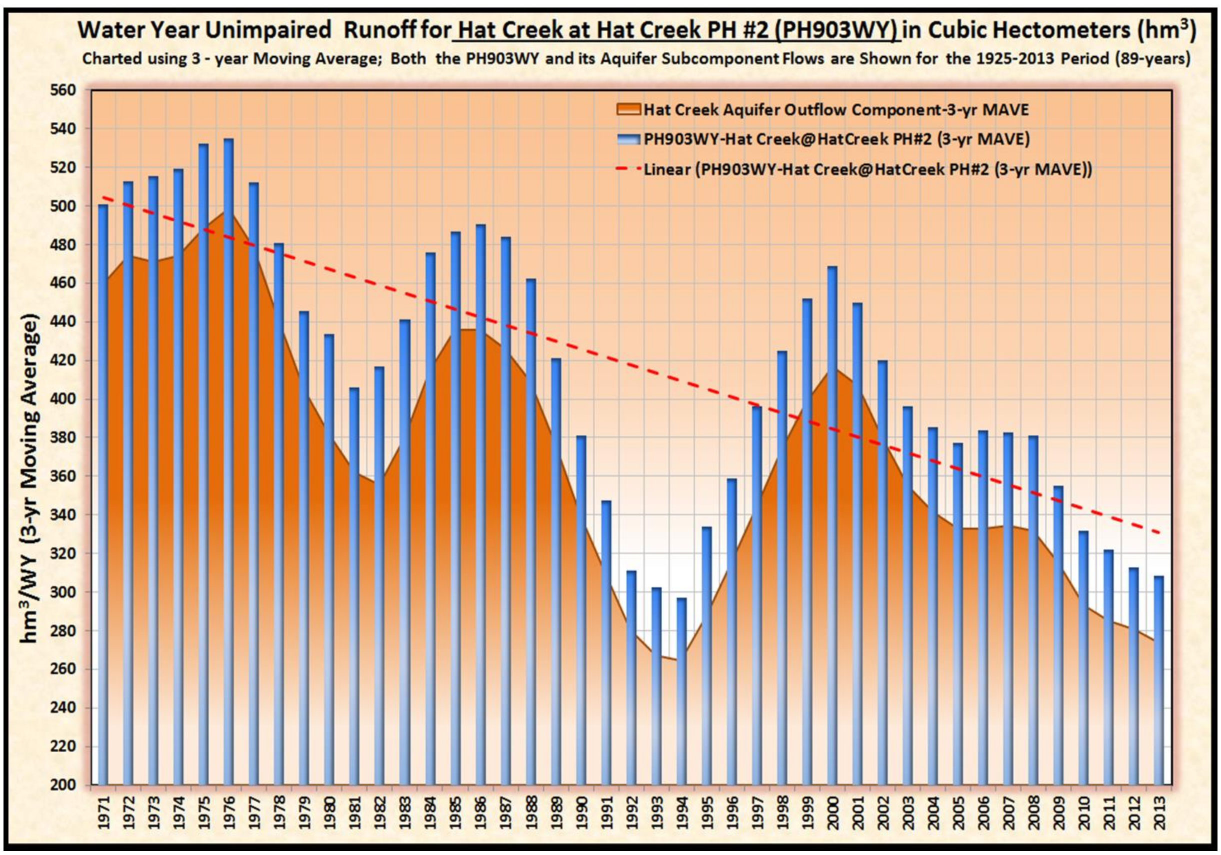

Figure 1. Hat Creek @ Hat Creek PH#2 (tributary to Northern California's Pit River) unimpaired flow including its aquifer outflow component for the period 1971 through 2013. All values are shown with a 3-year moving average.

drought. Knowing that long periods of severe drought were common in California's relatively recent past prepares us to plan for that possibility going forward. With regard to the persistent 'parking' of the Pacific High off of the California coast, the increasing loss of Arctic sea ice and warming of the Arctic may have influenced a slowing of the jet stream's zonal flow with greater amplitude of its waves leading to increased persistence of drought, floods, hot and cold spells (Francis, 2012). Increasing awareness that the persistent high may be caused from climate change led water management planning to become increasingly cautious in expecting a quick change in the pattern. Beginning in early January, water management's operational planning proceeded in a manner that assumed no additional runoff. If wetness returned than the 'little or no water release plan' would change accordingly. Recent research regarding atmospheric rivers increased overall awareness that should 4 or 5 atmospheric rivers occur, the drought could rapidly end and a possible return to normal could take place. However until such wetness happened, the plan would be to operate as if the high pressure ridging would continue to persist and that drought could possibly continue for several years. Moderate atmospheric rivers that occurred during the month of February were each watched closely for their forecasted positioning and whether or not they would be able to shift sufficiently far south to help the drought picture.

HYDROLOGICAL CONDITIONS FOR JANUARY, FBRUARY, AND MARCH 2014

The February snow surveys indicated a statewide snowpack snow water equivalent at only 24% of normal for that date. Even if normal snow accumulation was to occur between the first of February and April 1, the snowpack would only reach 65% of average. Precipitation overall statewide was likewise well below normal with the California Department of Water Resources (DWR) northern 8-station precipitation index indicating only 35% of normal for that time of year. With normal precipitation for the remainder of the season the index could be expected to reach 67% of average. The California Climate Tracker's statewide 12- month January 2013 through January 2014 precipitation shown in Figure 2 shows the past 12 months to be the driest such period on record for California. A growing awareness that this drought was in certain ways different from others experienced during the period of record quickly caught people's attention as requiring a higher level of planning and awareness than has previously been the case. In addition to being very dry, the average January temperatures for the Sierra Region where most of California's water comes from were also the warmest on record. The warm temperatures and general lack of soil moisture had also prompted a statewide fire alert. The expectation was becoming evident that if soil moisture was not restored, vegetation would likely be stressed the following summer with increased fire risk. For Lake Pillsbury, on the Eel River in California's coastal range, after several months with nearly no precipitation the first rains in 2014 required approximately 5.0 inches of soil moisture to be replenished before any significant inflow into Lake Pillsbury occurred. Likewise the first storms in 2014 gave a very limited runoff response in both the Sierra and southern Cascade streams. Figure 3 compares results from the State of California's DWR automated sensor system beginning on 12/31/2013 and displays results at approximate 15-day intervals. While PG&E's mountain lakes overall had almost near normal reservoir levels prior the spring snowmelt freshet, the lack of adequate snowpack for refilling them remained as a major concern. On March 1 most reservoirs did not have sufficient snowpack for filling the reservoirs. In 2014 most of the February and March storms were limited to far northern California and as such did not provide significant precipitation. The persistent high pressure ridge remained parked off the coast of central California, effectively deflecting the storm track into far northern California and into Oregon. Minimum temperatures accompanying storms as shown in Figure 4 have increased in recent years with the January and February minimum temperatures accompanying storms in 2014 being the highest on record for the Canyon Dam Weather Station on the North Fork Feather River.

CONCLUSIONS

The extreme dryness in California for the 2013 calendar year and record January and February high maximum temperatures were unprecedented. The 2014 California drought prompted PG&E's Water Management

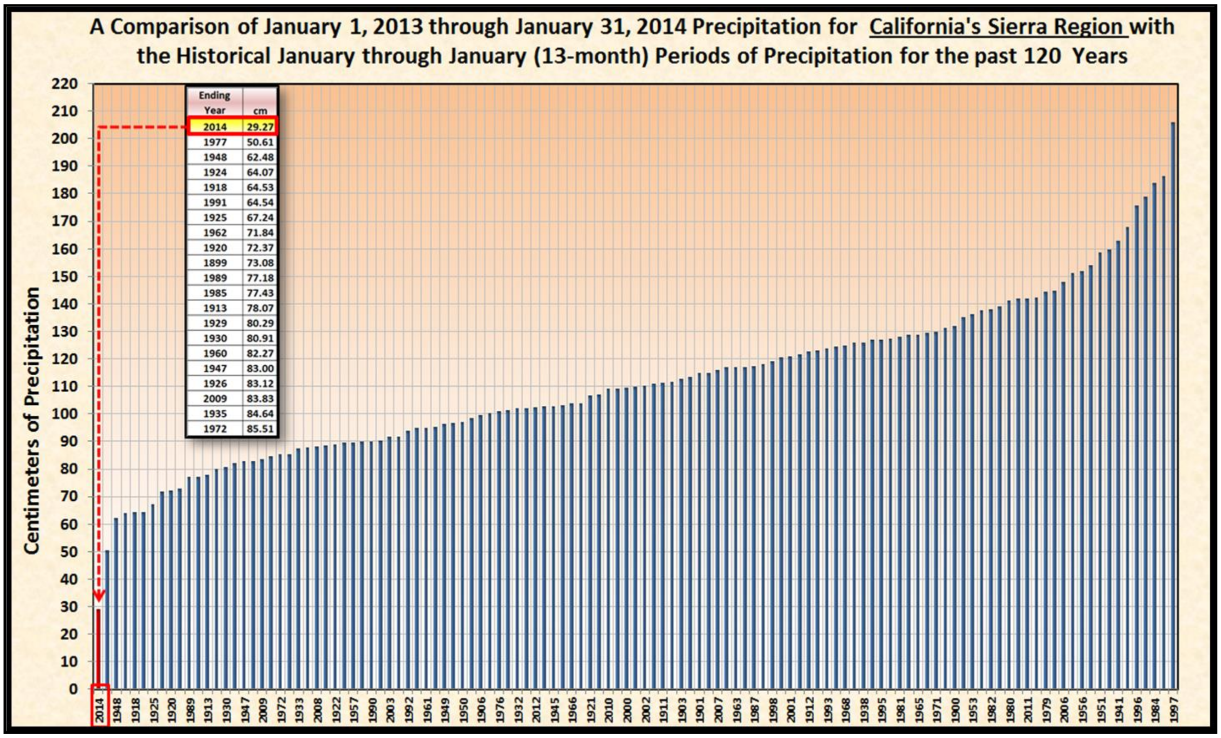

Figure 2. The January 1, 2013 through January 31, 2014 (13-month) period is shown in this chart from the California Climate Tracker as being the driest on record.

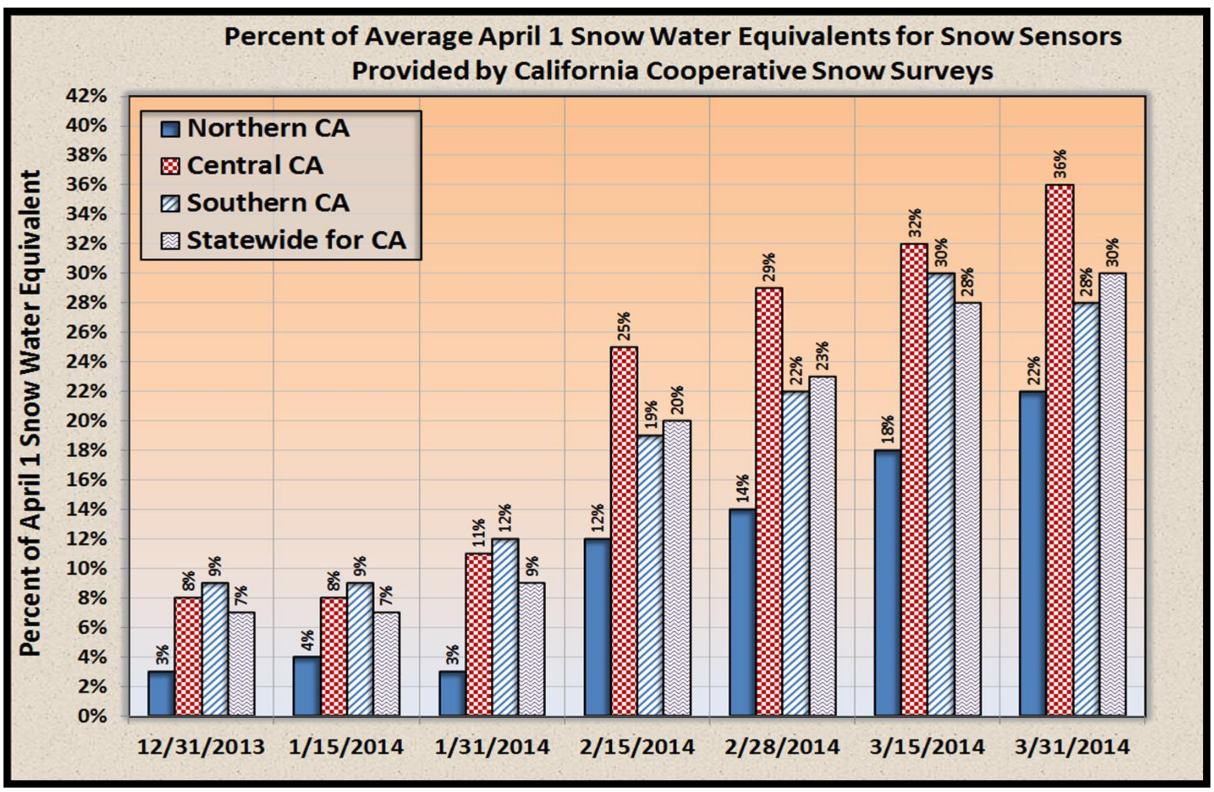

Figure 3. Percentage of average snowpack for the date shown. Data from all automated CDEC sensors statewide.

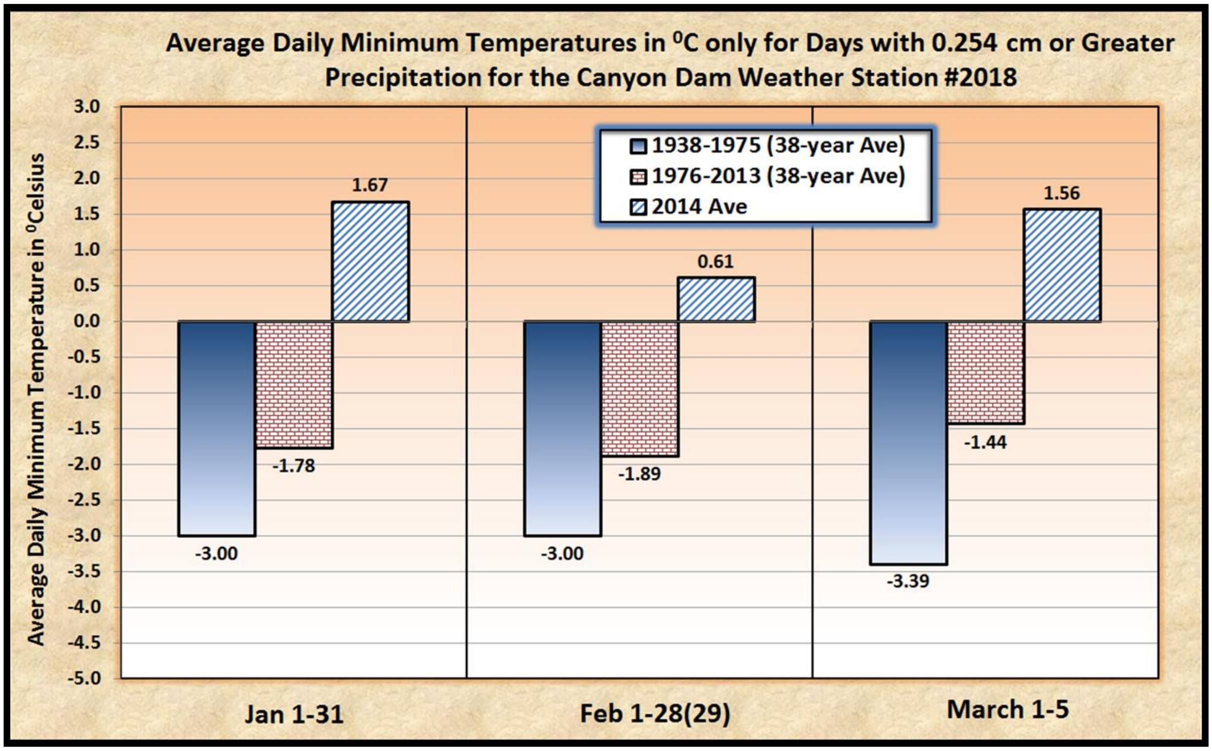

Figure 4. A comparison of two successive 38-year periods with the 2014 January, February and first 5-days in March for minimum temperature only on days with 0.254 cm or greater precipitation.

planning team to take into consideration a number of considerations with special consideration to: 1) recent paleoclimatological findings indicating that droughts lasting decades and centuries have been common and can be expected for California, 2) impacts of climate change may cause unexpected change outside of the recorded record, and 3) the Pacific Decadal Oscillation's current condition needed to be considered as likely having an influence on current drought conditions.

REFERENCES

Francis, J. A. and S. J. Vavrus, 2012: Evidence linking Arctic amplification to extreme weather in mid-latitudes, Geophys. Res. Lett., Vol. 39, L06801, doi:10.1029/2012GL051000.

Freeman, G. J. 2007. A program to increase aquifer outflow in northern California's McCloud and Pit River watersheds. Western Snow Conference 75: 31-42.

Freeman, G. J. 2011. Climate change and the changing water balance for California's North Fork Feather River. Western Snow Conference 79:71-82.

Freeman, G.J. 2012. Analyzing the impact of climate change on monthly river flows in California's Sierra Nevada and southern Cascade mountain ranges. Western Snow Conference 80: 3-14.

Ingram, B. L., F. Malamud-Roam, 2013. The west without water. University of California Press. 289 p.