PLANNING BEYOND CALIFORNIA'S THREE-YEAR DROUGHT - A 2015 HYDROELECTRIC PLANNING PERSPECTIVE

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ABSTRACT

Following three dry years, precipitation for the month of December 2014 was 131% of the Sierra Region's 120-year December average; however October-December 2014 as a 3-month period continued to remain below average. On December 31, 2014, precipitation for the California Department of Water Resources (DWR) northern California 8-station index was 129% of its historical 30-year average. However DWR's southern California 5-station index was only 70% of its 30-year historical average. Precipitation was much above average in northern Sierra and drier than average for the southern Sierra. In spite of this unbalanced situation statewide, the overall increase in precipitation appeared to many as a dramatic turnaround from one of the most severe droughts in California's recorded history. However, in spite of this dramatic precipitation recovery, California's snowpack at the end of December statewide was only 49% of average, thus remaining much below average, mostly due to the higher snowline accompanying the relatively warm December storms. For Pacific Gas & Electric Company which has historically produced about 38 percent of its conventional hydroelectric energy from the aquifer outflow of large volcanic springs in northern California and approximately 37% of its conventional hydroelectric energy from the snowpack, the fall rains after satisfying an unusually large soil moisture deficit made little difference in the outflow rates and added only meager amounts of recharge to northern California's porous volcanic aquifer storage which had lost approximately four million acre feet from underground storage since 1999. The 2014 calendar year was highly unusual beyond its single characteristic of being dry. Minimum daily temperatures for the 12-month period for the Sierra Region were the warmest in 120 years of record. This additional heating resulted in some of the driest soils moisture conditions for California in the past 1200 years. While rain dominated precipitation caused flood damage in December for parts of California, river flows quickly declined following the December rains. Aquifer outflows in northern California continued to remain much below normal following December's wetness. As of January 1, 2015, precipitation for the remainder of the water year would need to increase to about 135% of average to get 100% of average annual conventional hydro generation. (KEYWORDS: drought, reservoirs, climate change, Sierra, hydroelectric)

INTRODUCTION

Following an unprecedented 3-years of dryness with severity not experienced since the early 20th century, combined with much warmer than average temperatures not experienced within the past 1200 years in the Sierra and southern Cascades geomorphic provinces (Griffin and Anchukaitis, 2014; Woodhouse, et al., 2010), a period of December 2014 wetness brought some welcome relief to California's dismal water situation. However, statewide even with December's precipitation at 181 percent of average (California Climate Tracker, 2015), the situation while helpful in providing a temporary respite from the extreme dryness failed to significantly change California's drought situation. For Pacific Gas and Electric Company, which is based in San Francisco and which has the largest investor owned hydroelectric system in the United States, its water management operational planning team would make an early January 2015 assessment of both the snowpack and northern California porous volcanic aquifer storage situation, then begin to plan its spring and summer water releases accordingly. The Pacific Decadal Oscillation (PDO) had changed to its drier, cooler phase beginning about 1999 and the Atlantic Multi-Decadal Oscillation likewise changed to its drier and warmer phase about the same time. The combined impact of both oscillations appeared consistent with an overall decline in precipitation for northern California, which also began about 1999. Likewise R. Seager and M. Hoeling (2014) have indicated that beginning in the twenty-first century, natural decadal swings in tropical Pacific and North Atlantic sea surface temperatures (SST) have contributed to a dry regime for the United States. Long-term changes caused by increasing trace gas concentrations are now likely contributing to a modest signal of soil moisture depletion, mainly over the southwest United States, thereby prolonging the duration and severity on naturally occurring droughts. B. Cook et al. (2015) utilized general circulation models to show that these models project significantly drier conditions in the later half of the 21st century compared to the 20th century

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and earlier. The High Cascade porous volcanic aquifers in northern California likewise show a decline in in aquifer outflow rates beginning in about 1999. The decline in outflow rate reflects lack of recharge opportunity and decline in storage within these large aquifers (Freeman, 2014). The aquifer outflows of these northern California porous volcanic aquifers have historically contributed approximately 38 percent of PG&E's annual hydroelectric production (Freeman, 2007). Beginning about July 2014, the PDO started a return to its warmer positive phase. Whether or not this recent change will hold remains unknown. J. Francis and S.Vavrus (2015) have presented findings that support a hydro planning bias toward increased likelihood of pattern persistence. In about mid-January 2015, with the current continuation of Arctic amplification and resilient high pressure ridging holding along the California coast, PG&E's water management planning for 2015 made a decision to likewise include a planning bias towards a continuation of drought-like conditions for its hydroelectric operations in the Sierra and southern Cascades regions of California.

THE 2015 WATER YEAR WATER BALANCE AND STORAGE SITUATION FOR THE SIERRA AND SOUTHERN CASCADES

Aquifer Storage

Utilizing a relatively simple water balance approach to analyze the current state of California's multiyear drought can be helpful in that it can be used to define and account for some of the primary components of the hydrological cycle. Both water year precipitation and runoff can be utilized to reveal water year evapotranspiration and aquifer state. Since PG&E's hydroelectric system extends from the Pit River southward to High Sierra's Kern River, a number of flow sites and climate stations were reviewed. The northern volcanic aquifers that flow into the Pit, McCloud and upper North Fork Feather Rivers above Lake Almanor are strongly dependent on precipitation wetness and snowpack for recharge. Former studies of the northern volcanic aquifers by Freeman (2014) indicated that their aquifer outflow rates which are in turn affected by precipitation wetness appear to be moderate to

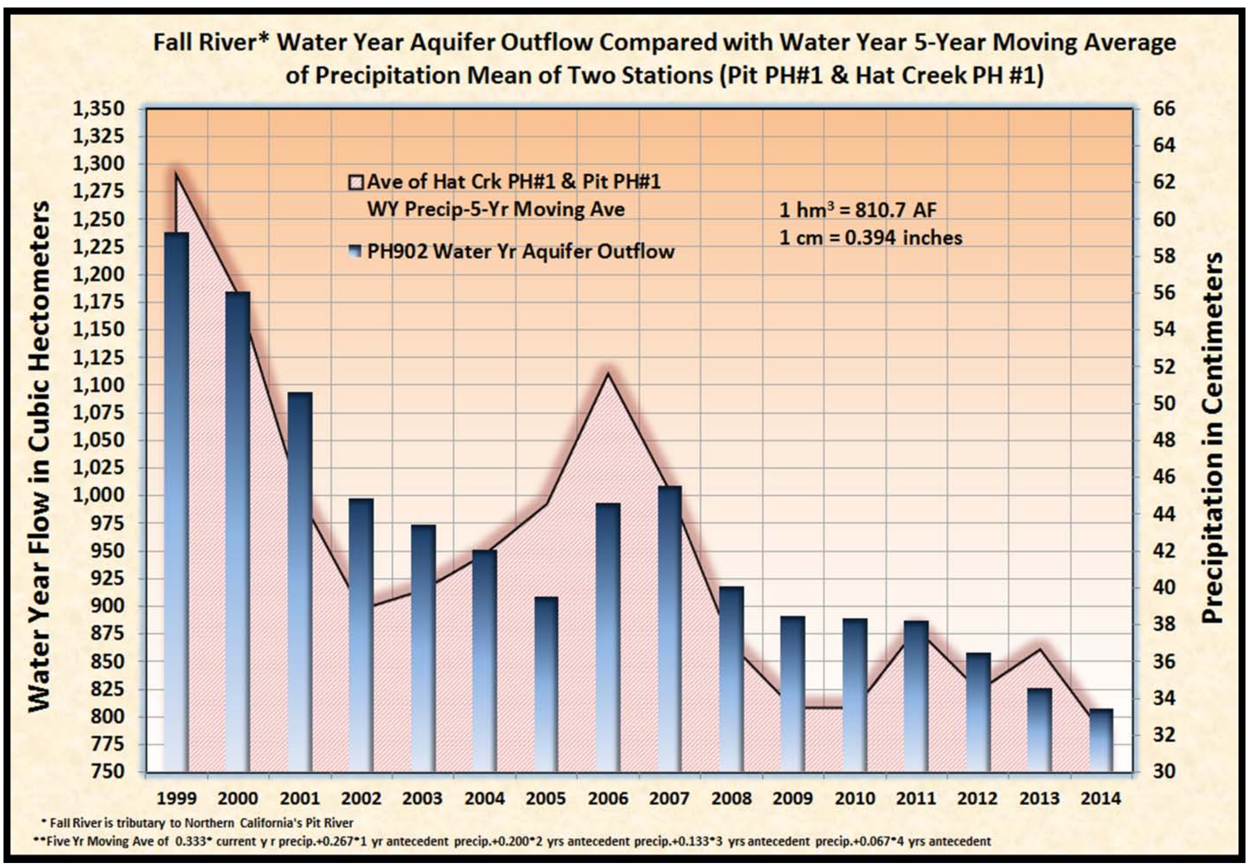

Figure 1. A water balance for 16 Years of hydrology on Shasta County's Fall River, which is tributary to the Pit River and Lake Shasta. A 2,960 hm^3 net loss in aquifer storage has occurred in the Fall River Aquifer system since 1999.

strongly influenced from a combination the Pacific Decadal Oscillation (PDO) and the Atlantic Multi-Decadal Oscillation (AMDO). The PDO and AMDO which changed phase to a drier regimen for northern California in about 1999 resulted in a relatively rapid decline of aquifer storage beginning about 1999. When an accounting as shown in Figure 1 is performed on climate stations in the area, Fall River as it enters the Pit River just below PG&E's Pit Powerhouse No. 1indicates about 3.1 years of precipitation was lost for the period 1999 through 2014 water years. For the Fall River Aquifer system, that equates to a net loss of approximately 2,960 hm^3 of water in the form of outflow from the large springs that has left the aquifer system and entered into the Pit River. This represented a buffered inflow to both Lake Shasta and the Sacramento River. For PG&E's Pit River hydroelectric system, this net drain of the aquifers provided buffered flow rates for continued daily hydroelectric peaking on the Pit River despite the ongoing period of reduced precipitation. In terms of aquifer replenishment, a number of years will be required to restore hydraulic head to these aquifers. For the 1908-1934 multi-decadal dry period, northern California's maximum aquifer outflow rates were finally restored in the early to mid-1970's some four decades later following the underground depletion and loss of hydraulic head. Conditions in California with regard to population, environmental, agricultural and other needs are very different today compared with some of the earlier California droughts (State of California, 2015). Fortunately for California, the aquifers were experiencing some of their all-time recorded high storages during the very dry 1976-77 two-year drought. When the remainder of the Pit River tributary drainage on flood basalts such as Hat Creek, Burney Creek, and some of the lower reaches of the Pit River including PG&E's import into the lower Pit River from the McCloud River through J.B. Black Powerhouse are considered, the total net loss beginning in 1999 of underground volcanic storage was over 4,935 hm^3 by the end of 2014, several times PG&E's usable surface water storage for its approximately 100 mountain lakes. For the porous volcanics supplying ground water into Lake Almanor, a combination of increased evapotranspiration in recent years associated with warmer temperatures along with less precipitation since 1999 likewise resulted in a net drainage of its aquifer storage (Freeman, 2010). While consistent with Yin's 2005 findings regarding a poleward shift of storm tracks, the southern Cascades and the Feather River tended to stay wetter than the central and southern Sierra, there was insufficient above-average precipitation overall to recover the groundwater situation. Since the outflow rate of the large springs lags the annual precipitation by several years, the outflow rate of these volcanics behaves very similar to that of a long period moving average. It is currently estimated that it may take 8-10 years and possibly more of wetter than normal conditions to sufficiently restore hydraulic head on these aquifers (Freeman, 2014). Multi-decadal swings aligned with longer term climate cycles such as the PDO and AMDO likely have a strong part in defining the outflow of the large springs in northern CA.

Snowpack

Statewide the 16-year drought period which started with the 1999 water year through the 2014 water year were as a period drier than average. Precipitation for the majority of the 16 years was wetter in northern California than for the southern Sierra. For PG&E, by 2014 the combined lack of snowpack in the central and southern Sierra along with loss of aquifer storage in northern California began to significantly impact hydroelectric production throughout the Sierra. Winter and spring storms that were arriving into California from the semitropical southern Pacific were increasingly in the form of atmospheric rivers. Minimum temperatures accompanying these storms were frequently 2.3-3.4 degrees C above average causing precipitation to occur mostly as rainfall into the middle and low elevation-snow zone. With increasing winter and spring temperatures, the snowpack in northern California has significantly declined in recent years (Freeman, 2011). Because the mountain reservoirs are typically relatively small for the drainages, precipitation in the form of rainfall runs off quickly and the inflows must be released to help assure that the reservoirs will be positioned correctly to catch the anticipated spring snowmelt which assumes that normal snowfall will occur during the period of remaining weather uncertainty. While it has generally been expected that with climate change, an increasing amount of precipitation would occur as rainfall, the warming situation during the past 3-4 years has occurred quicker than expected. When reservoirs are maintained higher than normal to help assure having sufficient water for summer instream flows and for meeting other downstream needs including hydroelectric production, unexpected precipitation in the form of rainfall can quickly fill reservoirs and exceed the powerhouses' ability to efficiently utilize the water for hydroelectric production. Also it's much more difficult to efficiently plan water releases when there is a shallow snowpack. It's much easier to forecast and plan for water releases when a large portion of the water is in storage in the form of a frozen snowpack that can be measured and planned for, rather than dealing with the shorter term uncertainty of storms that may or may not form out in the eastern Pacific. A seven to ten day quantitative precipitation forecast with a forecast of snow levels is about the maximum period that has sufficient skill to be useful in PG&E's water management planning. During that period water may have to be quickly drafted from reservoirs, sometimes exceeding the powerhouse capacity and often without benefit of capturing optimal energy pricing. For PG&E, where a combination of aquifer and snowpack storage has historically accounted for approximately 75 percent of its conventional hydroelectric production, with less precipitation now beginning to occur in the form of snowfall, the forecasting and planning effort takes a different turn toward uncertainty. With a fair amount of certainty it's reasonable to expect that the approximately 38 percent of its annual hydroelectric production that has historically come from the porous volcanic aquifers will likely remain below average for another 12-18 years. Currently the recharge opportunity from a combination of both snowpack and precipitation during the past 16 years has declined much more rapid than aquifer storage. It can be anticipated that the aquifer outflow rate, which significantly lags annual precipitation will continue to decline for several more years following a return to normal or above wetness. For the northern Sierra in areas where the snowpack is important for groundwater recharge, the eventual loss of snowpack will further aggravate the recharge opportunity situation. Currently multiple decades are needed to restore aquifer stores following long droughts such as occurred in the 1908-1934 period and again happening in the 1999 to present period. At this time it is unknown whether or not storms will once again start arriving with colder air creating a lower elevation snowline with sufficient snowfall to again replicate conditions experienced during the late 20th century. If so it would likely occur with declining frequency. Earlier studies by this author (Freeman, 2003, 2008, 2009, 2010, 2011, and 2012) indicated that climate change will increasingly result in less snowfall for the Sierra especially for the relatively lower elevation northern Sierra. Figure 2 shows the ratio of snow water equivalent (SWE) for the Meadow Lake snow course (elevation 2,195 meters) on the South Yuba River divided by the November 1 through March 31 Lake Spaulding precipitation using a two year moving average. This loss of snowpack and general increase in the potential evapotranspiration in the southwest was described in 2010 by R.

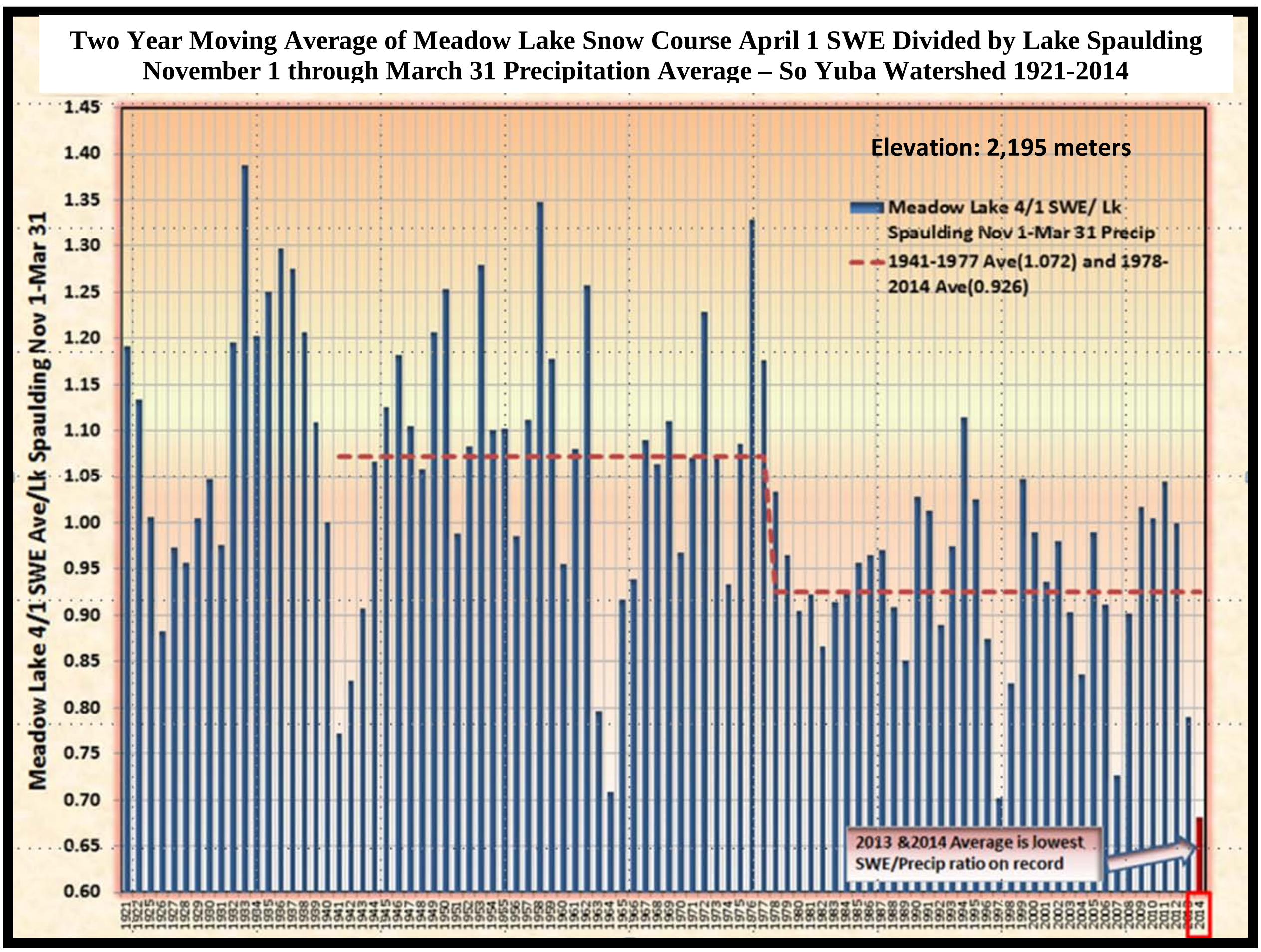

Figure 2. Meadow Lake April 1 SWE divided by the November 1 through March 31 Lake Spaulding precipitation – two year running average.

Seager and G. Vecchi from their modeled studies of strengthening and poleward spread of the winter Pacific storm track. They describe a stronger north Pacific storm track will increase the moisture transport, drying on its southern

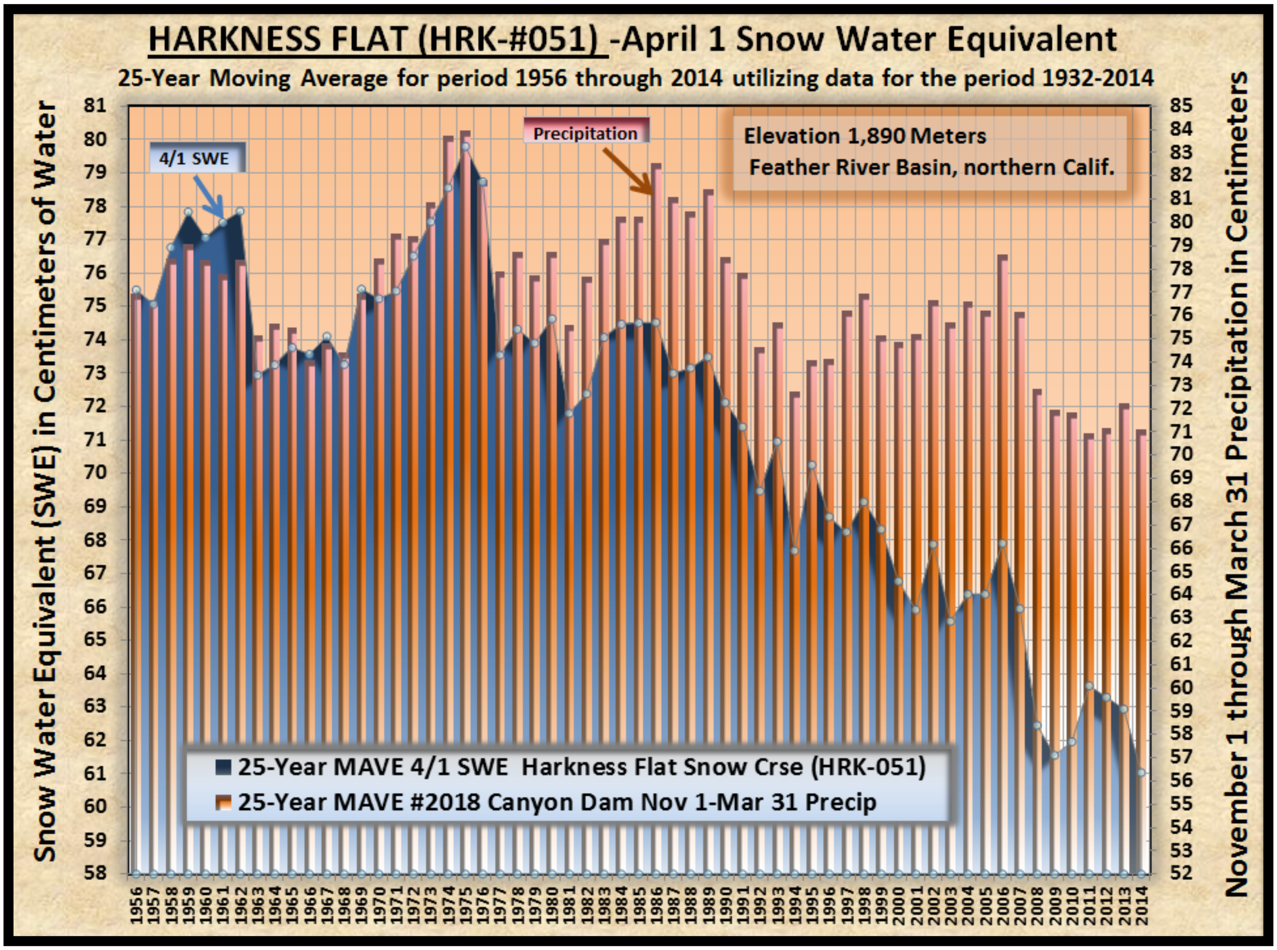

Figure 3. Shows the decline in snow water equivalent at Harkness Flat a representative snow course at the 1,890 meter elevation on the upper North Fork Feather River, which has mostly occurred since about the mid-1970s.

flank and moistening on its northern flank. The poleward shift will extend the region of drying poleward. They describe the southwest North American hydro-climate as being strongly influenced by natural decadal variability in both the Pacific and Atlantic Oceans. Their best estimates which they preface as quite uncertain, are that modes of both Pacific and Atlantic decadal are currently in phases that promote drought in the southwest and these oceanic conditions can be expected to last for years to come. Studies of hydro variability from actual data by Freeman, 2003 and 2012 show a distinct break in the statistical average takes place beginning about 1978. Many of the climate studies of the Sierra hydrology reveal a change that starts about the mid-1970's coinciding with the time of the severe 1976-1977 two year drought. For the Feather River in northern California, where approximately 25% of PG&E's conventional hydroelectric production has historically occurred, the basin overall is relatively low elevation when compared with watersheds of the American River southward. Lake Almanor for example, which produces about 1/3 of the annual runoff for the North Fork Feather River just upstream of Lake Oroville has about 4/5 of its watershed below the 1,890 meters elevation which is represented by Harkness Flat and is shown in figure 3. Figure 3 illustrates how the April 1 snow water equivalent appears to drop away from the November 1 through March 31 Precipitation. Since 1999, as the snowpack for the northern basin declines due to climate change and a reduction in precipitation, accurate forecasts of runoff, become increasingly challenging as the certainty historically associated with snowpack storage disappears. While both the snowpack and precipitation have declined in recent years, the April 1 SWE has declined much more rapid than the decline in November 1 through March 31 precipitation. It is much more difficult to efficiently forecast seasonal runoff as the level of uncertainty increases due to reduced reliance on the snowpack. Runoff forecasts that must account for the uncertainty of remaining seasonal precipitation in the form of rainfall rather than an 'in-place' frozen snowpack make the planning process much less certain and resource use efficiency likewise declines as additional uncertainty is added to the water planning process. The April 1 2014 snow survey for the Feather River revealed that several snow courses had no remaining snowpack. While the precipitation for the climate station located nearby at Canyon Dam for the November 1 through March 31 snow accumulation period had likewise declined since the mid 1970’s, the decline was insufficient to fully explain the full extent of snowpack decline. It’s likely that some of the decline can be attributed to snowmelt occurring during the month of March, but most of the decline must be attributed to storms simply having a higher snowline which began in the mid-1970’s. Both a 25-year average and the use of scalar comparison are utilized to help show the difference in declining rate of change.

Impact of Unusually Warm Temperatures and Rainfall on the 2015 Water Year Snowpack

Unusually warm temperatures and an above average number of atmospheric rivers delivered much of the 2015 water year’s precipitation into northern California as rainfall. The mid-December storms which had a few days of cooler temperatures allowed for a relatively shallow snowpack to develop in northern California. Figure 4 shows a chart of the snowpack for the Stouts Meadow snow course #25 (STM) at the 1,646 meter elevation. In late January warmer temperatures followed by rainfall in early February melted the accumulated snowpack causing McCloud Reservoir downstream to spill. While reservoir operators felt confident that they were reasonably well prepared to handle precipitation in the form of rainfall, unusually warm temperatures plus addition unanticipated rainfall initiated the spill. Without the snowpack storing water during winter storms, reservoir operators can anticipate an increased frequency of spill events. If the reservoirs are maintained too low and the remaining seasonal weather turns out to be dry, then reservoirs will not fill.

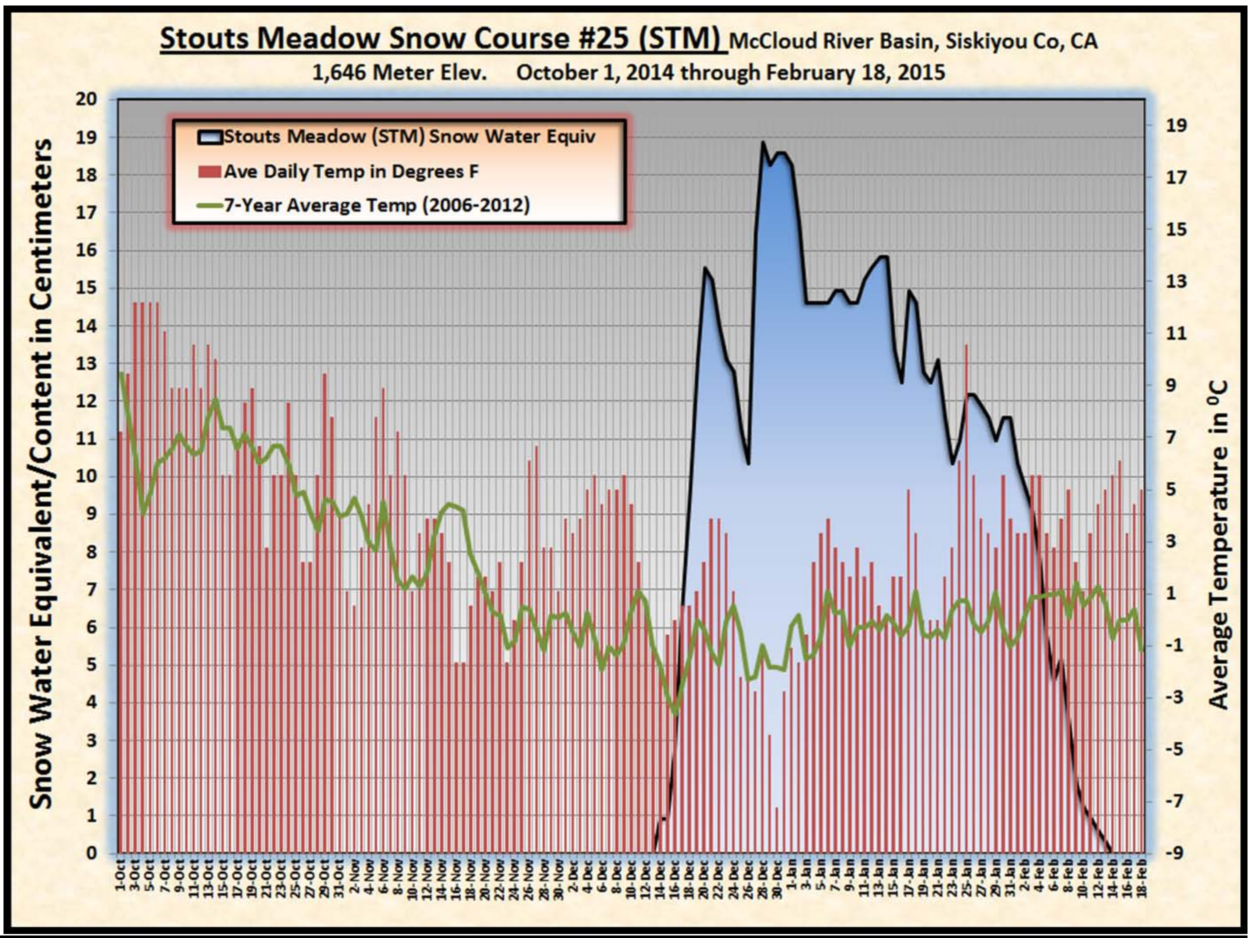

Figure 4. Stouts Meadow snow sensor SWE and average daily temperature for October 1, 2014 through February 28, 2015 to show early snowmelt from above average heating.

UNPRECEDENTED WARMTH IN THE SIERRA AND SOUTHERN CASCADES BEGINNING ABOUT 1999

Take any temperature data set from about 1976 forward in California and one will likely observe that the minimum average daily temperatures have trended warmer. This impact appears to have been greatest for the Sierra region. Figure 5 shows a chart of minimum temperatures 120 years of record for multiple climate stations in the Sierra Region that have been recorded beginning in 1895 (California Climate Tracker, 2015). The calendar year 2014 was significantly warmer than normal being approximately four standard deviations above prior years. This unusual warmth aggravated the drought situation and when taken together being both very dry and unusually warm set this drought apart from other California droughts during the period of record as being one of the most severe in the past 1200 years. This "Hot and very severe Drought" as described in Griffin and Anchukaitis' 2014 study carried over into January 2015 with both one of the driest and warmest Januarys on record for California. Figure 6 which shows a three-year moving January average for the Sierra Region illustrates this well. As a result there was some January snowmelt below the 2,135 meter elevation in northern California where ridges top out at about 2,135

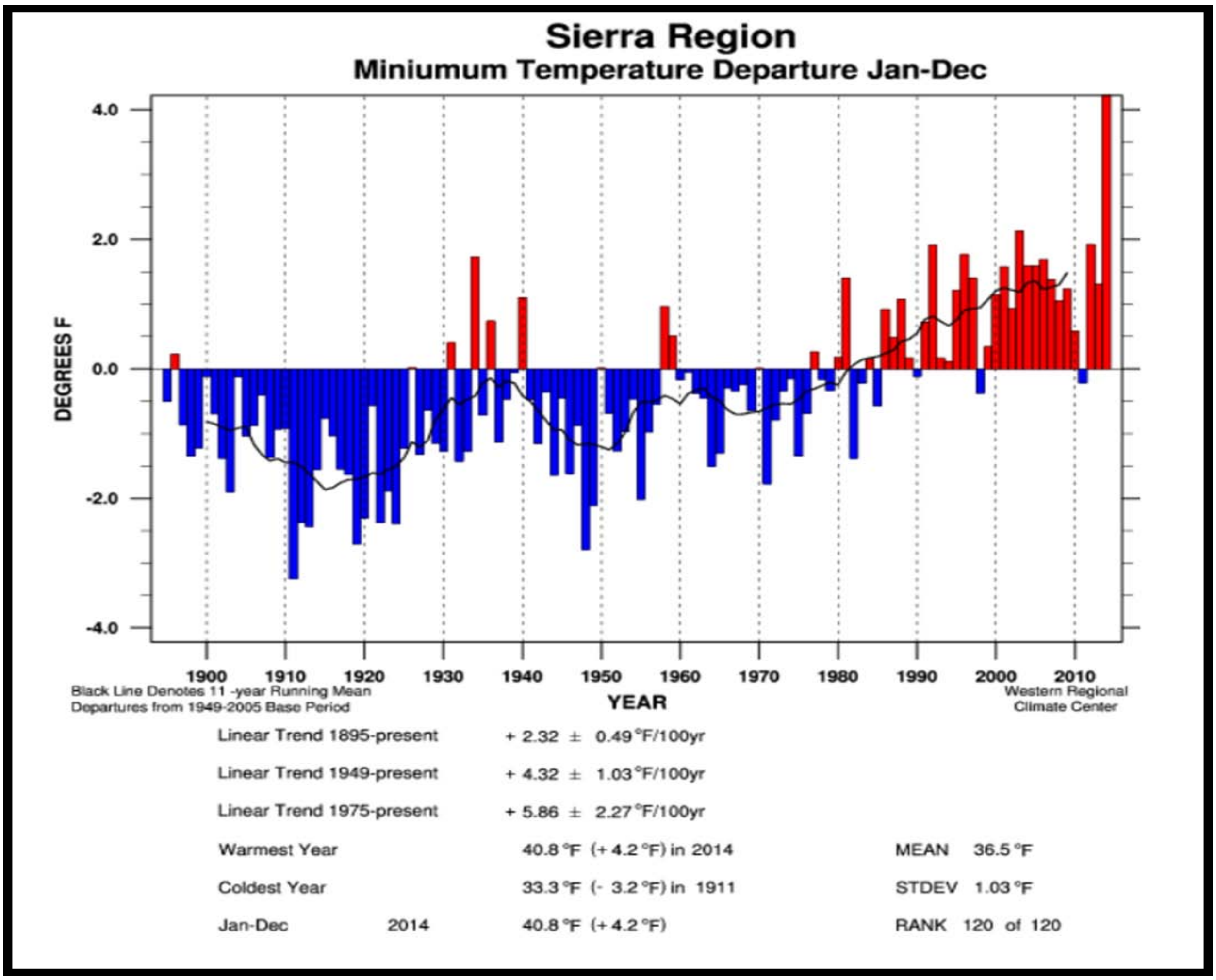

Figure 5. 120 years of record for average daily minimum temperatures for the Sierra Region.

meter versus almost 3,658 meter elevation in the southern Sierra. Beginning with the 2015 calendar Year, many of the northern CA storm fronts had warm atmospheric river signatures in the sense that they arose on the eastern pacific in the vicinity of the Hawaiian Islands and headed across the Pacific as relatively narrow elongated bands of moisture. A very strong resilient high pressure ridge dominated the weather during January 2015 shoving the storm track into far northern California and further northward into Oregon and Washington. This strong ridging of high pressure steered the storm track northward leaving the southern Sierra much drier than the northern Sierra. By

January 31, DWR's 8-Station northern California index was 93% for that date while the southern Sierra 5-Station Precipitation Index was only 48% for the same date. The high pressure ridging had created an unusually large difference in precipitation between the northern and southern Sierra. Consequently in terms of hydroelectric production planning water scheduling for the southern Sierra was performed as if the remaining weather would continue along a path of planning for 'no additional' seasonal precipitation. That would help preserve current storage in reservoirs such as PG&E's Courtright and Wishon Reservoirs (PG&E's Helms Pump Storage Project) which have high value for summer and fall peak power production. However, in spite of the northern Sierra and the southern Cascades being wetter than the southern Sierra, precipitation in the first four months of the 2015 water year

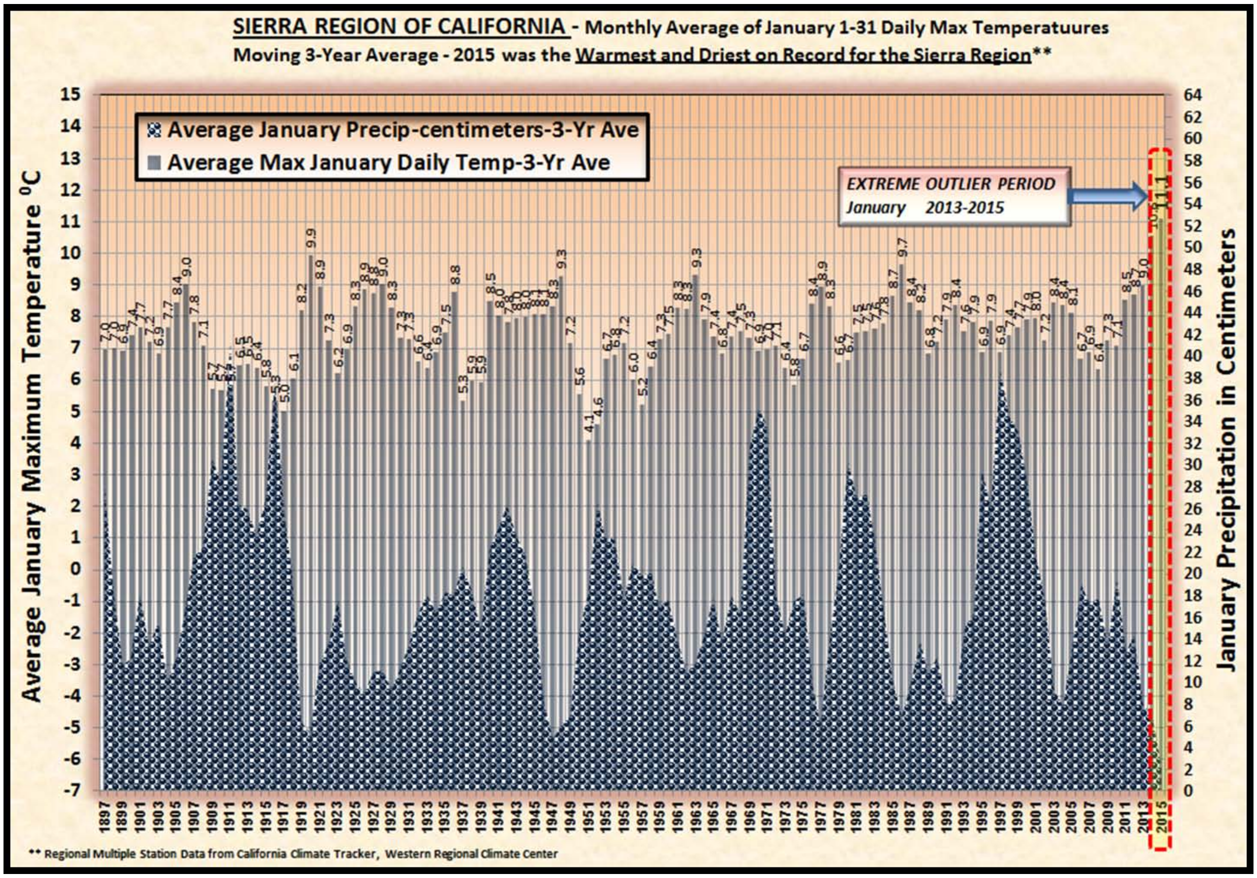

Figure 6. Average January maximum daily temperatures and precipitation for 2015 (moving 3-year average) compared with the period of record.

remained insufficient to influence aquifer outflows. The combined impacts of a much below average snowpack in the Sierra, low aquifer outflow, and much below average precipitation in the southern Sierra would all combine to limit hydroelectric production in 2015. Utilizing all available climate station data for the Sierra region of California, figure 7 illustrates how for those years which are 100% of average for the period of record (POR) or drier, the August 1 through October 31 average of minimum daily temperatures have increased in recent years. Because the current drought has lasted three years, both the precipitation and minimum temperature data are charted as 3-year averages.

Managing Mountain Reservoirs for a Below Average Snowpack

Reservoir planning for years when the late January and early February snowpack is below average becomes increasingly challenging for the water planners at PG&E to avoid spills. In order to help assure that reservoirs will fill by end of snowmelt in late May and early June, in recent years, planners at PG&E often deliberately held additional water in storage to help assure filling. Because the snowpack is measurable and can be planned for compared with a dependence of uncertain future seasonal weather, the risk for spill past the powerhouses from the reservoirs significantly increases as one holds the reservoirs higher. As the snowpack declines with coming climate warming, the whole challenge with regard to runoff forecasting becomes increasingly vulnerable to spills as uncertainty of the remaining water resource availability increases. Also as precipitation increasingly takes place in the form of rainfall rather than snowfall, the planning window and opportunity for capturing hydroelectric generation from precipitation decreases. In 2014 a general planning philosophy beginning in late January was to hold as much water as possible in storage and operate as if there would be little or no remaining precipitation (Freeman, 2014). One question that may enter the forecaster's mind is whether or not it is reasonable to assume that with a persistent high pressure ridge in place, one should assume that historical statistics of additional seasonal snow accumulation do not apply to the present situation, and that water management planning should include a bias toward holding reservoir storage in excess of what has historically occurred in late winter to help assure that reservoirs will have increased opportunity to fill for meeting summer and fall water needs. In general during very dry years, there is increased value to have full reservoirs during the summer and fall for hydroelectric power

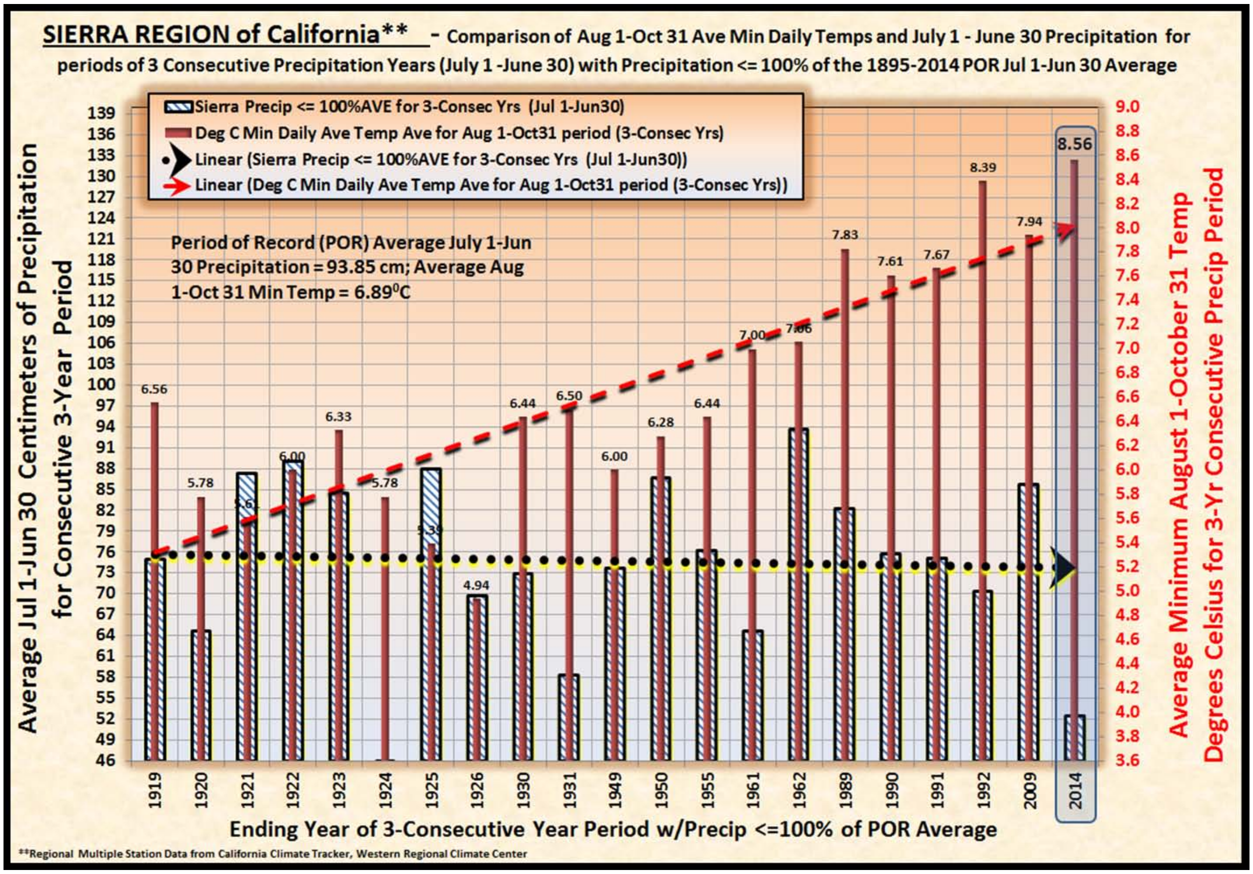

Figure 7. Consecutive 3-year dry year periods in the Sierra Region with July 1 through June 30 Precip <=100% of average for the period of record (includes the 2012-2014 recent 3-year period).

production, environmental, and recreational needs. Hydrological planning tends to be biased away from statistical analysis and the cost of equivalent energy replacement value, and instead leans increasingly toward meeting regulatory, water delivery, and other downstream commitment needs. During very dry years such as the 2014 water year, by the time a decision is made to hold onto water, there is often limited opportunity for capturing runoff from additional storms. As it turned out in 2014 the remaining 'normally wet' months had significantly below normal precipitation as the high pressure ridge remained in place, storms and opportunities for filling reservoirs remained scarce.

December 2014 Turned Wet with Local Flooding

A series of warm storms with relative high snow levels brought flooding to California in early to mid-December. The majority of these storm tracks had developed in the eastern Pacific as atmospheric rivers. Figure 8 from NOAA Earth Systems Research Laboratory, 2015 shows these modeled atmospheric river images. For the Sacramento-Delta and central Coast regions of California, December was the second wettest in the past 120 years of record, exceeded only by December 1955. Flooding was common in some of the local areas of these regions. Regardless of seasonal precipitation amount in the central Sierra since about the mid-1970's, less of it has fallen as snowfall. At the Meadow Lake snow course (#066) which is located at the 2,195 meter elevation in the south Yuba headwaters above Lake Spaulding, the proportion of precipitation which has fallen as snow has decreased (Figure 2). The 2013 and 2014 two year average had the lowest precipitation portion which has fallen as snowfall since records began at the snow course in 1921. Four other two consecutive year periods (1940-41, 1964-65, 1996-97, and 2006-2007 had low snow ratios, however only 2013-2014 appear to likely carryover into 2015 for a three year period of low snowpack relative to precipitation amount. Reservoirs such as Lake Fordyce and Lake Spaulding have historically been kept low in storage prior to snowmelt due to a relatively high frequency of spills. Then beginning in April after most of the concern with approaching storms has past, they are filled from the melting

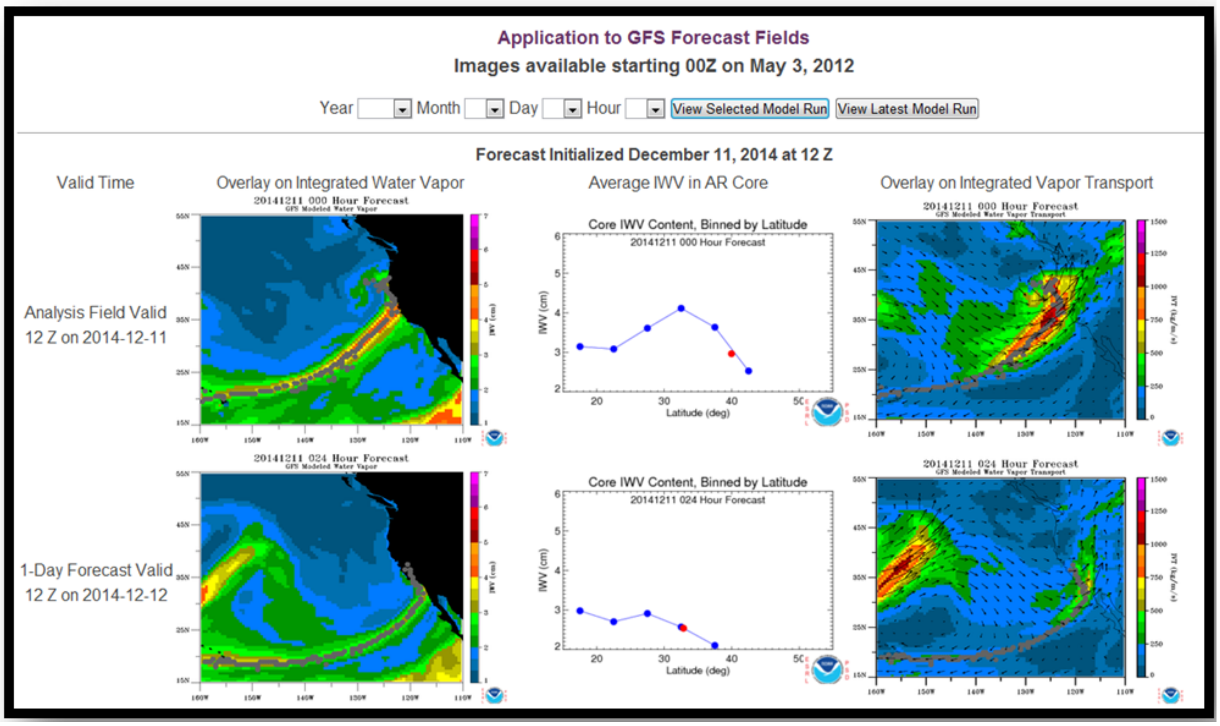

Figure 8. Atmospheric river forecast of December 11 and 12, 2014 showing a warm storm track

snowpack during the spring freshet. When the winter snowpack does not sufficiently develop in December and January such as occurred in the 2015 water year, reservoir operators typically conserve inflows and attempt to fill these reservoirs to the extent possible until such time that a snowpack has formed or if it doesn't, then continue to limit water releases until such time comes when the water is finally used to meet downstream needs with hydropower production. This risky practice of holding mountain reservoirs relatively high during the storm season can easily lead to large spills past downstream powerhouses.

DEPARTURE FROM TRADITIONAL SCHEDULING OPTIMIZATION DURING SEVERE DROUGHT PERIODS SUCH AS 2014 AND 2015

PG&E typically utilizes the following water planning methodology composed of the following basic steps: 1) produce a probabilistic ensemble seasonal runoff forecast of unimpaired runoff , 2) import the unimpaired runoff into an optimizing hydroelectric scheduling program with an objective function being to minimize energy replacement costs while satisfying all regulatory, recreational, environmental, storage, and other constraints, and 3) provide the guidance for water dispatch with the belief and understanding that it best meets the business objectives for efficient and affordable dispatch. The process is typically followed based on the belief and understanding that the 10-day weather forecast and statistical assumptions of randomness regarding remaining seasonal weather uncertainty are valid. However in recent years during severe drought situations, the typical scheduling procedures are less likely to be followed as increasing weight is given to conserving water, assuring that both political and regulatory concerns can be fully addressed. However, during severe drought periods, the consequences of running out of water are often sufficiently serious enough to interrupt the normal probabilistic "opportunity cost" type tradeoffs that would take place during more normal times. The consequences of not being able to meet instream flow rates for environmental reasons, downstream deliveries to water users in downstream communities and for other reasons take precedence over dollar based values used in normal type years. New rules from the Water Rights Control Board, new agreements on use, and political, social sensitivities begin to enter into decision making with increased focus on social, environmental, humanitarian, and other needs. The hydro scheduling can still be utilized to optimize the available water, but often the constraints will be imposed by the scheduler to partially bypass the objective function which is primarily based on equivalent energy cost replacement. During severe drought situations, financial considerations are often partially set aside while other needs, not necessarily dollar based assume higher value or take on a special high level constraint value. Often these deviations from historical optimization will be discussed and a consensus reached as to the hardness that should be assigned a particular constraint.

CONCLUSIONS

At the end of January 2015 with a strong possibility for a fourth consecutive dry year in store for California, PG&E's water management planners agreed in late January to start conserving reservoir storage in anticipation of a fourth consecutive dry year. The February 1, 2015 snow surveys revealed one of the shallowest February snow packs on record. Much warmer than normal temperatures made the past three years the driest consecutive three years on record for the Sierra Region. Aquifer outflow of California's northern California's porous volcanic aquifers had lost over 4,934 hm^3 from storage starting in 1999. Recharge of that deficit would likely require several years of above average precipitation including sufficient snowfall creating a snowpack which would enhance slow percolation from spring snowmelt. Continued warming and loss of the snowpack along with an anticipated increase in the atmospheric river type storms meant that PG&E planners would focus increasingly on avoiding spills. The southern Sierra would likely see less precipitation occurring as snowfall as the influence of high pressure off the California coast deflects storms northward away from California's southern Sierra.

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