The Impacts of Current and Past Climate on Pacific Gas & Electric's 2001 Hydroelectric Outlook

Gary J. Freeman

Introduction

California is currently experiencing the challenge of meeting energy shortages. Both the lack of normal precipitation this year to date and the low elevation freezing levels associated with this year's December and January storms have left PG&E's reservoirs at, and in some cases below their normal minimum winter operating levels. There is increased impact and risk of energy shortages in California during years when both the northwest's Columbia River Basin and California experience unusually dry conditions together. That is the case this year. The northwest is experiencing a much below normal year in terms of precipitation with very limited energy available to send into California. Available water from surface reservoirs for hydroelectric generation is currently limited for PG&E. The reservoirs will remain at winter minimum levels until either sufficient rainfall occurs or spring snowmelt runoff begins in April. During late December, January, and early February, approximately 65% of PG&E's January hydroelectric generation daily average of 22 GWh (all PG&E hydro sources), came from springs in the Pit/McCloud, Cow/Battle, and Lake Almanor watersheds. The remaining approximately 35% hydroelectric generation was mostly from surface storage draw down. Since about 46% of PG&E's normal year hydro generation comes from watersheds with significant aquifer outflow, the state of the aquifers as a reflection of past climatic variation is an important part of PG&E's hydroelectric energy picture. For the 2001 calendar year, aquifer outflow, mostly of springs, are anticipated to provide PG&E a relatively "firm" annual output this year in excess of 5,400 GWh, about 1,400 MW daily peaking capability, and nearly 3 million acre-feet (maf) of firm water regardless of current climatic dryness. The springs in northern California have increased in sustained outflow during the past several wetter than average years beginning with 1995. However they may now be about to begin a multi-year decline possibly the result of piezometric head dropping up slope of several large springs, which provide outflow to the river. The outflows from these aquifers reveal both short term cycling and long term trending. During very dry years, this contribution of past climatic wetness assumes an increased relative contribution to both sustained energy production and water availability for inflow to Lake Shasta, which drains into the Sacramento River.

California's Energy Problems

Following AB 1890, California's public utilities entered an era of preparing for deregulation (Brulte 1996). The unforeseen problems have been numerous and include transmission constraints, the unending rate freeze for utilities, a rapidly growing and changing load profile, large and uncertain expense related to siting difficulties and the environmental approval process, high energy prices, and a whole multitude of other influencing factors that have contributed to the current situation of energy shortages in California (Tison 2001).

Where and How Does Hydroelectric Generation Fit

Hydroelectric generation has historically provided about 20% of California's electric energy (Booth, 2001). A large portion of that hydro production normally is sent into California through the Intertie, which connects the northwest to California. Water Year 2001 is dry both in California and the Pacific Northwest. There has been little hydro energy available from the Pacific Northwest this year. While there appears to be a weak correlation between wetness and dryness in the Pacific Northwest and that in California, it is far from a given that both regions will be dry at the same time (Freeman 2000). However such is the case this year; both regions have experienced much drier than average conditions to date.

Value of Hydroelectric Generation in the Overall Power Mix

Hydroelectric powerhouses, even during reasonably dry conditions, are able to meet peak energy demands on very short notice. Hydroelectric generation is renewable. When compared with other sources of the generation mixes, PG&E' hydro generation is a relatively low cost source of energy production, with most of its powerhouses built several years ago. Depending upon water availability, a primary limitation becomes one of sustaining peak generation. In dry years in the absence of sufficient reservoir storage, water must be held back and used in a conservative manner that meets a reduced share of peaking needs.

Variability in PG&E's Hydroelectric Generation Availability

PG&E's hydroelectric system spans the Sierra Nevada and southern Cascades from Mt. Shasta and Goose Lake in northern California to the Kern River in the southern Sierra Nevada. There is a single powerhouse in the Coast Range, which uses water from the Eel River east of Willits. South of Lake Almanor on the North Fork Feather River, monthly hydroelectric generation from the Sierra Nevada's mostly granite watersheds is highly dependent on seasonal precipitation and the freezing levels of winter storms. PG&E has 99 storage reservoirs. Most PG&E reservoirs are relatively small in respect to their contributing drainage area. Therefore because a significantly large proportion of remaining seasonal weather uncertainty remains at the end of each calendar year, nearly all of the PG&E storage reservoirs in the Sierra Nevada are lowered to their winter minimum operating levels by about December 31 of each year. PG&E's one large reservoir, Lake Almanor (1,142,964 acre-feet capacity), which bridges the transition between Sierra granite and southern Cascade High Basin Volcanics makes up about 48% of PG&E's entire surface water storage. Lake Almanor is relatively large in terms of storage capacity in comparison to the lake's relatively small contributing headwater drainage area. While most of the PG&E reservoirs' water replenishment is from snowfall, rainfall frequently occurs at the lower elevations both to a limited drainage area immediately up slope of most reservoirs and to the side-water branches that contribute to the lower reaches of the rivers below many of the storage reservoirs. December through March rains are an important source for providing generation availability during months following early winter reservoir draw down.

Some reservoirs such as Bass Lake (east of Fresno), Bucks Lake, and Lake Almanor on the North Fork Feather River above Lake Oroville are deliberately held to relatively high levels at year-end to accommodate a variety of socioeconomic needs beyond that of hydroelectric energy production. Other limitations to energy production are routine scheduled facility outages for maintenance and a number of "forced" or unscheduled outages that occur throughout the year often from unanticipated mechanical failure or from other unforeseen needs. There are also instream releases that are made to accommodate the river environment for fish, amphibians, vegetation, sediment transport, and recreational use.

The Climate Situation in 2001

Following a wet October, California has experienced significantly below normal seasonal precipitation to date. The Pacific Northwest has likewise experienced very dry winter conditions. Storm fronts to date have been generally much cooler than normal with snow rather than rainfall occurring at relatively low elevations. PG&E's reservoirs were drawn down to their winter minimums almost a month earlier than normal in order to best accommodate California's energy shortages. Normally some reservoir inflow occurs from rainfall during December through February in the Sierra Nevada watershed. That did not occur this season.

California's climate for the Sierra Nevada and southern Cascades starting with 1987.

- 1987 through 1992 was significantly drier than average
- 1993 was wet; 1994 was dry
- 1995 through 1999 was wet
- 2000 was about average, wetter in the north and drier in the south
- 2001 is dry to date

The Ground Water Picture for the Southern Cascades

Five years of above average precipitation following six years of below normal precipitation quickly restored aquifer outflow from volcanic watersheds (mostly from springs) to their maximum observed rate of flow. To successfully track, study, and forecast the baseflow component from these watersheds, four times the August through October combined unimpaired runoff value was used to represent the stable annual baseflow component for PG&E's southern Cascade watersheds. Snow melts almost 2 to 4 weeks earlier in the Pit River than further south in the higher Sierra watersheds. With deep, porous volcanic soils, this early snowmelt leaves the August through October period mostly as an unbiased indicator of total calendar year baseflow, basically unaffected from earlier storm or snowmelt increases in flow. A few of the months within that three-month period required normalization due to thunderstorms and other intense rainfall events that caused interflow, and possibly some overland flows, to reach the river.

Using the above approach for defining baseflow, PG&E made the following assumptions regarding aquifer outflow from the many springs and from ground water, which provide the relatively stable baseflow component for flow in the McCloud and Pit rivers.

- About 38% of PG&E's Long-Term Annual Hydro Generation is provided from aquifer outflow of the volcanic basalts (Figure 1), mainly through some of the largest springs in the United States (Alt and Hyndman 2000; Planert and Williams 1999). During dry years, the relative percentage may increase to 50% or greater of PG&E's total annual hydro generation output.

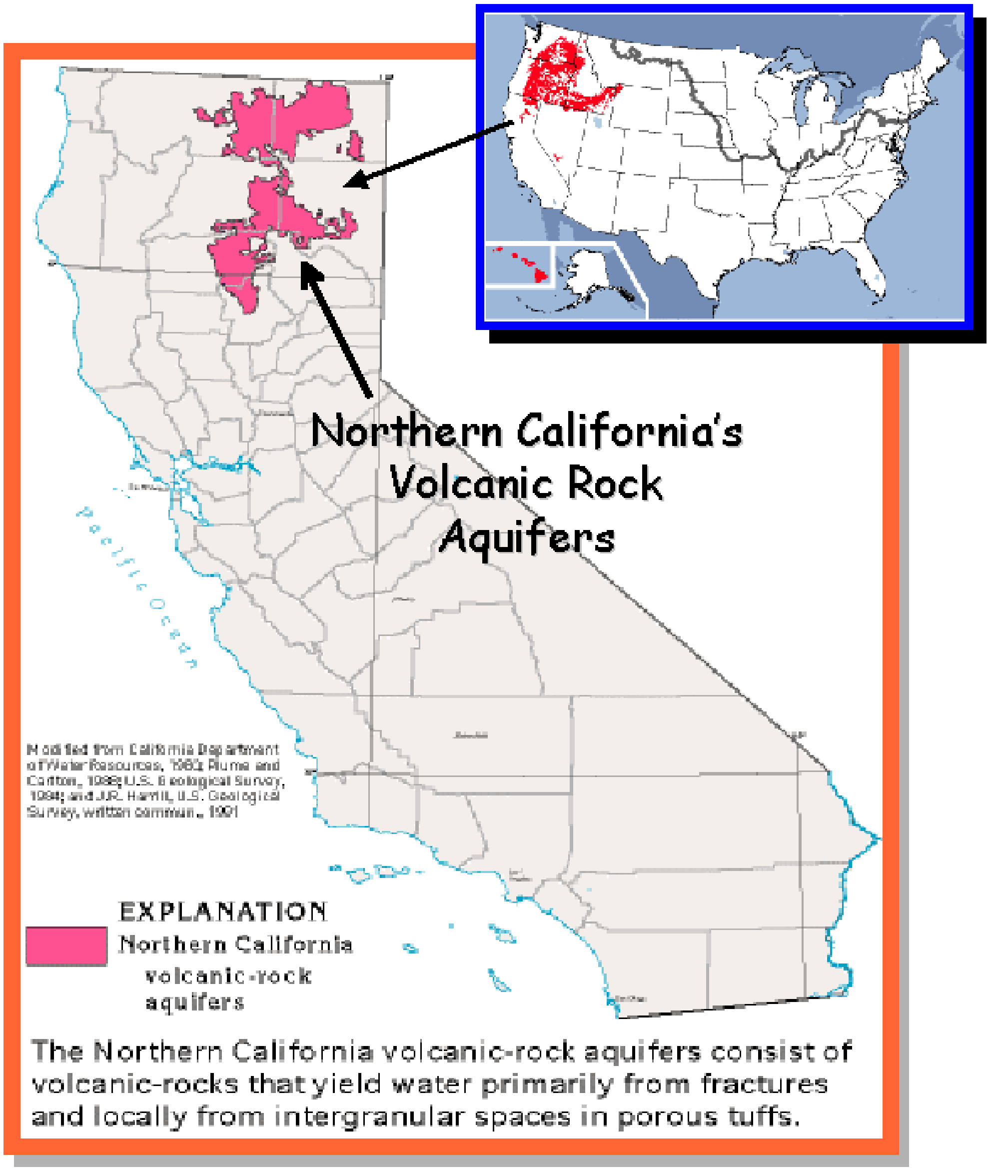

Figure 1 Northern California's volcanic rock. Source: California Department of Water Resoures and U.S. Geological Survey.

- When the annual baseflow is analyzed as a time series that is smoothed with a 3-year centered-moving average, there appears to be both a short term 14-16 year cycling and a much longer long term drain-and-fill trend observed for 1907 through 1958, lasting 52 years. Short successive dry year periods tend to quickly rebound if followed by a series of wet years. However, the prolonged period of below average precipitation such as occurred during the dry years of 1907 through the early 1930s required about 28 years for the springs to fully recover back to the earlier high outflow rates experienced during the 5-7 year period immediately following 1900 (Figure 2).

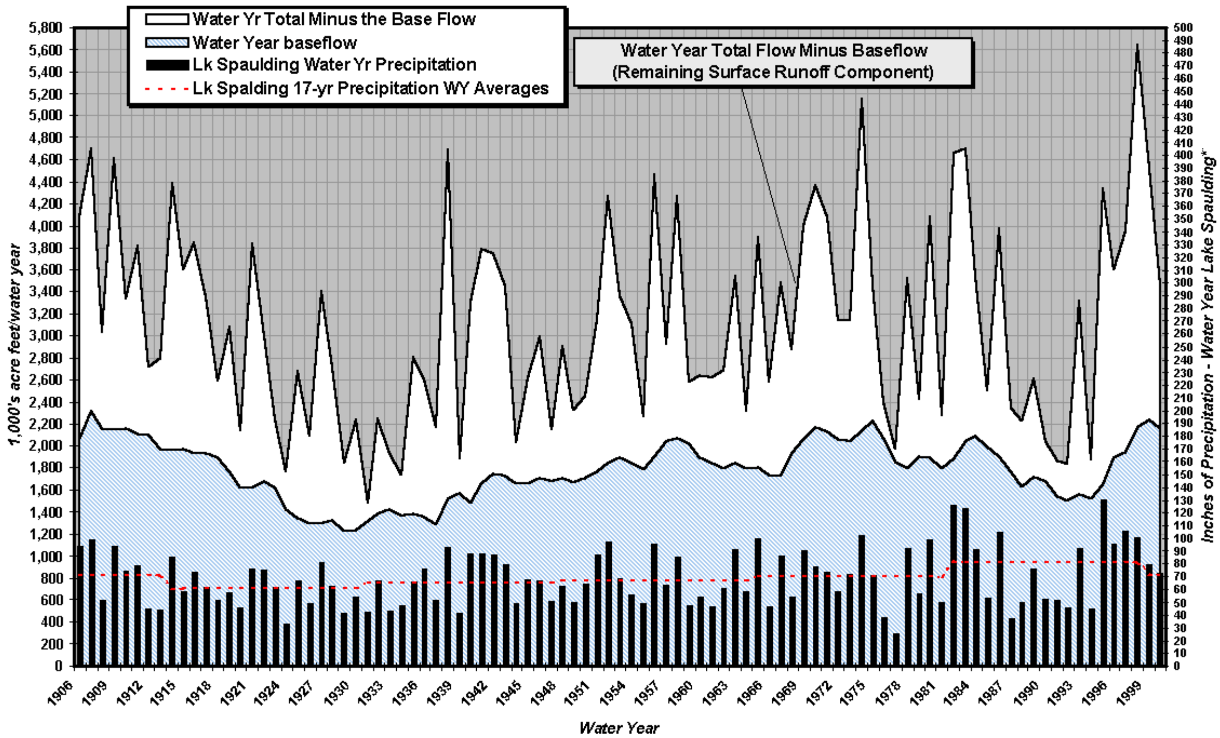

Figure 2 The Pit River annual unimpaired inflow to Lake Shasta for 1906 through 2000. Each year's total runoff is divided into both its annual baseflow component (bottom portion) topped by the more variable partial contribution of each year's seasonal precipitation, which is in excess of infiltration and evapotranspiration.

- This short term cycling and the longer-term net discharge and net recharge trends exert a significant effect on both water availability for Lake Shasta and for PG&E's Pit River hydroelectric generation output. During a normal year, based on the historic past 29 years, the Pit River makes up about 33% of PG&E's total hydro generation mix with about 28% of that generation calculated to come from the McCloud and Pit River aquifer outflow, most of which consists of precipitation of past years. The fall flows in the Pit and McCloud rivers are a resonating blended echo of the area's past climate in terms of precipitation. Some of the water may have traveled underground for many years before surfacing either at springs that feed into the Pit and McCloud Rivers or appearing within the bed of the channel. For example, one may visually observe water emerging in Burney Creek channel about 1/3 mile upstream of Burney Falls, a tributary to the Pit River. Starting with a dry river bed, within that 1/3 mile reach, there is approximately 150 cubic feet per second (cfs) flowing directly below the falls. A similar phenomenon exists on various tributaries to the Deschutes River in Oregon (Bastasch 1998). Without continuous sustained net balanced recharge to the aquifers from normal variance about a wet-period mean, the aquifer outflow rate after a couple years goes into a relatively rapid decline, which, if lasting long enough, has been observed to take almost three decades to restore springs to their original maximum flow rate. This creates droughts in water availability to the Pit and McCloud rivers, which drain into Lake Shasta, which in turn tends to create a sort of mini-drought sometimes out of synchronization with current climate conditions. This was most recently observed in 1993, when base flow remained below normal in spite of the very wet year overall.

Short-Term Cycling

As illustrated in Figure 3, an approximate 14-16 year cycle appears in most time series plots of the unimpaired volcanic baseflow component. The long-term record tends to average about a 15-year mean, therefore in this paper the 14-16 year periodicity and 15-year periodicity are used interchangeably. With the lag in pressure transmissivity between wet and dry years, it is almost as if the baseflow itself produces a natural moving average smoother, possibly dampening and smoothing the annual year-to-year precipitation variance. The observed lag in resulting outflow from the aquifers is relatively stable from month to month, which supports using aquifer outflow cycles as input for predicting over one-third of PG&E's hydro generation several years in advance. There is an observed approximate 16% range in annual generation movement within the short 14-16 year oscillatory periods for the 1972-2001 thirty-year mean annual Pit and McCloud River baseflow.

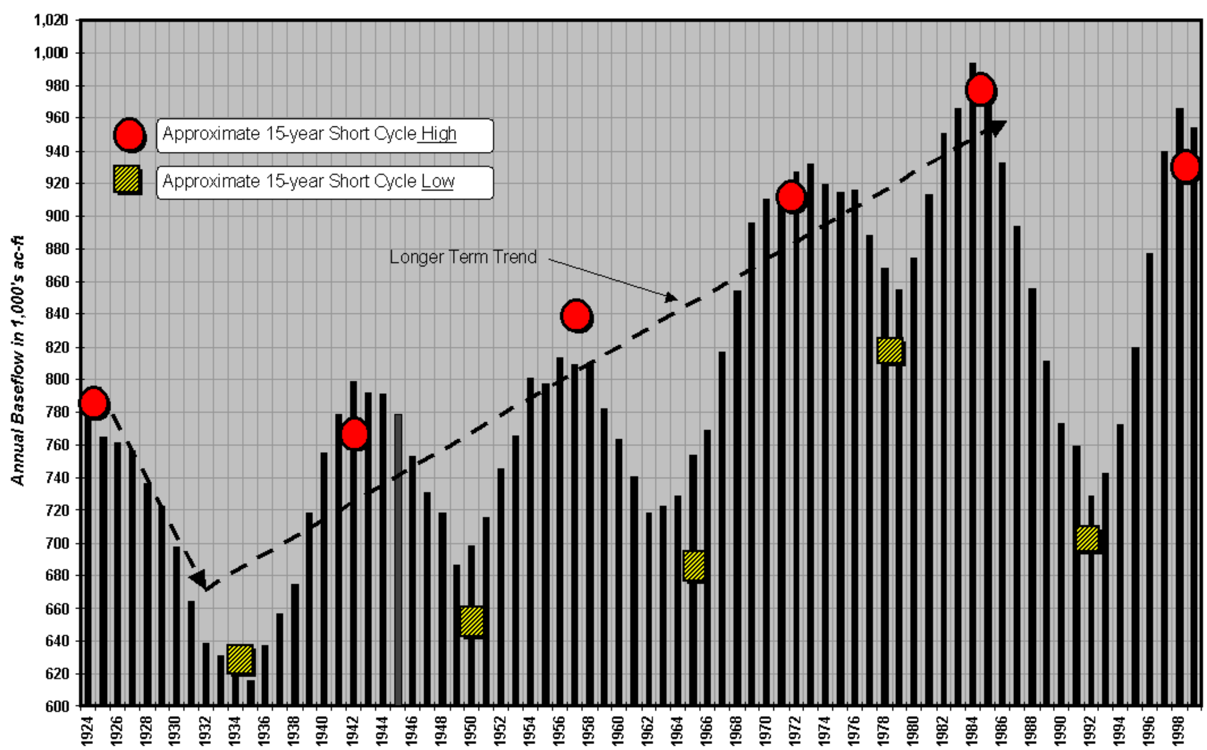

Figure 3 Fall River's annual unimpaired baseflow in thousand acre-feet for the 80-year period, 1922 through 2001. A centered 5-year moving average smoother was applied. Seventy-five years of smoothed data are shown. Fall River's return to maximum baseflow rates required about 50 years (1935 through 1984). This is 22 years longer than the Pit River as a whole, which required only 28 years for return to near maximum baseflow rates. Fall River is a major baseflow contributing tributary to the Pit River.

This year, while currently experiencing a dry seasonal outlook in terms of precipitation, the current energy short situation is continuing to benefit from the increased flow and generation benefits that come from being within three years of the 1998 peak outflow rate of the short term cycle. After starting a gradual decline in 1999, aquifer outflow rates from the northern California aquifers are anticipated to continue decreasing during the next 3-4 years, before baseflows begin a return toward increased rates of flow. The short-term flow cycles have been tracked back to about 1907 when flow data first began being collected on a regular basis. The cause for 14-16 year baseflow cycling likely lies in a similar cycling length, which appears to occur in the long-term precipitation record. An observed 14-16 year periodicity in precipitation appears in the 75-year long-term record for PG&E's 16-station precipitation index as well as for the Lake Spaulding climate station located in the central Sierra Nevada along Highway 80. Lake Spaulding's record extends back to 1894, providing a good mountain station for observing short term cycling over time. While an autocorrelation done on the Lake Spaulding water year precipitation extending back to 1894 does not provide significant forecast correlation in terms of a year's precipitation amount, the approximate 15-year periodicity appears quite strong in terms of a persistent climatic echo over time (Figure 4). No attempt is made here to address causative factors for precipitation cycles, such as possibly resulting from decadal type oscillation. Cycling in the annual precipitation record and the Pacific Decadal Oscillation is being researched and explored in terms of cause by a number of different scientists (Cayan 1998; Diaz 1995; Taylor 1995, 1999).

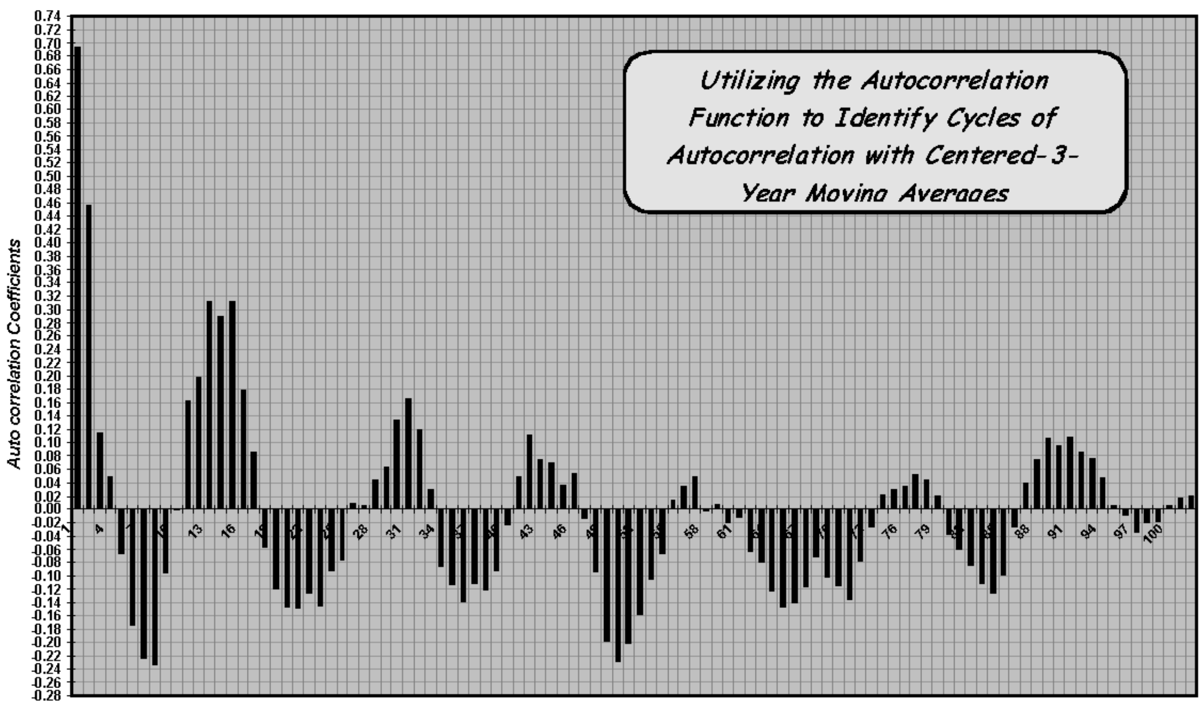

Figure 4 An autocorrelation performed on the centered 3-year moving average water year precipitation record fo the Lake Spaulding climate station in the Central Sierra along Hwy 80. While the specific ACF does not produce a significant predictor in terms of precipitation amount, the approximate 15-year cycle readily reveals itself. The cycling correlates closely with northern California's aquifer 1-2 year outflow lagged response.

Aquifer Outflow and the Current Energy Crisis

With reservoirs other than Lake Almanor being at their winter minimum carryover storage and almost no rain-generated inflows, about 65% of PG&E's January and February 2001 hydro electric generation was produced from groundwater or aquifer outflow. About 3 maf of runoff into Lake Shasta will come from aquifer outflow/springs this year. This aquifer outflow water through PG&E's Pit River powerhouses is anticipated to produce almost 3,600 GWh or almost 33% of our total forecasted PG&E hydrogeneration this year with about 1,400 MW daily peaking ability, enough energy to meet the needs of more than 1 million family homes. While its contribution begins to decline over several months, a dry year next year, regardless of its severity, will still provide about 85% of the 2001 hydrogeneration from baseflow or about 3,000-3,100 GWh from the Pit-McCloud aquifer outflow. Three additional very dry years beyond 2002 would push the firm dependable annual contribution down to about 2,100 GWh; an amount similar to both the estimated 1924 and 1992 calculated actual baseflow contribution. Based on a review of the 1907-1930 period, it appears that beyond six dry years, longer-term effects to the ground water may begin.

Effects of Climate Change on Aquifer Outflow

While it may seem speculative to make assumptions with regard to defining climate cycles of wetness or dryness from baseflow response, the Pit and McCloud River aquifers appear to react to periods of wetness and dryness with a slightly delayed response, somewhat similar in manner to a moving average type statistic. The effects of precipitation variance on runoff during any given season is buffered in a decayed manner by the effects of wetness from previous years.

Extended Periods of "Net Groundwater Discharge" and "Net Groundwater Recharge"

The extended dry "net discharge period" observed to start in 1907 was followed by an extended "net recharge period" before baseflow rates returned to their earlier maximum outflow rates. Because the 1907 through 1958 (52 years) period took up such a large portion of the available historical record, it seems almost impossible to speculate beyond the short-term cycle, which is currently in a decline mode, to speculate whether or not we are now entering another longer-term downward trend which may once again require a long refill period. The 28-year net recharge period, 1931 through 1958, followed 24 years of declining baseflow or net discharge during the 1907 through 1930 period (Figure 5; Figure 6). When compared with long-term precipitation records for climate station located at Canyon Dam, there is a corresponding mean difference for the two periods of 5.21 inches with period mean of 33.55 inches for the net discharge period and 38.76 inches for the net recharge period.

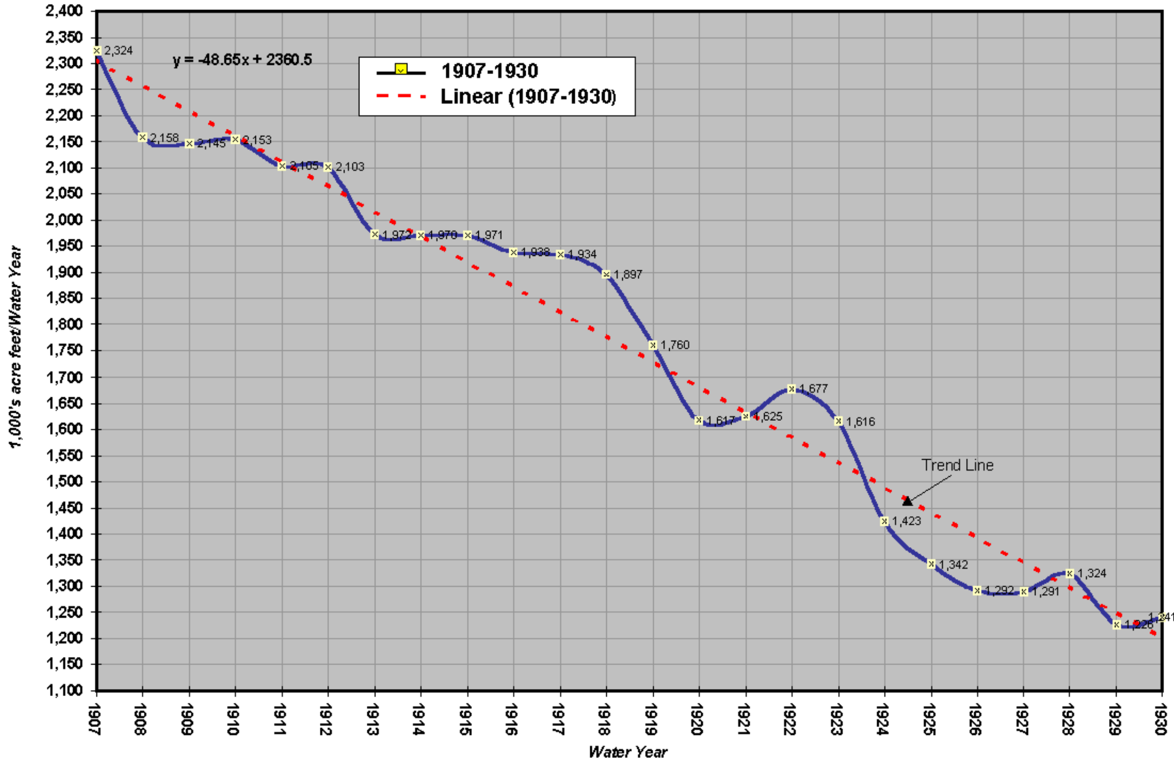

Figure 5 The 24-year (1907–1930) "decline" from maximum observed aquifer outflow rate for the Pit River unimpaired water year baseflow component of inflow to Lake Shasta

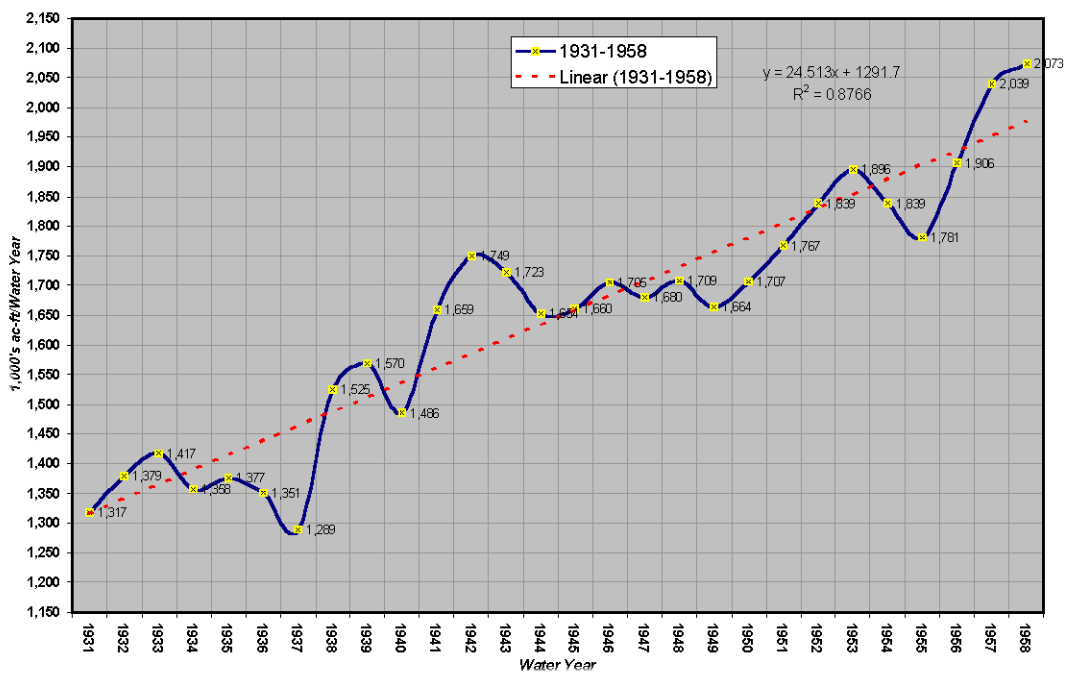

Figure 6 The 28-year (1931–1958) "climb" back to near-maximum aquifer outflow rate for the Pit River unimpaired water year baseflow component of inflow to Lake Shasta. This return to higher outflow rates follows the 24-year (1907–1930) decline from the prolonged dry period as shown in Figure 5.

52 Years of Reduced Baseflows

The aquifer outflow rate for the Pit River's unimpaired runoff to Lake Shasta was at the observed maximum annual flow rate of approximately 2.35 maf from 1901 through 1906. However, the 24-year period from 1907 through 1930 was characterized by mostly below normal precipitation. As a result of declining aquifer outflow, the annual accumulated 24-year departure from that of the 1906-1907 baseflow rates totaled a negative 11 maf in outflow by 1931. During the 1931 through 1958 recharge period (28 years) approximately another 16 maf was absent from the Pit River inflow to Shasta. In 1958 aquifer outflow rates were restored to about 93% the earlier 1906-1907 high rate of 2,225,000 maf per year. This 52-year period of below maximum aquifer outflow rates between 1907 and 1958 created an extended negative departure from the earlier full aquifer outflow rates for the Pit River. Since the Pit River is tributary to the Sacramento River, the effect was slightly over a half century of less than full baseflow availability (approximately negative 27 maf when compared with the maximum observed baseflow such as during the period just prior to 1907 and similar to that recently reached in 1998) from the northern volcanic drainage available for inflow to Lake Shasta for that period. Using the current hydroelectric capacity, hydroelectric generation production for the Pit River hydroelectric project was simulated back to the first of the century. Two equal length 44-year periods consisting of 1914-1957 and 1958-2001 were compared for the Pit River. The simulated difference was a 26,000 GWh reduction in energy for the earlier period compared with the mean baseflow rates experienced during the second half of the 20th century (Figure 7). A drop in average flow rate of 510 cfs occurred over a 23-year period, 1908 through 1930 . In terms of annual flow quantity, this equated to a drop from approximately 2,225,000 maf per year in 1908 to 1,240,000 maf per year in 1930.

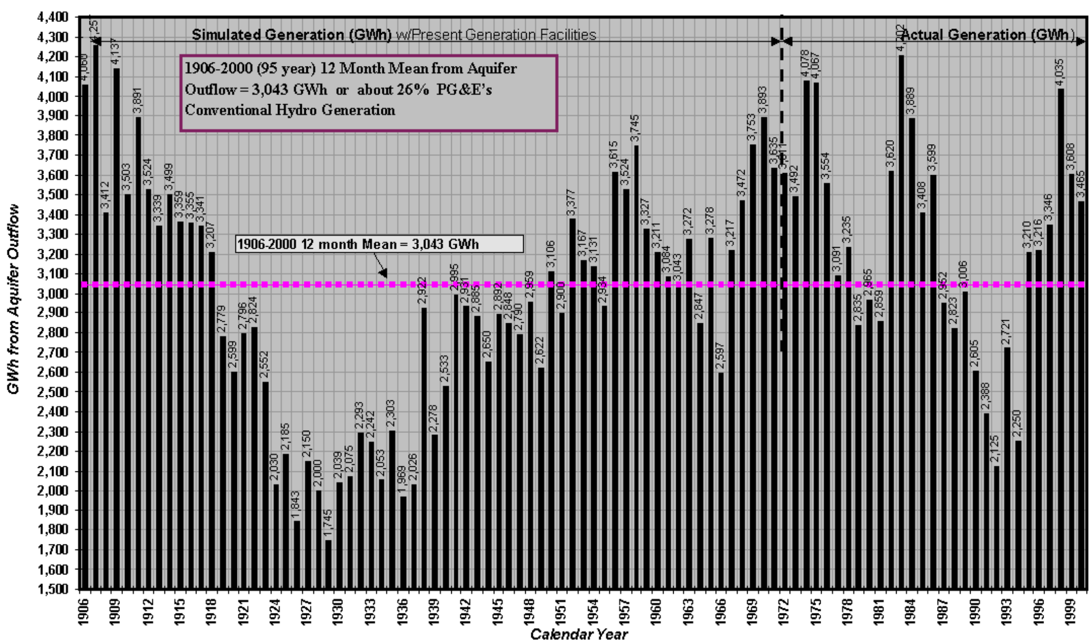

Figure 7 PG&E's Pit River annual calendar year hydroelectric generation from northern California's Pit and McCloud River aquifer outflow (springs). The 1906–1971 period was simulated based on historic baseflows passed through the current hydroelectric system. Water is imported from the McCloud River to the Pit River through the McCloud-Iron Canyon Tunnel.

From 1907 through 1930, precipitation was below average (Figure 8). While the drier period may hint at a possible low point in an approximately 95-100 year cycle, the data analyzed in this study is insufficient to draw any conclusions regarding the existence of a long-term cycle.

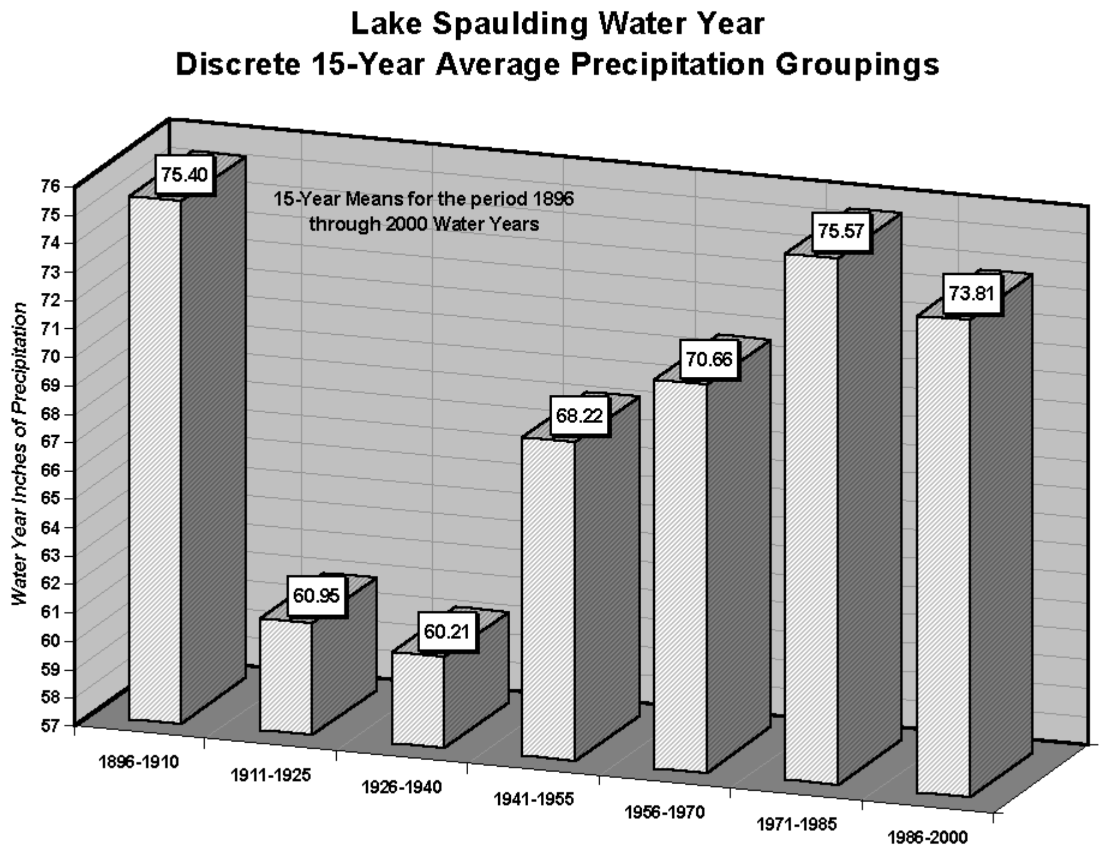

Figure 8 Water year precipitation shown as 15-year means. The mean precipitation (60.58 inches) for the 30-year period 1911 through 1940 vs. the mean precipitation (74.69 inches) of the 30-year period 1971 through 2000 readily illustrates the wetness of the latter period.

Recent Years

More recently, based on the recent six-year (1987-1992) consecutively dry period, the six-year average seasonal drop in accumulated precipitation for the Pit 5 PH climate station was 50.93 inches or 37.30 inches less than the prior 7-year (1981-1986) average of 88.23 inches. For the McCloud River at Shasta, the cumulative six-year annual decline in baseflow quantity from the preceding period was 1,596 thousand acre-feet (taf) for the six-year cumulative precipitation decline of 217.33 inches. The decline during the 1987-1992 net discharge period equates to 1,596 taf/217.33 inches or –7,340 af loss in baseflow for each inch decrease in precipitation at Pit 5 PH.

The following six years (1993-1998) was an unusually wet period. The net recharge was calculated to have an approximate 86% recovery factor or an accumulated 1,646,290 af increase above the earlier six-year total. The net recharge period equates to 6,310 af increase in baseflow for each inch net increase in precipitation.

The Long Term Hydrological Balance

A mass balance approach was used to analyze the hydrology for the Pit River. The long-term historic runoff record was used with the long-term precipitation average for Pit 5 PH. The calculations assume that the long term average recovery factor for ratio of runoff to precipitation for the Pit River Basin is the same as calculated for the McCloud Basin. The annual long-term average runoff for the Pit River Basin was calculated to be 3,107,000 af unimpaired runoff. To calculate a water balance, the 1906-2001 96-year Lake Spaulding mean annual precipitation record of 73.50 inches per water year average was used to extend the Pit 5 PH record back in time.

The long-term average water balance was calculated by first separating the aquifer outflow or baseflow component from the total river unimpaired outflow to Lake Shasta. It was then assumed that the remaining portion of the total annual runoff was from the non-baseflow component. For the Pit River unimpaired inflow to Lake Shasta, the average quantity of water per inch precipitation at Pit 5 PH was calculated to be 67,200 af.

The following average long-term mass balance was compiled:

- 26.58 inches of precipitation or 36.3% of the annual precipitation is computed from the recharge/discharge balance as aquifer outflow or baseflow. This annual component equates to 1,785 taf.
- 19.72 inches of precipitation or 26.9% of the annual precipitation is computed as unimpaired runoff from the current year's precipitation and is runoff other than baseflow. This annual component equates to 1,325 taf.
- 26.95 inches of precipitation or 36.8% of the annual precipitation is computed as evapotranspiration and is not available for river flow. This annual component equates to about 1,811 taf.

For example, one can assume that for a very dry year like 1977, with 34.92 inches of precipitation for the water year at Pit 5 PH, the normal full long-term average annual evapotranspiration component of Pit 5 PH of 1,811 taf (26.95-inch equivalent) is exceeded by 7.97 inches. The 1977 water year non-baseflow runoff was compiled as 1.88 inches or 126 taf . Since the observed baseflow component of the Pit River for the 1977 water year was 1,848 taf, then the remaining 6.09-inch balance of precipitation, equivalent to 409 taf of recharge for the twelve-month period was approximately 1,439 taf short; in other words, 1977 experienced a net discharge from the aquifer reserves of approximately 1,439 taf or the Pit 5 PH precipitation equivalent of 21.4 inches.

Possibilities for Precipitation Enhancement

PG&E is exploring ways to use and manage this aquifer storage for increasing hydroelectric generation. The Pit/McCloud River aquifers may provide a unique opportunity to enhance precipitation during wet years, store the added water underground with little if any evapotranspiration, and enjoy the availability of additional baseflow during dry years. Since PG&E's Pit River hydroelectric project has relatively large forebays, any increases to baseflow would provide additional water for hydroelectric production, most of which can be used for additional hours of peaking. Additional baseflow provides increased inflow to the rivers; after its use to increase hydroelectric production, the water flows into Lake Shasta and the Sacramento River providing increased freshwater supply available for Delta outflow.

Since, even in the driest years, naturally produced precipitation appears sufficient to meet nearly all evapotranspiration demand, most of the remainder is available for aquifer recharge and overland flow. If one assumes that most of the enhanced precipitation over the headwater drainage would become 100% available for infiltration and aquifer recharge, then it can be assumed that one inch at Pit 5 PH will have the effect of adding approximately 67,200 af/inch to baseflow in the Pit River Basin and approximately 17,400 af/inch to baseflow for the McCloud River inflow to McCloud Reservoir for a combined total aquifer recharge potential of 84,560 af/inch of additional precipitation. For reasonableness, it seems likely that unforeseen losses will occur and that a factor of 90% (0.90 times the 84,560 af) would be a more reasonable calculation. If a reasonable increase in precipitation is 5%, then 0.05 times 73.25 inches per year equates to 3.66 inches per year.

- McCloud River water:

  [(17,400 af/yr/in)(3.66 in)(1,343 KWh/af)]0.90 ÷ 1,000,000 KWh/GWh = 77 GWh/yr

- Pit River water:

  [(67,180 af/yr/in)(3.66 in)(1,600 KWh/af)]0.90 ÷ 1,000,000 KWh/GWh = 354 GWh/yr

Total potential generation for a 5% increase in precipitation over the Pit and McCloud river basins is equivalent to an increases of 431 GWh/year peaking energy. This would provide approximately 575 additional hours (24 days) per year of new energy at 750 MW by extending peaking time on existing powerhouses. Shasta Dam with its large reservoir and powerhouse would also likely benefit from a 5% annual increase in inflow (300 taf) and consequent increased hydro generation amounting to an additional 85 Gwh/year. There are five 125 MW units at Shasta Dam (three of the five units have been recently upgraded to 142 MW, but at the time of this writing, the upgraded capacity has not yet been released for service at the higher capacity rating) (USBR 2001). The five 125 MW units could generate approximately 135 additional hours at a full combined capacity of 625 MW.

PG&E Annual Hydroelectric Generation Oscillation

PG&E's annual total calendar year hydro generation appears to oscillate in synchronization with the groundwater in a somewhat predictable pattern (Figure 9). With the single exception of Lake Almanor, the remaining storage reservoirs are relatively small. Typically the smaller reservoirs empty and fill each year. PG&E's Lake Almanor however, contains about 48% of its PG&E's usable storage capacity. The effects of annual precipitation variance on this large body of water frequently requires a multi-year operational response to restore the reservoir resulting in lagged response to those years with annual runoff in terms of variance of the mean annual inflow. The combined lagged effect of retaining operational control over Lake Almanor and the aquifer outflow lag is sufficient to dampen typical weather variance creating an oscillating system generation pattern with a possible 14-16 year periodicity. While the 30-year record appears to follow the 14-16 yr cycle observed for baseflow and precipitation, the record period is too short to make any valid conclusions about whether or not the generation cycle actually exists. If additional records in the future reveal that there is a valid 14-16 year cycle, then this cyclic pattern may be predictable in terms of a 3-year moving average several years in advance with reasonable success. While the moving average effect for three or more years appears predictable with reasonable success, it's much more difficult to predict the effect of weather variance on the following year's generation. The effects of any given year's precipitation appear to be reflected through pressure changes on spring outflow, which lag 2-3 years. For Lake Almanor, one or more large years which fill the lake may require 1-3 years to return it to lower levels; the opposite effect is true for the effects of successive dry years, in which case it may require a refill period lasting 1-3 years. Lake Almanor and Cow-Battle creeks are likewise spring fed from aquifers formed within the flood basalts.

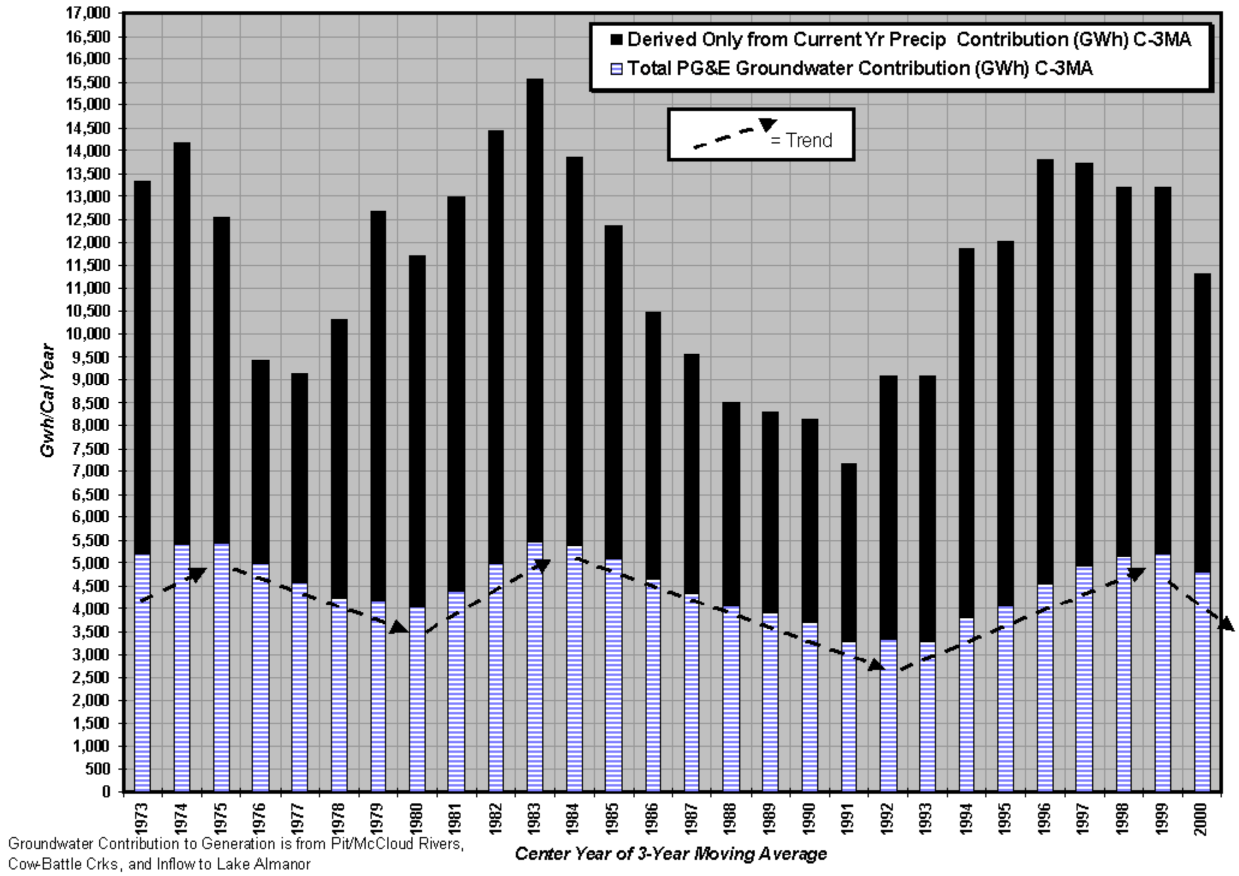

Figure 9 PG&E's Conventional Hydro Generation charted with a centered 3-year moving average for the 30-year period (1972-2001) (28 years shown). In addition to showing what may turn out to be an approximate 14-15 year periodicity, the 38% proportion of PG&E's hydroelectric energy from lagged volcanic baseflow (crosshatched base portion of columns) is readily apparent.

The Observed Effect of Climate on Rates of Aquifer Outflow

The buffering effects on hydroelectric generation of annual baseflow and Lake Almanor's large storage capacity not only lag current seasonal climate variance, but likely also reflect the smoothed lag of accumulated variance from the long-term historic precipitation mean. Baseflow response, during the net recharge phase, tends to echo and double in both time and quantity the effect of any longer term variance drift in precipitation variance from the long-term average. As such, the net discharge flow reduction of approximately 11 maf from the aquifer decay in observed baseflow rate for the Pit River at Lake Shasta during the 24-year (1907-1930) period was echoed in continued sub maximum baseflow during the following 1931-1958 28-year net recharge period. The overall loss in baseflow during this 52-year period was about 27 maf in terms of the difference from the maximum identified baseflow rate or an amount equivalent to almost 95% of the capacity of Lake Mead (28.5 maf). The 52-year period of decreasing then increasing baseflow rate such as occurred with the 1907 through 1957 period provides an excellent opportunity to compare the precipitation record with baseflow and reflect on what changes in precipitation availability for the half century period may lead to the observed long term reduction in baseflow from northern California's volcanic aquifers.

The effect of baseflows on defining PG&E's dependable capacity cannot be ignored. For example both 1924 and 1977 were the two driest years during the 20th century for Lake Spaulding in the central Sierra Nevada. 1977 was 6.66 inches drier than 1924 and for that reason and because of its more recent occurrence is often chosen to represent PG&E's dependable capacity. However if one compares baseflow in the Pit River for 1977 with that for 1924, 1977 had 425,000 af more baseflow. For the Pit River, which normally makes up about 33% of PG&E's long-term average year generation, 1931 was significantly drier than 1977 in terms of dependable capacity from available water. The consequence of experiencing a 1931 baseflow case with 1977 annual precipitation would have likely reduced PG&E's overall 1977 hydro generation by an additional 15%.

What Lies Ahead?

While there is no crystal ball that provides sufficient skill level for predicting next year's hydrogeneration or precipitation, certain likelihood's tend to reveal themselves for the next 12 to 15 years and possibly beyond, especially when analyzed as a moving average of three or more years. The baseflow cycle took a downward turn beginning with 1999 (a much drier-than-normal 2001 water year brought the fifth driest year since 1926 in terms of precipitation for PG&E's 16-station precipitation index) and Lake Almanor will be reduced to or possibly slightly below normal end-of-year carryover storage for 2001. The likely effect is that through about 2005, there is sufficient net deficits accumulating in PG&E's hydro producing resources that the 2-3 year associated lag will likely see the moving 3-year grouping of years' total system generation continue to decline, then begin a return to progressively higher levels of generation for the remainder of the 7-year part of the cycle through about 2012. Whether or not there will be a return to an extended below normal period such as was experienced beginning in 1907 is impossible to determine at this time. While a possible 94-100 year type cycling may exist, the available data is insufficient to draw any conclusions other than to appreciate that a long-term 52-year period of reduced baseflow from the Pit and McCloud river aquifers occurred during the last century and it seems reasonable to assume that similar long-term trends will recur. An extension of the Lake Spaulding climate record back beyond its 1894 start seems to hint at an orderly progression of precipitation change which may tend to repeat itself over a period lasting 94-100 years; however, the record is too short and too limited in terms of mountain stations to draw any valid conclusions.

Conclusions

Northern California's volcanic aquifers provide PG&E and the State of California with a unique resource, one that buffers the effect of California's large precipitation variability in terms of runoff for those watersheds that overlie the volcanic basalts. For PG&E, during extended dry periods, the sustained baseflow from springs represents an increased proportion of the hydro generation resource potential. Normally baseflow over the long-term record represents about 38% of PG&E's hydrogeneration. During 1977, a very dry year for California, baseflow from northern California's volcanic aquifer-fed springs supplied approximately 58% of PG&E available hydro generation, increasing PG&E's total hydro generation that year by approximately 3,514 GWh. The large aquifers on the Pit-McCloud watersheds exhibit both a short-term oscillation of 14-16 years and, for the period studied, a single 52-year extended period of reduced outflow rates during which phases of net discharge and net refill were revealed. During the extended 1907 through 1958 period, approximately 27 maf in accumulated baseflow reduction from the maximum sustained flow rate took place. In terms of today's facilities on the Pit River, that would equate to an approximate 25,000 GWh loss of energy if the same situation occurred with today's hydroelectric system in place. If the current observed periodicity holds as during past years, the 2002-2005 outlook for baseflow from northern California's springs can be anticipated to continue it's decline, possibly hinting that while any given year may be close to or above average, the average of the next four years of accumulated precipitation for northern California is likely to be less than the recent 40-year accumulated average (1961-2000). If another extended dry period should eventually occur, as with the 1907-1930 period, then once again we could experience 40-50 years of baseflow below the maximum aquifer rates.

References

Alt D, Hyndman DW. 2000. Roadside geology of northern and central California. Montana: Mountain Press. 369 p.

Bastasch R. 1998. Waters of Oregon. Corvallis (OR): Oregon State University Press. 278 p.

Booth W. 2001. States locked into western grid face severe energy test. Available via the Internet at http://www.greenspun.com/bboard/q-and-a-fetch-msg.tcl?msg_id=004Vol. Accessed on Aug 19 2001. The Washington Post Company.

Brulte J. 1996. Fact sheets on AB 1890 from the Office of Governor Pete Wilson—deregulation of the electrical industry. Available via the Internet at http://eerr.notes.org/california/ab1890factsheet.htm. Accessed on Aug 19 2001.

Cayan DR, Dettinger MD, Diaz HF, Graham NE. 1998. Decadal variability of precipitation over Western North America. J Climatology 11:3148–66.

Diaz HF, Anderson CA. 1995. Precipitation trends and water consumption related to population in the southwestern United States: a reassessment. Water Resources Research 31:713–20.

Freeman GJ. 2000. Comparison of Sacramento Valley Runoff Index with Columbia River Basin runoff. Pacific Gas & Electric Company. Unpublished internal files.

Planert M, Williams JS. 1999. Groundwater atlas of the United States—Segment 1: California Nevada, major aquifers, northern California volcanic-rock aquifers. Figure 137. U.S. Geological Survey.

Taylor GH. 1995. Long term precipitation cycles in Portland. Available via the Internet at http://www.ocs.orst.edu/reports/PDX_precip.html. Accessed on Aug 2 2001.

Taylor GH, Hannan C. 1999. The climate of Oregon—from rain forest to desert. Corvallis (OR): Oregon State University Press. 211 p.

Tison R. 2001. The true cause of California's energy crisis, energy-tech on-line. Available via the Internet at http://energy-tech.com/issues/html/we0102_001.html. Accessed on Aug 19 2001.

[USBR] U.S. Bureau of Reclamation. 2001 Shasta power plant. Available via the Internet at http://www.usbr.gov/power/data/sites/shasta/shasta.htm. Accessed on Aug 19 2001.