# A PROGRAM TO INCREASE AQUIFER OUTFLOW IN NORTHERN CALIFORNIA'S MCCLOUD AND PIT RIVER WATERSHEDS

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## ABSTRACT

Northern California's Pit and McCloud River watersheds overlay a combination of highly fractured porous, volcanic High Cascade and flood basalts. Pacific Gas and Electric Company (PG&E), an investor-owned utility with headquarters in San Francisco, is completing a project that will place 15 ground based cloud seeders in the mountains on and around Mt. Shasta to create one of the largest cloud seeding programs in California. These seeders will be remotely operated and disperse heated plumes of silver iodide crystals to enhance snowfall over several hundred square miles of forested watershed. Only cold storms will be seeded to assure that precipitation is added in the form of snow. Deep, porous volcanic soils on the watersheds facilitate rapid infiltration and minimize overland flow. While the added water entering the aquifer may take decades to reach the springs, an increase to hydraulic head from increased snowmelt contribution should transmit its increased pressure effect relatively quickly through the aquifer and is anticipated to result in increased outflow of the springs within 3-4 years. A natural lag in runoff response is expected to provide increased outflow from the springs, even during dry years when there may be a scarcity of clouds to seed. Adding additional snow to the snowpack utilizing cloudseeding is anticipated to enhance aquifer pressure increasing naturally occurring groundwater outflow from springs by as much as 9%. The increased artesian outflow is anticipated to increase the McCloud and Pit River combined runoff and ultimately California's annually available usable surface water by approximately 308 cubic hectometers (250,000 acre feet) or by approximately 0.35% producing approximately 330 gigawatt hours per year (GWh/year) additional hydroelectric generation. The increased runoff delivered daily throughout the year from springs can provide additional opportunity for downstream residential, agricultural, and industrial use as it passes through Shasta Lake, the Sacramento River, and eventually entering the San Francisco Bay estuary. No pumping will be needed to fully utilize the benefits of groundwater recharge from some of the largest springs in the United States.

## INTRODUCTION

The watersheds that contribute to PG&E's hydroelectric production are located primarily in the Sierra and the southern Cascade Mountain ranges. A single powerhouse is located in the California coastal range near Ukiah, California. The Sierra is characterized mostly by exposed hard, relatively impervious granite that supports only relatively small late summer and fall base flow runoff. This can be characterized for example by the Merced River @ Pohono bridge in Yosemite National Park where the 50-year (1946-1995) average water year is 559 $hm^3$ (461 TAF) and 25 percent of the historical monthly flows comprising that average are equal to or less than 11.8 $hm^3$ (9.6 TAF). Most of those monthly flows equal to or less than 11.8 $hm^3$ have historically taken place in late summer and fall. North of the Sierra granites, the mostly volcanic southern Cascade mountain range begins its southern end at Lake Almanor near the town of Chester in northern California. The southern Cascade drainage is significantly lower in elevation than the central and southern Sierra and is mostly characterized by lava flows from volcanic type eruptions and flood basalts that created volcanic rock aquifers (Figure 1), (Planert and Williams, 1995). The High Cascades is the younger of two volcanic mountain ranges that have raised parallel to the Pacific Northwest coast during the past 35 to 40 million years. The stratovolcanoes that dominate the range are mostly less than 2 million years old, but they stand atop a massive platform of basalts that has been built by eruptions from scores of vents during the past 12 million years. This entire suite of High Cascade rocks, in turn, overlies the eroded remnants of an older volcanic chain called the Western Cascades Series that was active between about 35 and 17 million years ago (McBirney and White, 1982). The High Cascade volcanic basalts are the result of the Juan de Fuca tectonic system of microplates subducting under the North American plate. The Juan de Fuca system of microplates that includes the Gorda plate is the disconnected remnant of the Farallon Plate, which once covered the whole eastern Pacific. Both Mt. Shasta and Mt. Lassen have experienced eruptions in fairly recent times. The flood basalt flows make up the Modoc Lava Plateau and are located mostly northeast of Mt Shasta and likely have their origin from the "hot-spot" once located in southeastern Oregon, but which has been located in the vicinity of Yellowstone Park during the past 17 million years (Alt and Hyndman, 1996).

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Modified from California Department of Water Resources, 1980; Plume and Carlton, 1988; U.S. Geological Survey, 1984; and J.R. Harrill, U.S. Geological Survey, written commun., 1994

The Northern California volcanic-rock aquifers consist of volcanic-rocks that yield water primarily from fractures and locally from intergranular spaces in porous tuffs.

Figure 1. The southern Cascade volcanic-rock aquifers in northern California (Planert and Williams, 1995)

Long term, approximately 58% of PG&E's conventional hydroelectric generation is produced in the North Fork Feather, McCloud, and Pit Rivers of northern California. Overall historically about 38% of PG&E's conventional hydroelectric generation comes from groundwater outflow to rivers, mostly by way of a few large northern California springs (Freeman, 2001). Some of the largest springs in the United States are found in this region of fractured volcanic basalts located in northern California (Meinzer, 1927). One example of these large springs is located on Fall River, a tributary to the Pit River. Late summer and fall baseflow of the springs for the Fall River typically average long term about 86.3 $hm^3$ (70.0 TAF) /month. March snowmelt during an average historical year typically increases the monthly runoff of Fall River to approximately 120 $hm^3$ (97 TAF) or about 21 percent over baseflow. This non snowmelt-produced daily aquifer outflow is the primary contributor of the springs and is approximately the same each and every day of the month throughout the year. The long-term average approximately 2.9 $hm^3$ /day aquifer outflow can be stored in the relatively small Pit #1 forebay for a few hours use each day as high value peaking power through PG&E's Pit #1 Powerhouse (P.H.). Historically about 87 % of the Fall River annual runoff is from aquifer outflow, nearly all of which has resided underground for several decades, with some smaller portion likely residing over a century in underground storage. The water that currently emerges from the springs is likely in large part water that while in slow transit for many decades is now emerging from the pressure transmittal effect of the much more recent precipitation of the past few years. Nearly all of the relatively recent precipitation is likely to reside underground for several decades. This aquifer outflow from Fall River and other contributing tributaries is stair-stepped down the successive reaches of the Pit River separated by diversion dams eventually flowing into the Bureau of Reclamation's large Lake Shasta. Each forebay diversion dam has an associated downstream powerhouse along the Pit River. Contributions of large tributary inflow to the main Pit River from the aquifer outflow of: Fall River, McCloud River, Hat creek, and subchannel contribution into the Pit River main channel results in a significant total base flow component from the volcanic basalts (Figure 2). Imported water from the McCloud River flows through PG&E's McCloud-Iron Canyon Tunnel to Iron Canyon Reservoir, then through J.B. Black Powerhouse where the imported water enters the Pit River above PG&E's

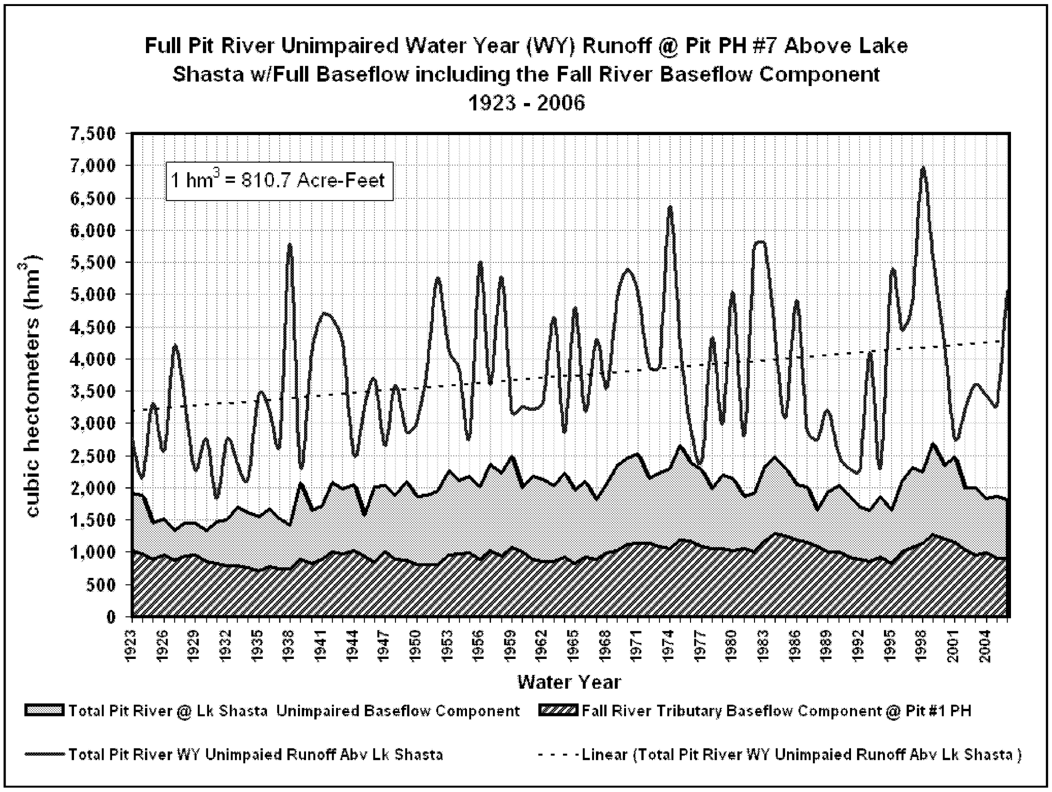

Figure 2. The full water year base flow including the Fall River Tributary component for the Pit River @ Lake Shasta revealed as a part of the total water year runoff.

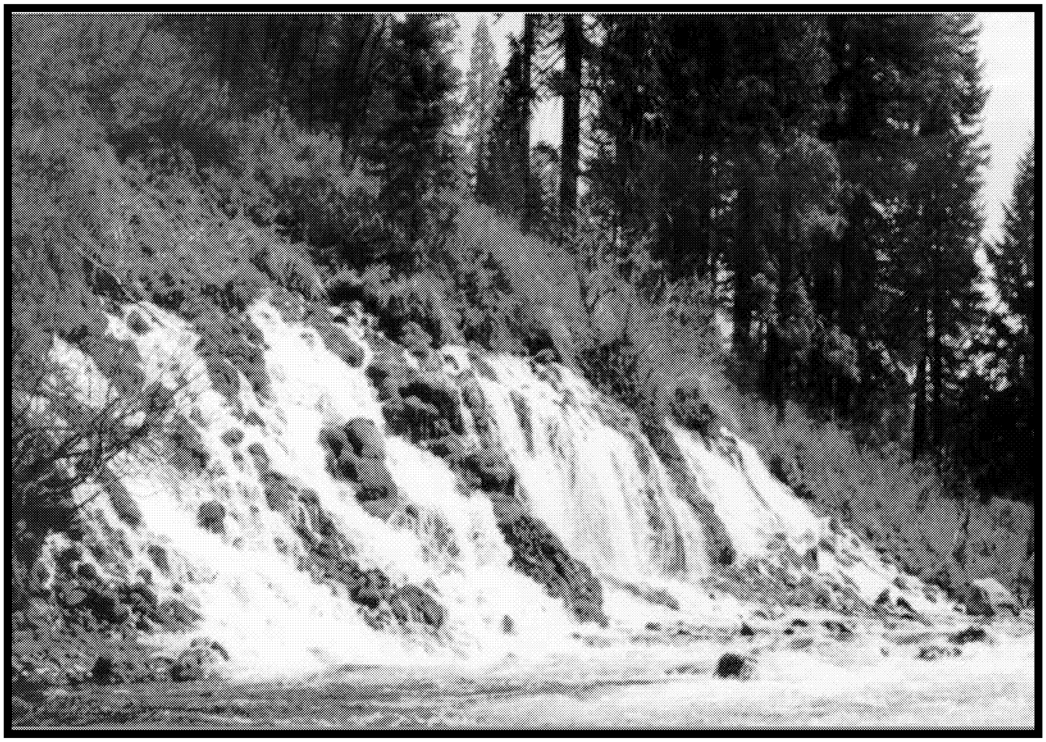

Figure 3. Big Springs on the McCloud River adds approximately 20 cms (700 cfs) to the flow of the upper McCloud River. This single spring represents about 81 percent of the unimpaired aquifer inflow to McCloud Reservoir.

Pit River PH #6. Most of the aquifer outflow for the McCloud River above McCloud Dam emerges from Big Springs, which nearly quadruples the size of the McCloud River (Figure 3).

The large baseflow component typical of the Pit River is probably best illustrated by the Fall River tributary example, which is characteristic of the porous lava flood basalts that make up a major rock type for much of the Pit River drainage east of Medicine Lake. The typical elevation of the drainage overall aside from Mount Shasta which towers to 4,317 m (14,162 feet) above sea level averages close to about 1,520 m (5,000 feet). This is significantly lower than the Southern Sierra, which has many peaks in the 3,960 - 4,270 m (13-14,000 feet) range.

## THE HYDROLOGY DESCRIBED

Figures 4 and 5 reveal the strong baseflow component characteristic of annual flows. Baseflow or aquifer outflow of the springs as used with this paper is defined as the minimum monthly flow for the three months: August, September, and October. Fall River has the largest baseflow component for tributaries into the Pit River. It likely owes that property to the Fall River graben faults and porous lava-tube bearing volcanics that extend south from the Medicine Lake Highlands toward The Fall River Valley. These are likely the best candidates for most of the recharge to the aquifer, which supplies the water that emerges from the Fall River Springs (Lowenstern, et al., 1998) and aquifer outflow is also possibly flowing underground in part from the extensive Modoc Lava Plateau to the northeast composed mostly of flood basalts. Long term approximately 87% of Fall River's runoff enters the Pit River from springs. A small snowmelt component mostly from the Medicine Lake Area increases outflow in early spring. Following a very dry 1976 water year, a second consecutive drought year occurred in 1977. Together these two sequential very dry years represent one of the driest two-year periods in recent years, but reveals almost no drop in Fall River's monthly base flow (Figure 5). The long-term multi-decadal trend for Fall River flows continues upward starting about 1930. This upward trend may be a continuing response to the multi-decadal loss of underground storage that took place during the first part of the twentieth century. The 1923 through 1964 period for Fall River unimpaired flow compared with 1965 through 2006 is shown in Figure 6. The base flow increased approximately 19%. Utilizing a known precipitation increase for the same period, it is relatively easy to compute the total increase that can be expected from a 9% increase in precipitation. For this single tributary, a 9% increase for example from cloud seeding would translate to approximately 125 TAF increase in outflow from the Fall River Tributary alone.

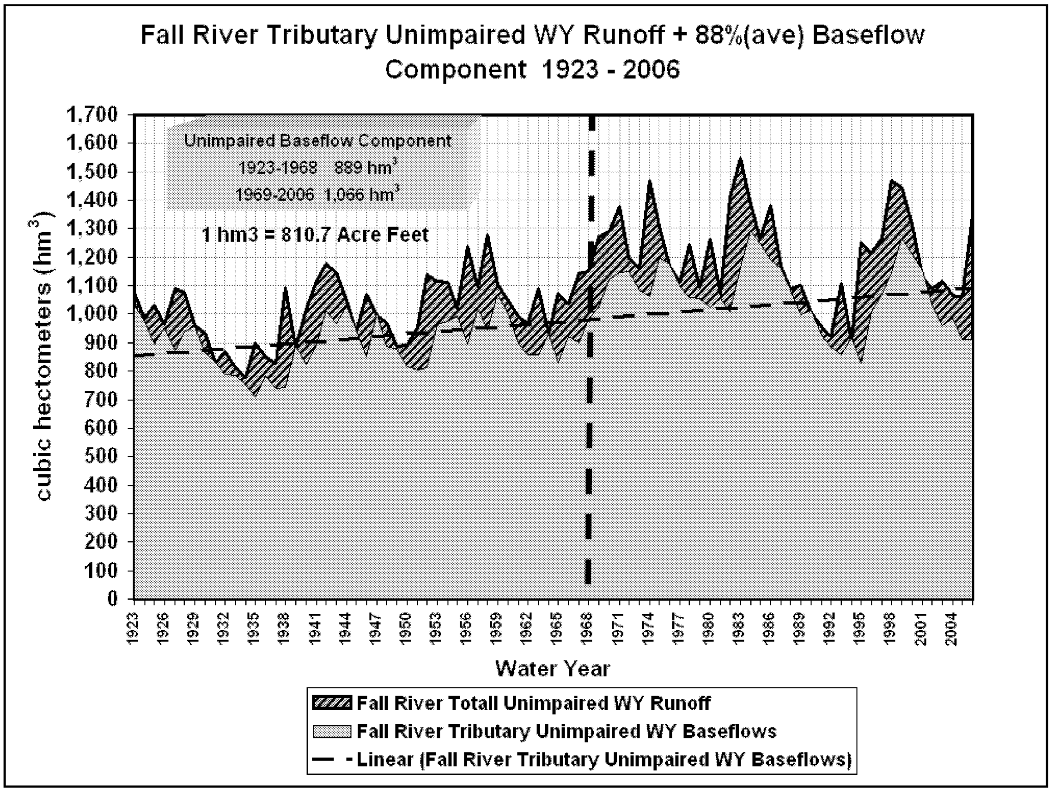

Figure 4. The 84-year 1923 through 2006 water year runoff broken down to show the baseflow component by year.

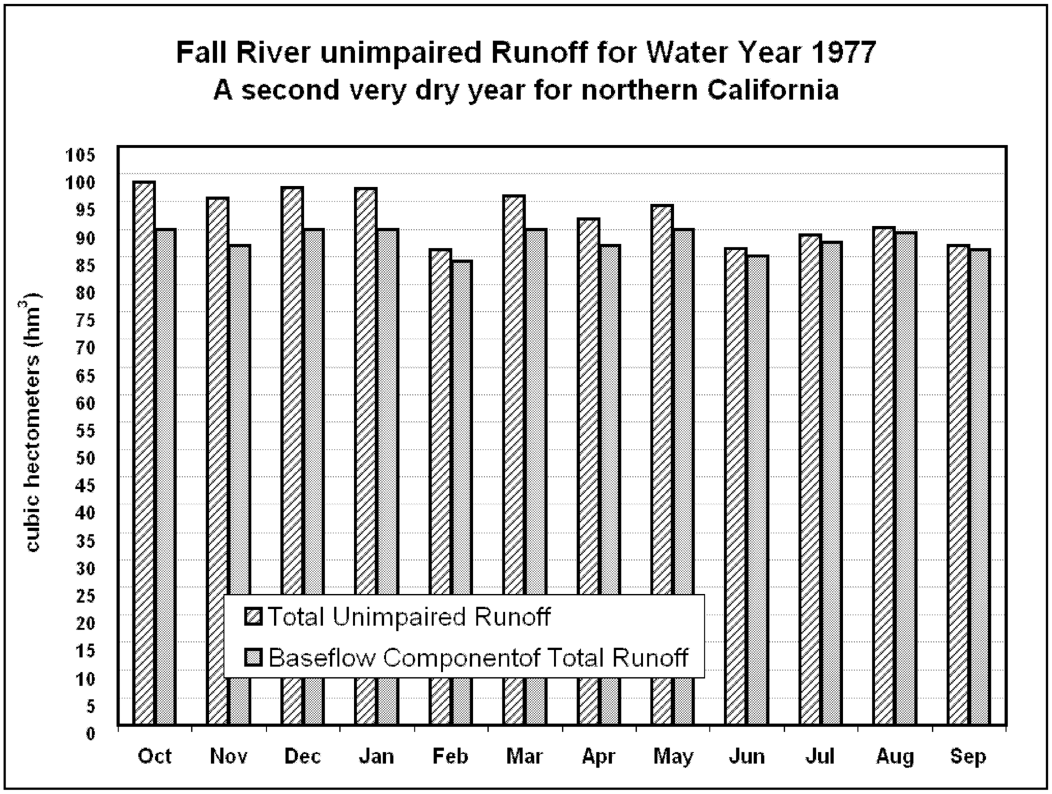

Figure 5. Fall River monthly baseflow remains unimpacted from northern California's very dry 1977 Water Year (second successive year of drought).

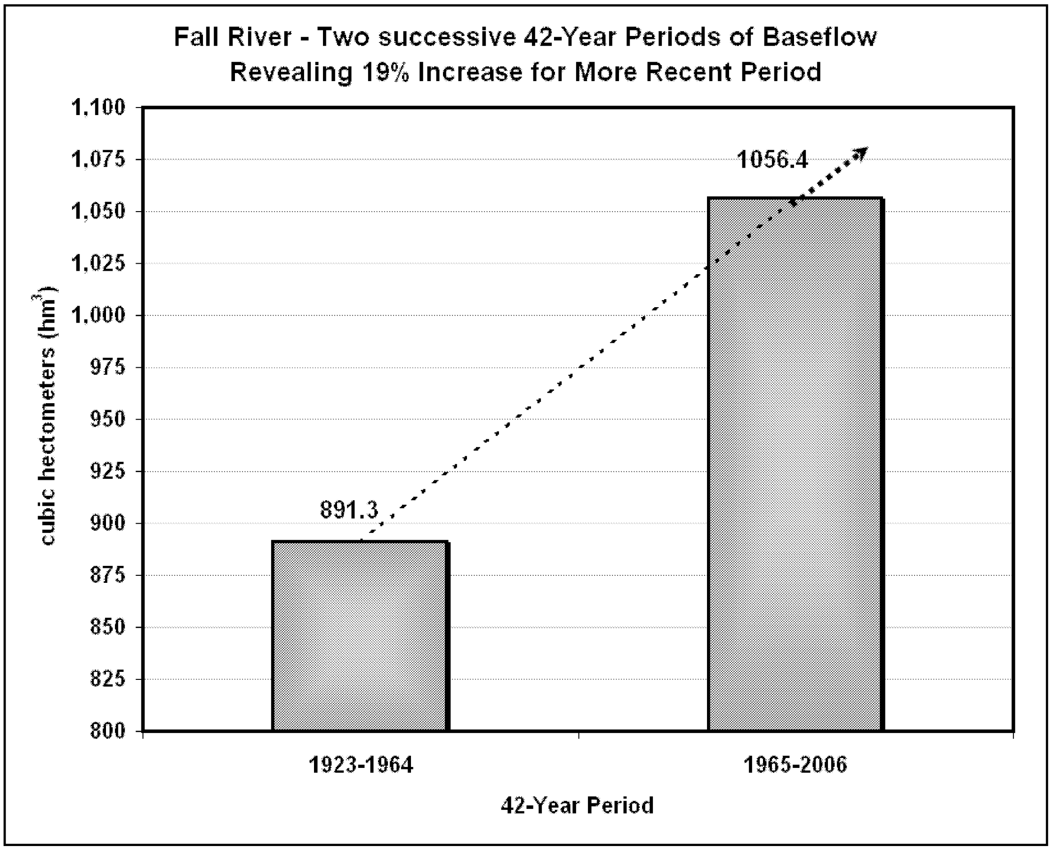

Figure 6. Two successive 42-year periods of baseflow revealing 19% Increase in baseflow for more recent period.

PG&E's McCloud-Iron Canyon Tunnel annually exports a long term average of approximately 774 $hm^3$ (627 TAF) from the McCloud River at PG&E's McCloud Reservoir southward into the lower Pit River above Lake Shasta. The McCloud River has a large volcanic aquifer outflow component characteristic of the Pliocene and more recent High Cascade fractured basalts. Both the McCloud River and the Fall River headwaters will be a main focus for cloudseeding and producing precipitation enhancement. The aquifer outflow component from the large springs that feed the McCloud and Pit Rivers exhibit only minor day-to-day and year-to-year variation in the aquifer outflow rate. The value of precipitation enhancement and groundwater recharge is that nearly none of the additional water spills and is available as a daily delivery from the springs during all months of the year and continues its availability during dry years when few seedable weather fronts occur and there is overall reduced opportunity for precipitation enhancement. The additional water is stored underground with little likelihood for evapotranspirational loss. With relatively slow actual downhill movement from the headwaters, the actual infiltrated water will likely not emerge for several decades; however the pressure related effect of recharge appears relatively quickly in terms of 3-4 years.

## HISTORICAL LONG 49-YEAR PERIOD OF BELOW NORMAL BASEFLOW

Long-term traces of the baseflow contribution from Fall River, Hat Creek, and the lower Pit River reveal a long-term 49-year decline in baseflow contribution took place between about 1910 and 1958 (Freeman, 2001). The period between 1910 and 1930 was a sustained period overall of below average precipitation, causing a large depletion in active aquifer storage, which required 28 years to recover. Both Figures 7 and 8 illustrate this effect for the baseflow of the Pit River into Lake Shasta. As a result of declining aquifer outflow, the annual accumulated 21-year departure from that of the 1906-1909 baseflow rates indicated a baseflow reduction totaling 12,460 hm3 (10,100 TAF) outflow by 1930 (Figure 7). During the 1931- 1958 recharge period (28 years) approximately 18,330 $hm^3$ (14,860 TAF) in baseflow was absent from the Pit River total unimpaired inflow to Lake Shasta (Figure 8). Overall for the 1910 through 1958 49-year period, approximately 30,375 $hm^3$ in aquifer outflow or about 30,840 $hm^3$ (25 million acre feet) disappeared from the Pit and McCloud Rivers and its daily use in California to meet daily hydroelectric, environmental, industrial, water supply, and other needs. That quantity of water is equivalent to approximately 91 percent of Lake Meade's full storage capacity.

Utilizing the historical runoff, hydroelectric generation through PG&E's current year Pit River hydroelectric system was simulated utilizing Pit River unimpaired flows for this early 20th century "drought period" to reveal an average annual loss of generation. Two equal length 44-year periods consisting of 1914-1957 and 1958 - 2001 were compared for the Pit River. The simulated difference overall was a 26,000 GWh reduction in energy for the earlier period compared with generation from the mean baseflow rates experienced during the second period. In addition it was observed that for the Fall River tributary, the annual unimpaired flows reveal an approximate 14-15 year moving oscillation in annual baseflow. This may be a natural harmonic that develops from natural lagging and filtering of year-to-year annual precipitation variation (Freeman, 2002). The response to annual precipitation can be noticed in the baseflow within 2-3 years, but the full harmonic period tends to take 14-15 years. Relatively short 2-7 year dry periods can recover relatively rapidly back to prior higher outflows, indicating the response is likely pressure related, as actual travel time for a specific unit of tagged precipitation to reach the springs point of outflow to the river may take in excess of 100-years (Davisson and Rose, 1997). Long periods such as the 1910 - 1930 lasting 15-25 years with below average precipitation overall, even though some years may be above average in terms of precipitation, lead to increasingly longer recovery periods for springs to return to full outflow rates. Perhaps with the continued loss of banked water from the aquifer, the water level and thus the pressure gradient along the inclined plain dropped sufficiently that flow rate could not recover quickly. Figure 9 illustrates the annual reduction from normal baseflow for the 49-year period 1910 through 1958. It was a strange anomaly for the author to discover in 1972 that compared with the Sierra's rivers to the south which showed no significant long term trends in annual average runoff, the annual flow from Fall River was continuing to significantly increase its baseflow component and thus its overall total annual flow.

## CLOUDSEEDING AND GROUNDWATER RECHARGE

PG&E has cloudseeded on two of its 16 watersheds for many decades and has found it to be cost effective in terms of producing additional runoff for hydroelectric generation. The Lake Almanor project on the north fork Feather River above Lake Almanor has been seeded since about 1954 and the North Fork Mokelumne River above Salt Springs has been seeded since about 1965. PG&E shares in the cost to seed one additional watershed located

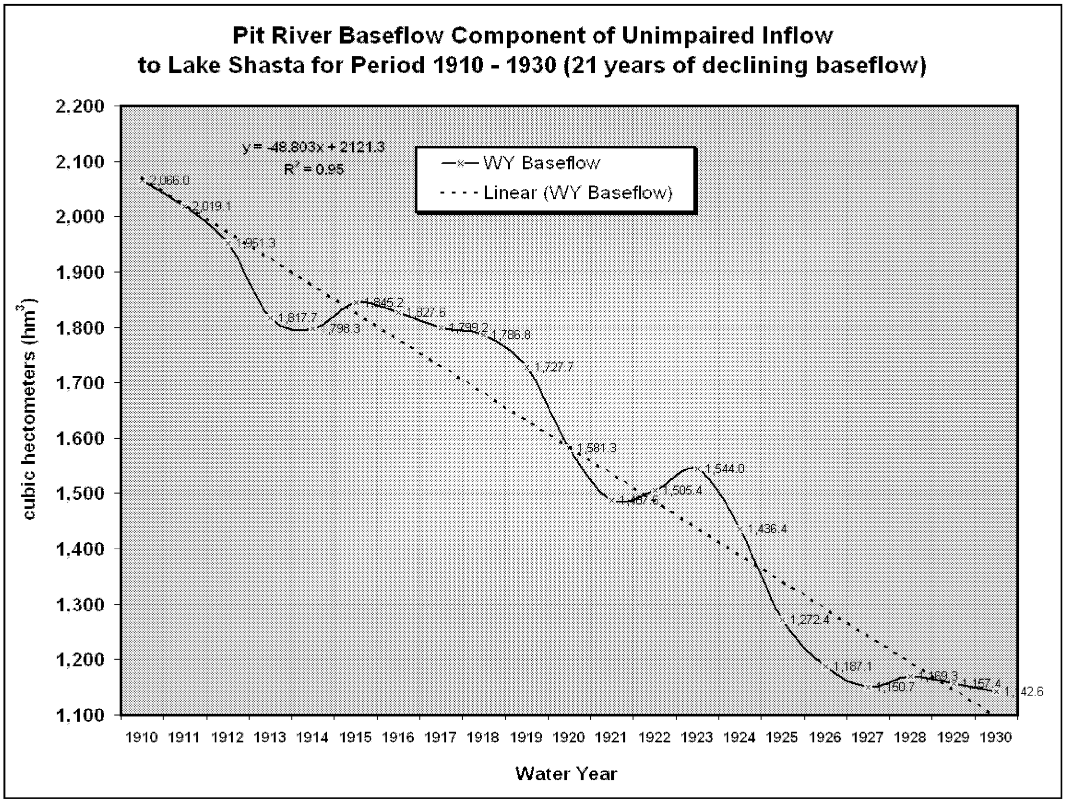

Figure 7. Pit River - declining baseflow for the 21- year period 1910-1930

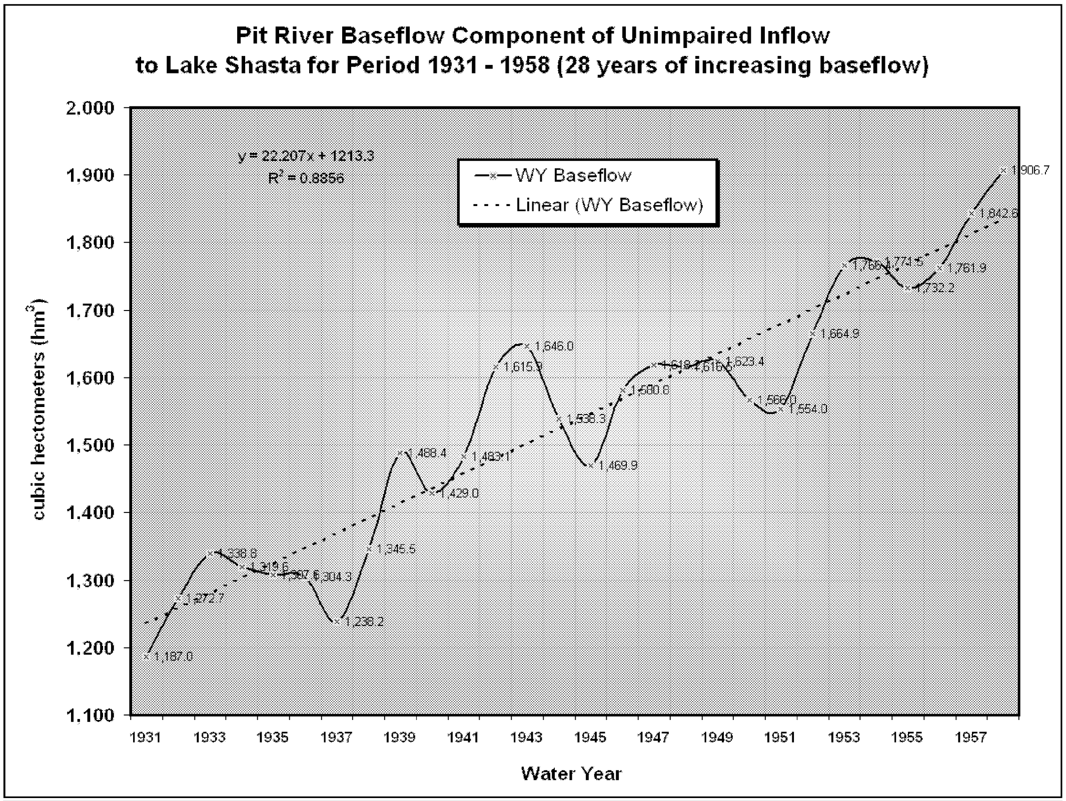

Figure 8. Pit River - increasing baseflow for the 28- year period 1931-1958

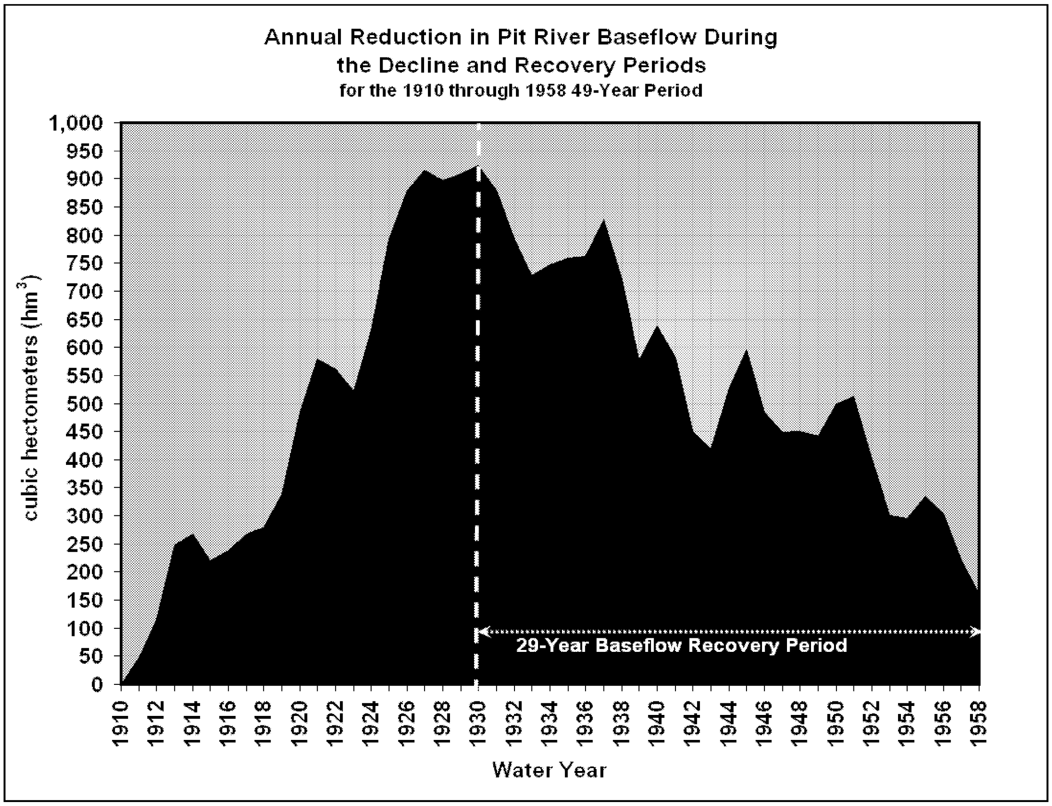

Figure 9. The annual quantity of baseflow reduction for the unimpaired Pit River into Lake Shasta. The increasing outflow rate of the springs reveal recovery of aquifer storage and pressure beginning about 1931.

on the upper north Fork Kings River above Lake Wishon. An outside contractor performs this project and the costs are shared with other Agencies on the Kings River Watershed. The seeding on the Kings River is performed with the overall objective to increase inflow to PG&E's Courtright and Wishon Reservoirs and the U.S. Army Corps of Engineers' and Kings River Conservation District's Pine Flat Reservoir. All three of the above PG&E seeding projects depend on seeding cold snow-producing weather fronts and capturing the increased snowmelt runoff during the final phase of snow ablation often in late May as snowmelt runoff from the highest drainage in the watershed enters the downstream reservoirs. Lake Almanor is sufficiently large to capture most of the additional runoff; however Salt Springs Reservoir, a relatively small reservoir in relation to its drainage area spills with a frequency close to 3 in 5 years. The additional runoff from snowmelt typically flows into the reservoir during 3-4 weeks in May, but has overall shown a trend toward earlier melt in recent years, a likely outcome of climate change. The effectiveness for increasing runoff from the Lake Almanor cloudseeding not only benefits from having a large Lake with multi-year storage capability, but gets a significant portion equaling or exceeding 40 percent of its annual inflow from springs, located both under the reservoir and in its tributaries, with some of the largest springs being on the Hamilton Branch tributary. Lake Almanor has most of its drainage on relatively recent volcanic lava flows from the Mount Lassen/Brokeoff-Tehama basalt volcanic flows. Several of the springs that release water either under Lake Almanor or from the Hamilton Branch tributary are from relatively recent porous basalt lava flows that likely encounter portions of the mostly impervious tilted granite at the northern edge of the Sierra. Granite plutons are likely continuing to rise and become exposed from erosion at the surface in the northern Sierra such as along Highway 70 between Pulga and Storrie. This highway 70-canyon area along the lower north fork Feather River is an area characterized by high rainfall causing rapid erosion and increasing exposure of the northern Sierra granite.

The potential to store additional water from cloudseeding in the northern California fractured basalt volcanic aquifers is large. There will likely be a relatively rapid increase over ambient snowmelt and a long term continuous buildup of aquifer storage in the more distant parts of the watershed far up country from the springs that release groundwater into tributaries to the Pit and McCloud Rivers or into the rivers directly such as at Big Springs on the McCloud River or Rising River on Hat Creek. The native vegetation likely satisfies most of its upper soil moisture needs from ambient snowmelt, allowing the additional infiltrated water from cloudseeding snow enhancement to filter downward during ablation adding to the water table.

If successful in terms of producing additional water, a second phase of project implementation would likely focus on the Hat Creek Drainage, a tributary that drains into the Pit River from the southern sides of Mount Lassen and the Hat Creek Rim. The area overall receives less annual precipitation than the McCloud River, lower Pit River reach, and the Medicine Lake Highlands, but nevertheless has excellent potential for increasing runoff into the Pit River and generation through several Pit River hydroelectric powerhouses. Hat Creek Powerhouse #2 currently has a long-term average annual unimpaired flow of about 410 $hm^3$ (330 TAF). Seeding the Hat Creek drainage tributary would likely contribute an additional 37 $hm^3$ (30 TAF/year). Long term, approximately 89% of the Hat Creek annual runoff comes from aquifer outflow. Above the town of Cassel is "Cassel Forebay," a shallow section where water gathers before passing through PG&E's Hat #1 powerhouse. Hat Creek's character changes in this area as springs enter from Rising River, transforming Hat Creek into more of a spring fed creek.

## DESCRIPTION OF THE PROJECT

Figure 10 illustrates how the silver iodide particles rise with the heated air from the seeders and cloud moisture begins to freeze as ice crystals around the condensation nuclei (Hunter, 2007). The simplified physical process description for winter seeding with silver iodide is as follows: 1) a minute amount of silver iodide is sprayed across propane flame; 2) the silver iodide particles rise into the clouds; 3) the silver iodide causes the cloud super-cooled liquid water to freeze and create ice crystals; and 4) ice crystals grow big enough to fall as snow before evaporating downwind of mountains. Extended area effect studies on cloud seeding have found snowfall is increased as much as 160 km (100 miles) miles downrange. No conclusive evidence has ever been found to show that cloud seeding in one area will decrease precipitation in another. Ground based silver iodide generators (Figure 11) can be remotely operated at high elevation, unmanned locations. The project discussed in this paper will be remotely operated from a hydroelectric facility utilizing a supervisory control and data acquisition (SCADA) system to monitor and control burner operation during winter storm periods. The cloud seeding generator is typically removed each summer, brought into a service center for servicing, then returned to the platform in the fall and the two propane tanks are refilled. Locating the sites alongside reasonably good mountain roads makes it possible to have a large propane truck visit the seeder site each year and also for the seeding technicians to utilize a boom-type truck to remove the seeders, service them in the shop, then later replace the serviced seeders back onto the elevated

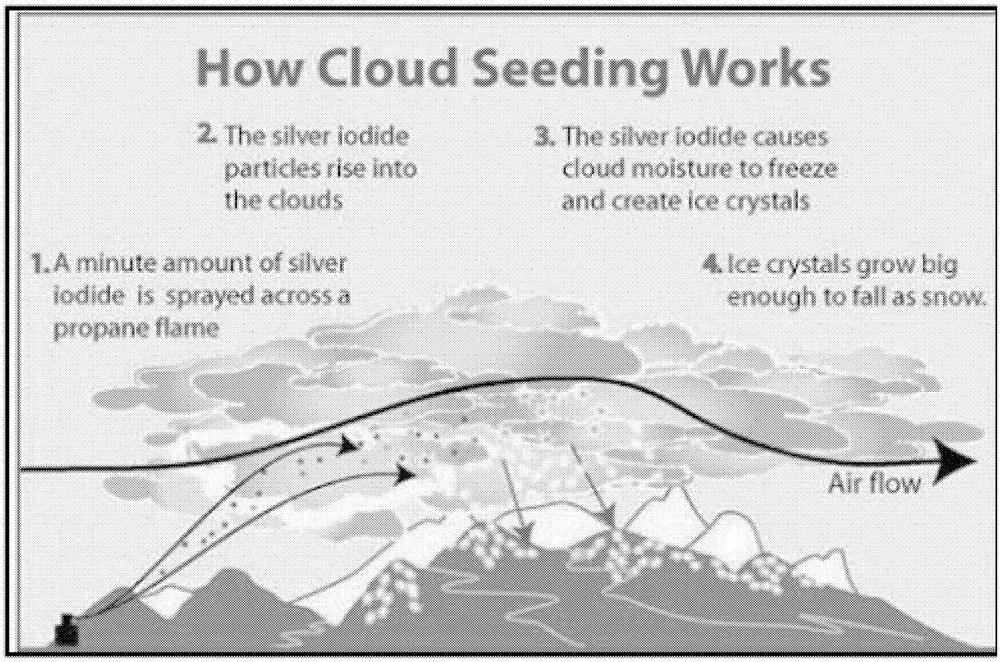

Figure 10. An illustration of how cloudseeding works when ground-based seeders with silver iodide are utilized. Courtesy, Steve Hunter, USBR.

platforms. Most seeder sites are being located behind locked gates and fences. In one case, plans are being put in place to install propane tanks underground for a communication site located on private land.

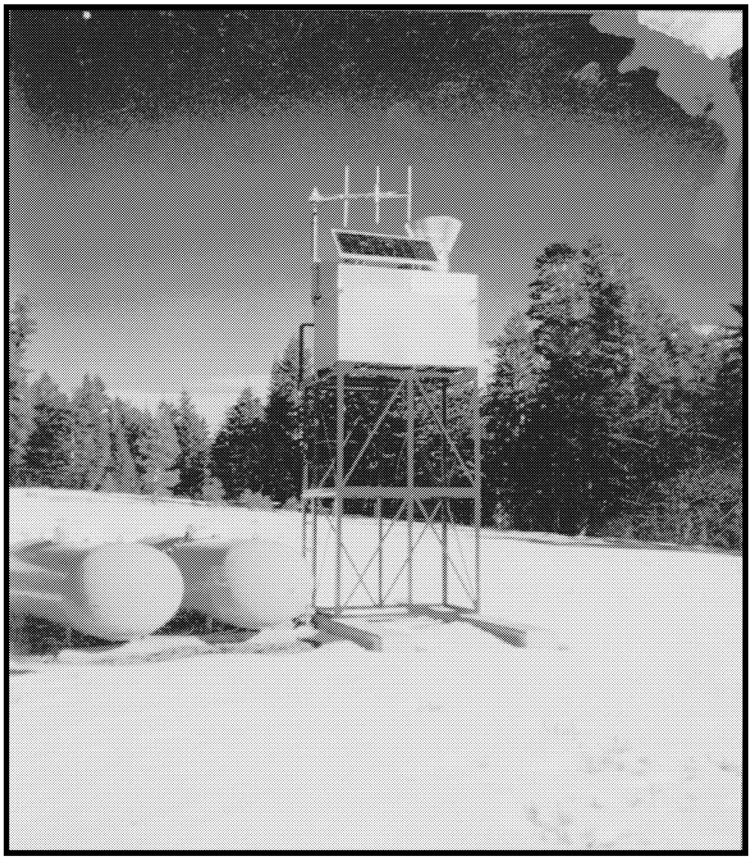

Figure 11. A typical ground based seeder installation with two propane tanks similar in layout to installation planned for the McCloud-Pit River Aquifer Recharge Project.

Placing the tanks underground along a relatively remote road spur helps reduce the landowner's concern of the public possibly shooting at the tanks and starting a fire on his property. A gate placed on the road spur will also help discourage the public from accessing the site.

The McCloud and lower Pit River watersheds were modeled to define the target seeding area. A further refinement was made to determine a number of possible sites for ground-based seeders. Approximately 48 sites were initially selected and each site was initially visited by helicopter to make a preliminary evaluation and determine an appropriate site-specific location for possible seeder installation. Road logs and access maps were then developed utilizing a handheld global positioning system. It was decided during this siting process, that all seeders would only be located on private land, eliminating those sites initially located on US Forest Service land. PG&E met with the county board of supervisors in both Shasta and Siskiyou counties to describe the project and get their approval before moving forward with contacting actual landowners. Landowners were then notified and contracts for leasing site locations were finalized. Approximately 20 sites were selected from which 15 would be chosen for final site installation. Most of the watersheds are logged or have been logged in the recent past. About one half the roads will need to be graded and vegetation that has encroached into the vehicle access space will need to be trimmed.

Most of the sites chosen for cloud seeders were selected along existing roads such that propane can be delivered during the summer and fall months and turnout areas along roads were wide enough along the side of the road to accommodate helicopter visits to the site for repair and routine servicing needs. Once installed the burners will be turned off and on remotely utilizing SCADA controlled from a centralized switching center. Orders for operation will go from San Francisco to the switching centers where operators will turn the seeders both on and off as needed. Storm fronts are monitored for freezing levels and only the colder storms from the southerly direction are possible candidates for seeding.

The initial project will place 15 seeders south of the intended target area. Many of the specific sites will be located on south slopes, a few hundred feet below the ridge tops to take benefit of rising orographic dynamics to lift the heated silver iodide particles high into the air and over the ridge. With PG&E's Lake Almanor cloudseeding project located on the adjoining watershed, it is likely that most decisions to seed one of the watersheds will likewise apply to the other watershed.

## CONSIDERATION OF FLOOD RISK AND EROSION FROM ADDED PRECIPITATION

Only relatively cold snow producing storms will be seeded. The additional precipitation will be in the form of snowfall and is expected to mostly infiltrate downward though the volcanic soils and fractured volcanic rock. Therefore the additional precipitation from cloudseeding will mostly become available for groundwater recharge during the snow ablation period. The McCloud and Pit Rivers are relatively low elevation and snowmelt generally takes place in March and April during most years. While rain-on-snow can occasionally take place during warm storms not being seeded, most of the water released from a rainfall-caused snowmelt is anticipated to also infiltrate downward into the porous volcanic soils and fractured rock. There should be negligible overland flow from additional snowmelt. Suspension criteria have been included in the agreements with landholders to suspend cloudseeding if the snowpack reaches or exceeds certain set criteria. The seeding for any given season can be suspended at the request of either party if there appears to be potential for increased flood risk or would have potential to impact timber harvest in the spring. The erosion potential is expected to be minimal.

## ANTICIPATED BENEFITS

### Additional Runoff

Regression studies indicate that the precipitation enhancement effect will likely begin to reveal itself significantly in about 3-4 years in terms of increased aquifer outflow rates from the large springs. The lag effect is the time it takes for the added precipitation to increase pressure and hydrostatic head along the gravitational gradient and translate to increased outflow of the springs. Once started the effect is anticipated to sustain itself as additional outflow regardless of seasonal wetness or number of cold storm fronts available for seeding. The overall outflow may drop off with extended dryness, but the added outflow of increased pressure from the precipitation enhancement will maintain that decreased outflow at a higher rate than would have otherwise been the case without cloud seeding.

For example the effects of seeding for the Fall River flows through PG&E's Pit #1 PH is anticipated to increase flows from 2.84 $hm^3$ (2.30TAF/day to approximately 3.10 $hm^3$ (2.51 TAF/day) or 0.26 $hm^3$ (210 AF/day) at the 9% level of seeding effectiveness. Once the increase in pressure has reached the springs, the aquifer outflow will continue uninterrupted to be delivered each day of the year as additional peaking power. The water will not need to be pumped from the ground. It will emerge along with the other naturally occurring aquifer outflow of springs entering the Pit and McCloud Rivers and flow uninterrupted by gravity through the Pit River into Lake Shasta, down the Sacramento River and into the San Francisco Bay Estuary by gravity only. No pumping is required for the new additional water to make its approximately 485 km (300 mile) journey to the Golden Gate. Approximately 88% or 1,079 $hm^3$ (875 TAF) of Fall River's annual 1,233.5 $hm^3$ (1,000 TAF) runoff can be classed as baseflow.

The entire target McCloud-Pit River drainage area contributes approx 3,084 $hm^3$ (2,500 TAF)/year with about 2,467 hm3 (2,000 TAF)/yr or 80% overall of that being baseflow in nature either entering into the river as aquifer outflow of springs or into the river channel itself. A 9% annual increase in annual runoff is equivalent to 308.4 hm3 (250 TAF/year) in additional runoff. PHASE II would target the Hat Creek volcanic basalt drainage and possibly upper Pit River increasing the annual additional runoff to approximately 370 $hm^3$ (300 TAF). The upper Pit River above its intersection with Fall River has approximately 7,770 $km^2$ (3,000 sq mi) drainage, but is characterized by much less precipitation and runoff.

### Additional Generation

PHASE I of the McCloud-Pit cloudseeding project is anticipated to produce 330 GWh of energy/year. About 85-90% of that will be utilized as peaking energy through PG&E's Pit River powerhouses with the remainder to be base/shoulder type generation produced and utilized outside of peak use hours. As a result of this groundwater recharge project, PG&E's conventional hydroelectric generation is anticipated to increase overall generation by approximately 2½% during normal precipitation years and by 4-5% during drier years when other sources of runoff are lacking. The additional generation from groundwater is gravity flow, so no energy will be consumed in getting it to the river. No new dams or powerhouses are needed to accommodate the additional water. The existing forebay and afterbay pondages along the Pit River are sufficiently large to accommodate the additional flow during all but the wettest days when overland flow is already occurring.

## CONCLUSIONS

PG&E plans to implement a groundwater recharge system on the McCloud-Pit River watersheds utilizing ground-based cloudseeding. Beginning in the winter of 2007-2008 and continuing into the winter of 2008-2009, 15 ground-based seeders will be installed to target northern California's McCloud and Pit River watersheds. The aquifer outflow is anticipated to increase its rate of outflow over a period of about 3-4 years, achieving significantly enhanced aquifer outflow by the winter of 2010 - 2011. The project will be located 100% on private lands with each seeder about ten miles south of the target zone. The anticipated additional water is anticipated to be about 300 $hm^3$/year and will provide approximately 380 GWh/year nearly all in daily delivered runoff for peaking use. Long multi-decadal aquifer outflow droughts such as occurred during the period 1910 - 1958 will likely occur again. It is the author's hope that this groundwater recharge program will increase aquifer outflow in all years including prolonged periods of reduced aquifer outflow.

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