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RESERVOIR RESPONSE TO CURTAILMENTS AT THE GEYSERS

K. P. Goyal

Calpine Corporation
10350 Socrates Mine Road
Middletown, CA, 95403, USA
e-mail: keshav@calpine.com

ABSTRACT

Curtailment tests were conducted at the Calistoga and Bear Canyon wellfields from March to June 2001. The curtailments are found to result in lower decline rates as well as in an increased steam flow rate following the curtailed period. This increase is referred to as a "puff" and its duration is proportional to the extent of curtailments. The data from these tests have been used to develop a relationship between curtailments and the puff. A plot of annual curtailments versus annual decline rate for the Bear Canyon wellfield from 1991 to 2000 supports the contention that the decline rate decreases with increasing curtailments.

INTRODUCTION

The Geysers steam field is located in the Northern California as shown in Figure 1. The curtailments in The Geysers have a long history. Initially, the field operators were reluctant to impose thermal and pressure cycles on their production wells by opening and closing control valves for the fear of damaging some wells and reducing the productive life of the others. This concern changed when faced with curtailments allowed in various PG&E contracts where plants originally owned by PG&E were routinely curtailed during the periods of abundant hydropower and low demand. Thereafter, the Geysers operators learned from experience which production wells could be curtailed and to what degree.

Four plants at The Geysers: Aidlin, Bear Canyon, Calistoga and West Ford Flat sell electricity to PG&E under Public Utility Regulatory Policies (PURPA) Act of 1978. Under this act, the utility (PG&E) purchases electric power from a facility that generates 80 mw net or less at the avoided cost of the utility. Such facilities are called Qualifying Facilities (QF). Under QF contracts for Bear Canyon (BC) and West Ford Flat (WFF), PG&E is allowed to order up to 1000 hours of Minimum System Curtailments (MSC) per year for each plant. In addition, Calpine can curtail the plant for certain economic and operational reasons in non-peak periods of the year.

The curtailment of the field results in two effects: (i) a lower declines rate of the field compared to that when produced without curtailments, and (ii) a temporary production of a steam puff. Decline rate is a function of steam withdrawal from the reservoir. The large mass of steam withdrawn results in high decline in reservoir pressure that, in turn, reduces the force that pushes the steam from the reservoir, resulting in lower steam flow rate. Curtailment of the field results in lower steam withdrawal and a rebound of reservoir pressure resulting in a lower decline rate, preservation of the resource and a temporary increase ("puff") in steam production subsequent to the curtailment.

This paper presents the results and analysis of the curtailment tests conducted at the Bear Canyon and Calistoga wellfields in The Geysers during March-June 2001. The effect of curtailments on decline rate of the Bear Canyon wellfield is also investigated by using annual production and decline rate data from 1991 to 2000.

CURTAILMENTS AT CALISTOGA

The Calistoga (Figure 1) wellfield was producing approximately 64 mw net during the first week of March 2001. The field was curtailed to 50 mw at night for 10 hours (from 10 pm to 8 am) on weekdays and all day on Saturday and Sunday effective March 6, 2001. These curtailments resulted in a puff, the magnitude of which is defined as the difference between actual generation during the test minus the generation before the start of the test on 3/6/2001. A plot of puff versus time is presented in Figure 2 for the data collected at 8 am, 2 pm and 10 pm. The amount of puff is the highest at 8 am just after the end of the curtailments, as expected. The puff continues to decrease during the day when wells were produced with wide-open valves from 8 am to 10 pm. However, the decrease in puff from 2 pm to 10 pm is quite small for all practical purposes as shown by the

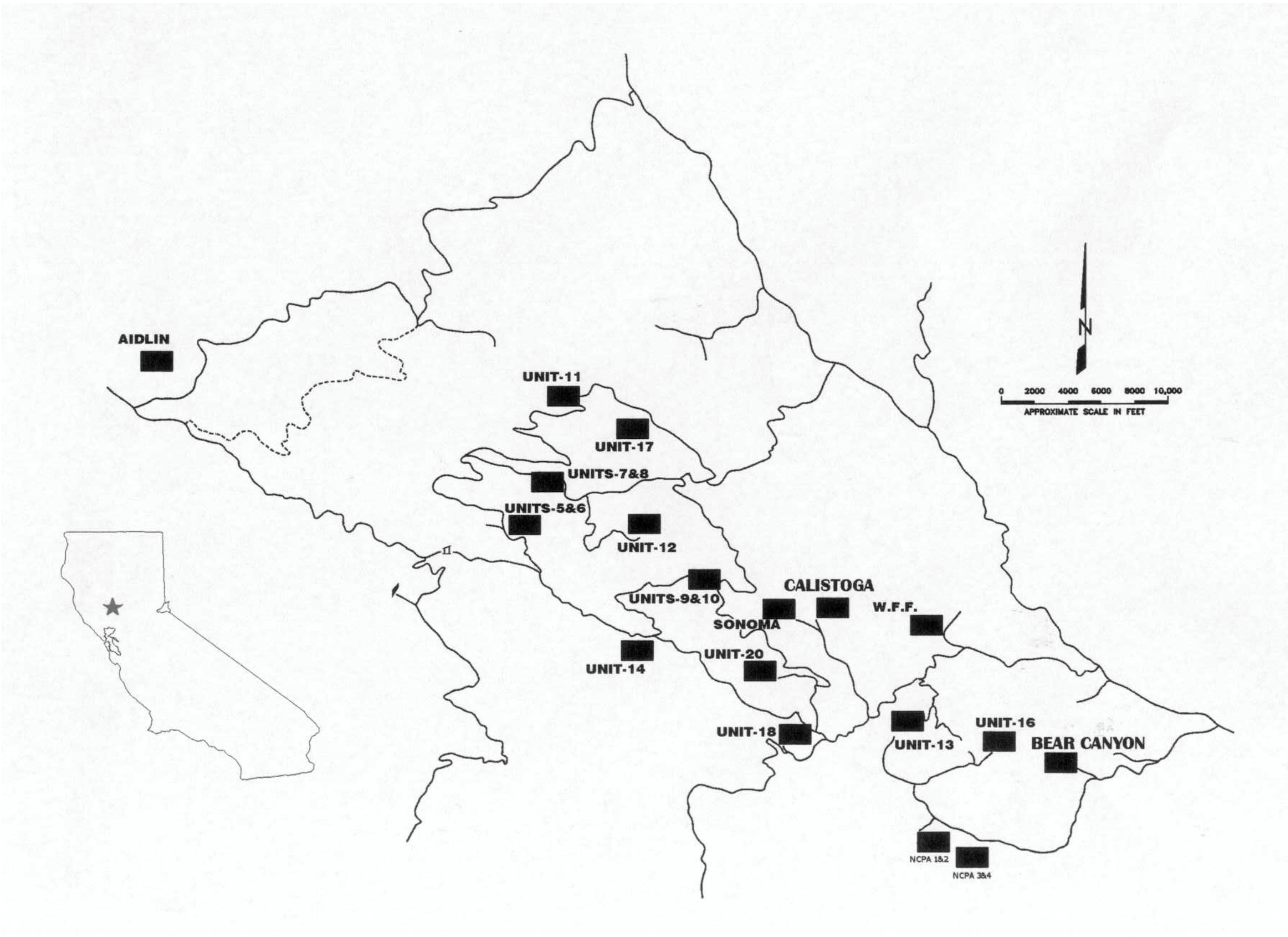

Figure. 1. Power plant Locations in the Geysers Geothermal Field, California

data points in Figure 2. Therefore, the amount of puff at 2 pm is used as a sustainable puff.

The curtailments discussed above resulted in a sustainable puff generation of approximately 2.5 mw (2 pm data) and a maximum puff generation of about 4.5 mw (8 am data) net in about 4 weeks as shown in Figure 2. During this period (March 6 to April 15, 2001) the ambient temperatures were generally below 40°F. However, the puff generation disappeared in the next two weeks (Figure 2) when the ambient temperature rose to 65°F on April 23-24, 2001. This suggests that a temperature rise of 25-30°F causes a drop in efficiency worth 2 to 2.5 mw at Calistoga.

During March-April, the Calistoga wellfield was curtailed by 12.8% as detailed below.

Normal generation per week=64*7*24 = 10,752 mwh
Curtailment per week=(64-50)*(5*10+2*24)=1,372 mwh
% Curtailment = 1,372/10,752 = 12.8%
Sustainable puff (2 pm) = 2.5 mw
Maximum puff (8 am) = 4.5 mw
% Puff (Sustainable) = 2.5/64 = 3.9%
% Puff (Maximum) = 4.5/64 = 7%

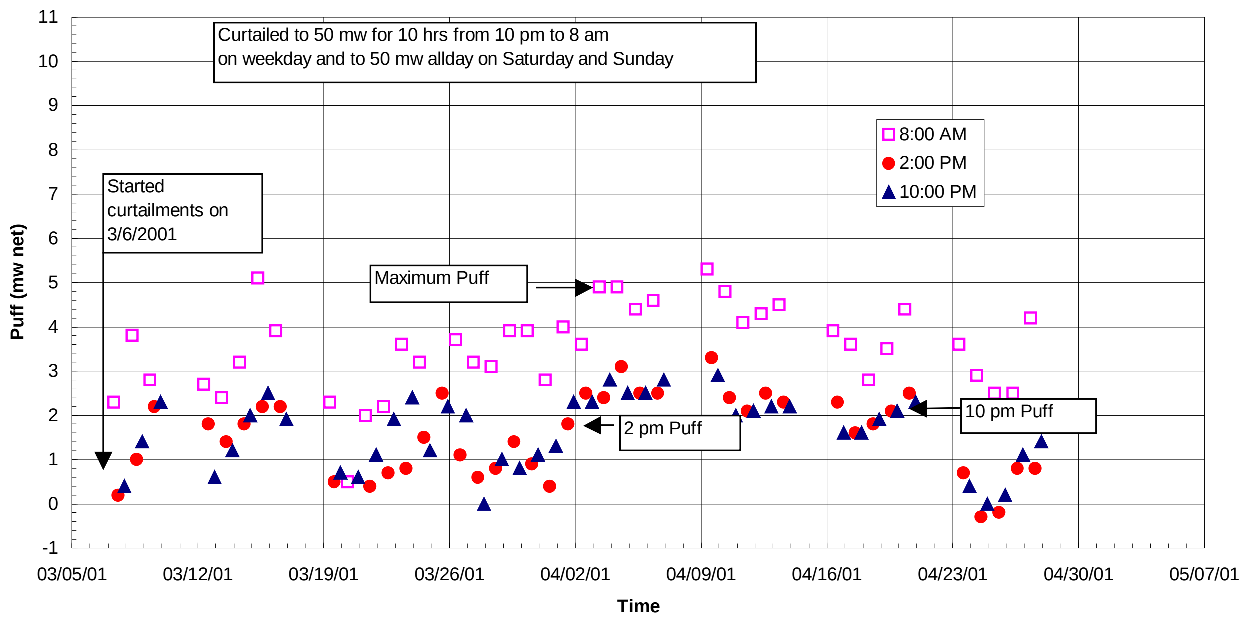

Figure 2. Puff Production due to curtailments at Calistoga.

CURTAILMENTS AT BEAR CANYON

The Bear Canyon (Figure 1) wellfield was producing 17.8 mw net before the start of curtailments on May 15, 2001. Initially the field was curtailed to 8 mw at night for 4 hours (from 0100 to 0500) each day effective May 15, 2001. Beginning June 1, 2001, the curtailments were increased from 4 to 10 hours (10 pm to 8 am) on weekdays and 4 to 24 hours on weekends.

The amount of puff generated at 2 pm as a consequence of curtailments in the Bear Canyon wellfield is shown in Figure 3. As discussed earlier for the Calistoga wellfield, the 2 pm puff is considered a sustainable puff for the Bear Canyon wellfield as well.

A sustainable puff of approximately 0.4 mw (2 pm data) was obtained during the first 2 weeks of curtailment (Figure 3). During this time, the Bear Canyon wellfield was curtailed by 9.2%. This curtailment resulted in a sustainable puff production of 2.2% as calculated below.

Normal generation per week = 17.8*7*24 = 2,990.4 mwh
Curtailment per week = (17.8-8)*7*4 = 274.4 mwh
% Curtailment = 274.4/2,990.4 = 9.2%
Sustainable puff (2 pm) = 0.4 mw net
% Puff = 0.4/17.8 = 2.2%

The increased curtailments from June 1, 2001, resulted in a sustainable puff production of 1.5 to 2.3 mw or an average of 2 mw as shown in Figure 3. During June, a curtailment of 32.1% generated a sustainable puff production of 11.2% as discussed below.

Curtailment per week = (17.8-8)*5*10 + (17.8-8)*2*24 = 960.4 mwh
% Curtailment = 960.4/2,990.4 = 32.1%
Sustainable puff (2 pm) = 2.0 mw net
% Puff = 2.0/17.8 = 11.2%

Bear Canyon and Calistoga curtailment data are summarized in the table below.

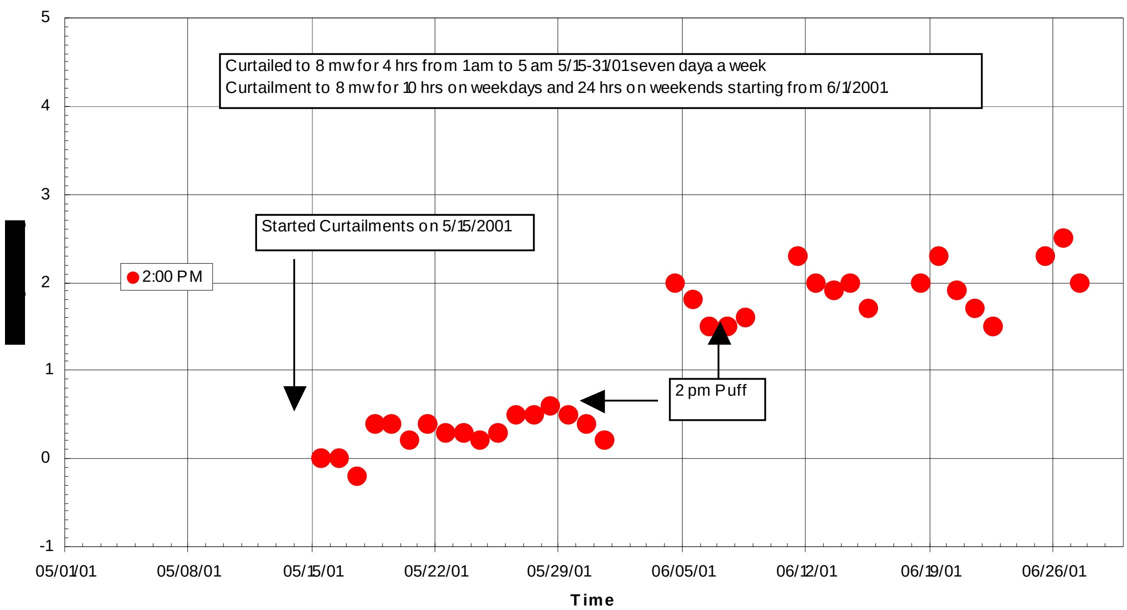

Figure 3. *Puff Production as a consequence of curtailments at the Bear Canyon wellfield*

SUMMARY OF CURTAILMENT RESULTS OBTAINED AT BEAR CANYON AND CALISTOGA

Wellfield	Duration	% Curtailment	% Puff
Bear Canyon	2- weeks	9.2%	2.2%
Bear Canyon	4- weeks	32.1%	11.2%
Calistoga	7-weeks	12.8%	3.9%

A plot of % Curtailment versus % Puff is shown in Figure 4. Using regression analysis, the following relationship was derived from these data for an R^2 value of 0.999.

% Puff = 0.3881 * % curtailment – 0.0123 (1)

Where;

% Puff = Ratio of sustained mw after curtailment to normal mw without curtailment

% Curtailment = Ratio of mwh curtailed to normal mwh generation without curtailment

Figure 4 can be used to evaluate puff production for assumed curtailments in various Geysers wellfields. The amount of curtailed generation recovered due to the puff is calculated from equation (1) for the various curtailments scenarios and shown in Figure 5. In developing this figure it is assumed that the duration of puff production is equal to that of the curtailment as suggested by the test data from Calistoga and Bear canyon wellfields discussed earlier. Figure 5 suggests that for a curtailment ranging from 10% to 25%, only 13% to 17% of the curtailed generation can be recovered.

CURTAILMENTS AND THE RESULTING DECLINE RATE AT THE BEAR CANYON WELLFIELD

The Geysers is a large, continuous steam field in which smaller contiguous areas produce steam to individual plants. The decline rate in a given wellfield in The Geysers is not only affected by its own production, injection and curtailment activities but also that of the nearby wellfields. The Bear

Canyon wellfield is situated in the southeast corner of the field (Figure 1) and is not surrounded by other wellfields on its northern and eastern side. Therefore, the effect of the adjoining wellfields on the performance of Bear Canyon is considered minor.

The Bear Canyon power plant is rated to generate 20 mw net and came on line in September 1988. This wellfield was able to produce 20 mw net until 1999 from the current nine producers.

The effect of the curtailments on the decline rate was evaluated for the Bear Canyon wellfield by using the annual production and decline rate data from 1991 to 2000. The maximum annual steam production (P_{max}) during the early 90's was assumed as the amount of steam needed to generate 20 mw net without any curtailments. The percentage curtailment for a given year was then calculated as the ratio of the P_{max} minus the actual steam production for that year and the P_{max}.

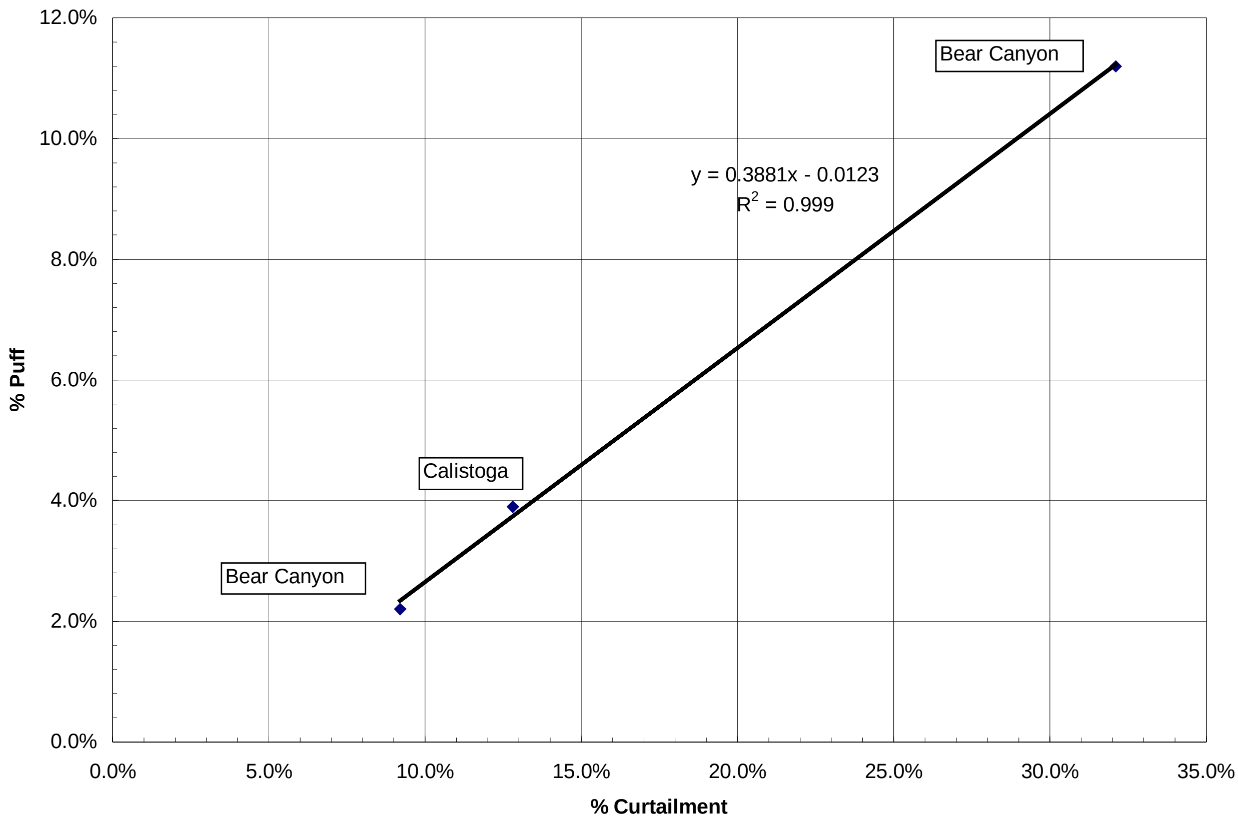

Figure 4. Puff Production as a function of Curtailment in Bear Canyon and Calistoga wellfields

A plot of annual percentage curtailment and annual decline rate is presented in Figure 6. Some abnormal fluctuations in data points may not represent true reservoir decline. The one or more of the following factors may have contributed to large fluctuations in the data shown in Figure 6. Wellbore scaling and wet wells that load up with water can cause high decline rate. Moreover, small flow rate wells can exhibit high decline rates due to wellbore condensation. Pressure interference with a new makeup well can also cause high decline in an existing production well. Normalizing flow rate at more than one wellhead pressure (110 and 120 psig), the use of normalized flow rate during excess capacity period and actual flow rate when all wells were wide open may influence decline rate numbers too. On the other hand, injection support and wellbore cleanout can produce increased flow rate or negative decline rate. Despite the effect of all these factors, the data in Figure 6 show a clear trend in which the decline rate decreases with increased curtailments and the line shown by the regression analysis provides a reasonable decline trend for the Bear Canyon wellfield.

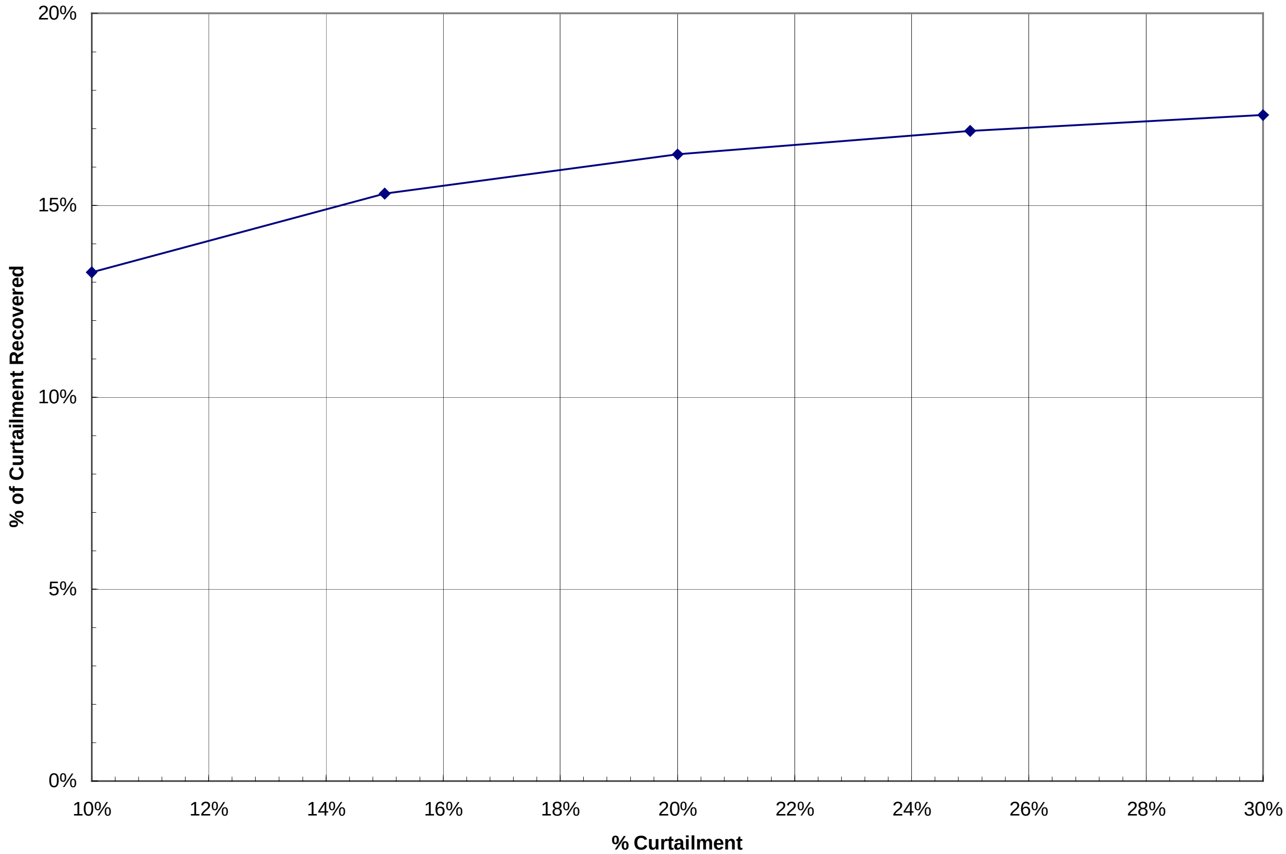

Figure 5. Recovery as Puff Production versus Curtailments in The Geysers

Using regression analysis, the following relationship was derived from these data for an R^2 value of 0.292.

DR = -0.3871 * Curtail +0.1144 (2)

Where;

DR = Annual decline rate

Curtail = (P_{max} – annual steam production for a given year)/ P_{max}

P_{max} = Maximum annual steam production in early 90's, klbm.

Figure 6 can be used to estimate decline rate for an assumed curtailments in the Bear canyon wellfield. It suggests that an increase in curtailments from 4% to 9% decreases decline rate in the Bear Canyon wellfield from 10% to 8%.

CONCLUSIONS

The curtailments in The Geysers help reduce the decline rate of the field thereby preserving the resource as well as providing a small increase in steam flow rate (puff) following the curtailment period.

Curtailment tests conducted in two wellfields (Bear Canyon and Calistoga) in The Geysers suggest a linear relationship between curtailments and the resulting puff as shown in Figure 4. This figure suggests that for a curtailment of 10 to 25%, The Geysers field can generate a puff of 2.6% to 8.5% respectively. For this range of curtailments, only 13% to 17% of the curtailed generation can be recovered as puff as presented in Figure 5.

10-year decline and curtailment history shown in Figure 6 for the Bear Canyon wellfield suggests that curtailments reduce decline rate. For an increase in curtailments from 4% to 9% decline rate in the Bear Canyon wellfield decreases from 10% to 8%.

ACKNOWLEDGMENTS

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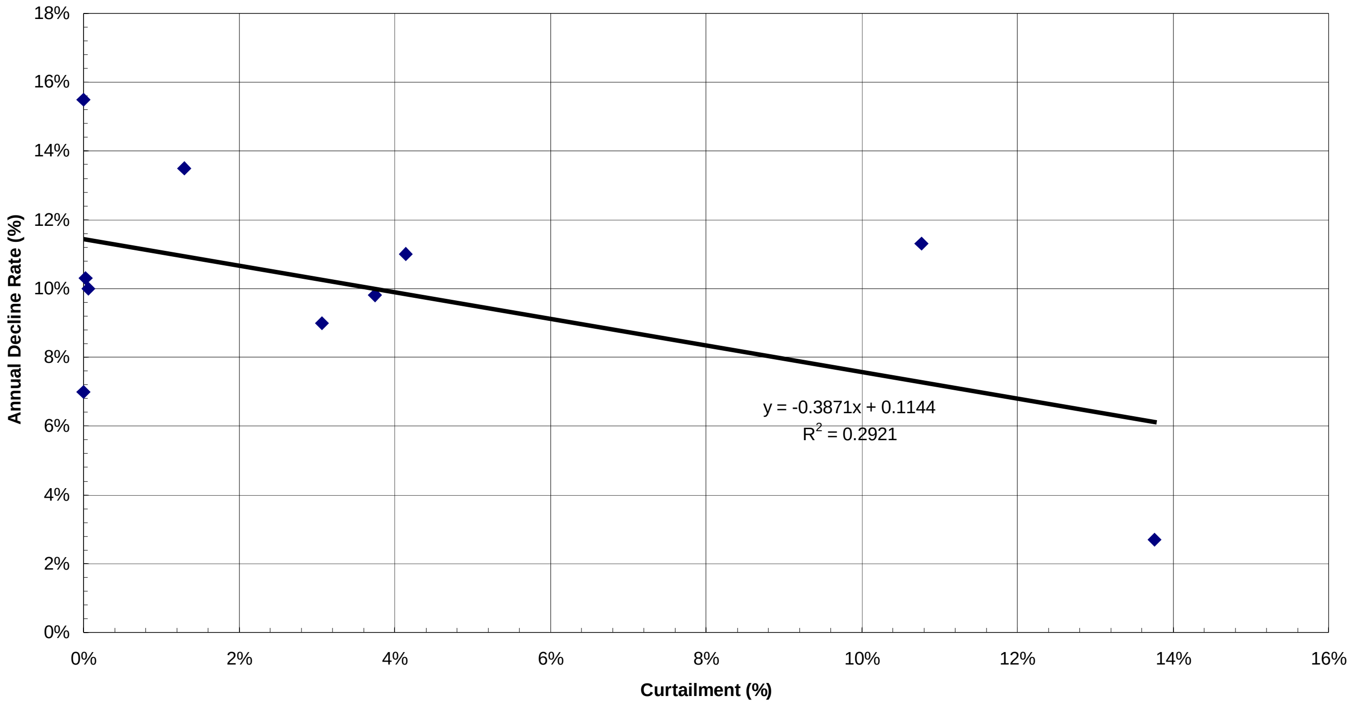

Figure 6. Annual Decline rate versus annual curtailments in Bear Canyon wellfield