SGP-TR-50-3

# PROCEEDINGS
# SIXTH WORKSHOP
# GEOTHERMAL RESERVOIR ENGINEERING

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## DISCLAIMER

# PRODUCTION HISTORY OF THE GEYSERS STEAM FIELD

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## INTRODUCTION

A rather comprehensive reservoir engineering study made by Ramey (1968) of the Big Geysers area contains a table of yearly production, cummulative production, and average pressure of wells producing from the shallow zone in the Big Geysers area for the period from 1957 to 1967. Production prior to 1957 is not included in the cummulative production because of incomplete records. He used the information to plot a p/z curve versus cumulative production to obtain an ultimate steam recovery of 135 billion pounds from the shallow zone to an abandonment pressure of 65 psig.

A brief engineering study was presented by Lipman, et al (1977), at which time eleven power generating plants were in operation. Included in that study is a brief picture of the regional drainage system around the Sulphur Bank, Happy Jack, and Big Geysers area showing the shallow reservoir anomaly in relation to the larger regional fracture system. Also presented is a pressure map showing the change of the 500 psia isobar with time and an isobaric map as of April 1977. These two maps cover the area from which wells produced steam into Units 1 to 11. These authors, however, did not present production data to correlate with the pressure behavior that they described.

This paper presents a brief history of the development of the field, followed by several examples of production decline curves for wells having six or more years of history. The wells selected have varying production rates and original well spacings. The paper concludes with a section on the monthly, yearly, and cumulative production data as reported to the California Division of Oil and Gas.

## BRIEF HISTORY OF DEVELOPMENT

The development of the Geysers Field began in 1921 with the drilling of a well in the Big Geysers area. By 1925 eight wells had been drilled but further development ceased because of a lack of market for energy developed from steam (Allen and Day, 1927).

In 1955 development started again when Magma Power Company obtained a lease from the Geysers Development Company and drilled well Magma 1. Magma Power Co. then joined with Thermal Power Co. to drill additional wells to test the potentialities of the Geysers steam reservoir and to aid in marketing the steam. (McMillan, 1970; Garrison, 1972) Drilling continued until by the end of 1959 thirteen more wells had been drilled.

In September, 1960, the first power plant of 12 MWe was installed. Experience with this plant indicated the viability of produced steam as a source of energy for generating electric power. In 1961 two wells were drilled and in 1963 eight more wells were drilled with Unit 2 of 14 MWe installed in March of that year. Drilling continued until by the end of 1965 the Magma-Thermal group had drilled 37 wells.

In 1966 Union Oil Company drilled and completed Ottoboni Federal 1 as a successful producing well. In that year Union and the Magma-Thermal group pooled their leases to further develop the area with Union as the operator. By the end of 1968 a total of 54 wells had been drilled, of which two were drilled by Geothermal Resources International, and Units 3 and 4 had been installed for a total generating capacity of 80 MWe.

The drilling activity increased in 1969 in anticipation of additional power plants to be put in operation. In the years 1971 through 1974 seven more units were installed and placed on line. It was almost five years before another plant was placed on line. By September 1980 fourteen units were on line with a total installed generating capacity of 930 MWe.

A list of the plants in operation along with field operator, date of installation, and size of plant is given in Table 1. In addition to Union, Thermogenics and Aminoil now also supply steam to power plants. As can be seen Aminoil supplies steam to the largest plant.

## INDIVIDUAL WELL PRODUCTION BEHAVIOR

The initial steam production rate of a new well depends on the size and number of fractures penetrated by the well, on the hole and casing size, on the depth of the well, on the reservoir pressure, and on the reservoir itself. For high rates the well will be limited primarily by hole size. For low rates the well will be limited by the effective kh (permeability-thickness product) of the reservoir around the wellbore. The wellbore effects of depth and hole size were illustrated by Budd (1972) who presented two graphs showing how rate versus wellhead pressure was effected by hole size and by depth.

Typical production decline curves for eleven wells are shown in Figs. 1 to 7. The data plotted are as reported by the operator to the California Division of Oil and Gas. The history period ranged from six to twelve years. The initial rates varied over about a five-fold range. The initial well spacing varied also being about five acres per well for the Happy Jack, Sulphur Bank, and Thermal wells in the old part of the field to about 40 acres per well for the other wells. All of the production data were not available for wells Sulphur Bank 7 and Thermal 10 because prior to April, 1968, only the kilowatt-hours generated were reported. Thermal 10 actually went on production into Unit 1 in September 1960; Sulphur Bank 7 into Unit 3 in July, 1967.

These production curves can be compared with those of Budd (1972) for well spacings of 45, 20, and 5 acre spacing. The average curve for these wells falls about midway between the 20 and 5 acre curves with the actual curve showing a decline at the end of six years that is greater than the decline of the calculated curves presented by Budd.

## FIELDWIDE PRODUCTION

The monthly production rate of the Geysers Field based on reported data is shown in Figure 8. As of the end of 1979, when 684 MWe were on stream, the maximum rate was 7489 million pounds of steam for the month of December, 1979.

Yearly production data and cumulative data are shown in Table 2. The total steam production data include field production from wells on stream and estimated production consisting of flow from blowout well Thermal 4; from wells that are being vented; and from tests on wells that are being drilled (PG&E 1979). The reported production was obtained from the files of the California Division of Oil and Gas. The cumulative production at the end of 1979 was 624 billion pounds of steam.

## REFERENCES


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3. Garrison, L.E., 1972; "Geothermal Steam in The Geysers - Clear Lake Region, California"; Geol. Soc. of Am. Bull. 83, p. 1449-1468.

4. Lipman, S.C., Strobel, C.J., and Gulati, M.S., 1977; "Reservoir Performance of The Geysers Field"; Proceedings of the ENEL-ERDA Workshop, Larderello, Italy, p. 233-255.

5. Magma Power Co. Annual Report, Year Ended December 31, 1979; Six Months Ended June 30, 1980, p. 5.

6. McMillan, D.A., Jr., 1970; "Economics of The Geysers Geothermal Field, California"; U.N. Symposium on the Dev. and Util. of Geothermal Resources, Pisa Vol. 2 Pt. 2 P. 1705-1714, or Geothermics Spec. Issue 2.

7. PG&E, 1979, Application for Certification of Geysers Unit 18, April 17.

8. Ramey, H.J., Jr., 1968; "A Reservoir Engineering Study of The Geysers Geothermal Field"; Reich and Reich, Petitioners vs. Commissioner of Internal Revenue 1969 Tax Court of the United States 52, T.C. No. 74, 1970.

TABLE 1

POWER PLANTS INSTALLED
GEYSERS FIELD, CALIFORNIA

| Unit | Operator | Date on Line | MWe | Cum MWe |
|---|---|---|---|---|
| PG&E 1 | Magma-Thermal (a) | September 60 | 12 | 12 |
| PG&E 2 | Magma-Thermal (a) | March 63 | 14 | 26 |
| PG&E 3 | Union | April 67 | 27 | 53 |
| PG&E 4 | Union | November 68 | 27 | 80 |
| PG&E 5 & 6 | Union | December 71 | 55/55 | 190 |
| PG&E 7 & 8 | Union | Aug. & Nov. 72 | 55/55 | 300 |
| PG&E 9 & 10 | Union | Oct. & Nov. 73 | 55/55 | 410 |
| PG&E 11 | Union | May 75 | 110 | 520 |
| PG&E 12 | Union | March 79 | 110 | 630 |
| PG&E 15 | Thermogenics | June 79 | 55 | 685 |
| PG&E 13 | Aminoil | May 80 | 135 | 820 |
| PG&E 14 | Union | September 80 | 110 | 930 |

(a) Magma-Thermal group was operator prior to joining with Union

TABLE 2

YEARLY PRODUCTION*
GEYSERS FIELD, CALIFORNIA

| Year | Field Production (a) | Estimated Other (a) | Total Steam Production (a) | Reported Production | Cum. Production (b) |
|---|---|---|---|---|---|
| 1957 | 110 | 997 | 1107 | | 1.11 |
| 1958 | 113 | 2470 | 2583 | | 3.69 |
| 1959 | 442 | 2429 | 2871 | | 6.56 |
| 1960 | 1013 | 2192 | 3205 | | 9.77 |
| 1961 | 2273 | 2219 | 4492 | | 14.26 |
| 1962 | 2422 | 2024 | 4446 | | 18.70 |
| 1963 | 4025 | 2098 | 6123 | | 24.83 |
| 1964 | 5892 | 2058 | 7950 | | 32.78 |
| 1965 | 5763 | 1988 | 7751 | | 40.53 |
| 1966 | 6639 | 1864 | 8503 | | 49.03 |
| 1967 | 9079 | 1722 | 10801 | | 59.83 |
| 1968 | 9822 | 1791 | 11613 | | 71.44 |
| 1969 | 15019 | 1743 | 16762 | 15019 | 88.21 |
| 1970 | 14365 | 1892 | 16217 | (c) | 104.44 |
| 1971 | 17321 | 1720 | 19041 | 17226 | 123.46 |
| 1972 | 34783 | 2039 | 36822 | 34783 | 160.29 |
| 1973 | 47320 | 2231 | 49551 | 47320 | 209.84 |
| 1974 | 58045 | 2418 | 60463 | 58046 | 270.30 |
| 1975 | 67387 | 2440 | 69827 | 67229 | 340.13 |
| 1976 | 71015 | 2191 | 73206 | 70498 | 413.33 |
| 1977 | 71567 | 1714 | 73281 | 71709 | 484.57 |
| 1978 | -- | -- | -- | 60960 | 545.53 |
| 1979 | -- | -- | -- | 79140 | 624.67 |

* In million pounds
(a) Reference (PG&E 1979)
(b) In billion pounds
(c) October production data missing from files

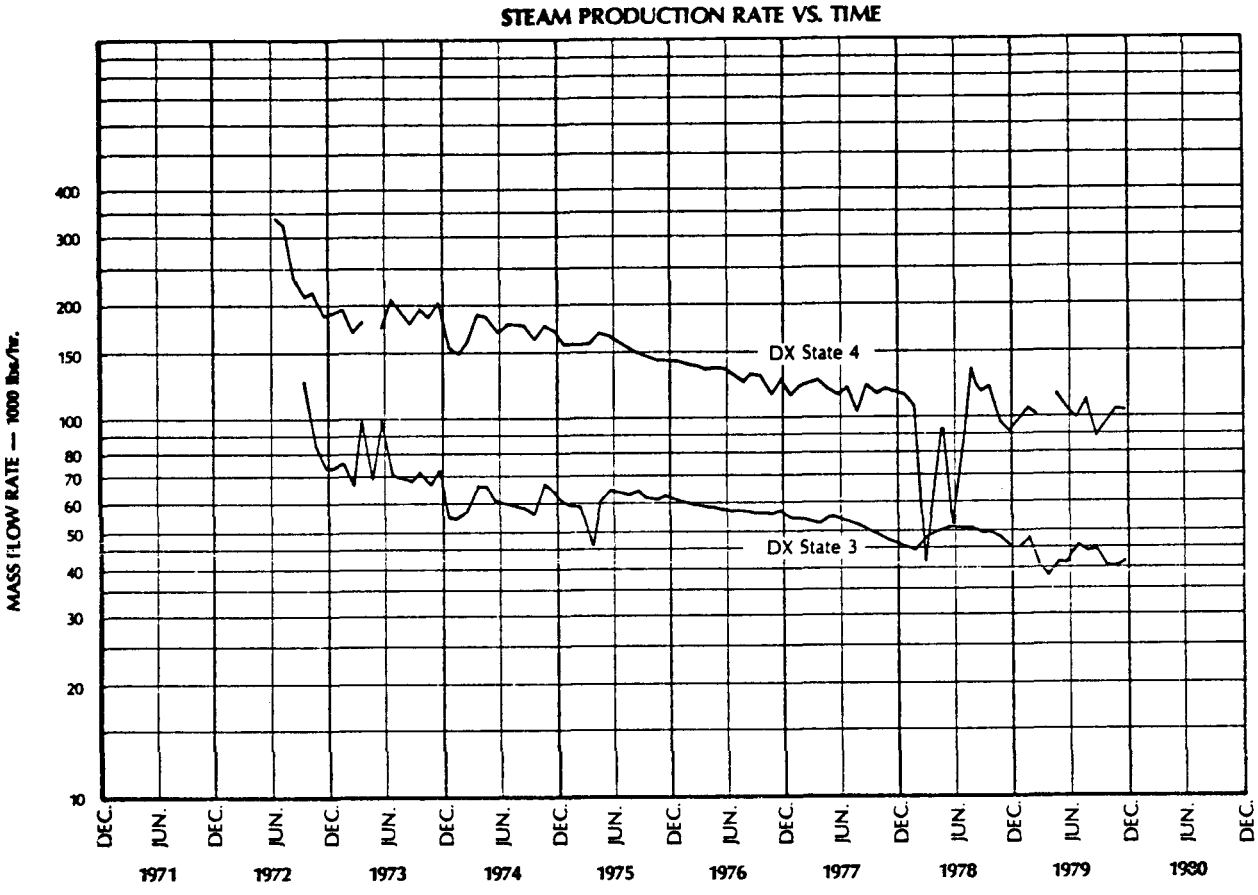
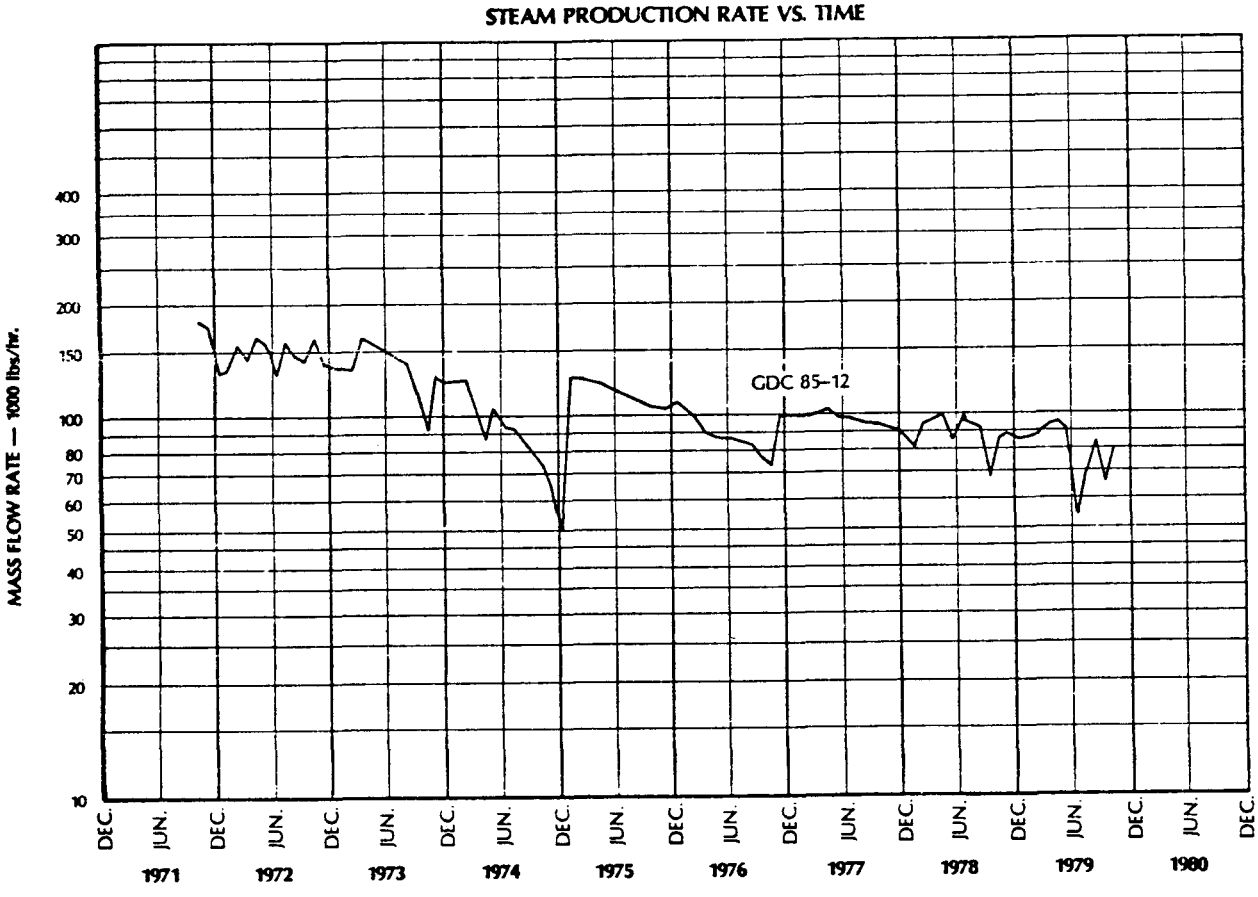

STEAM PRODUCTION RATE VS. TIME
MASS FLOW RATE — 1000 lbs/hr.
400
300
200
150
100
80
70
60
50
40
30
20
10
DX State 4
DX State 3
DEC.
JUN.
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980

Figure 1


STEAM PRODUCTION RATE VS. TIME
MASS FLOW RATE — 1000 lbs/hr.
400
300
200
150
100
80
70
60
50
40
30
20
10
GDC 85-12
DEC.
JUN.
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980

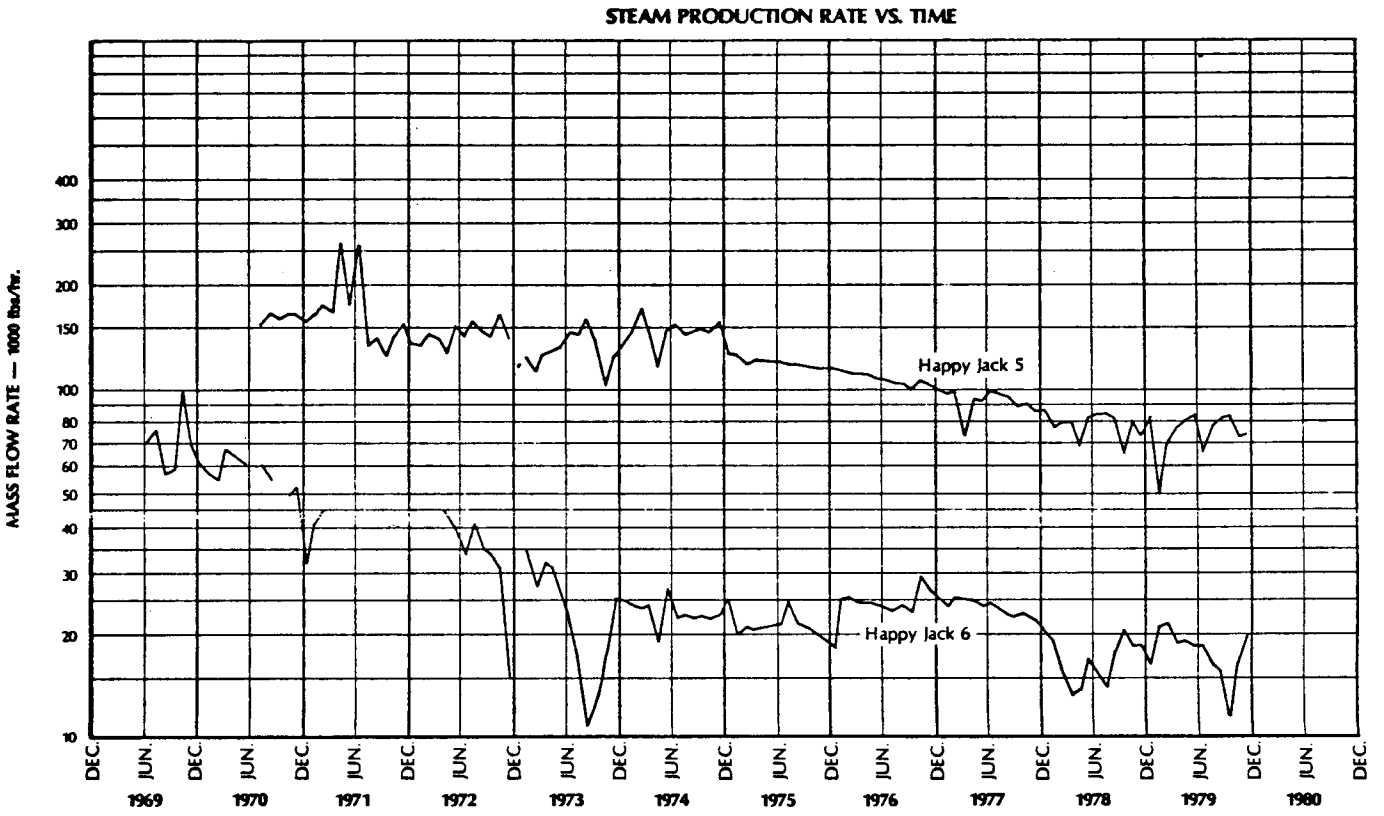



Figure 3

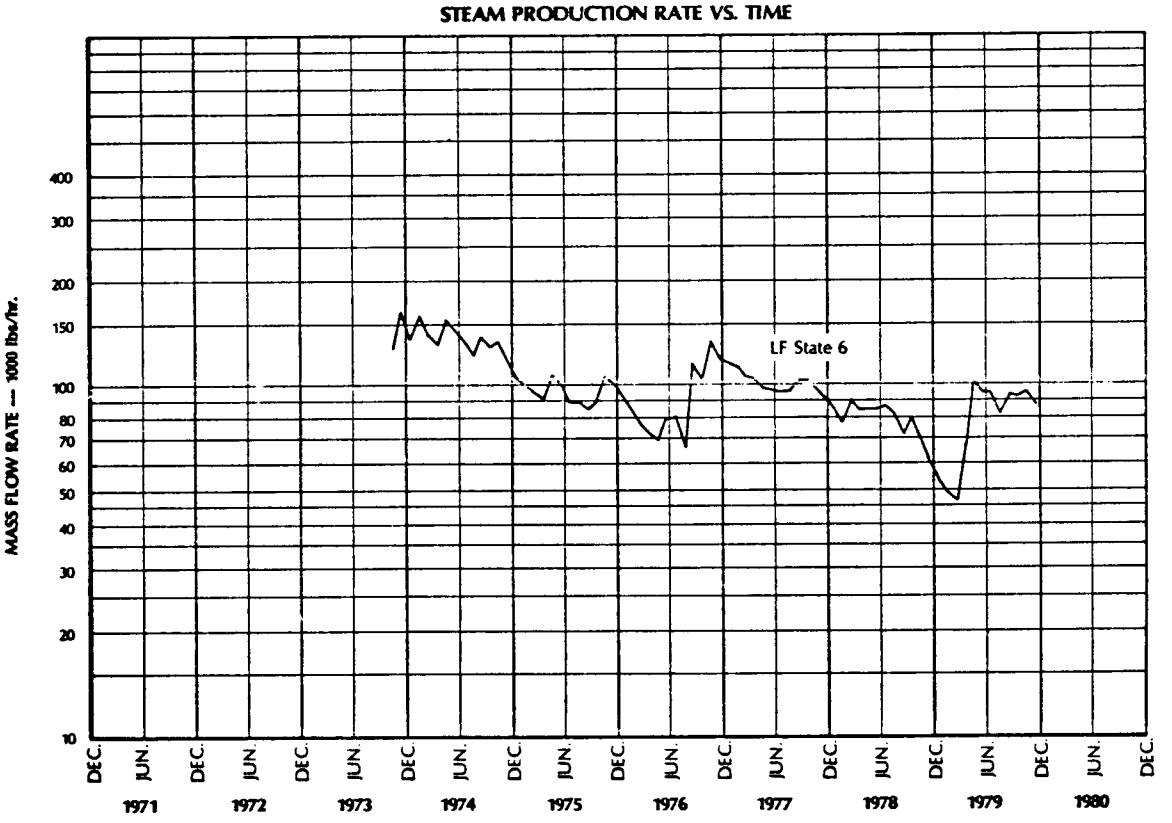
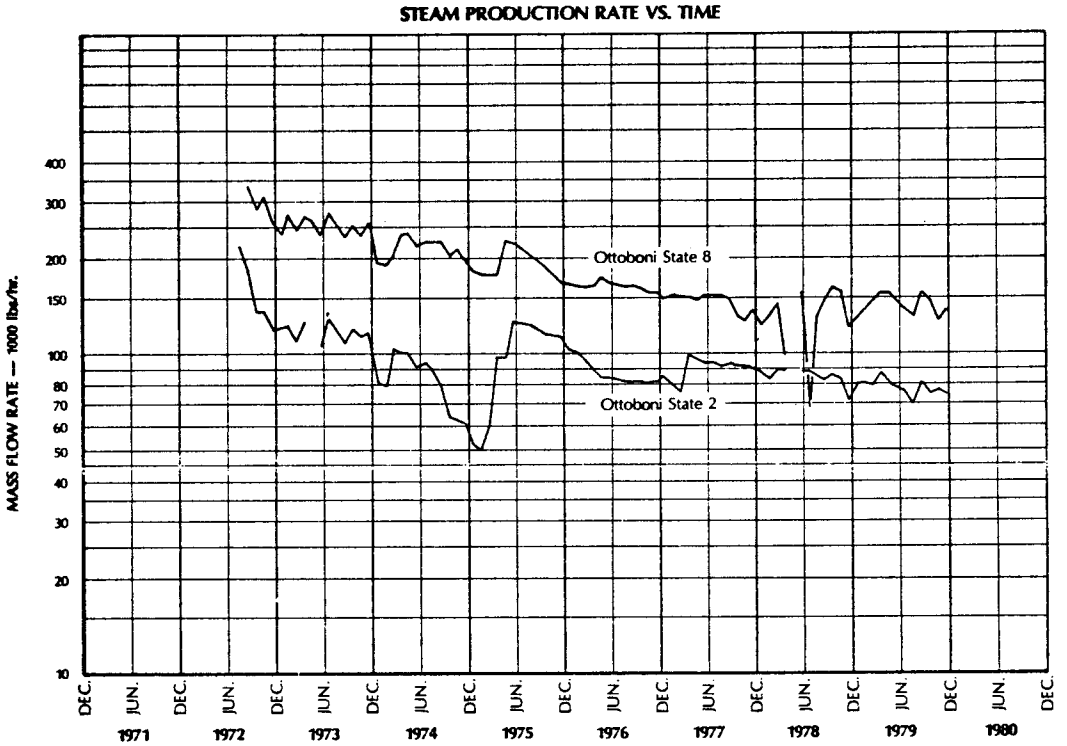



Figure 4

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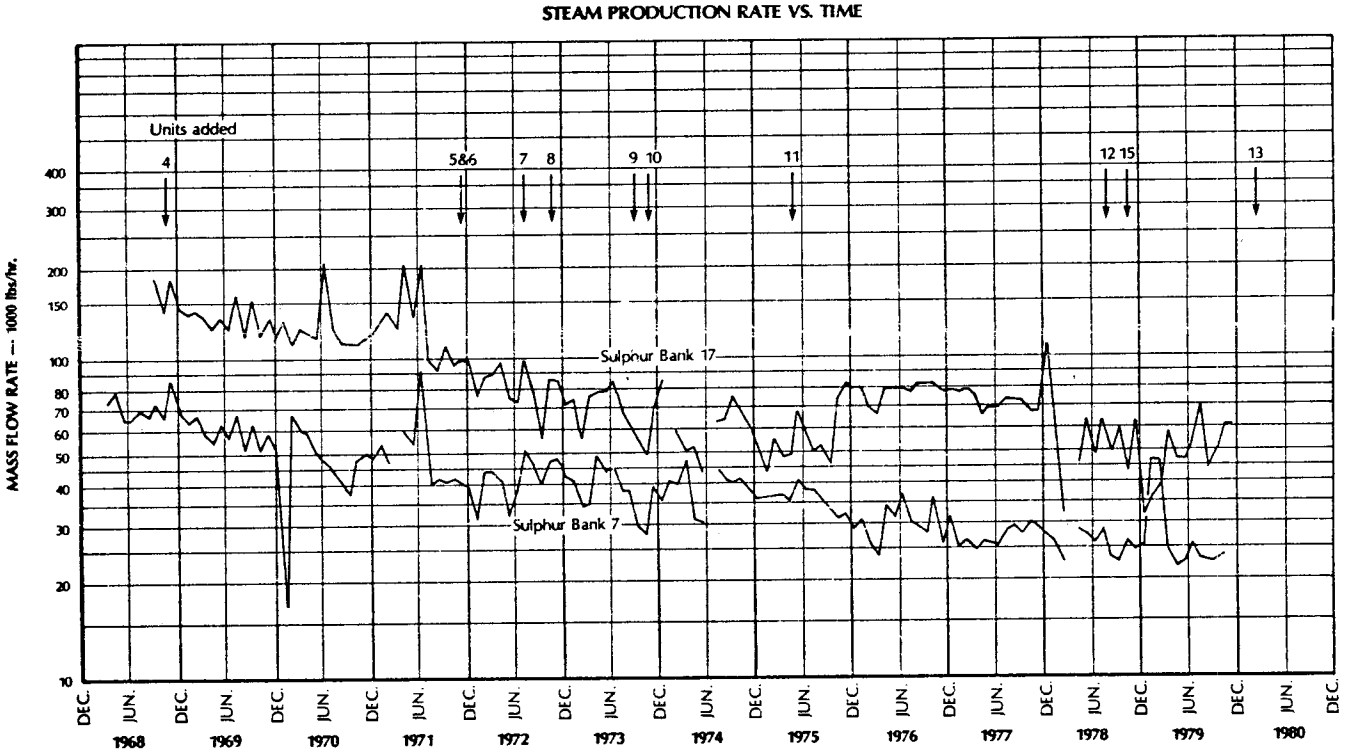


Figure 6

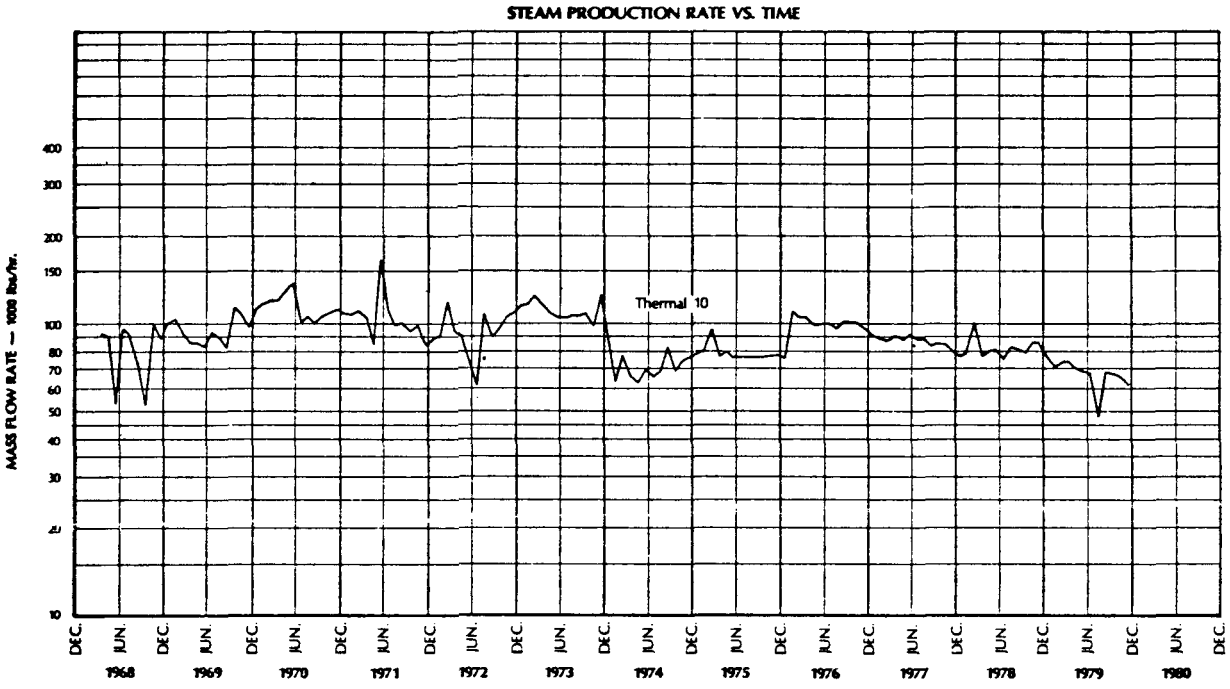


Figure 7

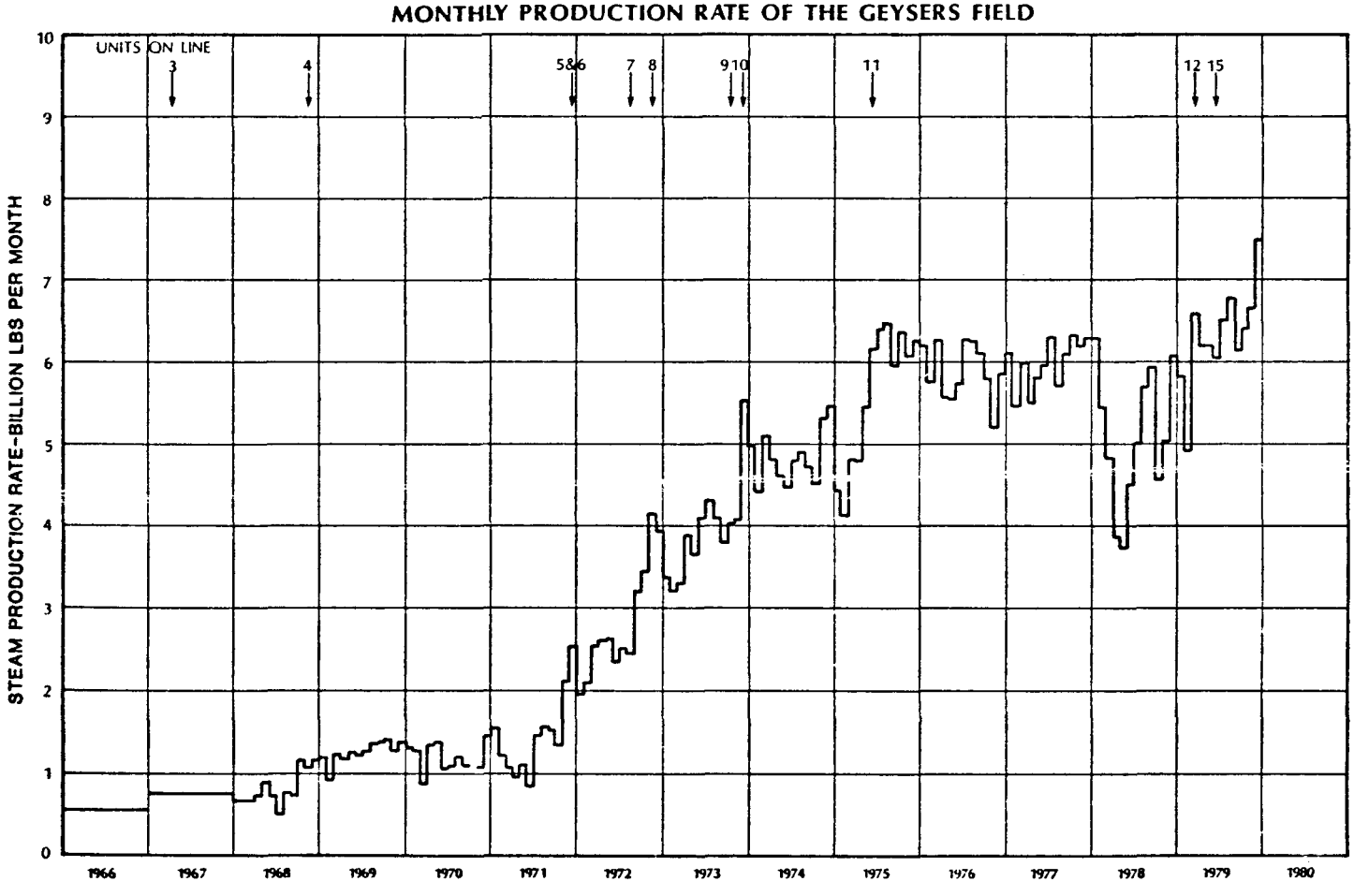


Figure 8