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EXPANDING RESOURCE DEVELOPMENT OF THE SOUTHEAST GEYSERS STEAM FIELD

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ABSTRACT

In 1974 Shell Oil bid $4.5 million for two federal leases (4077 ac.) located south of production at The Geysers. Shell's second well discovered dry steam, triggering five stages of expanding resource development. Initial development of 69MW of steam prompted a 110 MW power plant commitment from NCPA in 1978. Stage Two saw completed development drilling for Plant #1, a 55 MW Plant #2 commitment, ending with Grace Geothermal buying the steamfield in Sept 1983. Limited drilling by Grace constituted Stage Three. NCPA consequently purchased the steam field in 1985, undertaking the accelerated development drilling required to supply impending startup of Plant #2 (meantime doubled to 110 MW capacity). The Stage Five objective is to now maintain 265 MW of available steam. To combat depletion the steam field area was recently expanded by 76%, and augmented injection is planned for improved reservoir pressure retention.

INTRODUCTION

The first U.S. Federal Government Geothermal (KGRA) Lease Sale was held in January 1974. Included were two adjacent parcels totaling 4077 acres, at the time located south of all existing (private lands) steam production at The Geysers (see Fig. 1). These two parcels received 13 bids, with Shell Oil winning both for $4.5 million. Shell began drilling ten months later at a location slightly east of the Big Sulfur Creek Fault, on trend with Union's production 1.5 miles NW. That first well (A-2), which included two redrilled legs, reached 8975 ft without finding steam. In June 1975 Shell spudded their second well (B-2) one mile farther east, discovering 182,400 LBS/HR (12.2 MW) of dry steam at 4951 ft. That success has triggered to date five stages of progressively increased resource development, including the present drilling operations designed to further expand reservoir development in this Southeast Geysers area.

STAGE ONE- Exploration, Initial Development

Immediately following the success of well B-2 a wide-ranging temperature gradient hole program was conducted and evaluated, while three more successful producing wells were being drilled from B and C pads. After adding two (initially) successful wells on D pad, for a total of six producers, a steam sales agreement was signed between Shell and Northern California Power Agency (NCPA) on June 27, 1977. That agreement committed NCPA to permit and build a 110 MW (two 55 MW turbine) power plant, while requiring Shell to dedicate all the production from the central and western portions (the "Primary Block") of its leases to this plant. The Shell development program continued uninterrupted for another year, with three wells (E-10, G-l, J-l) of the next five drilled being unsuccessful attempts to laterally expand the proven reservoir area, and with one (E-9) of the two new productive wells being damaged after completion. By early September 1978 Stage One had been completed; 12 wells had been drilled, six were productive, and of those six the four wells located within the Primary Block were collectively capable of producing 740,000 LBS/HR (49.3 MW) of steam.

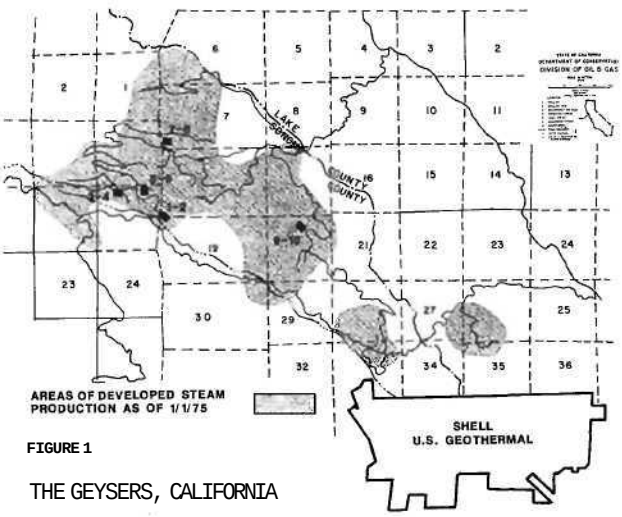


FIGURE 1

THE GEYSERS, CALIFORNIA

STAGE TWO- Project One Completion, and Plant #2 Commitment

Further development of the steam field was suspended a year until State and Federal approvals for construction of the power plant were imminent. Starting in November 1979 Shell renewed drilling, plant construction approvals were received in April 1980, and by August 1982 a series of 12 more wells had been drilled. Nine of those were productive, with eight located in the Primary Block. 2,116,000 LBS/HR (141.1 MW) of steam was now available for Plant #1, completing its initial steam supply requirements. In the meantime Shell had developed 26.3 MW of steam deliverability from 3 wells located on its adjacent East Block, and an additional sales agreement had been made in September 1980. NCPA was thereby committed to build a second power plant of 55 MW capacity, plus add an additional (fourth) 55 MW turbine if sufficient steam supply were later developed.

Power generation at Plant #1 was initiated in January 1983, and full capacity was reached by June 1983. Three months later, on September 6, 1983, Shell sold to Grace Geothermal Co. all its geothermal interests for $107 million, including the Southeast Geysers steamfield. That brought to a close Stage Two of this development history.

Table 1 and Figure 2 summarize the results of the nine years of Shell operations. The 15 production wells were limited to locations within the north-central portion of the lease block, with dry holes existing to the west, south and east. Consequently the area of reservoir development was about 300 acres, as approximated by taking the withdrawal area of each production well to be about 2 0 acres, and the fact that these 15 producers were adequately spaced.

TABLE 1

Shell Drilling Results at Southeast Geysers

Well Name	Year Drl'd	Total Depth (1)	Status	Prod Rate(2) M#/HR	Cum Prod Rate
Primary Block					
A-2**	1974	8975	Abd	0	
C-l	1975	4968	Prod	235	235
C-2	1975	5626	Prod	240	475
D-3	1977	9082	Prod	65	540
D-4	1977	8030	Inj(3)	100	
F-l	1977	5469	Prod	200	740
G-1*	1978	9156	Abd	0	
J-l	1978	9008	Abd	0	
C-4	1980	5431	Prod	113	853
C-5	1980	5440	Prod	135	988
F-2	1980	5888	Prod	180	1168
F-3	1980	8304	Abd	0	
F-4*	1980	7538	Prod.	101	1269
D-5	1981	5375	Prod	150	1419
D-6	1981	6512	Prod	117	1536
N-l	1981	4616	Prod	317	1853
N-2	1981	5919	Prod	263	2116
A-3	1982	6807	Inj	0	
East Block					
B-2(4)	1975	5540	Prod	120	120
B-3**	1975	8161	Prod	180	300
E-9	1977	6967	Abd(5)	119	
E-10*	1977	8222	Abd	0	
Q-l	1979	6975	Prod	95	395
M-l*	1980	8753	Idle	0	

Notes: (1) Max depth,, including redrill(s).
(2) Initial rate, at 160 psig WHP#
(3) After completion well damaged.
(4) Ran liner in 1976, reducing flow.
(5) Casing collapsed following test.
* Redrilled once ** Redrilled twice

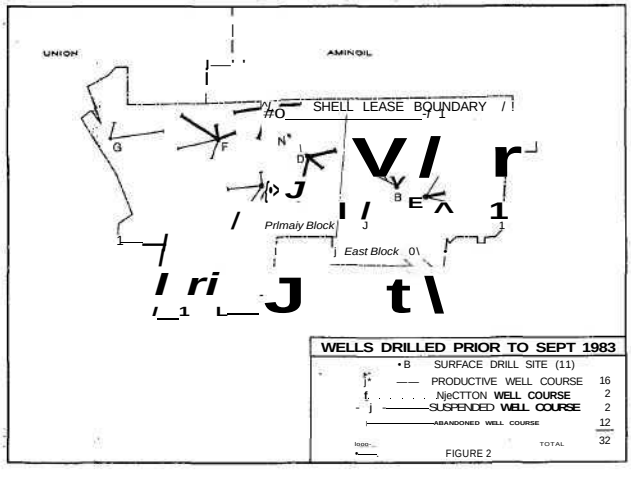


FIGURE 2

STAGE THREE- Steam Field operations During Grace's Ownership

Within 3 months after acquiring the steam field Grace drilled Q-2 as their first well, attempting to expand the East Block development area. During this time construction of NCPA Plant #2 had been approved and was underway, having been increased in capacity to 110 MW as of December 1982 so that NCPA could: (1) have an installed backup turbine for interim use during overhaul periods, thereby maintaining normal output levels, and (2) utilize any excess (>165 MW) steam if it were to become available.

Following the failure of Q-2, which became an injector, Grace was not inclined to aggressively pursue the drilling activity necessary to either timely develop an adequate steam supply for scheduled Plant #2 start up, or maintain a level supply for Plant #1 continuing generation. All further drilling under Grace's ownership was consequently under the agreements• non-consent provisions, with NCPA necessarily advancing all the drilling costs that were to be then repaid 150% by the production obtained.

Drilling resumed under these conditions in mid-1984, first with the failure of A-l, followed by the successes of Q-3, Q-4, N-4, and Q-l deepening. Later well A-3 was also deepened, successfully resulting in its conversion to production. Drilling was underway with the third well at P Site, in the East Block, when on 29 August 1985 NCPA purchased the steamfield, paying Grace $165 million. Stage Three was over, with the five new production wells (totaling 38.2 MW) having increased the development area to about 390 acres (refer to Figure 3 and Table 2).

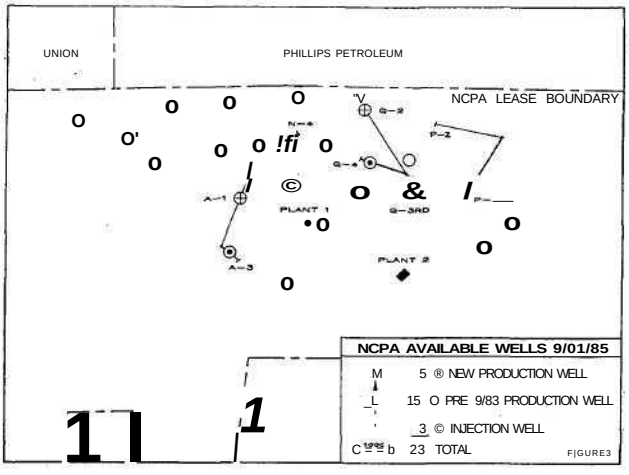


FIGURE3

TABLE 2

Drilling Results During Grace's Ownership

Well Name	Year Drl'd	Total Depth	Status	Prod Rate	Cum Rate
Primary Block					
A-l	1984	8066	Inj	0	
N-4	1984	7171	Prod	96	96
A-3(1)	1985	7421	Prod	108	204
East Block					
Q-2	1983	7340	Inj	0	
Q-3*	1984	4768	Prod	93	93
Q-4	1984	5518	Prod	166	259
Q-l(2)	1984	8975	Prod	0(2)	
p-1*	1985	5482	Prod	110	369
P-2*	1985	7428	Idle	0	

Notes: (1) Deepened, converted to producer.
(2) Deepened, no increased production

STAGE FOUR- Accelerated Development for Plant #2

With total control of all operations, NCPA's development well drilling began in earnest in September 1985 with the simultaneous operation of three drilling rigs. In eight months 12 new wells were drilled, resulting in 11 successful producers and one (P-3) dry hole (see Table 3). The total active wells had thereby increased to 30 production wells plus 3 injectors. Steam supply capability had increased from 2,128,000 LBS/HR (142 MW) to 3,344,000 LBS/HR, sufficient to produce 223 MW by the end of April 1986.

This additional development had taken place almost exclusively at previously existing multiple well sites, specifically at F, C, and N; the only "new" area brought into production was E Site. Those 11 new wells had therefore been positioned mainly at infill locations (ref. Figure 4), to minimize risk, but they effected a reduction in average well spacing. The development area had reached 48 0 acres, an average of 16 acres per well.

Plant #2 had begun operating in November 1985, it first reached full capacity during April 1986, and by May 1, 1986 NCPA had achieved a total generation level of 220 MW (gross). With this accomplishment Stage Four was complete.

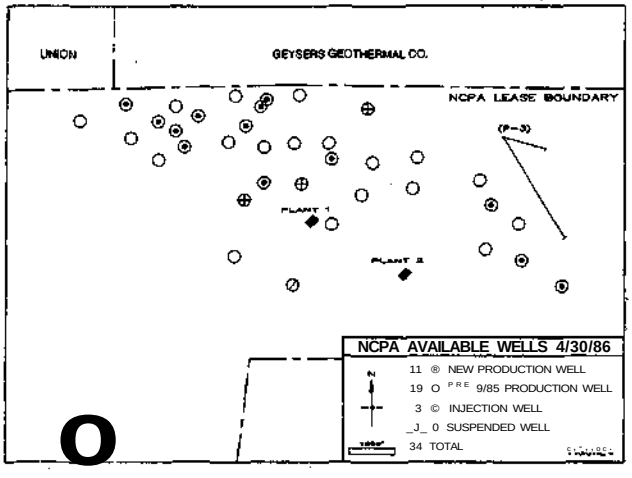


TABLE 3

NCPA Drilling Results: Sept 1985-April 1986

Well Name	Year Drl'd	Total Depth	Status	Prod Rate
P-3*	1985	6731	Idle	**0**
E-1*	1985	7744	Prod	**97**
F-5	1985	6315	Prod	180
F-6*	1985	6904	Prod	175
C-6*	1986	5540	Prod	100
C-7	1986	5516	Prod	102
C-8*	1986	6516	Prod	102
N-3	1986	6960	Prod	197
N-5	1986	6511	Prod	**97**
N-6**	1986	6937	Prod	155
F-3	1986	6828	Prod	120
F-7*	1986	7592	Prod	85

Notes: * Redrilled once
** Redrilled twice

STAGE FIVE- Reservoir Development Expansion and Extension

By the start of the present (fifth) development stage NCPA had recently assembled the technical employee staff to undertake in-, house all drilling, geologic and reservoir engineering responsibilities, including overall steam field management.

Two principal objectives were initially established. The first was to increase our steam deliverability (total well potential) to at least 275 MW. The second objective was to extend the depth and expand the area of steam supply, increasing the reservoir volume being tapped, in order to reduce the trend of increasing interference that was accelerating the well flow rate declines.

Toward these goals the three rigs were continuously operated for another 13 months, completing 3 additional producers at both B and C Sites, 5 each at E and Q Sites, and 3 of the 5 wells drilled at Y Site. As in the past, about 25% (5 of 19) of these new production wells as originally drilled obtained only subcommercial steam production, and each had been plugged back (abandoning that marginal steam flow) in favor of redrilling a new well course.

In one other case, however, an innovative well completion technique was attempted for the first time by NCPA. The original hole was intentionally plugged back in such a manner that after having redrilled the well the original hole could then be successfully reentered, allowing combined simultaneous steam flow from two open legs, resulting in a "forked" completion. This completion method has since been used for half of the 10 subsequently drilled wells (at P and H Sites), cost-effectively increasing the total steam flow obtained.

The combined drilling results for the past 26 months (thru June 1988) are summarized in Table 4 and illustrated in Figure 5. This development program accomplished the first objective by increasing the total well potential to a maximum of 4,375,000 LBS/HR (292 MW) in late June 1987, after which it has been maintained above 265 MW (see Figure 6). Steam flow was generally obtained from greater depths; the wells producing from the underlying felsite reservoir was increased from two to 10.

The 29 new wells have also successfully expanded the development area by 365 acres to 845 acres (a 76% increase), thereby achieving the other important aspect of the second objective. A further result of significance is that some of these stepout wells have been recently completed within areas at essentially virgin reservoir conditions, with an initial steam pressure of 475 psig.

Over these past two years (including the unit overhaul periods) NCPA's steam production has averaged 3,180,000 LBS/HR (212 MW). The maximum (24 hour) generation rate has been 250 MW (gross), and significant periods in excess of 2 30 MW have occurred. During this same period the average well flowrate potential has declined, in part as a response to a declining average static reservoir pressure. These declines are a reflection not only of NCPA's own production rate but also that of nearby operators. In the years 1983 to 1986 steam production for the entire Geysers steam field increased from 109 to 235 billion pounds per year. As a result of that four-fold change in the

annual rate of increase, more steam has been withdrawn during the past four years than throughout the previous 24 years.

Consequently, in order to extend the effective lifetime of the Southeast Geysers Field, the current and future plans for NCPA include (1) reinstituting the drilling of true exploratory wells in attempts to significantly expand the proven reservoir area for wider development, (2) doubling the rate of water injection to 65% of the total mass withdrawal rate by augmenting the available condensate with ponded stream runoff, and (3), to more optimally make use of the steam reserves available, continue our recently instituted power generation schedule in which a peak output level of 246 MW is maintained during daytime on weekdays, load is then stepped-down to a 140 MW minimum at night and on weekends, with the average weekly output being equivalent to 183 MW.

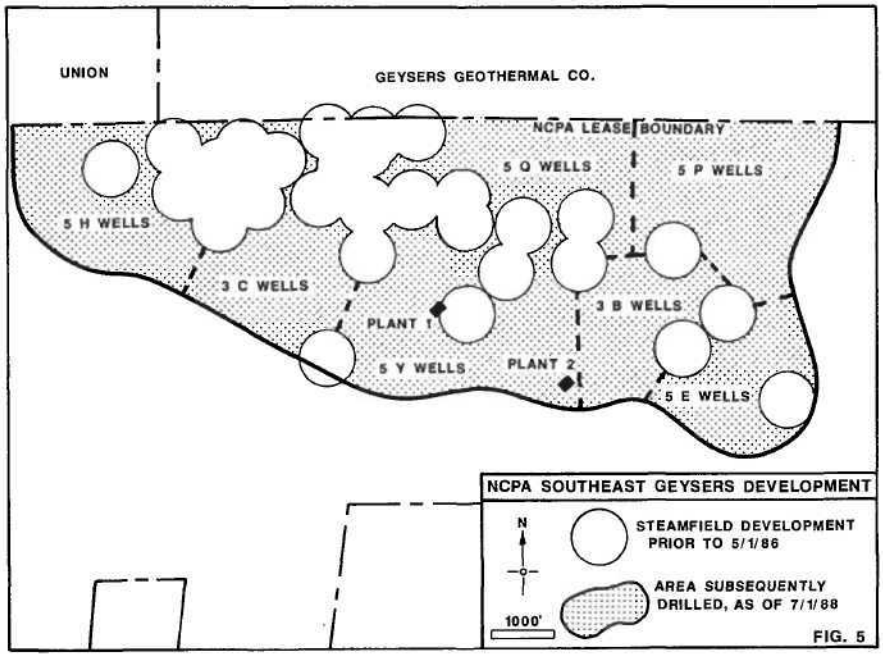
The drilling and development history to date of this steamfield is summarized in Figure 7

TABLE 4

NCPA Drilling Results May 1986 - June 1988

Well Site	Wells Drl'd	Num Rd'd (1)	Num Forked (2)	Max Prod (3)	Total Prod	Max Depth
B	3	1	0	197	437	7621
C	3	1	0	180	378	10002
E	5	1	0	196	628	7732
Y	5(4)	3	0	125	299	9296
Q	5	1	1	288	710	8161
P	5	3	2	142	535	9385
H	5	4	3	158	607	8930

Notes: (1) Number of these wells redrilled.
(2) Number with 2 producing legs open
(3) Maximum initial rate @ 160 psig.
(4) Includes 3 producers, 2 injectors



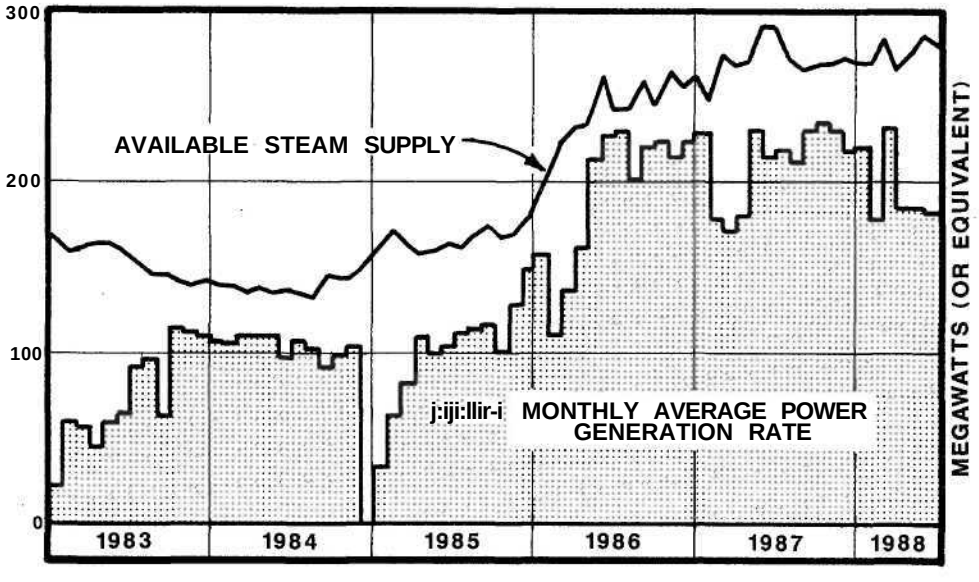
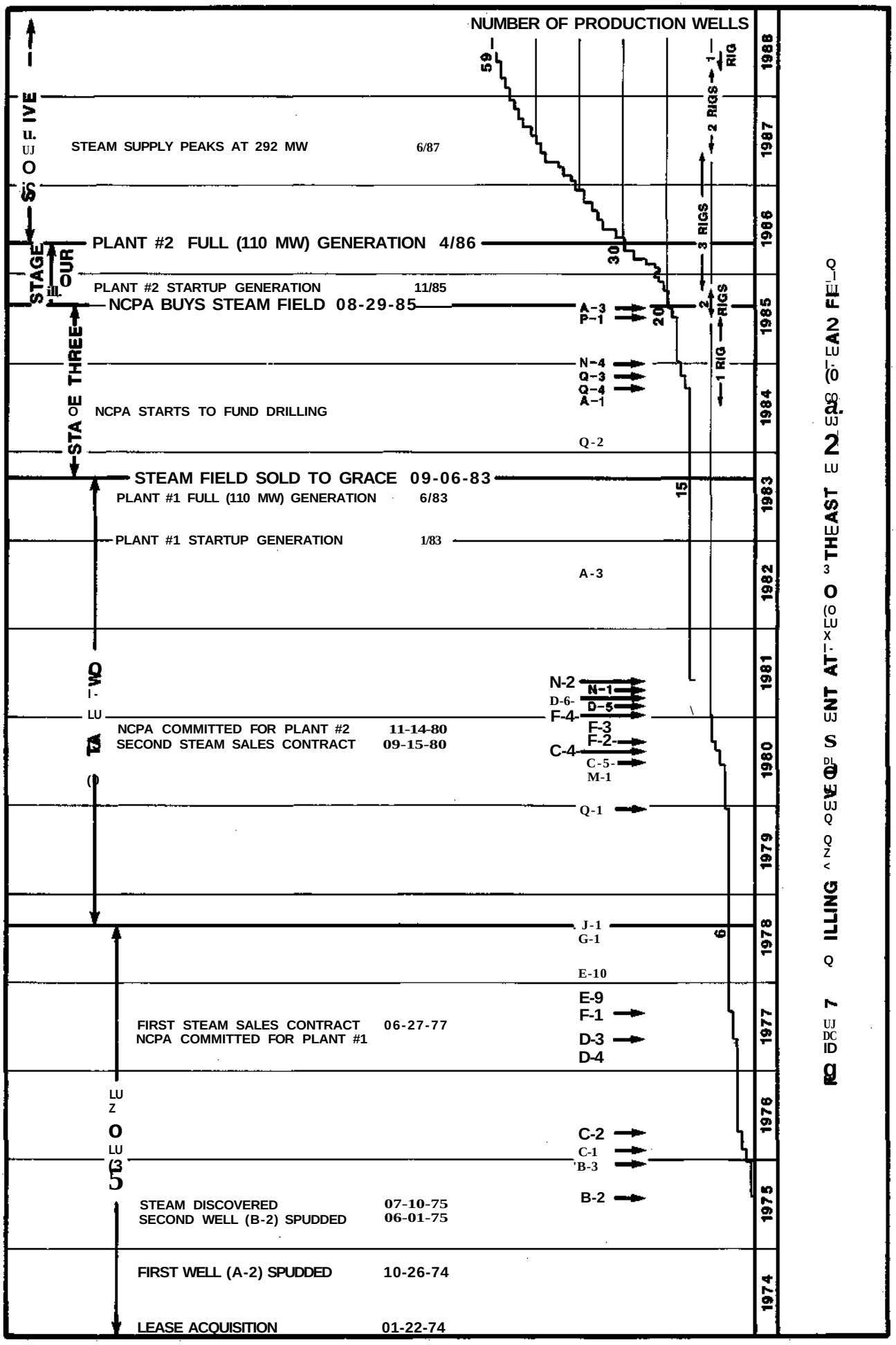


FIG. 6 HISTORY OF NCPA POWER GENERATION AND STEAM SUPPLY DEVELOPMENT AT THE SOUTHEAST GEYSERS


NUMBER OF PRODUCTION WELLS
59
30
20
15
6
1 RIG
2 RIGS
3 RIGS
2 RIGS
1 RIG
1988
1987
1986
1985
1984
1983
1982
1981
1980
1979
1978
1977
1976
1975
1974
STAGE FIVE
STAGE FOUR
STAGE THREE
STAGE TWO
STAGE ONE
STEAM SUPPLY PEAKS AT 292 MW 6/87
PLANT #2 FULL (110 MW) GENERATION 4/86
PLANT #2 STARTUP GENERATION 11/85
NCPA BUYS STEAM FIELD 08-29-85
NCPA STARTS TO FUND DRILLING
STEAM FIELD SOLD TO GRACE 09-06-83
PLANT #1 FULL (110 MW) GENERATION 6/83
PLANT #1 STARTUP GENERATION 1/83
NCPA COMMITTED FOR PLANT #2 11-14-80
SECOND STEAM SALES CONTRACT 09-15-80
FIRST STEAM SALES CONTRACT 06-27-77
NCPA COMMITTED FOR PLANT #1
STEAM DISCOVERED 07-10-75
SECOND WELL (B-2) SPUDDED 06-01-75
FIRST WELL (A-2) SPUDDED 10-26-74
LEASE ACQUISITION 01-22-74
A-3
P-1
N-4
Q-3
Q-4
A-1
Q-2
A-3
N-2
N-1
D-6-
D-5
F-4
F-3
F-2
C-4
C-5-
M-1
Q-1
J-1
G-1
E-10
E-9
F-1
D-3
D-4
C-2
C-1
B-3
B-2