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FEASIBILITY OF INCREASING OIL RECOVERY IN PITTS AND COCKRELL LEASES PANHANDLE FIELD (TEXAS)

by

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Dedicated to:

MY ADVISOR - DR. DANIEL BASS

MY PARENTS

ABSTRACT

A reservoir engineering study was made to review the past or existing pressure maintenance, and secondary recovery projects in the Texas Panhandle oil field. This engineering study was extended to determine the feasibility of designing a successful project in the area of Pitts and Cockrell leases. The oil in place, in the two leases selected for possible secondary recovery operations was calculated volumetrically and was found to be 95.8 million stock tank barrels.

Primary performance in the area selected showed that 6.6 million stock tank barrels of oil had been recovered through December, 1980. Water injection was suggested to recover the remaining oil in the two leases.

Secondary recovery performance calculations were made to determine the additional oil that would be recovered. The calculations indicated that 13.25% of the total area in Pilot No. 1 and 21% of total area in Pilot No. 2 would be swept at the time of water break-through, or 37 barrels of oil/acre-feet in Pilot No. 1 and 59 barrels of oil/acre-feet in Pilot No. 2 would be displaced.

In conclusion, the water flood project will be feasible.

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INTRODUCTION

The Panhandle field in Texas is a part of the Panhandle-Hugoton field, which is the largest gas field in the United States.

The oil leg of this field is over a hundred miles long and varying in width from a few miles to ten miles, covering more than two hundred thousand acres in six counties.

Most of the oil produced from the Panhandle oil field has been by solution gas expansion (J.D. Kenworth, 1966). Secondary oil recovery projects, which include gas-injection water flood, LPG, and thermal began where oil production had been declining for several years. For certain reasons some of the projects succeeded and some of them failed.

The primary purpose of this study is to evaluate the secondary recovery projects, find out the kinds of reservoir or fluid parameters involved and the kinds of techniques used to make the project successful.

The other purpose is to do an engineering study to determine the feasibility of designing a successful project to recover additional oil over the primary production.

Required data were obtained from well logs, fluid and special core analysis, and production history.

For evaluating the secondary recovery projects, decline curves of oil production with time for some of the projects were plotted, and the increase in the oil production per acre-feet due to water or gas that has been injected was calculated.

Contouring maps of oil production, the gas-oil ratio produced, and the water-oil ratio produced were constructed to show the activity of the water or gas that has been injected. Based on the final results of the evaluation and the screening factors analysis of the enhanced oil recovery methods, water flood was found to have the best chance of being feasible.

Two water-flood pilots were suggested to be designed in the Pitts and Cockrell area, for two reasons:

1) This area does not have any secondary recovery projects except for gas injection which was for pressure maintenance purposes.

2) The only data available and adequate for such a study was in this area.

FIELD GEOLOGY

The Panhandle field in Texas covers an area of two hundred thousand acres in six counties which are Moore, Hutchinson, Potter, Carson, Gray, and Wheeler (Figure 1).

In the Panhandle field the trap is mainly structural and most Panhandle pays are in the Wolfcampian stage of the Permian system.

Local nomenclature for the pay zone is, in descending stratigraphic order: Brown Dolomite, White Dolomite, Moore County Limestone, Arkosic Dolomite, Arkosic Lime and Granite Wash (Halbouty, 1969).

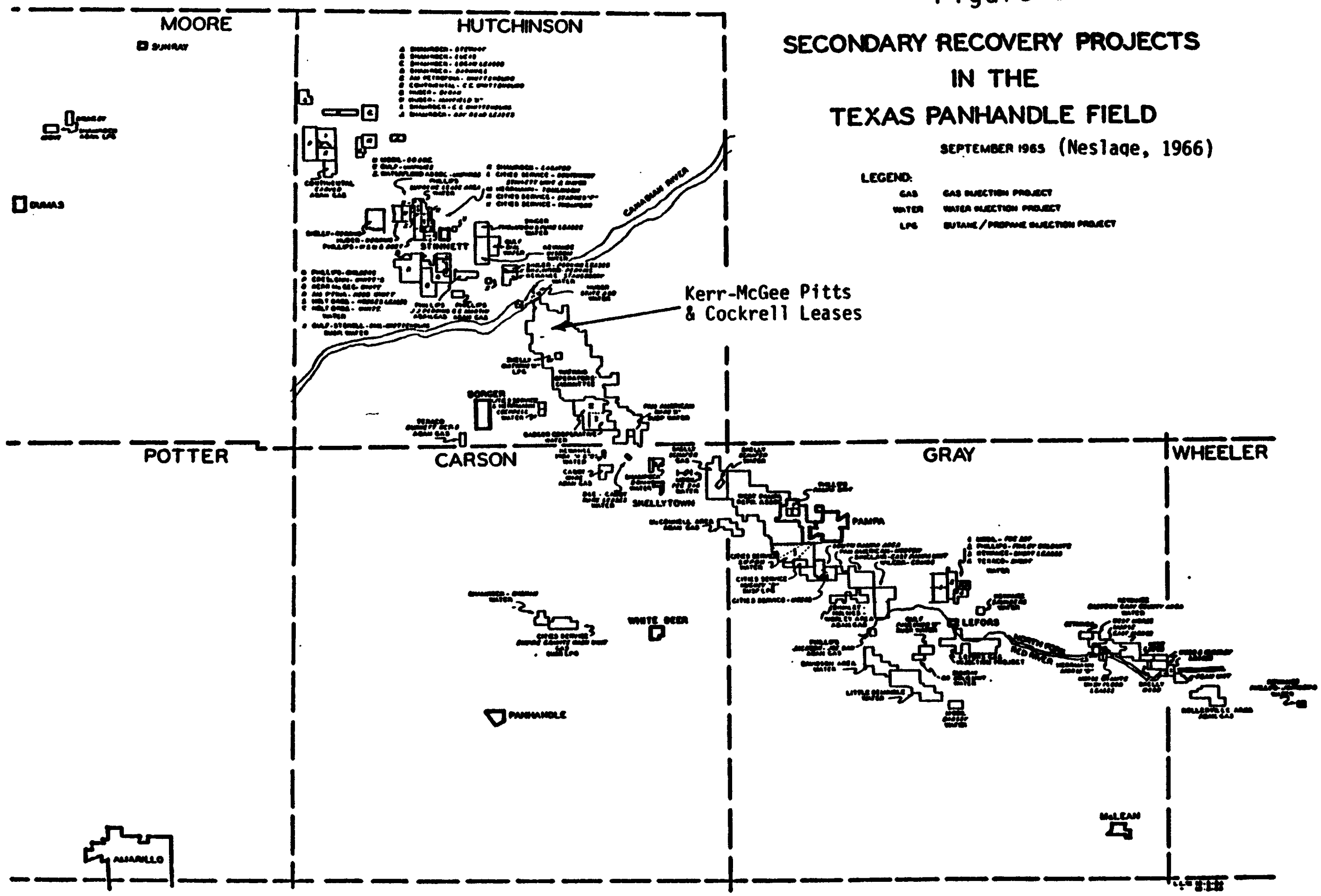
The angle of dip in Southern Hutchinson and Northwestern Gray Counties is low compared with the steep dip in Eastern Gray and Wheeler Counties. This is important, for the productive area of the field is much broader where the dip rate is low because the oil column is about the same thickness and is relatively flat. Normally, gas, oil, and water are consistent in relation to a specified reservoir. This is not true in the Panhandle field, where gas, oil and water cut across formational boundaries. Hence, in this field, the relations of the reservoirs to the gas, oil and water must be considered. The width of the field is determined by the angle of dip and the aggregate thickness of reservoir beds.

Figure 2, Section B-B' is a structural and stratigraphic

Figure 1

SECONDARY RECOVERY PROJECTS IN THE TEXAS PANHANDLE FIELD

SEPTEMBER 1965 (Neslage, 1966)



section along the axis of the Amarillo Mountains (Halbouty, 1969). The highest unit shown is the Leonardian Red Cave, which consists of red shale and fine-grained sandstone. The Wichita Formation, below, consists of anhydrite and dense anhydrite dolomite. The Brown Dolomite is a buff, cherty, saccharoidal dolomite. The White Dolomite is a white vuggy, coarsely, crystalline dolomite. The lower most, sedimentary rock is the Granite Wash, which ranges from loose, unconsolidated gravel to fine-grained arkosic red shale; it overlies precambrian granitic rocks. The highest structural point on the cross section (Figure 2) is at the west end in Potter County, the Wichita, Brown Dolomite and Granite Wash are thin in this area. As the strata thicken eastward across Carson County, the White Dolomite and Moore County limestone develop.

The Brown Dolomite thins eastward and pinches out against a granite peak in western Wheeler County, but is present again east of the peak. The peak was buried near the end of the time of Wichita deposition, Section E-E (Figure 3). The dip rate is low, and the aggregate thickness of reservoir beds is great. As a result, the width of the band of oil pay is great. Section F-F (Figure 3) extends from northeastern Potter County into northwestern Carson County, passing near the discovery oil well in the Panhandle Field, and terminates in central Hutchinson County. There

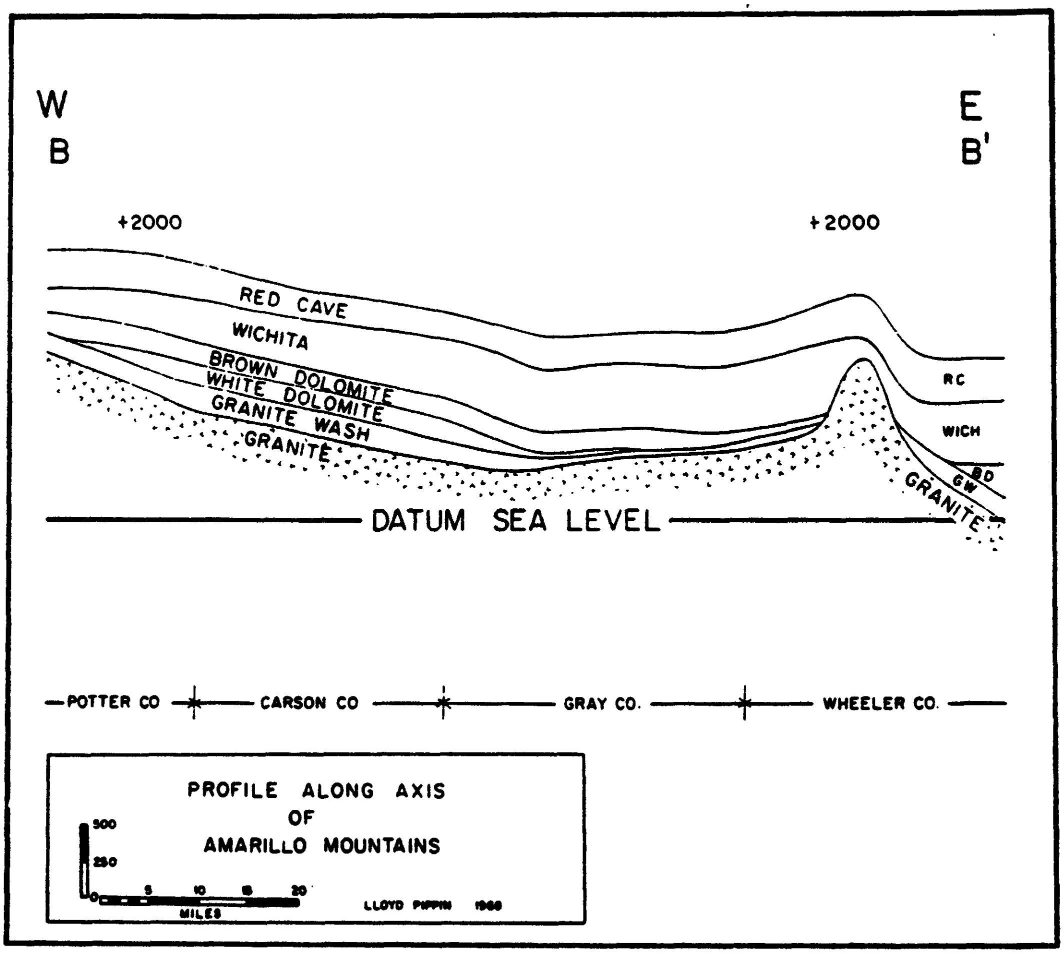


Figure 2: West-East Section Along Axis of Amarillo Mountains, Showing Structure and Stratigraphy (After Halbouty, 1970)

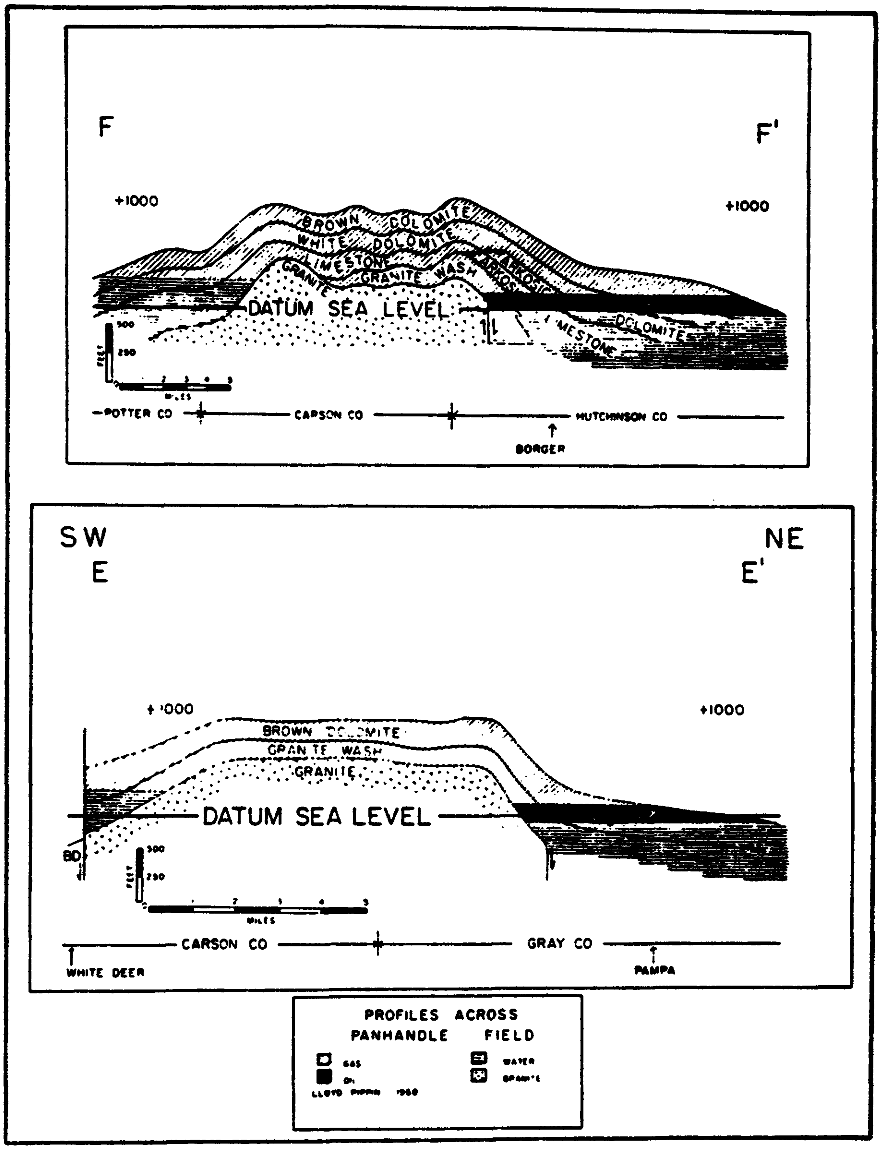


Figure 3: Section E-E' and F-F' Show Relations of Oil, Gas, and Water to Reservoirs in Panhandle Field. (After Halbouty, 1970)

are more reservoir beds present in this area than in any other part of the Panhandle field. They are from top to bottom, Brown Dolomite, White Dolomite, Arkosic dolomite, Arkosic limestone, and Granite Wash. The angle of dip is low in this area, so that the intersection of the oil column with all these reservoir beds produces a wide band of oil pay. Migration of oil was limited southward by intersection of the oil column with granite. If a profile were drawn across northwestern Hutchinson County, it would show the oil column intersecting Brown Dolomite, White Dolomite, and the Moore County Limestone from east to west. Migration of oil would have been halted by the dense Moore County limestone. A band of oil production is present in the Moore County Limestone along the edge of the field as a result of porosity development in the top of that unit. It is productive in very few places beyond this contact, except where intense fracturing has created a local reservoir. The dip is low in this area; hence, the band of oil production is relatively wide in northwestern Hutchinson County. Figure 4 (Halbouty, 1969) shows the oil productive areas for the reservoirs of the Panhandle oil field. Each symbol represents the intersection of a reservoir bed width of the oil column. Progressively older reservoirs are found in an updip direction. The width of the productive band and the number of reservoirs are greatest where the angle of dip is

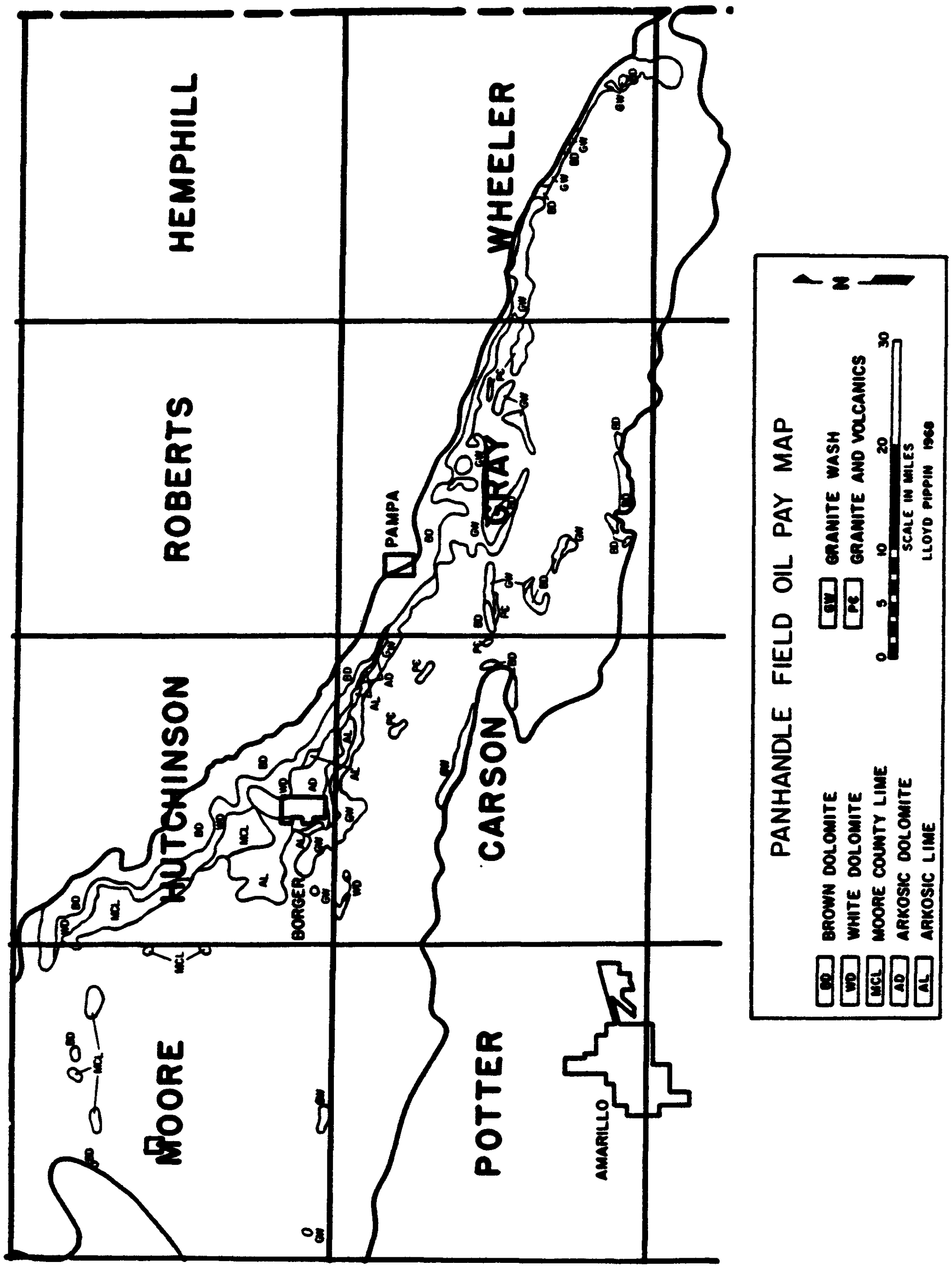


Figure 4: Oil pay map of Panhandle Field showing intersection of oil column with various reservoir beds. (After Halbouty, 1970)

least, as in southwestern Hutchinson County. Conversely, the productive bed is narrowest where the reservoirs are the fewest and the dip is steep, as in Wheeler County. The most productive reservoir is the oolitic zone in the Brown Dolomite.

FIELD HISTORY AND DEVELOPMENT

The Panhandle oil field which was discovered in 1921 is the second largest oil field in the United States in terms of cumulative production, approximately 1.7 billion barrels. The oil field is actually an oil rim on the giant Hugoton-Panhandle gas field, with approximate cumulative production of thirty-five TCF (William Diffin, 1982).

This field is over a hundred miles long and varies in width from a few miles to over ten miles. It is continuous except at the southeastern end, where there are small skips and along the southwestern flank where there are scattered outpost pools. All oil reservoir underlie the Panhandle gas field (Bryan Denson, 1960). Oil is found in the series of dolomites, limestones, and granite washes at depths approximately a hundred feet below sea level to two hundred feet above. The well depths vary from two thousand one hundred feet to over three thousand four hundred feet.

Early major development began in 1925 and lasted until 1930. Development of the field extensions has been more or less continuous since then, the rate depending upon the economic conditions at the time. Most of the early wells were drilled with cable tool rigs. If stimulation was needed, nitroglycerin in either liquid or jellied form was used. Later, the practice of using rotary tools to set the production string of casing became popular. Most of the wells are now being drilled by rotary methods all the way, cementing casing through the formation, perforating, and using hydraulic fracturing methods. The new developments in drilling and completion techniques have resulted in the development of areas with less and less pay section and oil reserves. Solution gas expansion has been the principle producing force with gravity drainage. Early attempts at increasing the recovery were made by putting an external force into the reservoir. The first attempt, 1944, was begun by injection of water by Magnolia Petroleum Company in Hutchinson County. Later, in 1946, gas was injected by West Pampa Association in the West Pampa area where oil production had been declining for several years. In 1946, a thermal flood was attempted south of Pampa, in Gray County but proved to be unsuccessful. Since then, many projects including gas injection, water flood, LPG, and thermal recovery were tested as a means to increase the recovery. (Performance of these projects varied between failure and success).

Reviewing and evaluating the performance of some of the projects will be discussed later.

REVIEW OF THE SECONDARY RECOVERY PROJECTS IN THE TEXAS PANHANDLE OIL FIELD

Since 1944, many attempts have been made to increase the oil recovery from the Texas Panhandle oil field, which are in Hutchinson, Gray, Carson, and Wheeler Counties, as they are shown in Figure 1.

One thermal recovery, sixty-six water flood, seventeen gas injection, and four LPG injection projects were undertaken.

The field in general showed a wide range of responses to the different projects, which is probably due to one or more of the following reasons (Robert Gray, 1962):

a) Wide range porosity and permeability;

b) Wide range in the relative permeability to water, possibly due to different saturation conditions;

c) Formation fractures inherent in the reservoir.

The only thermal project using in situ combustion was ignited in Gray County the first week of October 1965, and was suspended in September 1966 (Fred J. Neslage, 1966). The oil production data indicate that possible benefits were minor.

Four LPG projects were undertaken (Neslage, 1966): one in Moore County, two in Gray County, and one in Hutchinson County. These projects did not show any increase in oil production. The one in Moore County was suspended in 1958, the two in Gray County were suspended in 1962, and the one in Hutchinson County was suspended in 1966. Of all the gas and water injection projects initiated in the area, 12 gas injection and 39 water injection projects were suspended because of no response in the oil production rate. These projects were distributed as follows:

a) Three gas injection and five water injection projects in Gray County;

b) Three gas injection and four water injection projects in Carson County; and

c) Five gas injection and 30 water injection projects in Hutchinson County.

Characteristics of the gas injection projects are:

1) Few injection wells were used compared to the total producing wells, ratio of 1 to 10 through 1 to 28, and

2) Gas was injected for an average time of seven years with little or no appreciable benefits.

The characteristics of the water injection projects are:

1) Few injection wells were used in a small area;

2) Water was injected for a short time; and,

3) Quick response in the oil production was observed due to the injection of water, but this response lasted for a short time. Five gas injection and twenty-seven water injection projects were active in the Panhandle oil field

in Texas at the time of this study.

The twenty-seven active water flood projects were distributed as follows:

1) Two projects in Carson County (No. 13 and No. 21, Appendix A), consist of two leases and one operator having a total of two hundred and seventy-eight wells, drilled on ten acres spacing. In the first project (No. 13, Appendix A), water injection commenced in August 1961 at six water input wells, in two five-spot patterns with an injection rate averaging 500 - 600 BWPD/input well.

In the second project (Project No. 21, Appendix A), water injection commenced in July 1963 into a single five-spot pattern, using four wells for water input and one well as a producing well. Two years later response had not yet occurred even though 1.3 million barrels of water had been injected. Injectivity surveys indicated that the water was entering the producing formation at the well bore but what happened to it after that remained a mystery (Moring, 1967), (J.C. Henry and J.D. Moring, 1967). A test well was drilled halfway between one of the four injection wells and the center production well, to find out if the water was actually staying in the formation. The test well was put on pump and tested for 18 days. Then a bottom hole pressure reading was taken and the chloride content of the produced water was measured. From this data, the following three factors emerged as proof that the flood front had passed the test well at the time it was drilled:

a) High reservoir pressure: Most of the wells in the vicinity of the test well had bottom hole pressures close to 100 pounds. When the test well was shut-in for 72 hours, a bottom hole pressure of 181 psi was measured. Two and a half months later the pressure was 228 psi, and eight months later it was 290 psi. This is one of the best indications that the flood front had passed the test well at the time it was drilled.

b) High water cut: The well was production tested for 18 days and it averaged 4 barrels of oil per day and 20 barrels of water per day (a water cut of 83 percent). This is significant because the offset wells had never produced any water.

c) Low chloride content in the produced water. The produced water was analyzed two different times, once on August 2, and again on August 27, 1965. On the first test, the chloride content was 24,000 ppm, and on the second test it was 29,000 ppm. Normally, the chloride content of the produced water from the production zone will be over a hundred thousand parts per million. This project was expanded twice, first in March 1966 with the addition of five more input wells, second at the end of 1966 with the addition of seven more input wells. The area affected by the water flood project had been under gas injection since 1952.

2) Six projects in Hutchinson (No. 1, 5, 6, 9, 15, 18; Appendix A), consist of fourteen leases and six operators, having a total of three hundred and ten wells, most of them drilled on ten acres spacing.

Projects No. 1 and No. 6 are reviewed in Appendix B. In Project No. 5, water injection commenced in June 1965 with four input wells, and one well outside the flood area was used for salt water disposal. Initial injection rates were about 320 - 340 BWPD per input well, and as of August 1966, an average of 482 BWPD per input well was injected at zero surface pressure. In Project No. 9, water injection commenced in October 1960 with ten input wells. On April 1, 1966, three producing wells were converted to injection wells and one injection well was suspended, then the number of injection wells became twelve to 22 producing wells. Oil response was obtained in December 1960, two months after start of injection and reached its peak of 343 BOPD in March 1961, then began to decline. This decline continued to June 1966, when the lease was producing 124 BOPD.

In Project No. 15, water injection commenced in April 1964, at three input wells, and by September 1966 there were seven input wells and twenty-four producing wells. Water injection rate was 300 BWPD per input well; and later, the rates were increased to 450 - 500 BWPD per input well.

Project No. 18, consists of seven leases, which are Gary, Houck, Kay, Lizzie, Staples, Supreme, and Thompson. The producing formation is the Brown Dolomite. The well pattern is irregular with approximately 16 to 20 acres per well. Water injection was commenced in July 1958, on the Supreme lease and accordingly, oil production on the Supreme lease was the first to show an increase.

On the Gray lease, water injection commenced in January 1961, using one input well and by February, three input wells were used.

The Houck lease has two producing wells, and no injection well, and is east and adjacent to the Phillips-Supreme lease. This lease showed oil response soon after injection commenced on the Supreme lease.

The Kay lease is west of the Supreme and Lizzie leases and has five active injection wells and one injection well that has been discontinued. First response appeared on the north end of the lease in 1960, soon after the start of water injection.

Water injection on the Staples lease commenced in September of 1961 in one input well, by May 1962 four injection wells were used. Results from the injection were rather disappointing except for Well No. 2 which responded in June 1961, and reached a peak of 69 barrels of oil per day in March 1962. By June 1963, the well was down to zero barrels of oil per day.

The R.E. Thompson lease has four water injection wells and eight producing wells. Injection commenced during September 1961. No particular pattern of oil production response has occurred; however, slight oil and water increases were noted initially on the south end of the lease. At the time water injection started, the lease was producing 27 BOPD. During 1965, the lease has averaged 157 BOPD, which was its peak year. Currently, the lease is producing 58 BOPD.

3) Nineteen active water injection projects exist in Gray County (Nos. 2, 3, 4, 7, 8, 10, 11, 12, 14, 16, 17, 19, 20, 22, 23, 24, 25, 26, 27; Appendix A), which consists of a hundred and twenty leases.

In Project No. 2, water injection was commenced in December 1963. Stage 1 area consists of 650 acres with 46 producing wells, 18 water injection wells. Two pilot operations have been started on the Stage 1 area. In the northeast sector a twenty-acre five-spot with fourteen water injection wells was developed and in the southwest sector, a line drive with four water injection wells was developed. Water injection was commenced in December 1963 in the eighteen water injection wells. Initially, the rate of injection was controlled at 300 BWPD per well, but in March 1964, this rate was increased to 500 BWPD per input well. Seven producing wells indicated some oil response. Stages

2, 3 and 4 include the remaining 1,431 acres in the unit with 99 producing wells, 18 gas injection wells and 7 idle wells. In Project No. 3, there were twelve wells drilled on a ten-acre pattern. The producing formation being flooded is the Brown Dolomite at a depth of approximately 3150 - 3250 feet. This lease is offset on the west, north, and east by the Kewanee-South Pampa water-flood (Project No. 8). Water injection commenced in September 1964 in three input wells. During 1966, the lease was producing 75 BOPD and 95 BWPD, of which 50 BOPD is credited to the water injection program.

In Project No. 4, there are 14 leases, in which water injection commenced in July 1963. Most of the 31 input wells were placed in operation in July 1963, with the remaining input wells placed in operation within three months. The formation is the Brown Dolomite at 2900 feet with an effective thickness of 43 feet, average porosity 16.9% and average permeability 20.4 mds (Fred J. Neslage, 1966). Substantial oil response occurred on all leases.

In Project No. 7, there is one operator, Kewanee, with 13 different areas, distributed as follows:

a) Champan, which consists of nine wells. One of them was converted to salt water disposal during February 1963, and three more wells were converted to water injection during March 1966. No response in oil production rate has been reported, but response in water production at one well was noted soon after injection commenced.

b) East Morse unit, which consists of seven leases with a total of 60 wells. Water injection commenced in September 1960 in 32 input wells. The area is developed on a regular ten acre spacing pattern. Oil production declined from 150 BOPD in July and August 1960, to 80 BOPD in December 1960. From December 1960, oil production was on a rising trend, but it peaked at 759 BOPD in October 1964. As of June 1966, the lease is producing at a daily rate of 521 BOPD.

c) Gething, which consists of three leases, has a total of 30 wells. Development is on a ten-acre pattern and the flood is developed as a line drive. The producing formation is Brown Dolomite. Water injection commenced in February 1963 at six wells, another three wells were converted to water injection in May 1963. One well was converted to an input well in December 1964, and another well was converted to an input well in February 1965. During June 1963, only four months after injection started, the first response was noted. Since then, response in oil production has been noted in all producing wells. It is estimated that approximately 90 percent of the current oil production is due to the water injection program.

d) The Johnson A Waterflood, which consists of a total of three wells. Water injection commenced in October 1962, at one input well. There was no evidence of response in oil production from the water injection as of July 1966 (Fred Neslage, 1966).

e) KSAM Unit, which consists of four leases with a total of 26 wells developed on a ten-acre pattern. Twelve input wells were used ot inject water, in the Brown Dolomite formation. Water injection commenced in March 1962 at ten input wells, followed by one input well in December 1963, and the other one in December 1965. During March 1962, the unit area was producing 20 BOPD. This rate gradually increased, reaching a peak of 601 BOPD in January 1965. During June 1966, the unit averaged 270 BOPD, all of which was credited to the water injection program (Fred Neslage, 1966).

f) Morse Area, which consists of nine leases, with a total of 28 wells. Water injection commenced in 1959, using ten input wells. Oil production from this area followed a normal decline trend through July 1962, at which time oil production was only 22 BOPD. From this time, oil production gradually increased and during 1963 averaged 50 BOPD. In 1964 it averaged 94 BOPD, in 1965 it averaged 105 BOPD and during the first six months of 1966 it averaged 112 BOPD.

g) Morse Flood, consisted of a total of 68 wells. Water injection commenced in July 1955 in two wells. From the pilot stage, injection wells were added until July 1962, when there were 31 active injection wells. Since then, five additional wells have been added. The injection well pattern is irregular, ranging from a ten-acre line drive pattern in one area to a twenty acre five-spot in one area and a ten-acre five-spot in another. During June 1966, the Morse Flood produced 16,303 barrels of oil, all of which is credited to the water injection program.

h) Phillips, which consists of a total of four wells drilled on a ten-acre pattern. One input well was used for water injection. No evidence of response in oil production from water injection has occurred (Fred Neslage, 1966).

i) Short and Short A and B, which consists of a total of 14 wells drilled on a ten-acre spacing. The producing formation is the Brown Dolomite at 2,959 feet which is 89 feet thick with 18% porosity, 6md permeability and 30% connate water. Five wells were used for water injection. Major response in oil production rate has been noted in Short A where Well No. 1A increased from 1 BOPD to 100 BOPD and the No. 4A has increased from 1 BOPD to 12 BOPD. As of June 30, 1966, 82,845 barrels of waterflood oil had been produced.

j) Webb and Huselby ABC Waterflood, which consists of a total of 88 wells, drilled on a ten-acre pattern. In preparing for the flooding operation, an injection well was drilled in the center of each vacant ten-acres on the Kewanee-Webb lease. These wells were used for injection and the flooding pattern is a ten-acre five-spot. Water injection commenced in March 1959 at 32 input wells. Injection wells were added until by May 1965 when there were fifty injection wells. Peak production of 2,403 barrels of oil per day was recorded in March 1963. Since then the lease has been on a gradual decline and during the first six months of 1966 averaged only 144 barrels of oil per month or 4.6 BOPD per producing well.

k) West Morse Group, which consists of a total of 35 wells. Water injection commenced in July and August 1959 at 19 input wells. Oil production began to increase soon after the injection commenced. Production gradually increased from a low of 69 BOPD in September 1959, to a peak of 273 BOPD in June 1961. From the peak reached in 1961, oil production decline through 1964 when it averaged 135 BOPD. During the last quarter of 1965 remedial work was performed such that the production during the first six months of 1966 averaged 180 BOPD.

1) West Webb contained a total of 24 wells. The producing formation is the Brown Dolomite and the property was developed on a ten-acre pattern. A line drive injection pattern was used when water injection commenced in October 1962 at eleven input wells. In October of 1962 the production was 53 BOPD. From this point, it began a gradual uptrend until it reached a peak of 512 BOPD in July 1964,

from which it has gradually declined, reaching 241 BOPD in June 1966.

Project No. 8, which consists of twelve leases and has a total of 88 wells drilled on a ten-acre pattern. Water injection commenced in July 1964 at 27 input wells developed with a five-spot pattern, including the 61 producing wells. Initially, it was planned to inject 500 BWPD per input well, but this goal has not been maintained due to high injection pressures encountered soon after injection started (Fred Neslage, 1966). Some response in oil and water production rate has been noted at 43 wells. Fractures and high permeability streaks in the producing formation have permitted water to migrate to offset wells which have resulted in high water oil ratios.

In Project No. 10, the area includes 1,740 acres with 160 wells drilled primarily on a ten-acre spacing. Formation data are: Brown Dolomite at 2,800 - 2,900 feet, thickness 30 - 70 feet, porosity 12% - 18%, permeability 10 - 20 mds, and connate water 35% - 42%. In this area there were six operators working on twelve leases, which contain a total of 136 wells. Water injection commenced August 1962 at 62 input wells, and by March 1963, the total of the injection wells was 65. Response in oil production rate began to appear about six months after water injection commenced and by the end of 1965, all leases in the project had shown response.

In Project No. 11, the water injection commenced in February 1965 at six wells of a total of 24 wells. The injection rate was 250 BWPD per input well to August 1965. Then 300 BWPD per input well was injected to January 1966, and about 350 - 450 BWPD per input well has been injected since. No significant response in oil production rate has been indicated.

In Project No. 12, a pilot project with six water input wells commenced in August 1961. There have been two expansions of water injection operations. The first expansion involved 36 wells converted to input wells, of which 29 were converted in June 1964 and seven were converted at intervals to September 1965. The second expansion took place March 1, 1966, and put on an additional 37 input wells. Substantial increases in oil production have been obtained over a period of approximately three years.

In Project No. 14, water injection commenced March 1966 in 12 of 21 wells on the lease. Formation data are: Brown Dolomite at 2821 feet, porosity 15%, permeability 37.1 mds, and connate water 35%. No affect of water injection operations was noted during the first five months of operations through July 1966.

In Project No. 16, water injection commenced December 1961 in seven input wells of a total of 27 wells. Formation data are: Brown Dolomite at 2950 feet, 60 feet thickness, 15% porosity 10 mds. permeability, and 30% connate water. During the six months prior to start of water injection, the lease averaged 63 BOPD. During the next 35 month period, little change was noted as the lease averaged only 59 BOPD (Fred Neslage, 1966). The first sustained increase occurred during December 1964, when the lease averaged 187 BOPD. During 1965, the lease averaged 233 BOPD, and during the first six months of 1966, the lease has averaged 359 BOPD.

In Project No. 17, there were nineteen leases which cover some 1,980 acres and contained a total of 181 wells. The pilot flood area covers 320 acres and included six water injection wells and 24 producing wells. The area being flooded is Brown Dolomite at approximately 3,220 - 3,290 feet. Water injection commenced in February 1965. Response in oil production rate has been marginal.

In Project No. 19, water injection commenced in September 1965, at eight input wells of a total of 23 wells. Formation data are: Dolomite formation at 3,000 feet, 25 feet thickness, 12% average porosity and 20 md. permeability. During 1965, prior to start of injection, the project area averaged 21.6 BOPD. During the first six months of 1966, the project area averaged only 19.3 BOPD.

In Project No. 20, water injection commenced in June 1964 in nine wells of the total of 113 wells developed on regular ten-acre spacing. The injection rate was 474 BWPD per input well. The formation data are: Brown Dolomite at 3,150 feet, effective thickness 79 feet, porosity 18.7% and water saturation 38%. The oil decline rate has decreased and oil production has leveled out since water injection commenced.

In Project No. 22, there were three leases affected by waterflood operations. Water injection began March 1959 at seven wells and by January 1965, 13 water input wells were on operation and injection rate was 100 BWPD per input well. Substantial response in oil production has occurred.

In Project No. 23, water injection commenced in February 1963 at eight of the 13 wells; injection rate was 400 - 450 BWPD per input well. Formation data are: Brown Dolomite at 2,800 feet, effective thickness 20 feet, porosity 14%, and permeability 10 to 500 mds. All oil produced currently is believed to be attributed to water flooding operations.

In Project No. 24, water injection commenced in May 1965 in 13 wells, then operations were expanded in March 1966 with the addition of six more input wells. There were no significant, sustained increases in oil production.

In Project No. 25, water injection commenced in March 1966 at 12 wells of a total of 31 wells developed on a ten-acre spacing. The input pattern was a twenty-acre five-spot. The formation data are: Brown Dolomite at 2,800 feet, 66 feet pay, 14.5% porosity, 3 mds. permeability and 35% connate water. No affect from water injection was reported.

In Project No. 26, water injection commenced in May 1966 in 26 wells of a total of 59 wells. The input pattern was a twenty-acre five-spot. The formation data are: Brown Dolomite at 2,900 feet, 62 feet pay, 14.5% porosity, 5 mds. permeability and 35% connate water. No affect from water injection operations was reported.

In Project No. 27, water injection began in April 1962 at one input well, more input wells were added and by January 1965 there were nine input wells in operation. Formation data are Brown Dolomite at 2,750 feet, 50 feet thickness, 14.9% porosity, 6.5 mds. permeability and 35% connate water. Between November 1962 and July 1963, oil production rate increased steadily to a peak of approximately 4,200 BOPM, from which it dropped to a level of about 3,400 BOPM during the first half of 1964. Most of the response to water injection has been in the original pilot area. The five active gas injection projects are distributed as follows:

1) Two projects in Carson County which are:
   a) Cities Service - Empire Granite Wash Unit, which is a consolidation of five former leases and is composed of 24 producing wells and four gas injection wells on a thousand acres. Unit development has been generally on a twenty-acre spacing. Gas injection commenced in September

1960, at a rate of 250 MCF per day per input well. Since the start of gas injection, six new wells have been drilled. By September 1966, there was a projected increase in oil recovery of 806 barrels per acre. This increase in oil recovery could be due to the new wells or both the new wells and gas injection.

b) Skelly-Schafer Ranch, which has 16 gas input wells of which sixteen were placed in operation in April and June 1952, and the last in October 1953. Injection rates averaged between 115 MCF per day per input well. The rapid decline in oil production experienced from 1949 through 1951 was retarded soon after injection commenced in 1952. Oil production declined at a 3.6% rate during the period 1952 - 1956 as compared to the prior decline rate of about 18% (Fred Neslage, 1966). It was estimated in August 1963 that increased oil recovery above the normal decline after allowance for new wells and remedial work amounted to 1,550,000 barrels oil; and, similarly that 4,700,000 MCF of additional gas had been produced. Water flood operations commenced on these leases in July 1963. Ten of the original 17 gas input wells were re-moved from gas injection service. Two of these were reconverted, one to production and the other to water input, in connection with the waterflood pilot operations. The other eight gas injection wells were converted late in 1965 and early 1966 to producing wells in anticipation of expansion of the water flood operations.

2) Two projects in Gray County, which are:

   a) Lefors area project, in which gas injection commenced in August 1955 in 12 wells, at an average rate of forty-three MCF per day per input well. Prior to the start of gas injection, oil production had leveled out at about 2,300 BOPD, decreasing to 2,000 BOPD when gas injection commenced. Then oil production increased to an average of about 2,500 BOPD the following year and remained near the 2500 - 2600 level for seven years, then a small decline occurred to about 2,200 - 2,300 BOPD which is comparable to the oil production level prior to the start of gas injection, eleven years earlier.

   b) West Pampa Repressuring Association, which commenced gas injection operation into the Dolomite formation March 1946, and currently consists of fifteen operators with fifty-six leases having 140 gas injection wells and 855 producing wells developed on ten-acre spacing. As of July 31, 1966, 138.3 billion cubic feet of gas had been injected into the Dolomite reservoir and cumulative benefits are estimated to total 25.1 million barrels of oil and 135.7 billion cubic feet gas (Neslage, 1966). Results of the gas injection at the different leases is shown in Appendix A.

3) One project in Hutchinson County, under Watkins operators committee which commenced gas injection October 1950 into the Dolomite formation. The project consists of 26 operators with 93 leases having 125 gas injection wells and 1,176 producing wells developed primarily on a ten-acre spacing. Through July 1966, 95.7 billion cubic feet of gas has been injected, and cumulative benefits are estimated to total 17.9 million barrels of oil and 92.9 billion cubic feet of gas (Neslage, 1966). The results of the gas injection at the different leases is shown in Appendix A.

EVALUATION OF THE SECONDARY RECOVERY PROJECTS IN THE PANHANDLE - OIL FIELD IN TEXAS

Information from the discussion of the secondary recovery projects in the previous chapter and production data of some of the projects were used to evaluate the success of the projects. The oil recovery allocated to waterflood from the published data or from the analysis of the decline curve, prepared for this study were used to determine the degree of project success. The amount of oil production allocated to waterflood was divided by the reservoir volume (acre-feet) to obtain the incremental secondary recovery oil expressed as barrel/acre-foot.

In this report, incremental secondary oil recovery equal to 12 barrels per acre-foot or more is defined as a successful result (Fred Wilson, 1981). In Figure 5 through Figure 15, oil production decline curves for ten waterflood projects and one alternating gas-water injection project in twelve different leases are shown. All the projects have shown an increase in oil production after the start of the water injection, the incremental increase is different from one project to another and from one area to another. All the results are presented in Appendix A. The results of the projects for which decline curve were prepared are discussed below.

Water was injected in southwest Pampa Dolomite unit in

December 1963 (Figure 5) when the area was producing an average of 145 BOPD. This rate increased and reached its peak of 271 BOPD in July 1966. The water injection rate was controlled at 300 BWPD per input wells for the time water was injected December 1963 through April 1964. Oil production rate decreased to 135 BOPD in January 1964, increased to 164 BOPD in February 1964, and decreased again to 159 BOPD in March 1964. Better rate stimulation was noticed after increasing the water injection rate to 500 BWPD per input well in March 1964. The increment of the secondary oil recovered per acre-foot was found by subtracting the total primary production (extrapolating the straight line from the time of starting water injection) from the total of production after the start of water injection. The increment of the secondary oil was found to be 5.3 barrels per acre-feet (partial success).

Water was injected in Meers C Lease (Gray County) in September 30, 1964 (Figure 6). Stimulations was noted on the lease after the start of water injection, the lease oil production was 328 bbls/mo. and increased to a peak of 3,642 bbls/mo. in March 1966 when one well was recompleted in the White and Brown Dolomite. Oil production decreased to 2,145 bbls/mo. in July 1966. The incremental recovery of the secondary oil was found to be 7.6 barrels per acre-feet (partial success).

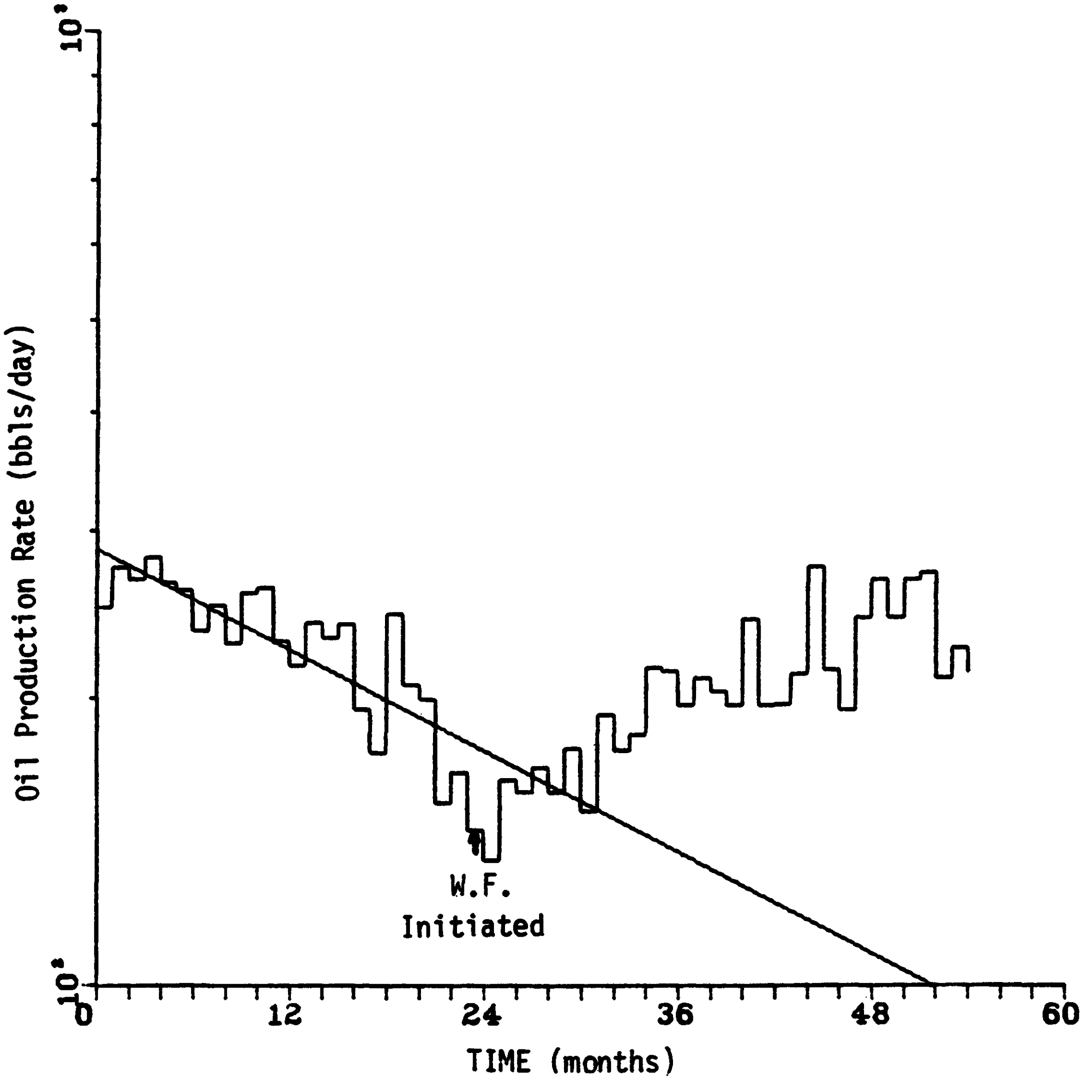


Figure 5: Water Flood Evaluation in Southwest Pampa Dolomite Unit (Gray County)

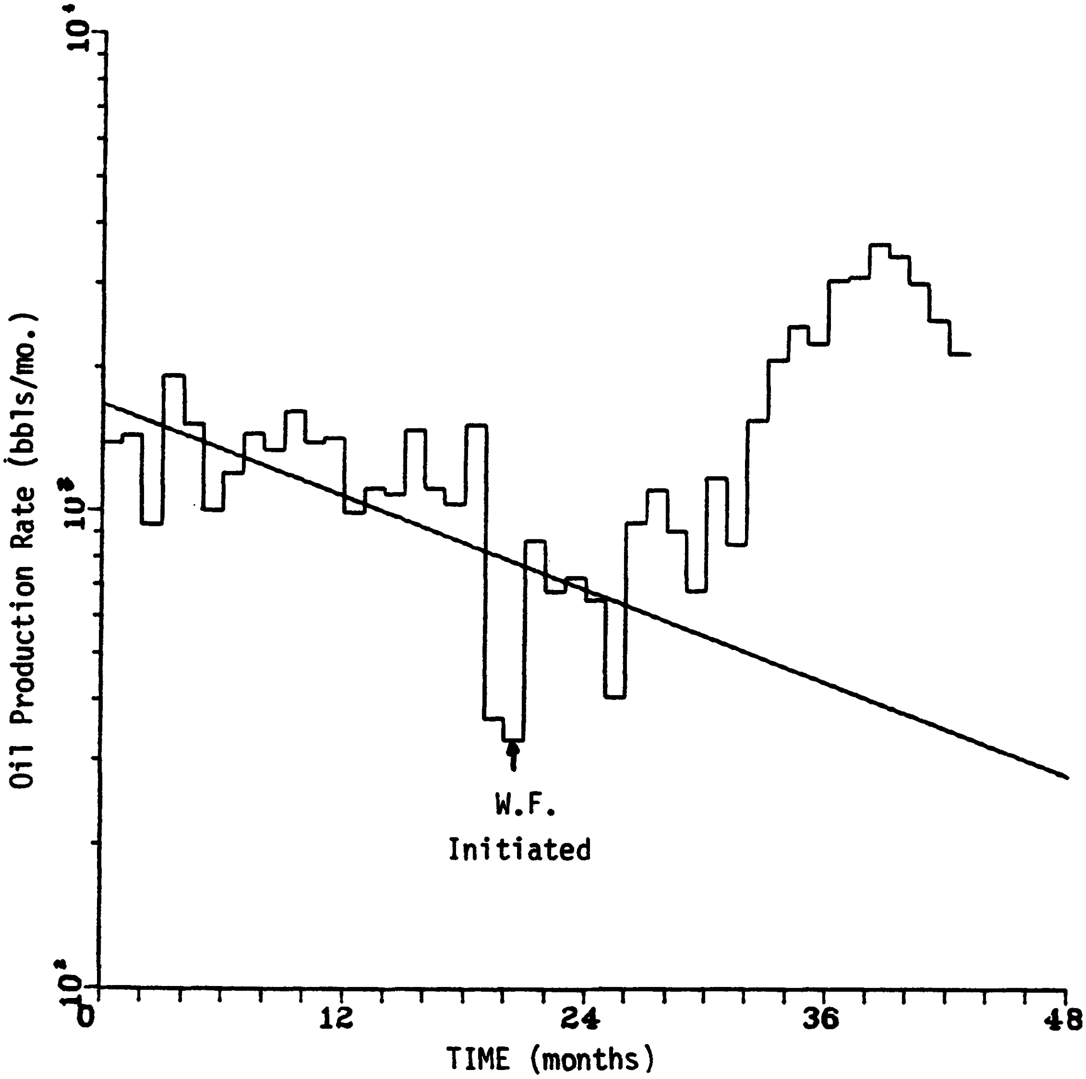


Figure 6: Water Flood Evaluation in Meers C Lease (Gray County)

In Kewanee East Morse Unit (Gray County), water was injected in November 1960 when the area was producing an average of 143 BOPD (Figure 7). Oil production increased until it peaked at an average of 737 BOPD through 1965, then decreased to an average of 552 BOPD through the first six months of 1966. The increment of the secondary oil was found to be 25 barrels per acre-feet (the project is successful).

Water was injected in Kewanee-KSAM Unit in March 1962, then two input wells were added, one in December 1963 and the other in December 1965 (Figure 8). At the time water injection began, the area was producing 23 BOPD and gradually increased to a peak of 409 BOPD in 1965. During the first six months of 1966, the area was producing an average of 289 BOPD. The oil production was very sensitive to the number of the input wells. The increment of the secondary oil was found to be 27 barrels per acre-foot (project is successful).

In the Little Seminole area (Gray County), water was injected in August 1962 (Figure 9). Response in the oil production rate began to appear in March 1963. The oil production rate continued to increase, reaching a peak of 95,550 in December 1965. Then production decreased to 80,060 bbls/mo. in June 1966. The increment of secondary

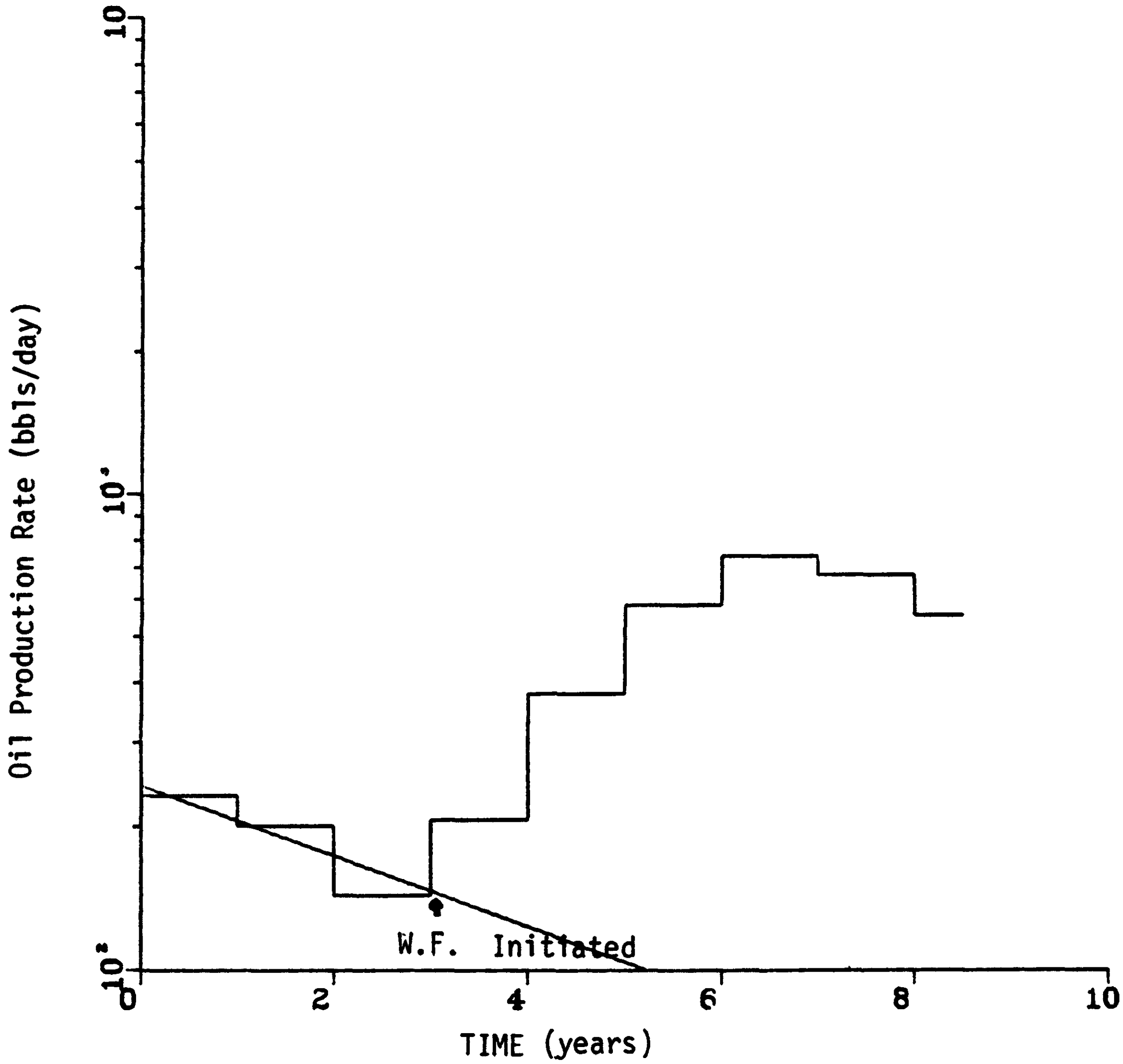


Figure 7: Water Flood Evaluation in Kewanee-East Morse (Gray County)

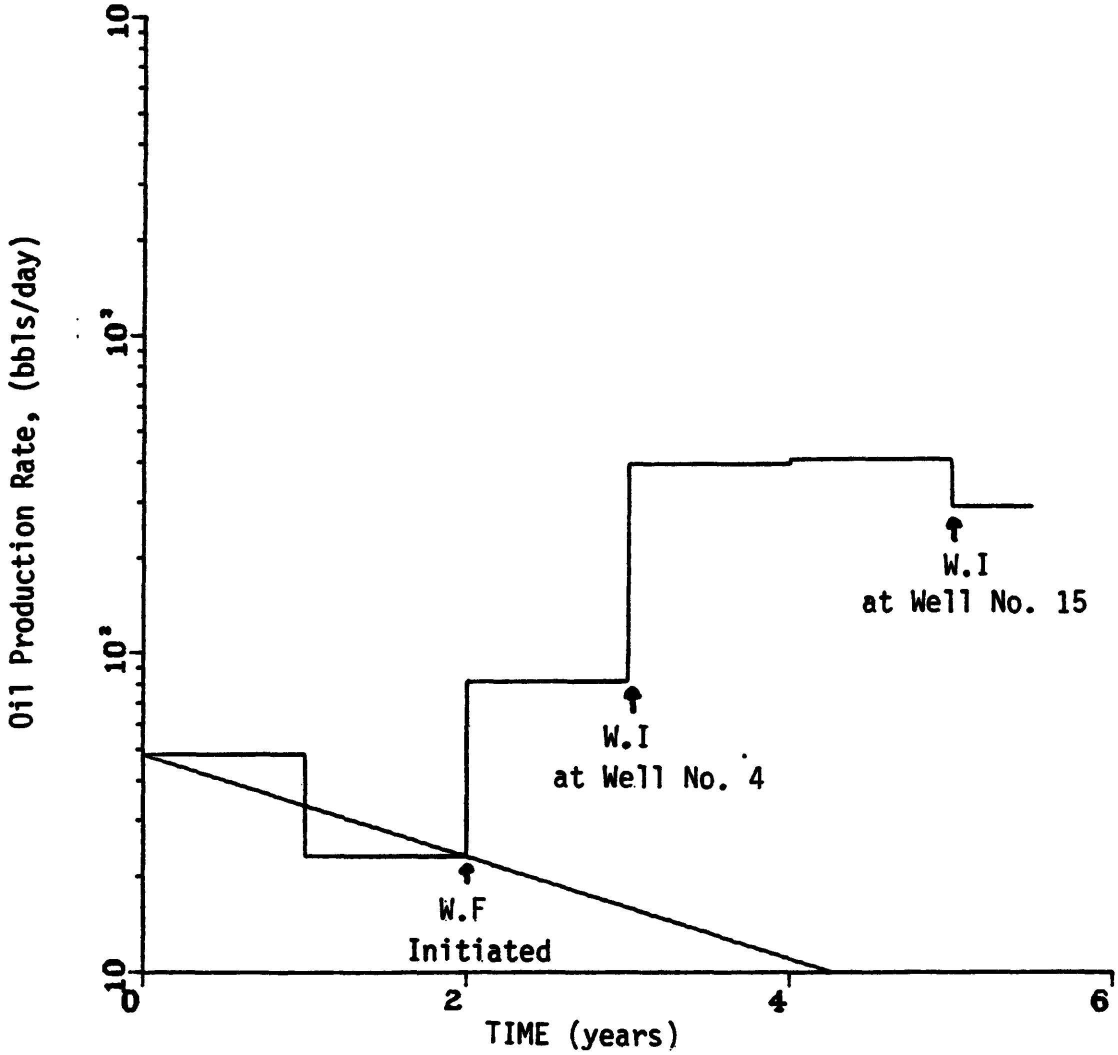


Figure 8: Water Flood Evaluation in Kewanee-KSAM (Wheeler County)

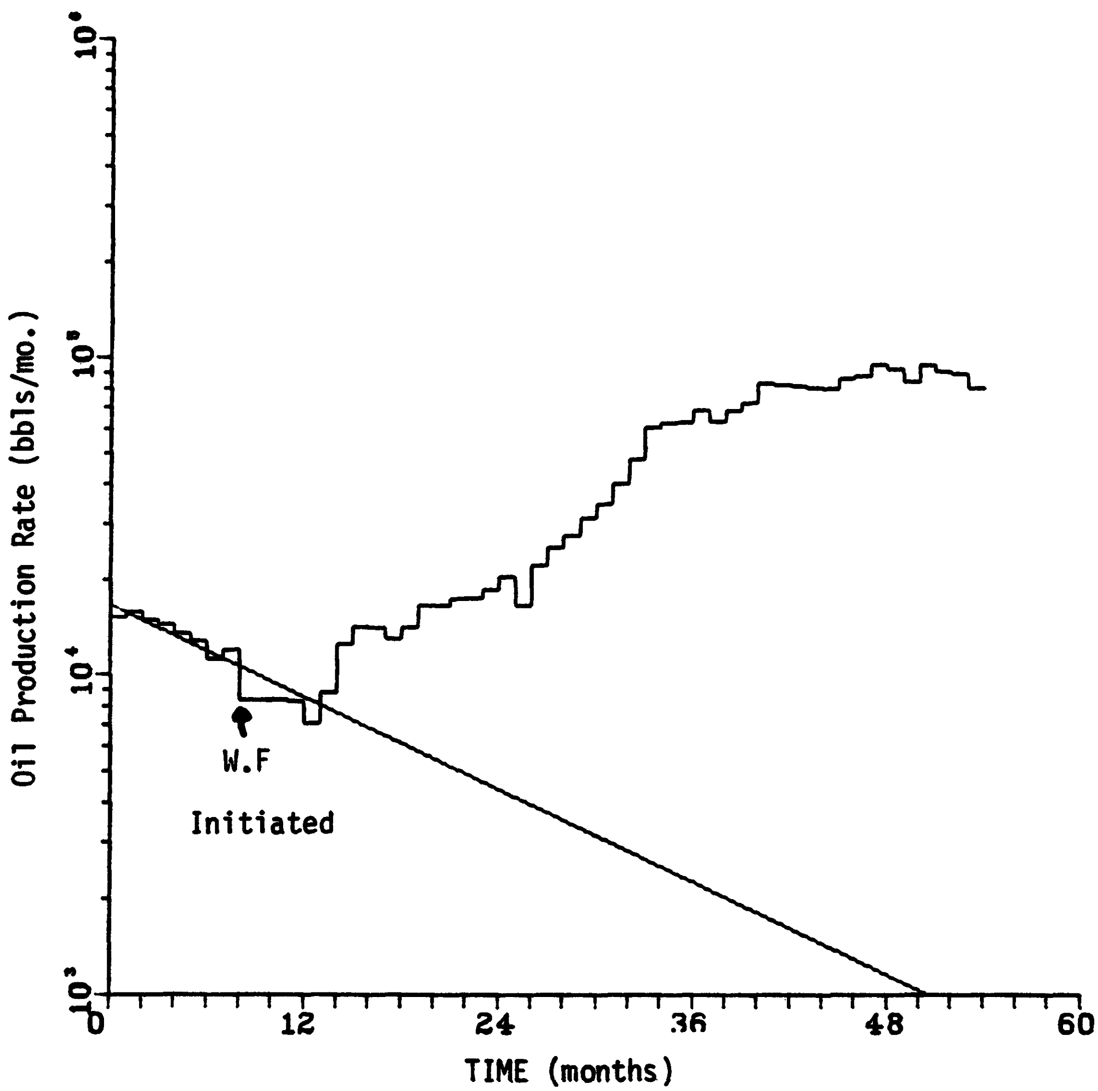


Figure 9: Water Flood Evaluation in Little Seminole Area (Gray County)

oil was found to be 27 barrels per acre foot (project is successful). In the finely Dolomite area (Gray County), water was injected in December 1961, when the area averaged 60 BOPD (Figure 10). The first increase in oil production occurred during December 1964 and by 1965 the area production averaged 233 BOPD. During the first six months of 1966, the production averaged 359 BOPD. The increment of secondary oil was found to be 12.5 barrels per acre-foot (project is successful).

Water was injected in Phillips Lizzie area (Hutchinson County) in November 30, 1960 when the area was producing 7,607 bbls/yr (Figure 11). Thereafter, the annual oil production increase reached a peak of 87,573 barrels of oil in 1962, then annual oil rate decreased to 19,814 barrels of oil in 1965. In the first six months of 1966, the oil production was 5,153 barrels. The increment of secondary oil was found to be 489,581 barrels. No information about the area or the pay thickness was available, but the Lizzie area was considered the area which has recovered the greatest amount of water flood oil (Fred Neslage, 1966).

Water injection started in September 1961 in the Phillips Thompson area (Hutchinson County) (Figure 12). The oil production at the start of the water injection was 14,751 barrels per year. This rate was increased and reached a maximum of 57,237 bbls/yr in 1965. This area was

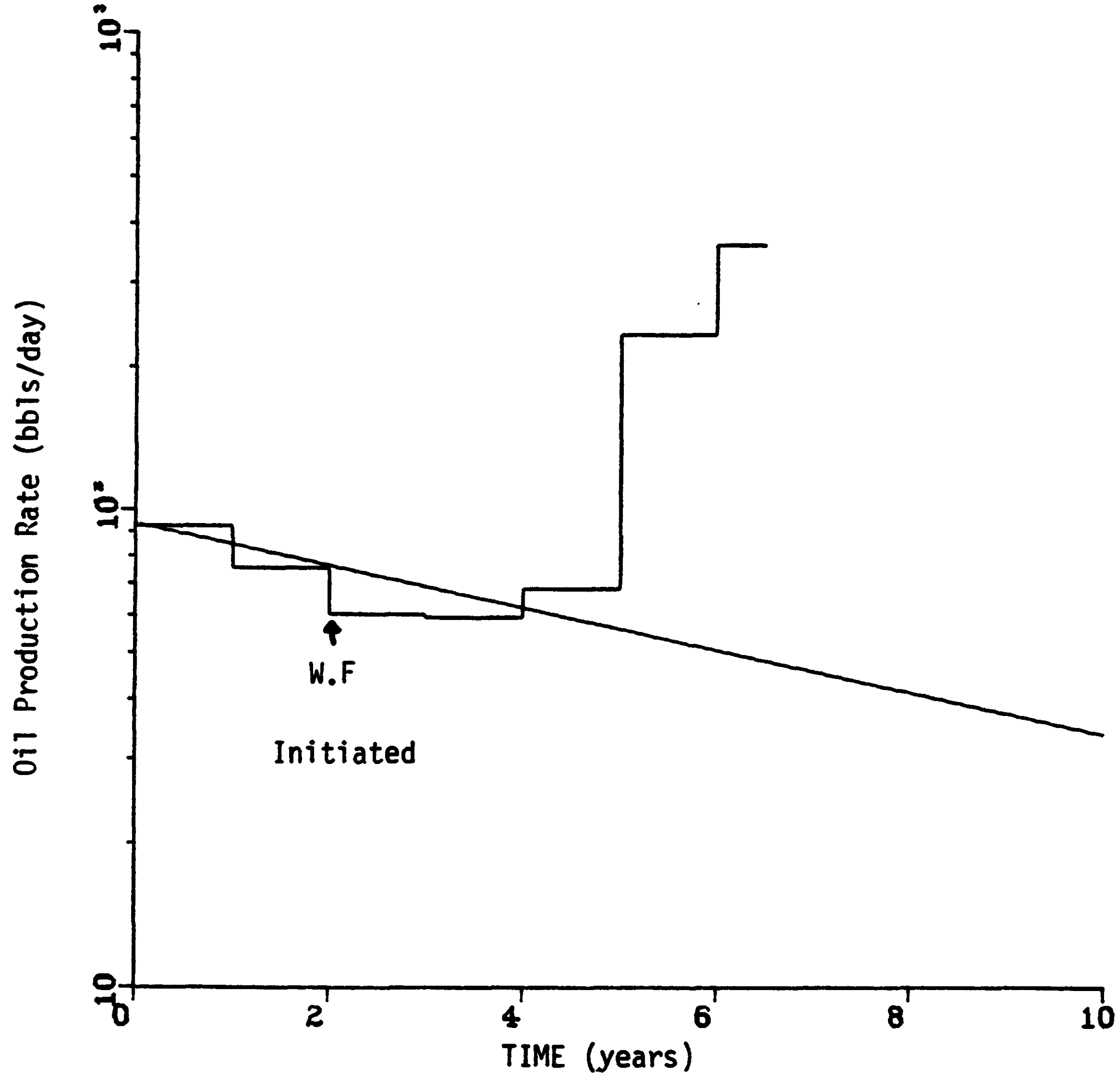


Figure 10: Water Flood Evaluation in Finely Dolomite (Gray County)

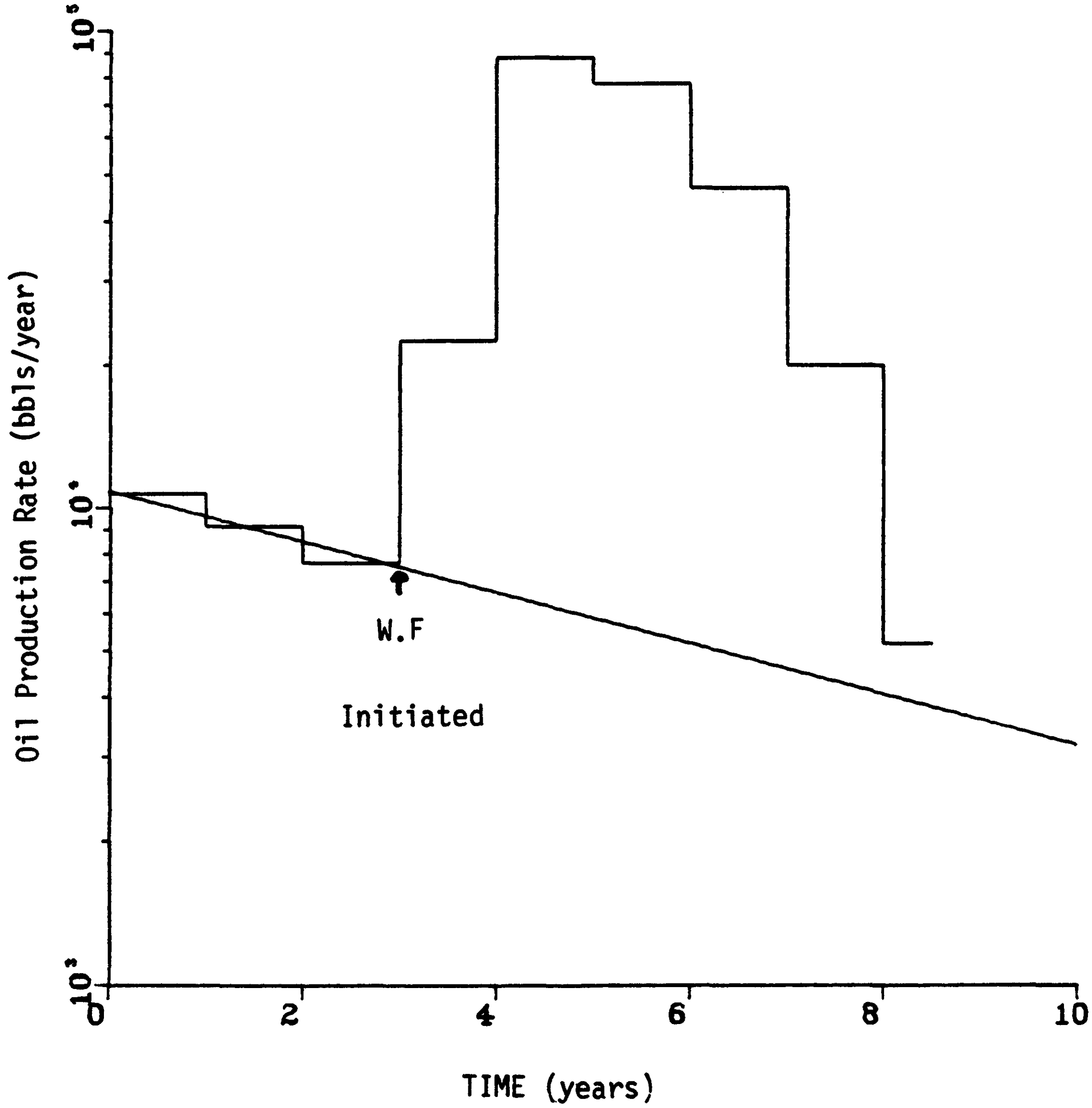


Figure 11: Water Flood Evaluation in Phillips Lizzie (Hutchinson County)

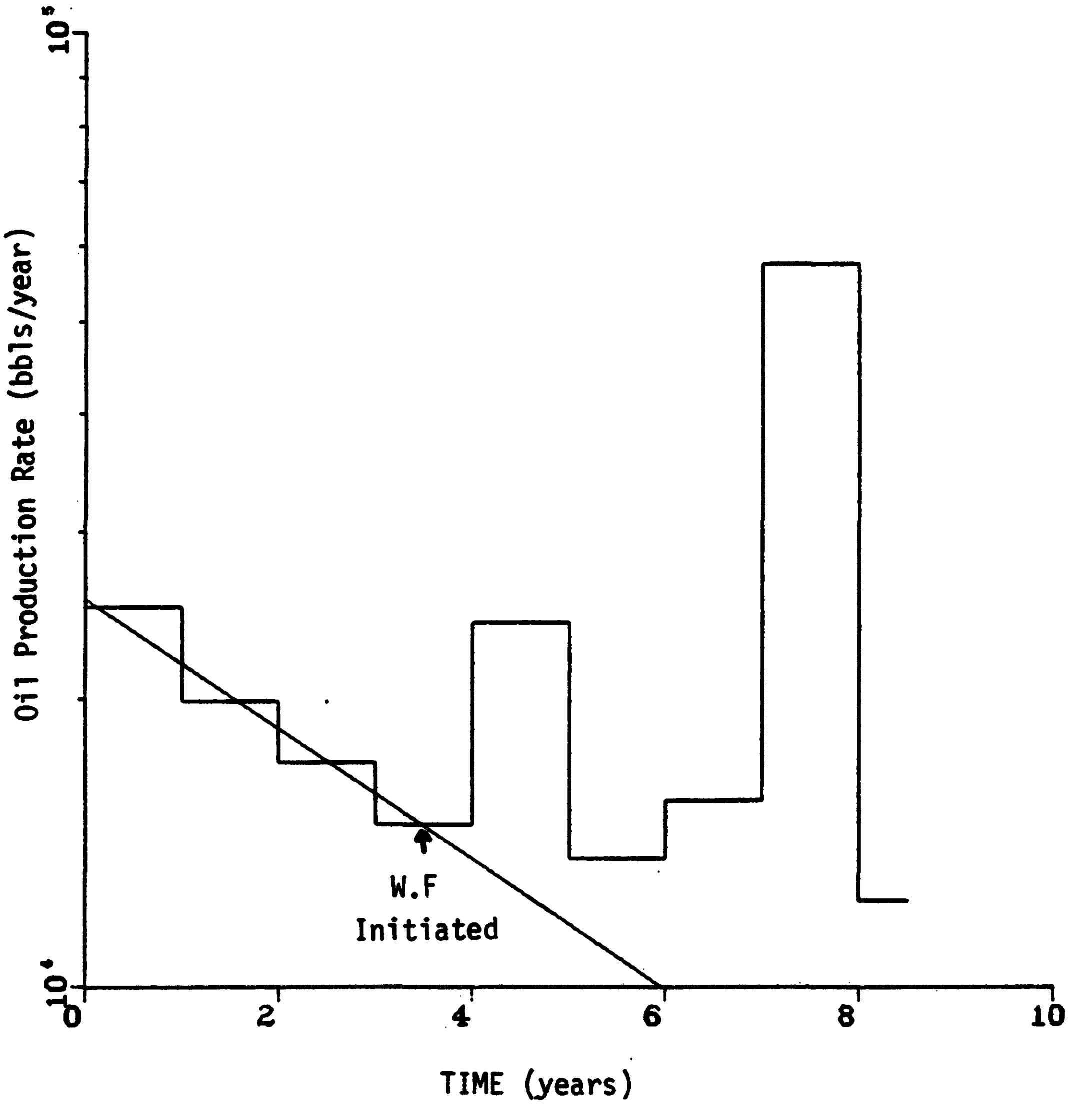


Figure 12: Water Flood Evaluation in Phillips Thompson (Hutchinson County)

also considered to be of a great amount of water flood oil (Fred Neslage, 1966).

Water injection commenced in August 1961 in the Mobil Fee 227 area (Gray County) when the area was averaging 850 barrels of oil per day, or a monthly production of 25,502 barrels of oil (Figure 13). The oil production rate fluctuated up and down from the time the water injection started to the time of the first expansion of water flood: thirty-six input wells were added in June 1964 and another seven were added at intervals through September 1965. After this expansion, an increase in oil production was noticed and the increment of oil recovered by water flooding was calculated to be 14 barrels per acre-feet. The second expansion took place in March 1966 which resulted in an additional thirty-seven input wells. There was not enough production data after the time of the second expansion to evaluate the results.

In Skelly Schafer area (Carson County) water was injected in July 1963 (Figure 14). Some of the production data on this lease was not available, but the project has shown an increase of oil production. The water flooded oil recovery was calculated to be 14 barrels per acre-feet (a successful project).

Figure 15 presents the water flood and the alternate gas-water injection projects in the Amoco Cobb area in Gray

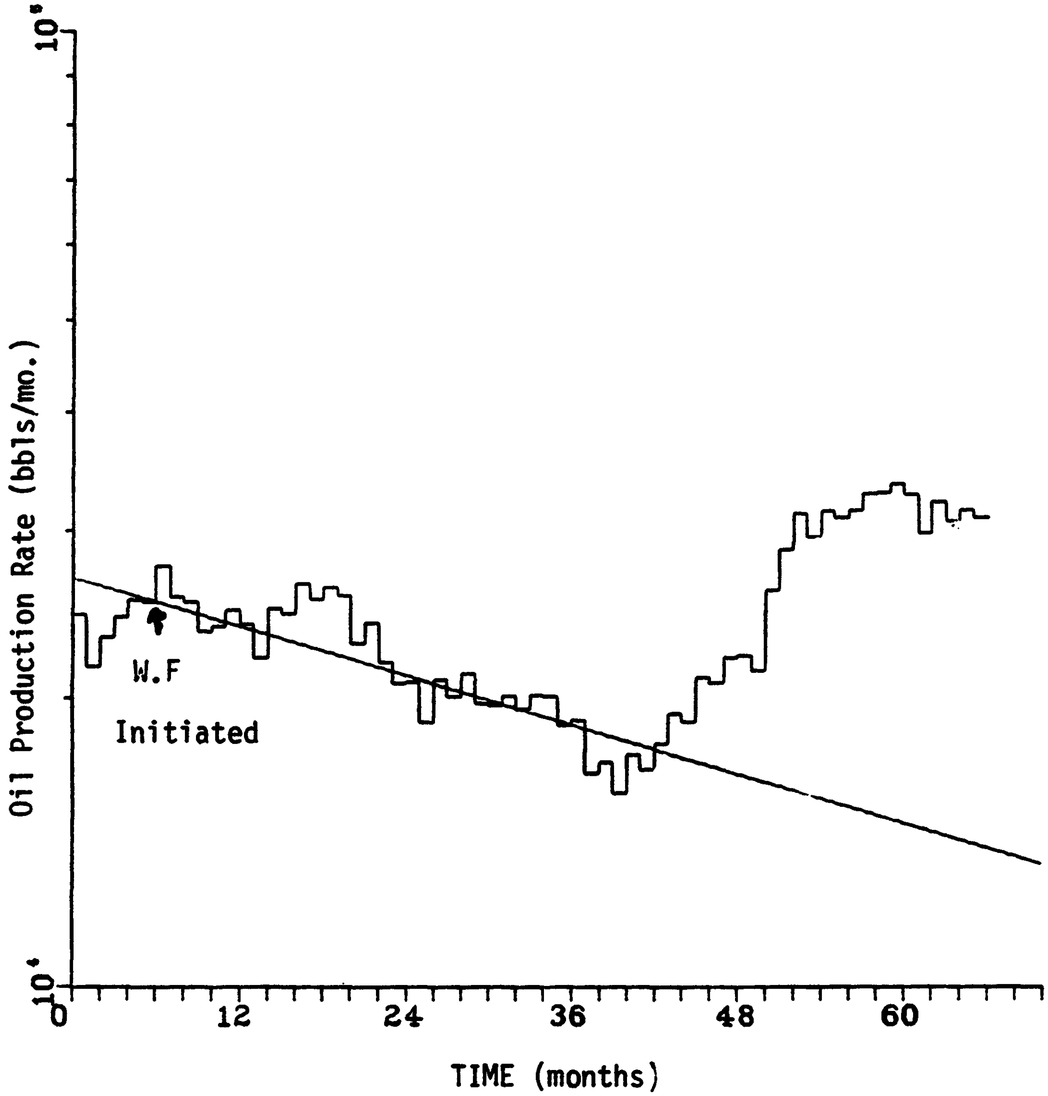


Figure 13: Water Flood Evaluation in Mobil Fee 227 (Gray County)

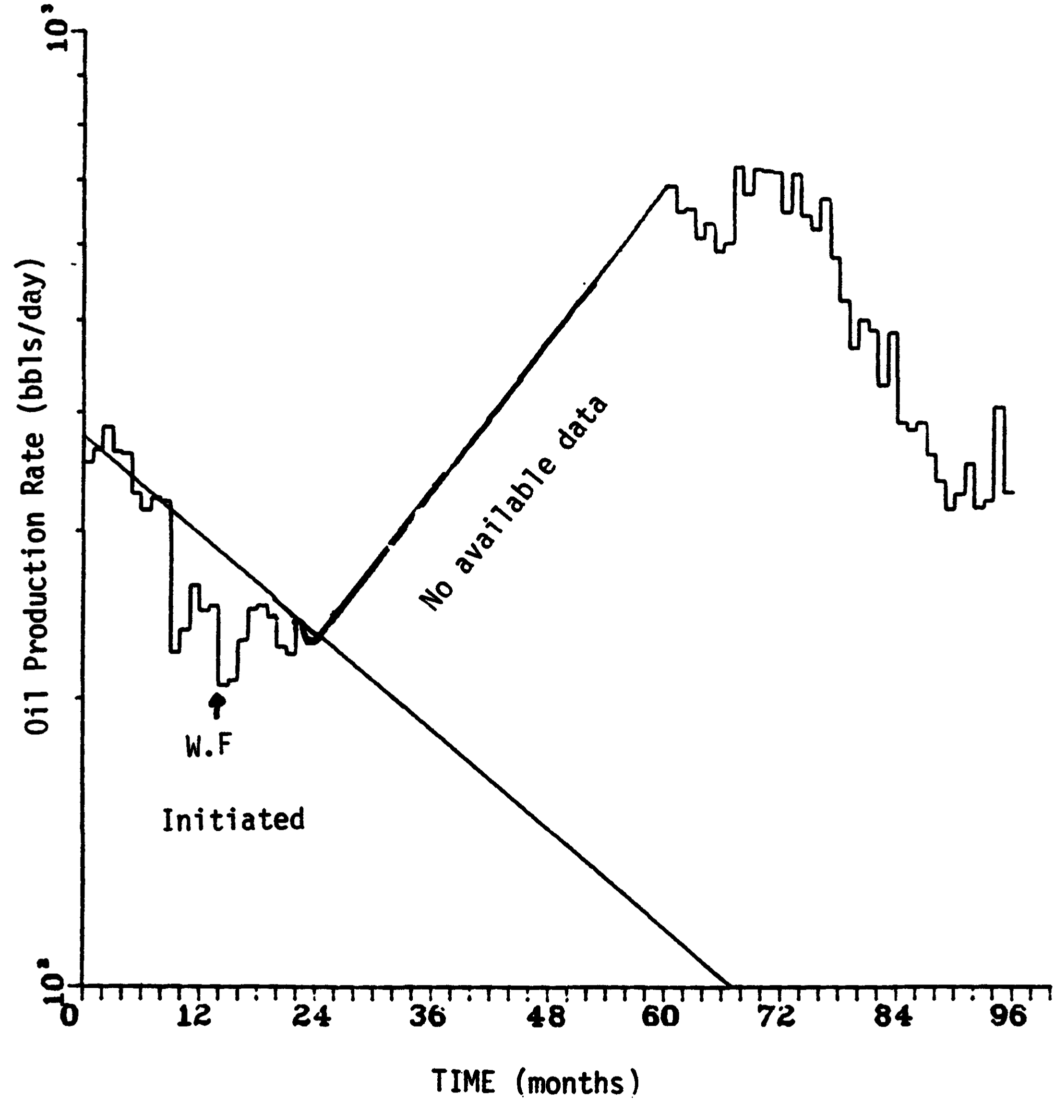


Figure 14: Water Flood Evaluation in Skelly-Schafeer
(Gray County)

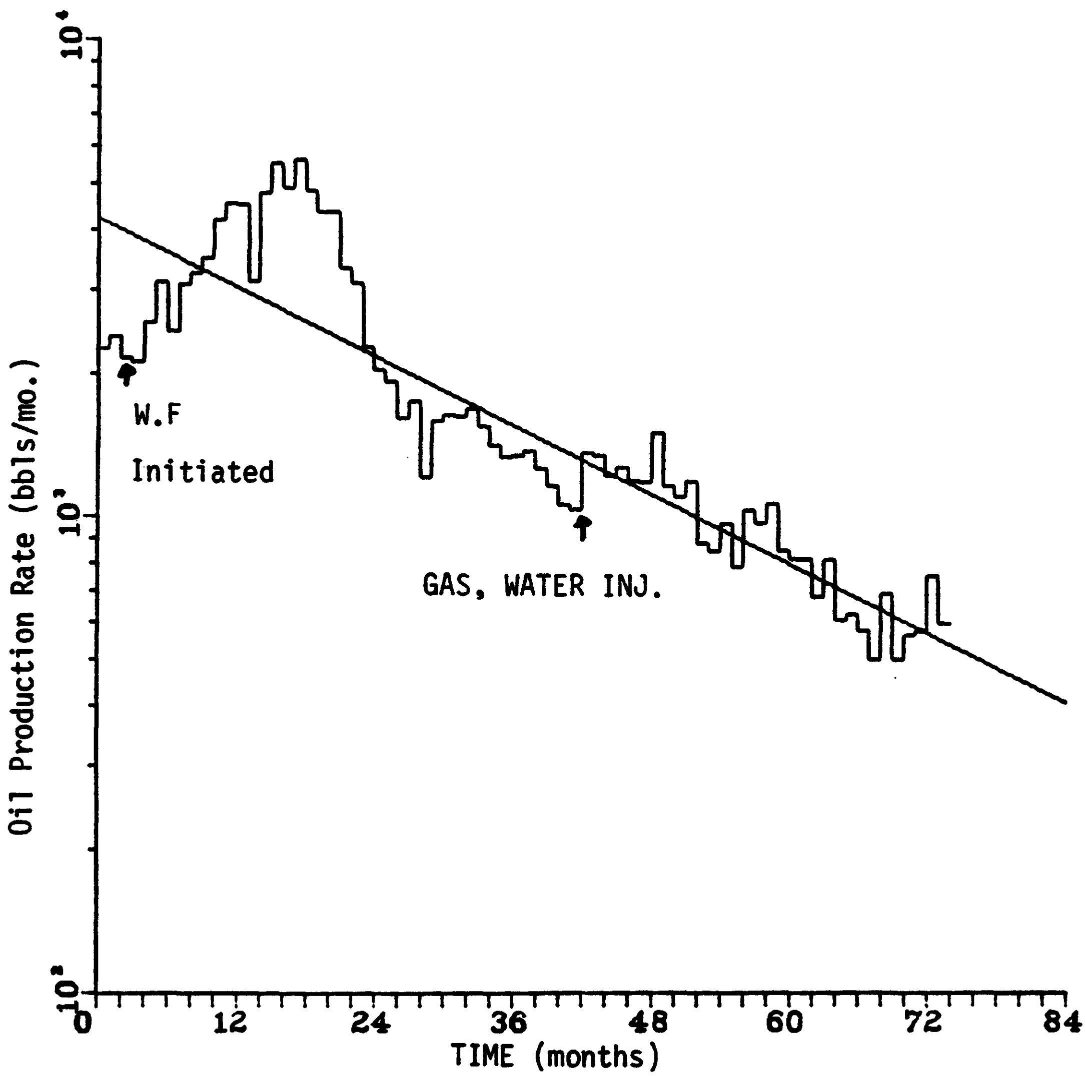


Figure 15: Amoco Cobb Alternate Gas-Water Injection Project (Gray County)

County. There was not enough data to evaluate the water flood projects. No oil production response was shown due to the alternate gas-water injection.

RESULTS AND OBSERVATIONS OF THE SECONDARY - RECOVERY PROJECTS IN THE PANHANDLE OIL FIELD

1) Results of the water flood projects:
   a) Carson County: 50% of the total projects were successful;
   b) Hutchinson County: 17% of the total projects were successful, 33% were partially successful and 50% failed; and
   c) Gray County: 58% of the total projects were successful, 14% were partially successful, and 28% failed.
2) Results of the gas injection projects:
   a) Carson County: 100% of the gas injection projects have failed;
   b) Hutchinson County: 10% of the projects were successful and 90% were partially successful; and
   c) Gray County: 8% of the projects were successful and 92% were partially successful.

Note that the percentage of the degree of success of gas-injection projects was not very accurate because during the period of gas injection, new producing wells were added.

OBSERVATIONS ON THE EVALUATION OF PREVIOUS AND EXISTING PROJECTS

1) Most of the water flood projects that failed had a low injection rate (between 300 to 350 barrels per day per input well.

2) Oil production rate was very sensitive to the injection rate, and it increased with the increases in the injection rate, such as in Project No. 2 (Figure 6), where the oil production rate indicated a large increase after increasing the water injection rate from 300 barrels per day per input wells to 500 barrels per day per input well.

3) The degree of success depends on the size of the pilot area, most of the pilots which were classified as a failure or a partial success were conducted in a small area.

4) The projects with lower permeability values indicated a better chance to succeed than the projects with higher permeability values, this may be because the higher permeability the greater the chance of rock heterogeneity and vice versa.

FEASIBILITY OF INCREASING OIL RECOVERY IN THE TEXAS PANHANDLE OIL FIELD

In order to decide what method of enhanced oil recovery might have a chance to succeed, a review of the screening factors of different methods was performed.

1) Polymer Flooding: This method cannot be used because of the following restrictions;

a) Low average permeability across the field except some leases of high permeability. In polymer flooding, a permeability of 20 md. and up is required (I.O.C.C., 1974); and

b) Panhandle Pay Zone is generally a Dolomite with some Limestone. In polymer flooding, Sandstone reservoirs are preferred.

2) Micro Emulsion Flooding: There are two kinds of micro emulsion flooding which are:

a) Caustic flooding; and

b) Surfactant flooding. Neither flooding process can be used in the Panhandle oil field because of the foregoing restrictions. The surfactant needs to be injected as a slug driven by thickened water (polymer solution) which is in turn displaced by water or brine (I.O.C.C., 1974). This kind of flood needs high pressure displacement and high reservoir permeability. The other restriction against caustic being used is the existence of the divalent ions such as Ca^{++} and Mg^{++} in the Panhandle field formations which could react with caustic to precipitate the insoluble hydroxides with resulting loss of alkalinity and plugging of the formation.

3) Miscible Flooding, such as:
   a) High pressure gas injection
   b) Enriched gas drive
   c) LPG
   d) CO_2

The first three kinds of miscible flood require high reservoir pressure and low oil viscosity to achieve the miscibility between the displaced and displacing phases. A high reservoir pressure does not exist in the Panhandle oil field. LPG has already been tried and did not work, as was mentioned earlier in this report. Carbon dioxide has some advantages in the Panhandle area because it reduces the viscosity of the crude oil. Swelling of oil would increase the oil permeability by increasing the oil saturation. CO_2 could also react with the limestone and change the wetability of the rock from oil wet to water wet (I.O.C.C., 1974). The only disadvantage is the requirement of 1000 - 1200 psi reservoir pressure for the achievement of miscibility with oil. Water injection would be required prior to CO_2 injection to increase the reservoir pressure to carbon dioxide miscibility pressure. To determine the CO_2 miscibility pressure, the two pilots were designed, one with four injection wells (Figure 16), and the other with nine injection wells (Figure 17) in the area of the Cockrell lease. Pressure distribution during water injection was calculated and equipotential lines were plotted (Figures 18 and 19). The results of the calculations indicated that only small areas around each injection well would reach carbon dioxide miscibility pressure with oil. Therefore, carbon dioxide injection will not be an efficient or an economical project in the Panhandle oil field.

From the previous review of the methods of enhanced oil recovery, it is apparent that none of them can be feasibly applied in the Panhandle oil field. As the discussion of the secondary oil recovery projects in the Panhandle oil field points out, water flood appears to have the best chance of success.

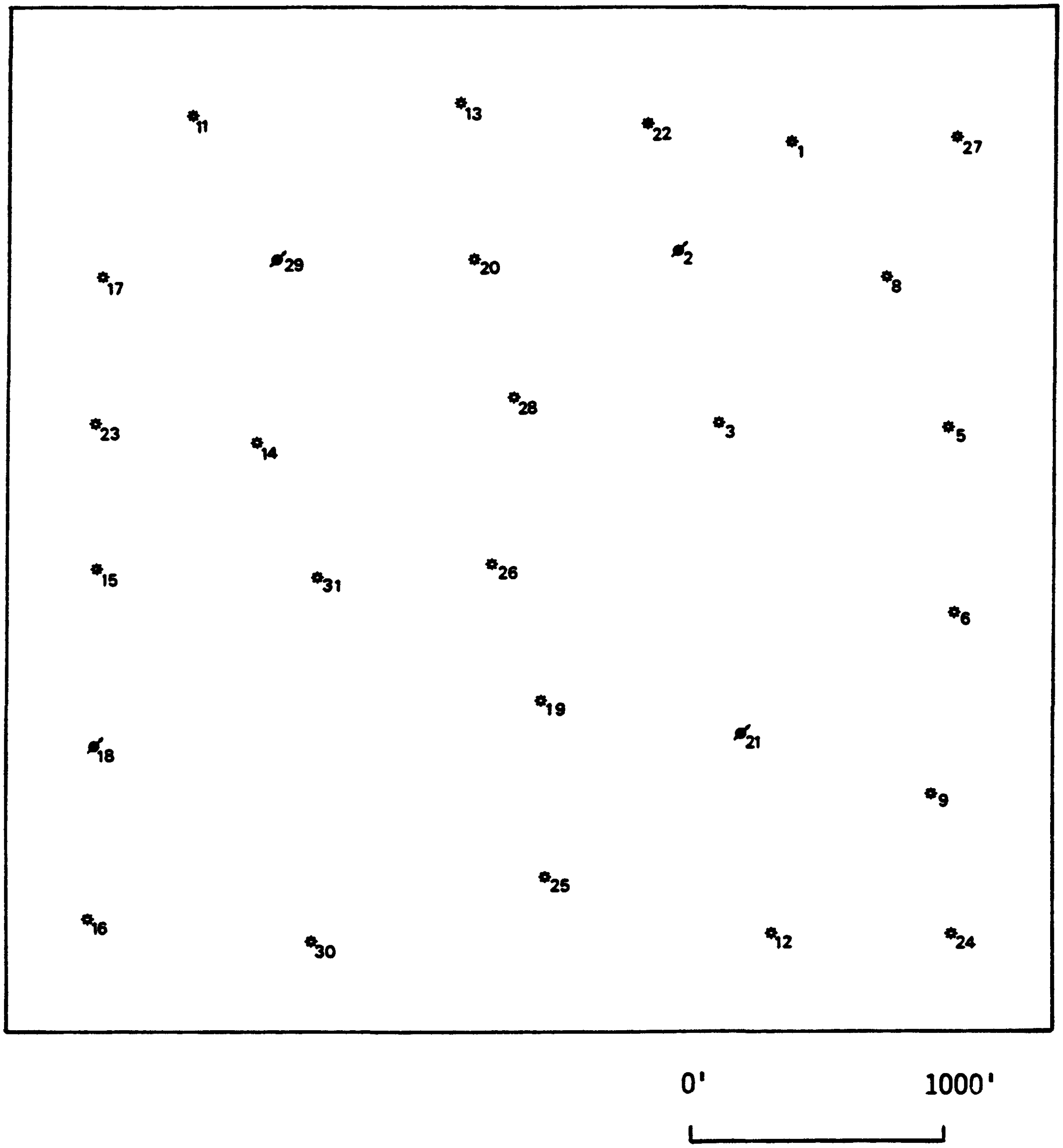


Figure 16: Pilot No. 1 (Four Injection Wells)

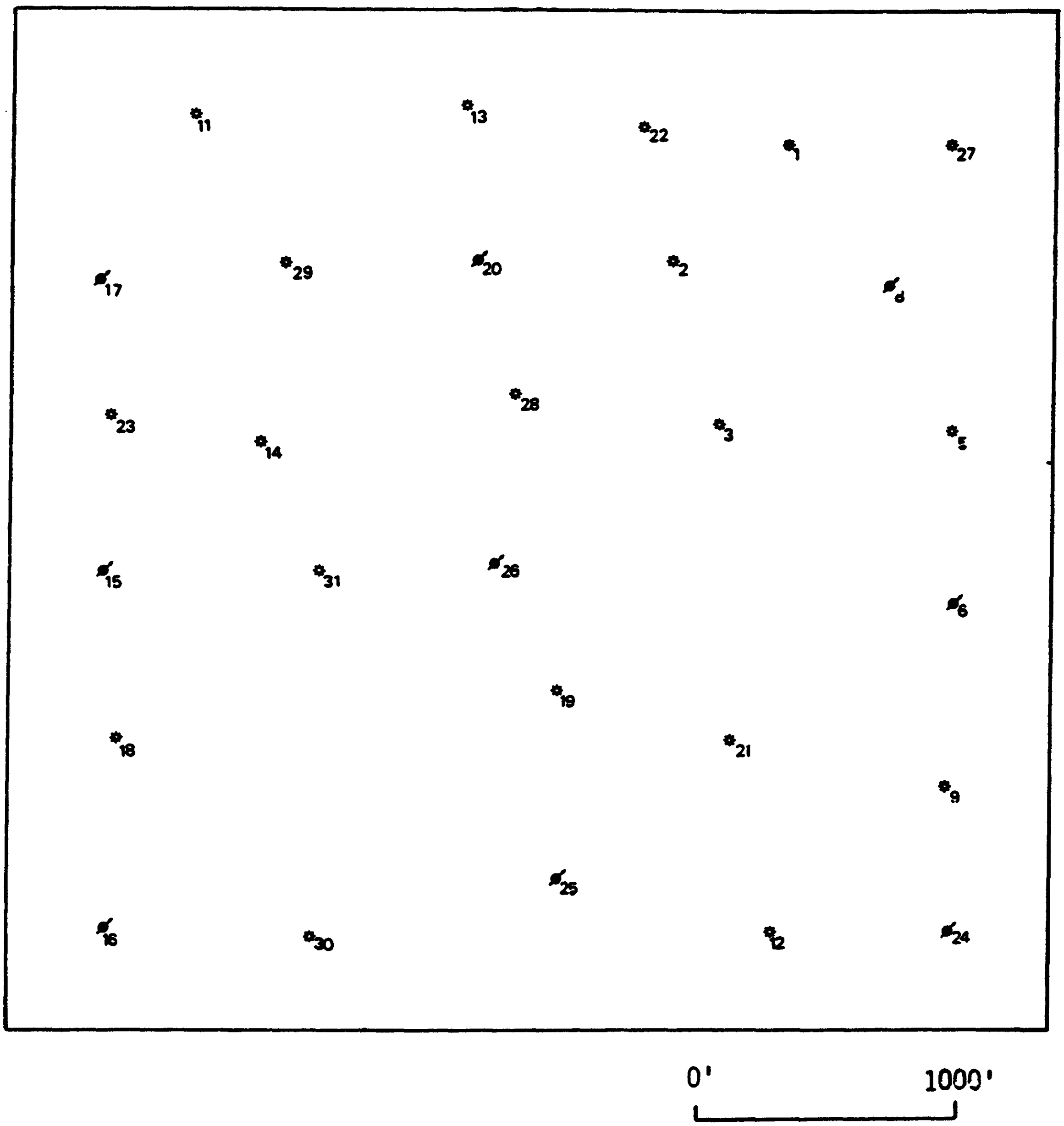


Figure 17: Pilot No. 2 (Nine Injection Wells)

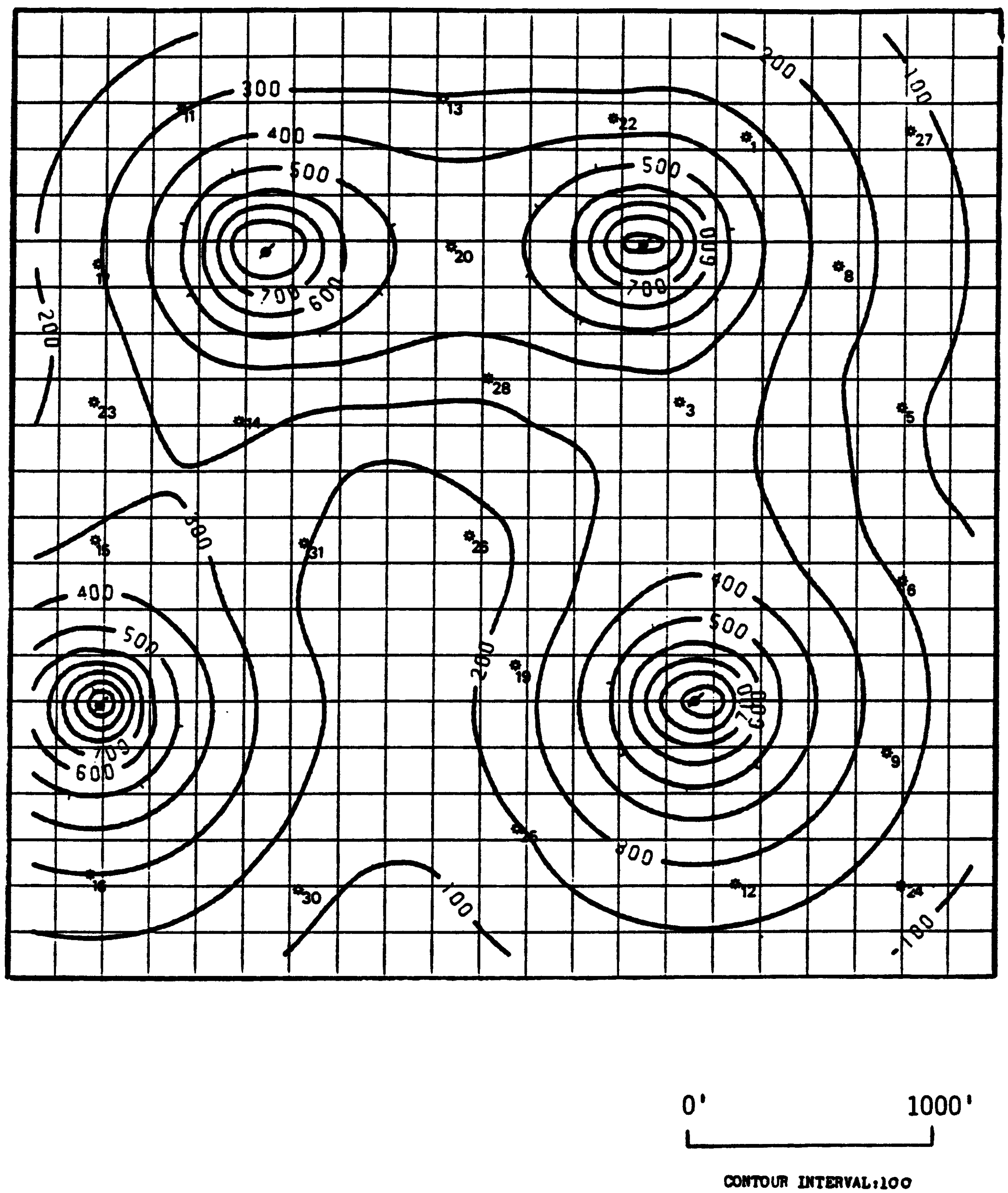


Figure 18: Pressure Distribution in Pilot No. 1

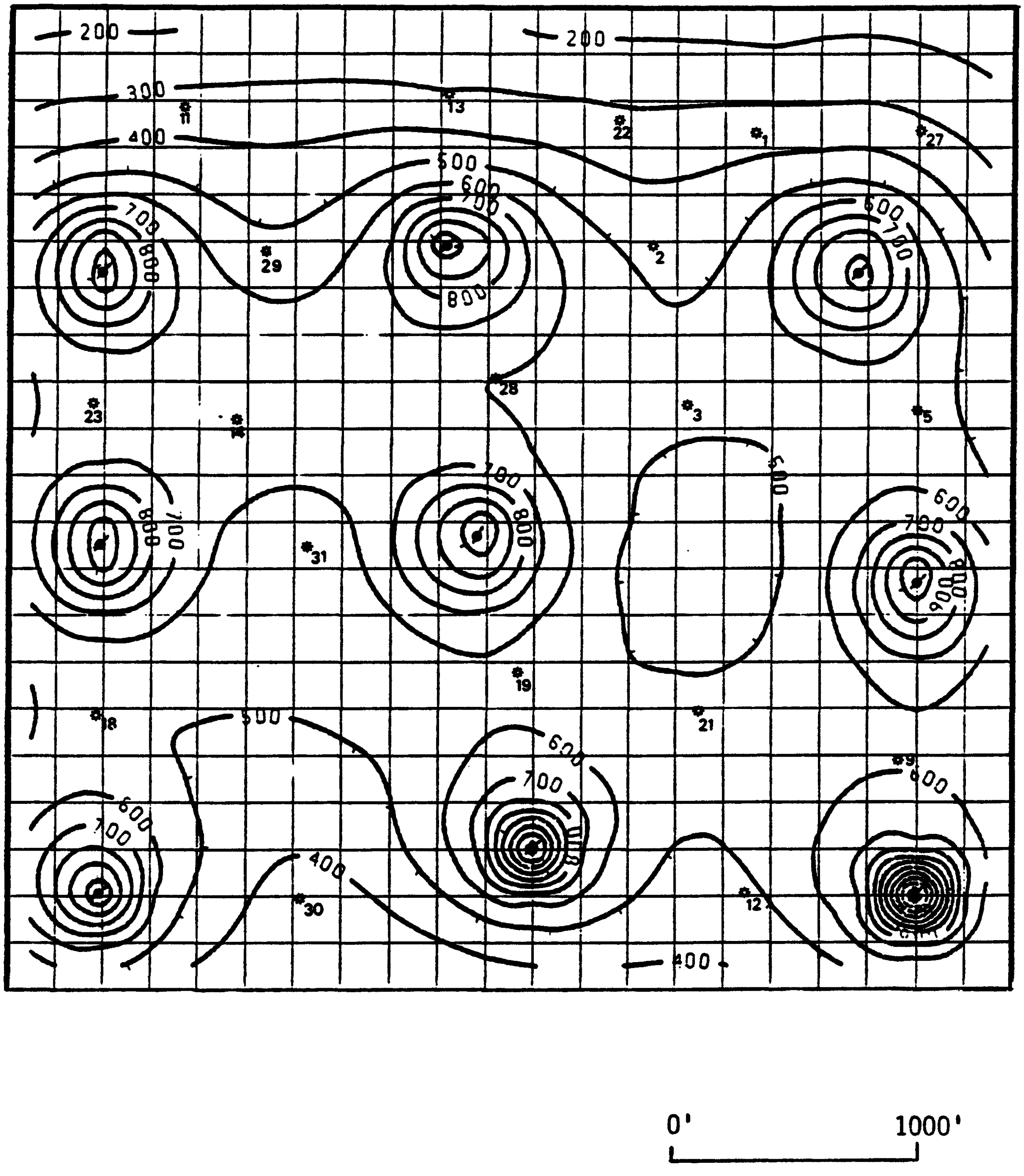


Figure 19: Pressure Distribution in Pilot No. 2

AREA OF INTEREST

This area consists of two leases, Pitts and Cockrell. They are located in Section 7, 9, and 14 in the TC and RR survey in the south central portion of Hutchinson County, Texas. The main producing zone is the Brown Dolomite at 2,900 feet. These two leases are part of the Watkins Operator's Committee project area, formed in 1946 to inject natural gas into the Brown Dolomite to increase the crude oil recovery. Gas injection began on these two leases in 1950, in eight wells (Pitts No.'s 9, 12, 26, 33, 34, 63 and Cockrell No. 3) and Pitts No. 37 was used for a salt water disposal (Figure 20). Contour maps were plotted for oil production, producing gas-oil ratio and producing water-oil ratio, during June and December 1980 and during June and December 1981 (Figures 21 through 32). The dark lines around the injection wells represent the high gradient of gas-oil ratio, water-oil ratio due to the high volume which was given to the injection wells (2500 GOR and 10 WOR).

From matching every set of oil production, producing gas-oil ratio, and water-oil ratio during the different periods of time, the following observations were made:

1) No or slight growth in the oil production rate as the produced gas-oil ratio increased. This means that the injected gas was circulating from the injection wells to the producing wells;

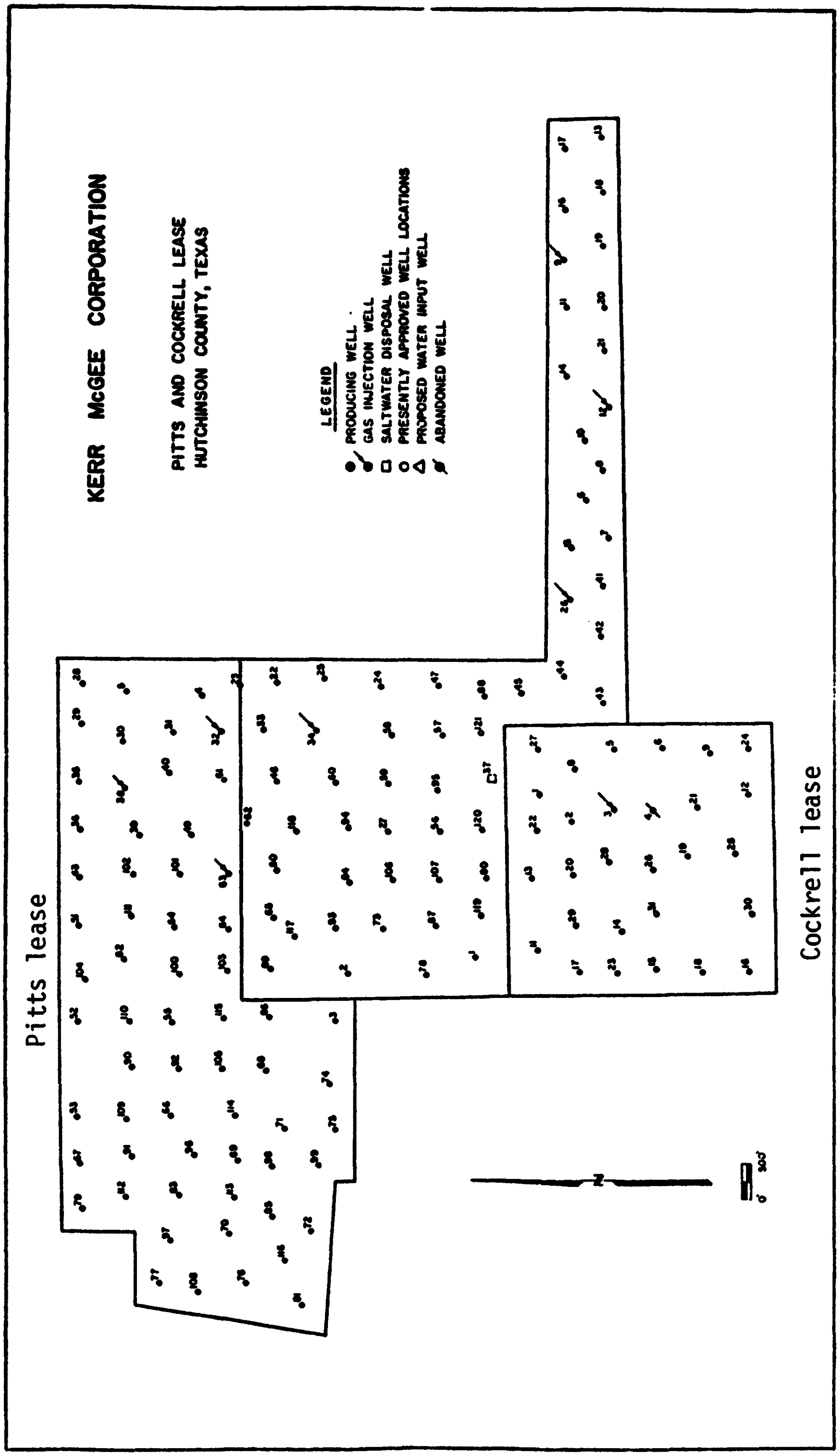


Figure 20: Pitts and Cockrell Leases

2) Slight growth in the oil production rate with increasing produced water-oil ratio in the area close to the salt water disposal well. This means that the water front was pushing some of the oil to the surrounding producing wells causing the increase in the oil production rate.

The area of the Pitts and Cockrell was selected for the study, for these reasons:

1) Adequate available data on the area;

2) The area did not have any secondary-recovery projects going on except the gas injection which was for pressure maintenance purposes as shown in Figures 21 through 32;

3) A slight response in oil production rate from the injection of salt water in Pitts Well No. 37; and

4) Good or fair increase in oil production rate from water injection in the area near the Pitts and Cockrell leases (review of two projects close to the area, in Appendix B).

The cumulative production from the Pitts lease through December 1980 has been 5.7 million barrels of oil, 12.3 billion cubic feet of gas, and 1.5 million barrels of water. The cumulative gas injection was 9.0 billion cubic feet and an estimated 2.2 million barrels of water has been injected through 1980.

The Cockrell lease began production in 1940. This

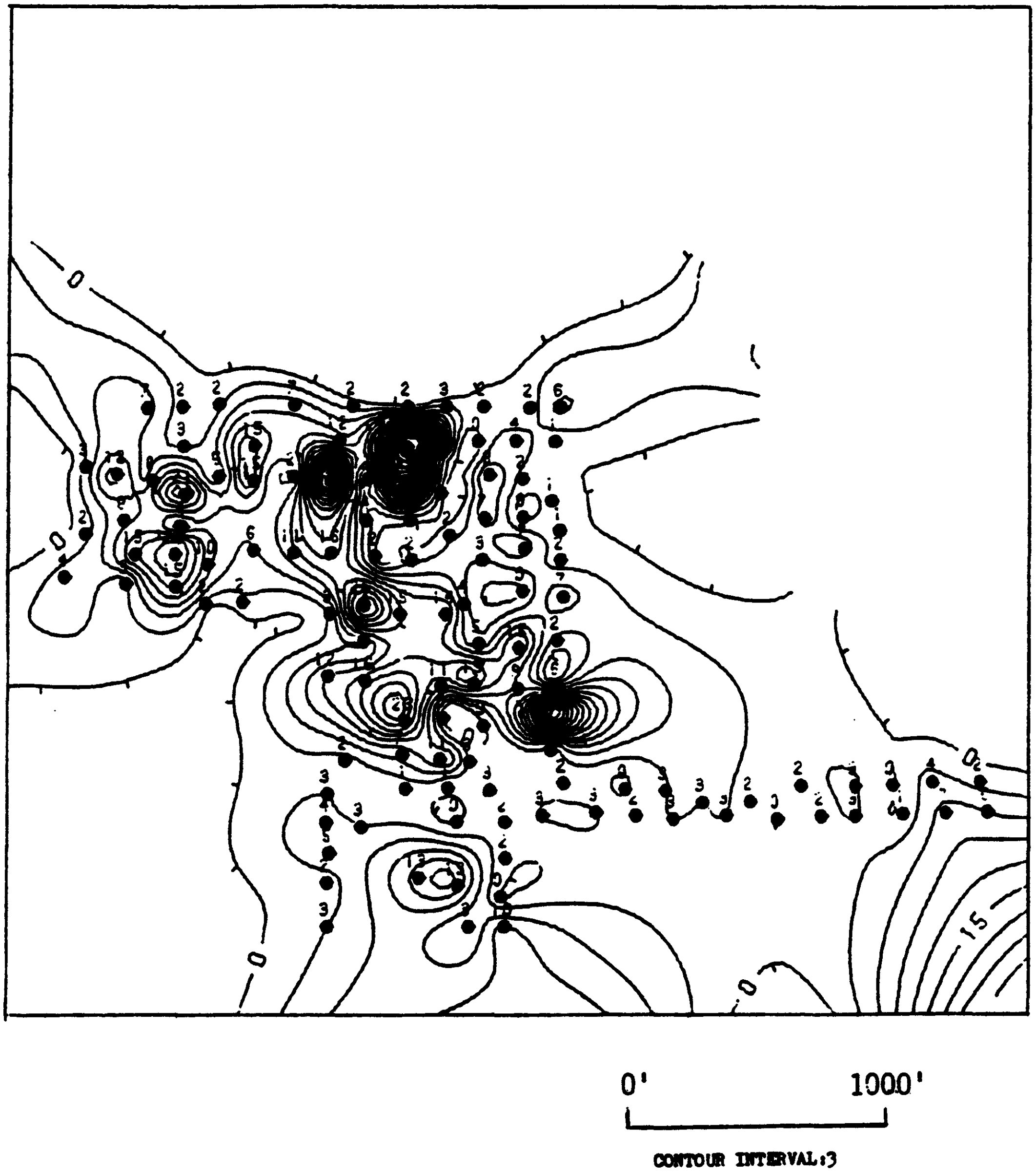


Figure 21: Oil Production Contours in June 1980 (Pitts and Cockrell Leases)

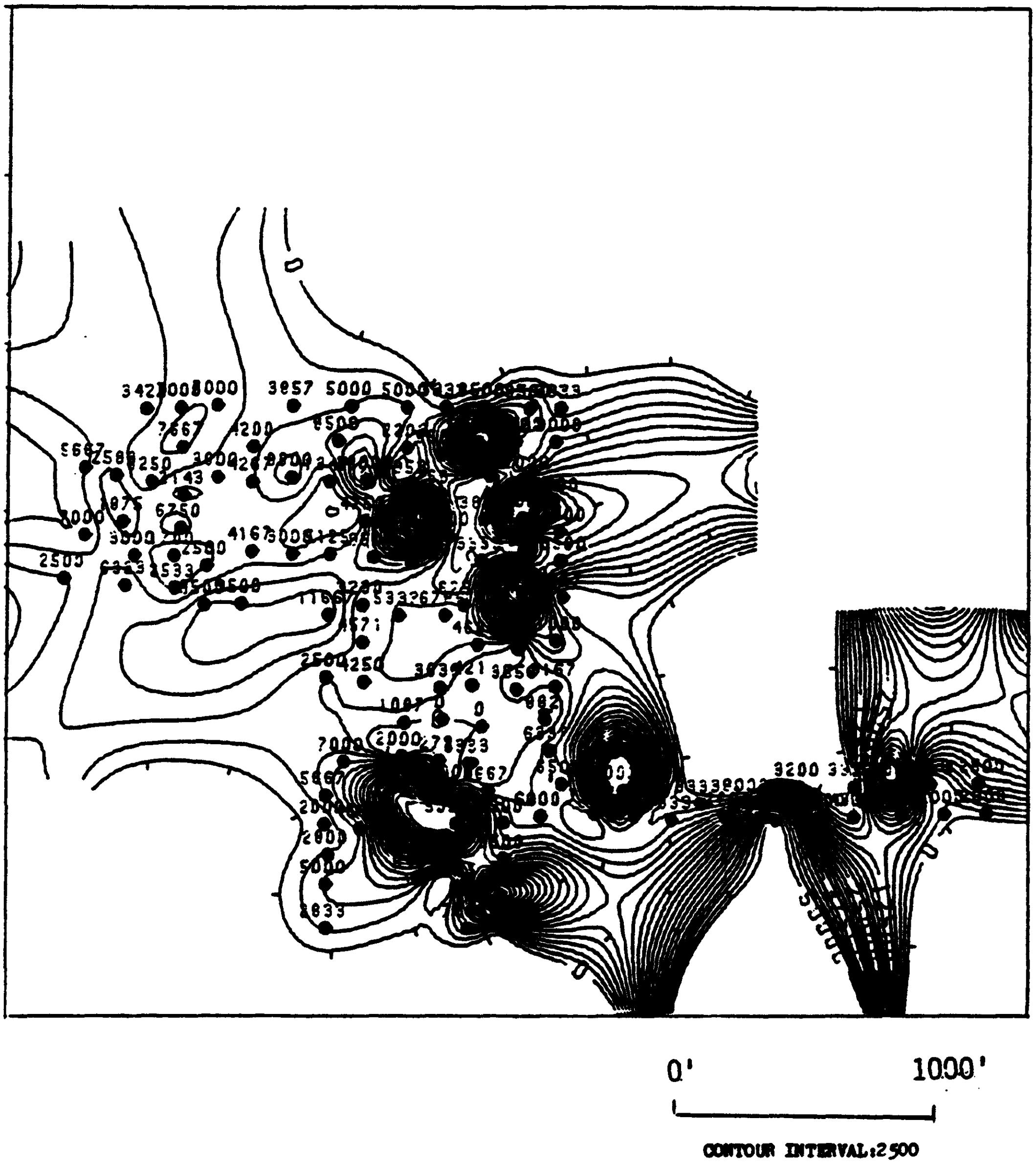


Figure 22: G.O.R. Production Contours in June 1980
(Pitts and Cockrell Lease)

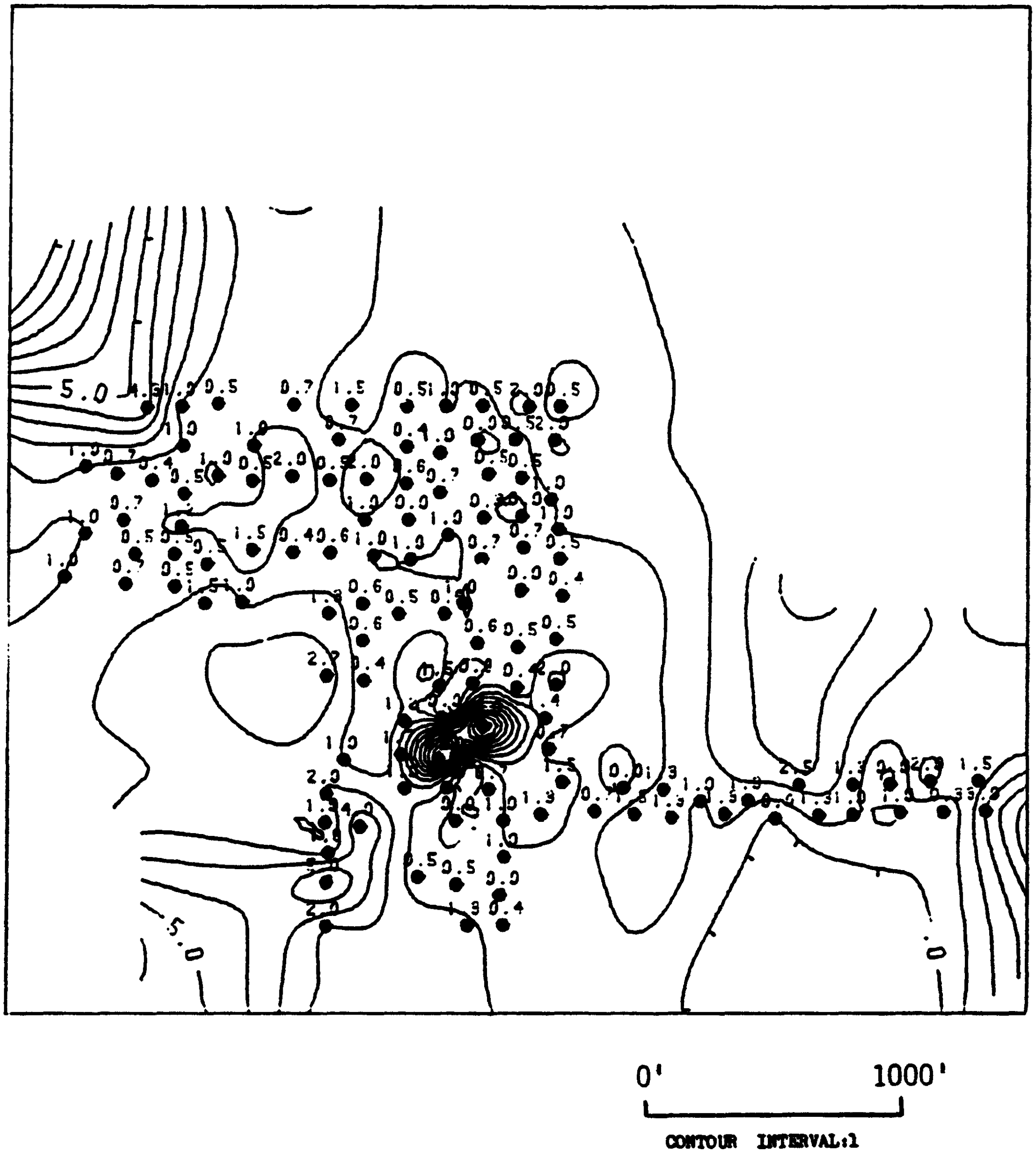


Figure 23: W.O.R. Production Contours in June 1980
(Pitts and Cockrell Lease)

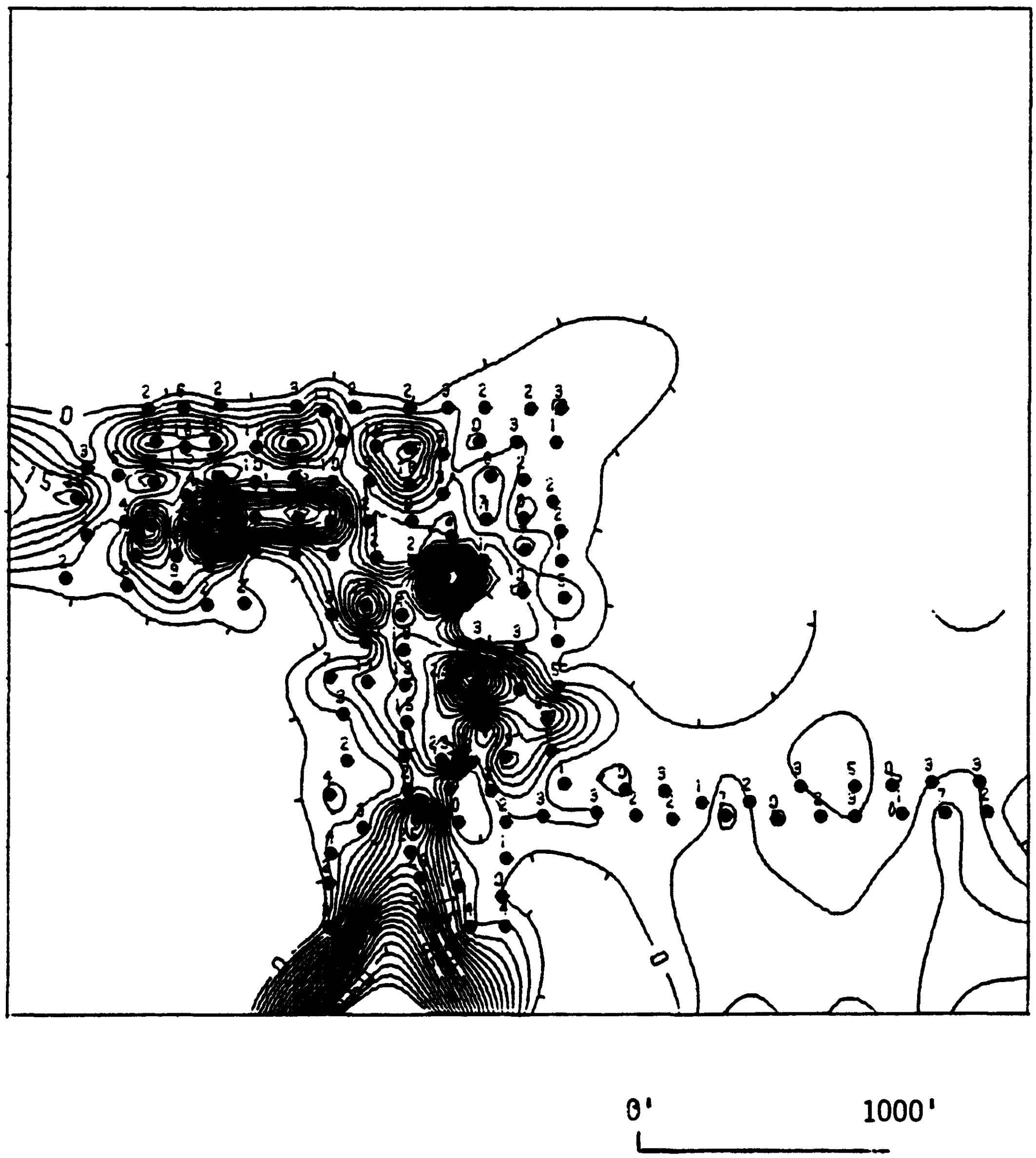


Figure 24: Oil Production Contours in December 1980
(Pitts and Cockrell Lease)

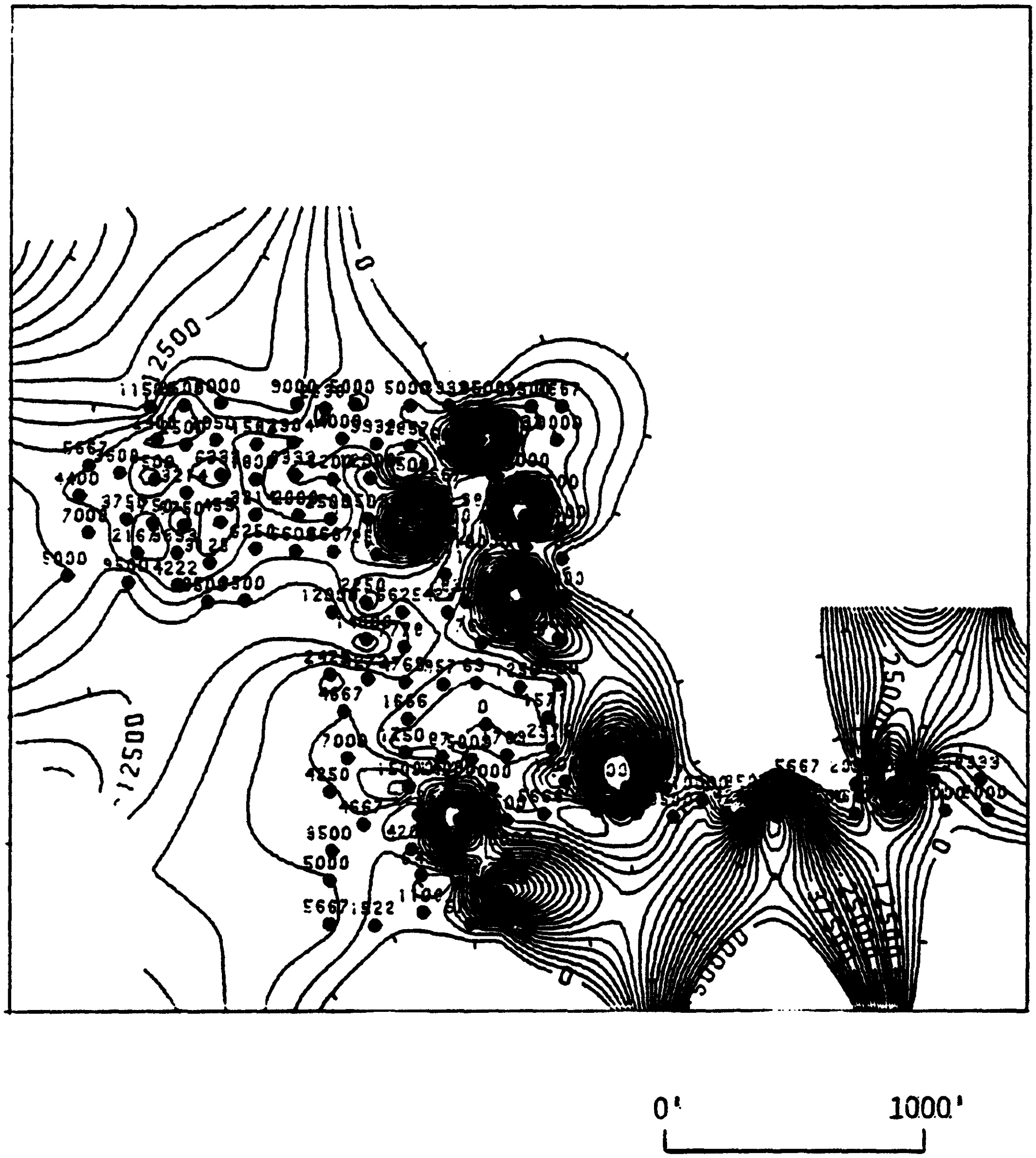


Figure 25: G.O.R. Production Contours in December 1980
(Pitts and Cockrell Leases)

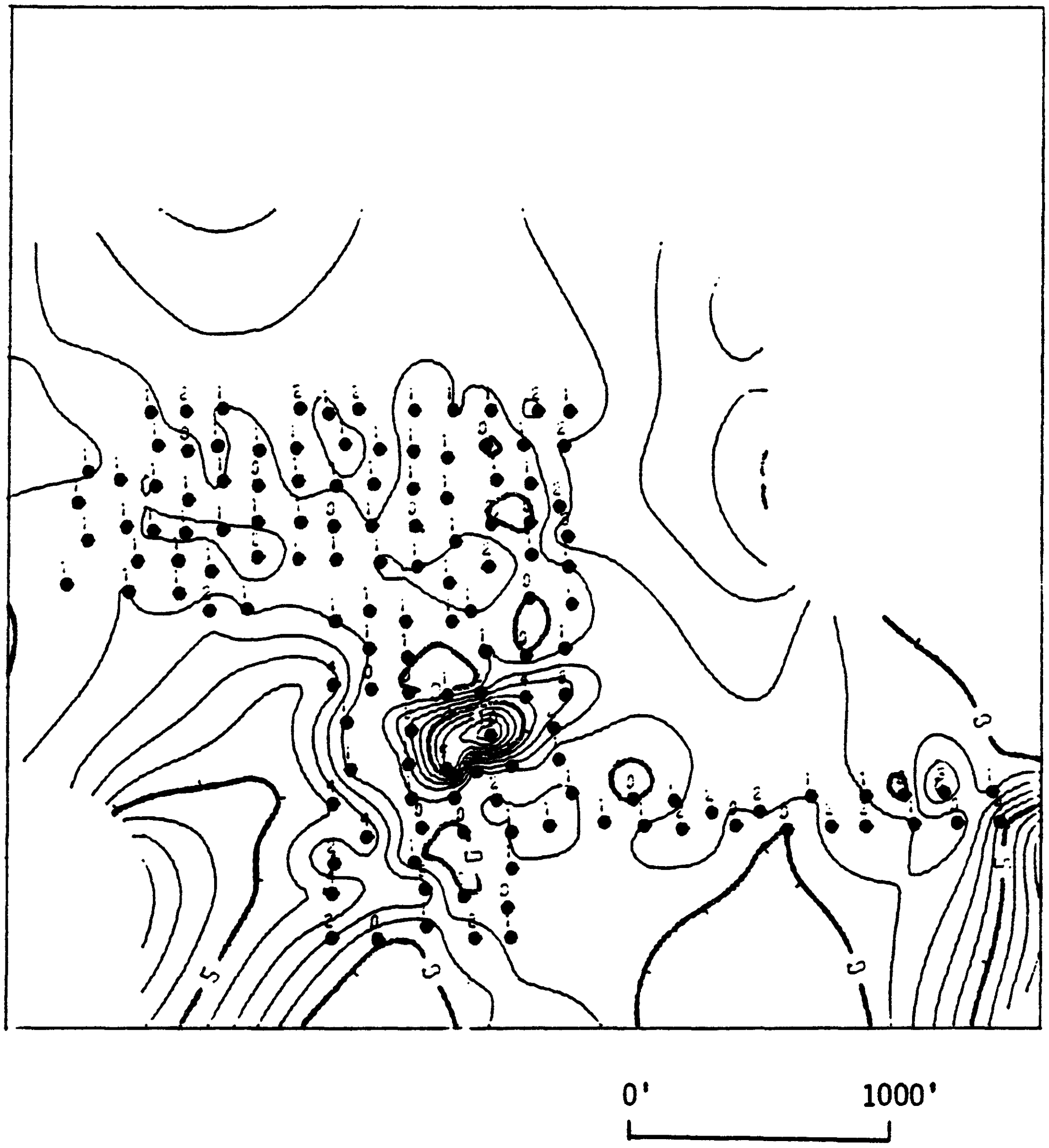


Figure 26: W.O.R. Production Contours in December 1980
(Pitts and Cockrell Leases)

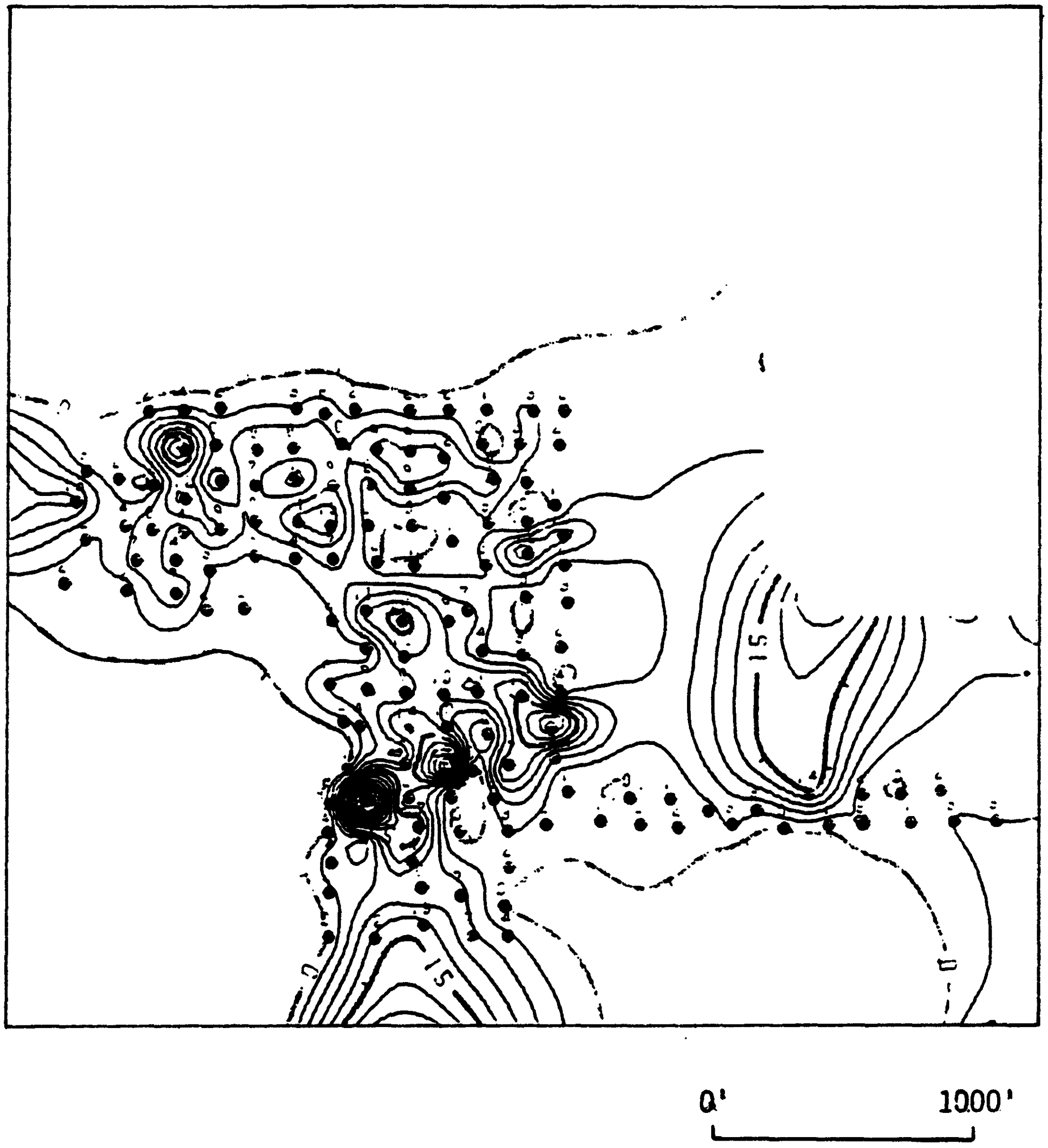


Figure 27: Oil Production Contours in June 1981
(Pitts and Cockrell Leases)

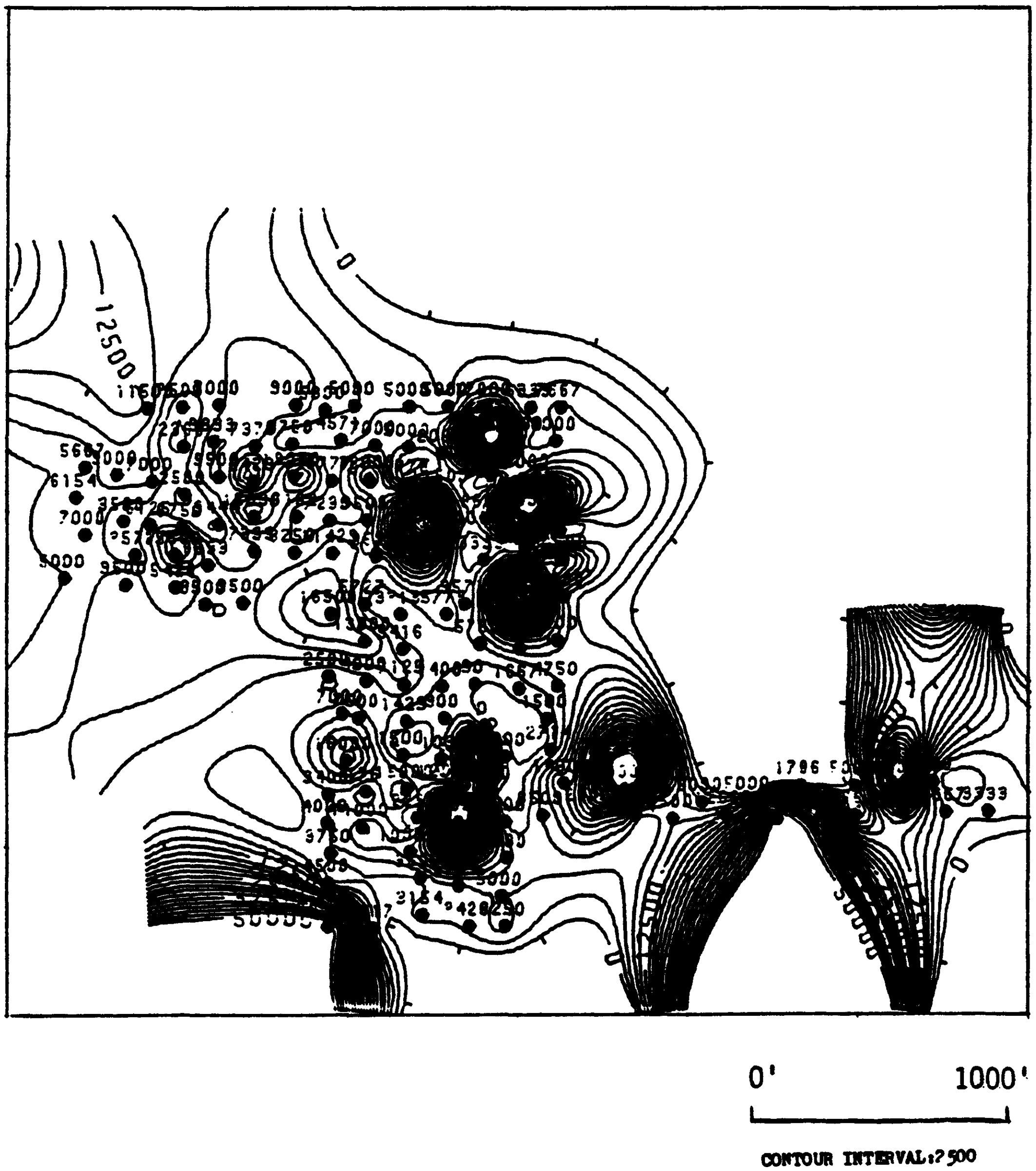


Figure 28: G.O.R. Production Contours in June 1981
(Pitts and Cockrell Leases)

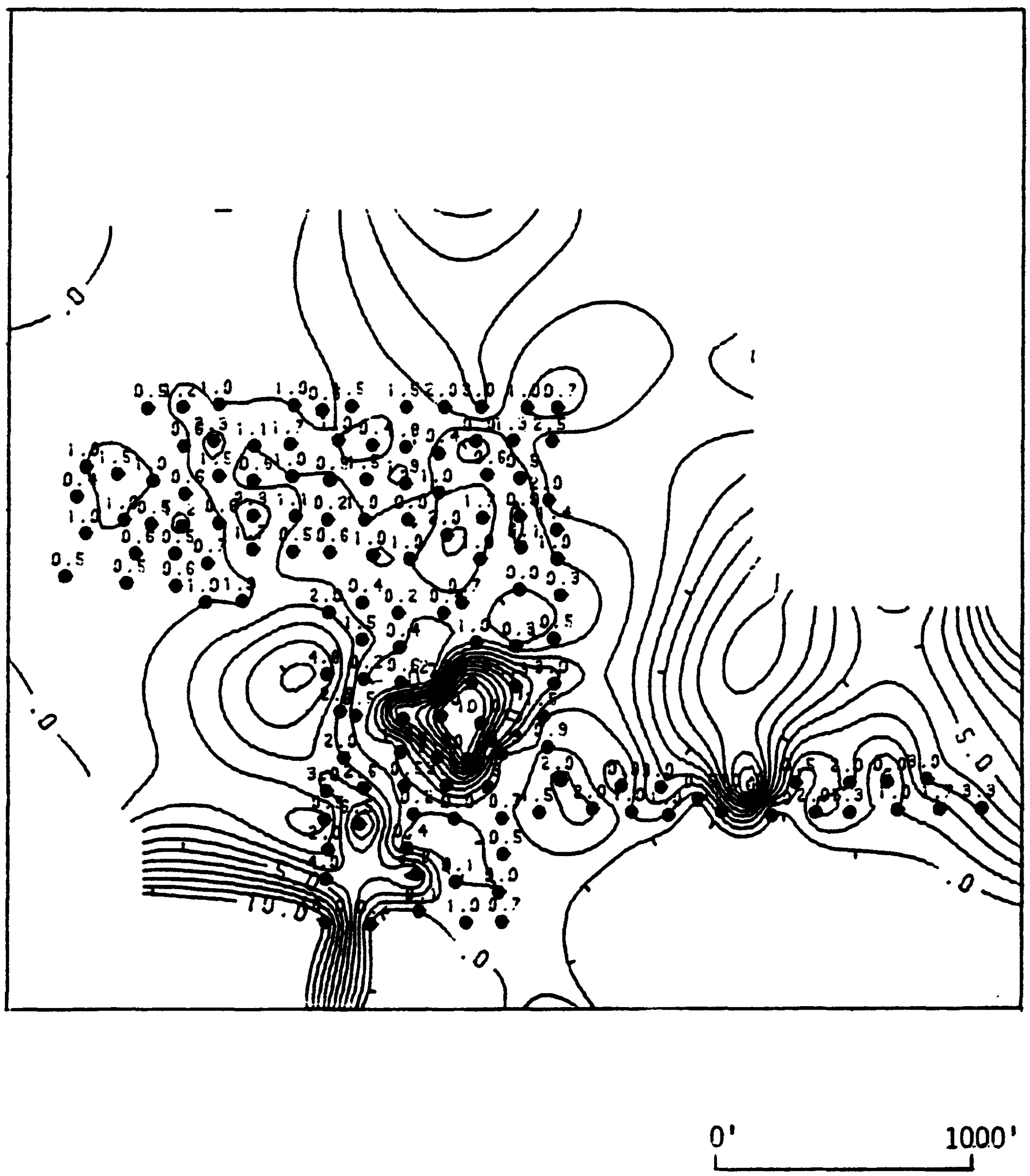


Figure 29: W.O.R. Production Contours in June 1981
(Pitts and Cockrell Leases)

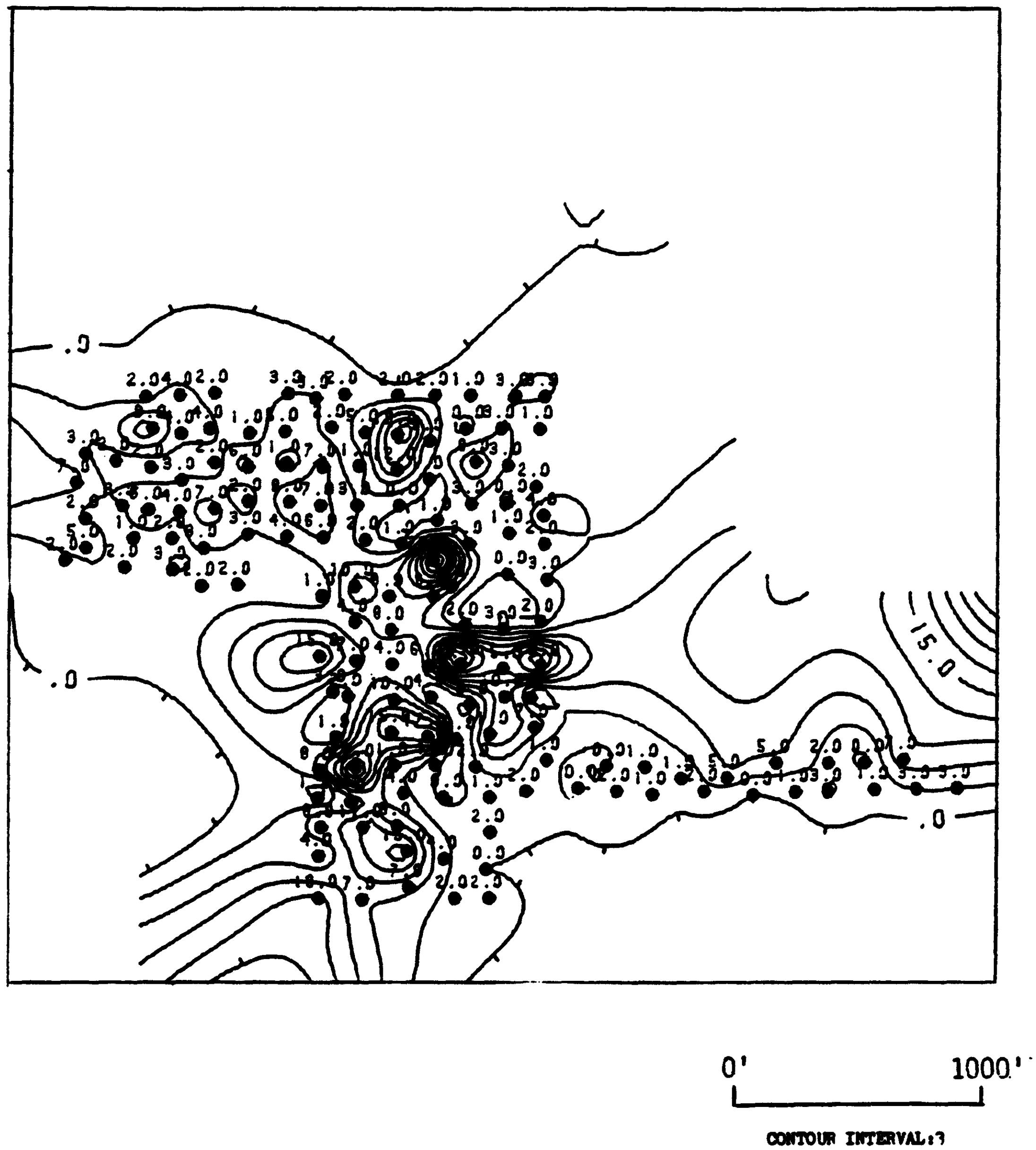


Figure 30: Oil Production Contours in December 1981
(Pitts and Cockrell Leases)

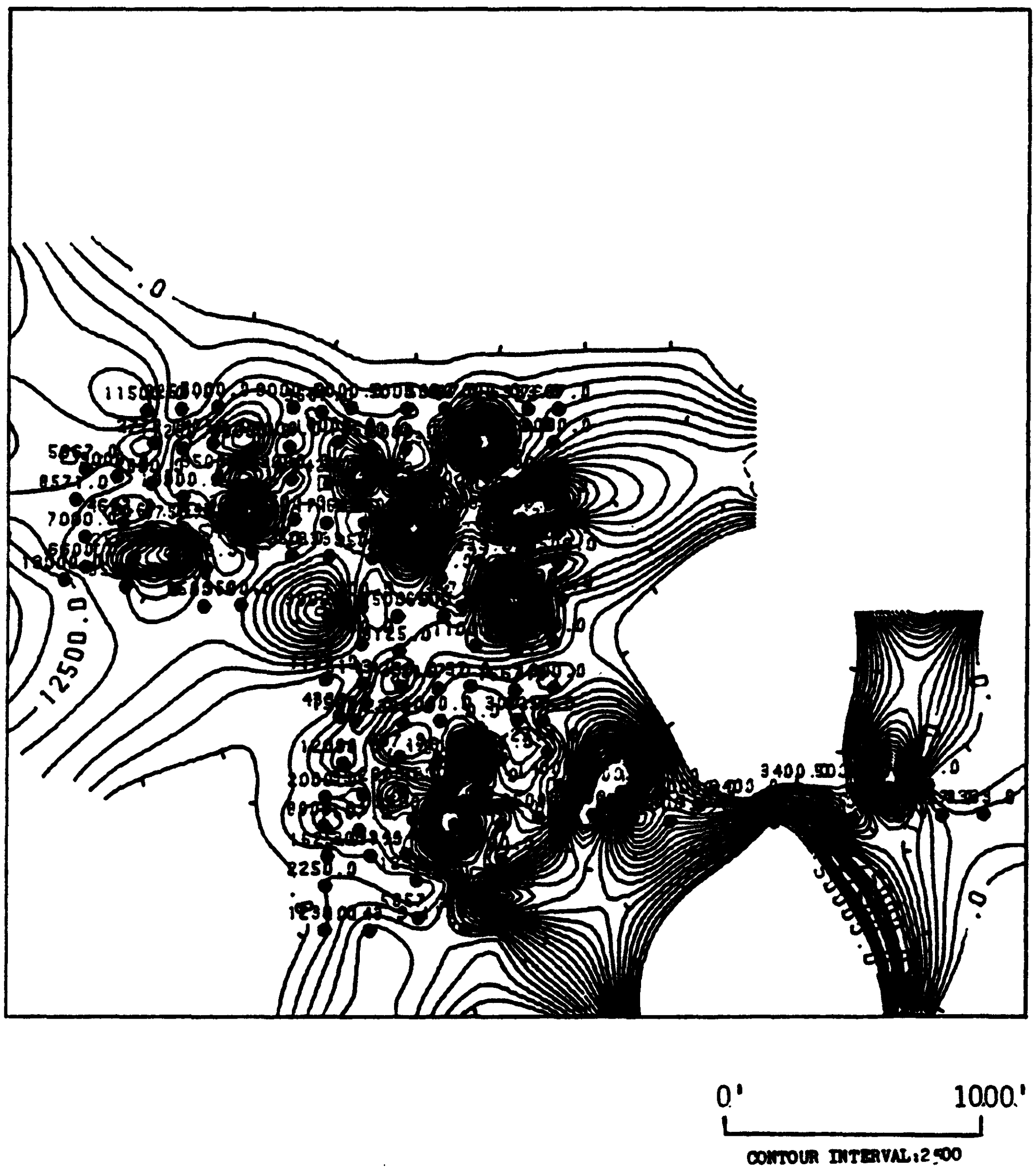
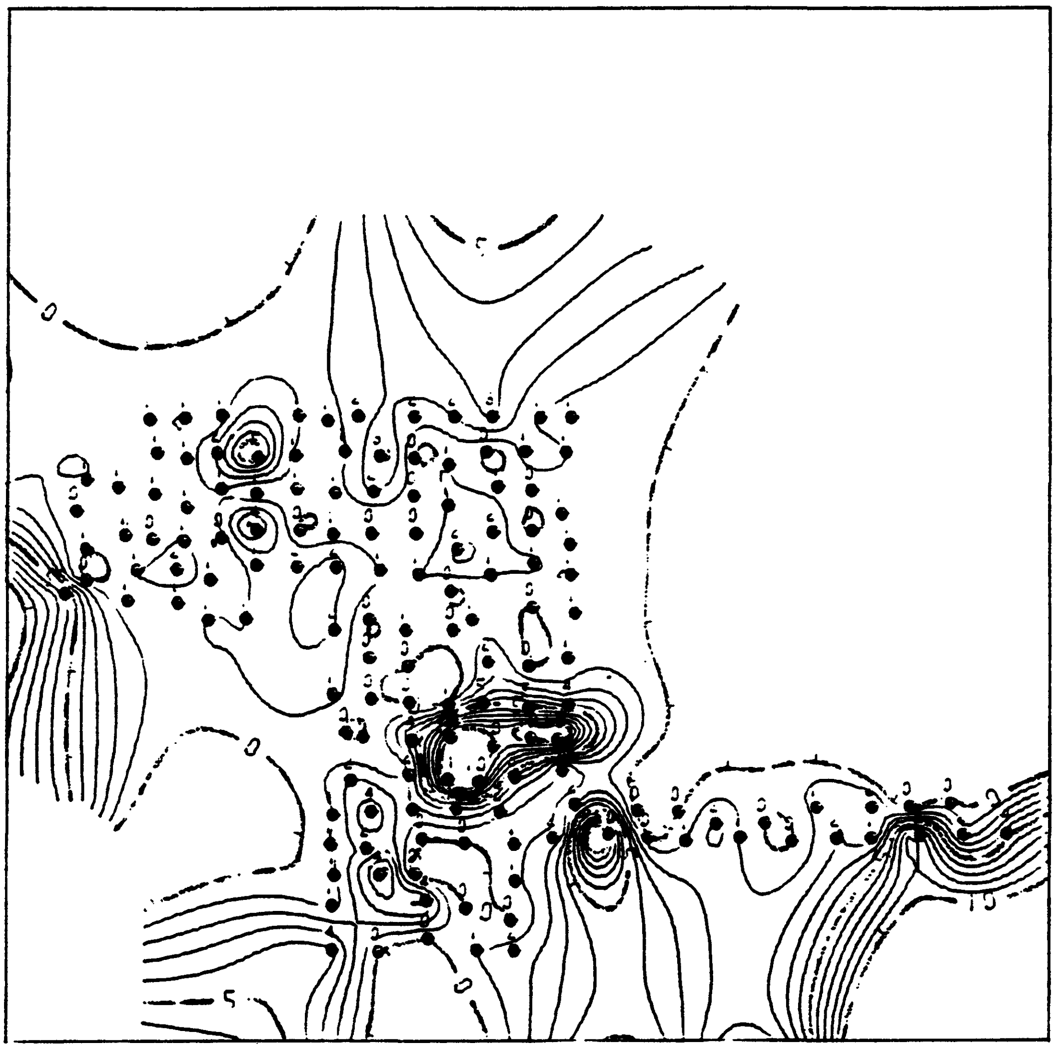


Figure 31: G.O.R. Production Contours in December 1981
(Pitts and Cockrell Leases)



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CONTOUR INTERVAL:1

Figure 32: W.O.R. Production Contours in December 1981
(Pitts and Cockrell Leases)

lease has a cumulative production through December 1980 of 0.89 million barrels of oil, 3.8 billion cubic feet of gas, and 0.57 million barrels of water, with a cumulative gas injection of 1.2 billion cubic feet. As of December 1980, there were 29 wells in the Cockrell lease and 121 wells in the Pitts lease. The December 1980 combined producing rate for both leases was 790 BOPD, 1750 BWPD, and 1425 MCFPD. Production was increasing as a result of an ongoing drilling program.

GEOLOGY OF THE AREA OF INTEREST

The Brown Dolomite is the main productive zone of the Panhandle field in the area of the Pitts and Cockrell leases. It is encountered at an average depth of 2600 feet below the surface and has a relatively uniform thickness of approximately 230 feet.

The zone is overlain by dense dolomite, chert, and anhydrite. Underlying the interval is a thin shale section separating the Brown from the White Dolomite. The White Dolomite is productive in some wells, but is not continuous across the field.

Hydrocarbons are trapped by truncation of the formation against the buried Amarillo Mountains. The gas zone is nearly nonexistent to the northeast and gradually increases to a considerable thickness on the southwestern margin of the area as porous zones rise with structure and get above the oil pay into the gas-bearing zone. There is no water encroachment in the area of interest; however, the water contact in the fifty-foot zone at the base of the oil-bearing zone represents the initial water saturation (R. Sugarek, 1980).

The best porosity occurs in the bottom 160 feet of the Brown Dolomite interval. This pay interval is further subdivided into two seventy-foot layers by an 18 foot radioactive Gamma Ray marker at an average depth of 2700 feet.

This interval is characterized by low permeability and is considered impermeable to vertical migration unless fractured. Although the interval is dolomite, it is evidenced by a Gamma Ray kick on the log and can be seen in every well on the two leases. Above the low permeability barrier lies a layer of dolomite with ten to twenty percent porosity. However, several logs indicate a gas effect in the upper layer of this interval. The best prospect for a water flood is the bottom seventy feet of the Brown Dolomite. This layer is very heterogenous dolomite, containing anhydrite, chert, and some shale.

RESERVOIR ROCK AND FLUID PARAMETERS

Logs from three new wells (Pitts 82, 83, and Cockrell 19) and core analysis from four wells (Pitts 82, 83, 84 and Cockrell 19) were used to obtain the important reservoir and fluid parameters.

Effective Pay Thickness

The logs from three wells (Pitts 82, 83 and Cockrell 19) were used to calculate the average net pay thickness. A value of 85 feet net pay thickness was found.

Porosity

The average reservoir porosity was calculated to be 15% using the following equation:

$$\text{Average } \phi = \frac{\sum_{i=1}^{n} \phi_i h_i}{\sum_{i=1}^{n} h_i}$$

where:

ϕ_i = porosity for individual sample fraction

h_i = pay thickness for individual sample feet

Water Saturation

Average connate water was calculated to be 30% using the following equation:

$$\text{Average } S_{wi} = \frac{\sum_{i=1}^{n} \phi_i h_i S_{wi}}{\sum_{i=1}^{n} \phi_i h_i}$$

where:

S_{wi} = connate water saturation for individual wells, fraction

ϕ_i = reservoir porosity for individual wells, fraction

h_i = net pay thickness for individual wells, feet

Fluid Properties

The fluid properties were calculated based on averaging the fluid properties for four wells.

Oil Viscosity

Oil viscosity was calculated to be 5.08 c.p. at 100^{o}F. Initial oil formation volume factor was calculated to be 1.156 reservoir barrels per stock-tank barrels at 450 psia (Fred Wilson, 1981). Current oil formation volume factor is reported as 1.032 reservoir barrels per stock-tank barrels at 60 psia (Fred Wilson, 1981).

Effective Permeabilities and Residual Oil Saturation

A core sample of 15% porosity, 46 md. permeability, 45.7% oil saturation, 40% water saturation, and 14.3% free gas saturation was used to obtain the following results for displacing oil by water:

Effective permeability to oil = 30 m.d

Effective permeability to water = 4.4 m.d

Residual oil saturation = 34%

CALCULATION OF THE OIL IN PLACE

The oil in place was obtained on the basis of the following equation:

$$N = 7758\ A\phi h\ (1 - S_{wi})/B_{oi}$$

where:

N = initial oil in place, stock-tank barrel

A = surface area, acre

ϕ = average reservoir porosity, fraction

h = effective pay thickness, feet

S_{wi} = average initial water saturation, fraction

B_{oi} = oil formation volume factor at initial pressure reservoir barrel per stock-tank barrel

The initial oil in place was determined to be 95.8 million stock-tank barrel based on the reservoir volume of 135,898 acre-feet (A = 1598.8 acre, h = 85 feet).

Saturation values at the time the water flood start were calculated as shown in the following discussion.

Oil Saturation

The following equation was used to calculate the oil saturation, assuming the net transformation across the lease lines equal to zero. The oil saturation was calculated to be 58.2%.

$$So = (1 - \frac{Np}{N}) (\frac{Bo}{B_{oi}}) (1 - S_{wi})$$

So = oil saturation, fraction

$\frac{Np}{N}$ = recovery, fraction

where:

Np was found to be 6.6 million stock-tank barrels (Figures 33 and 34) and N was calculated to be 95.8 million stock-tank barrels.

Bo = current oil formation volume factor, reservoir barrel per stock-tank barrel

B_{oi} = initial oil formation volume factor, reservoir barrel per stock-tank barrel

S_{wi} = water saturation

Gas Saturation

Gas saturation was found to be 11.8% from using the following equation:

$$Sg = 1 - So - S_{wi}$$

where:

Sg, So, S_{wi} are the gas, oil and water saturations, respectively.

The Dardaganian correlation was used to find the residual gas saturation. A residual gas saturation value of 9.5% was obtained.

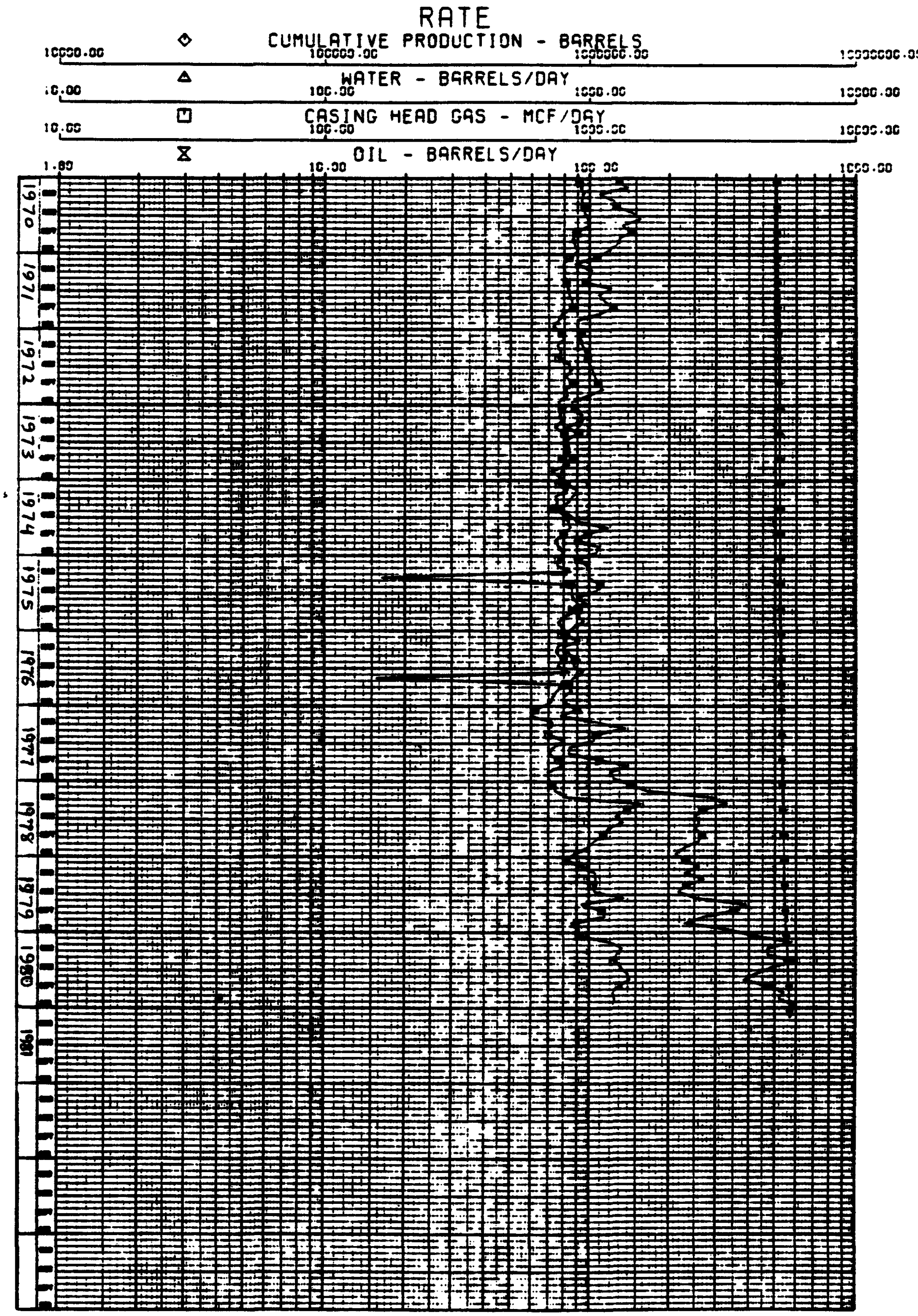

Figure 33: Production With Time (Cockrell Lease)

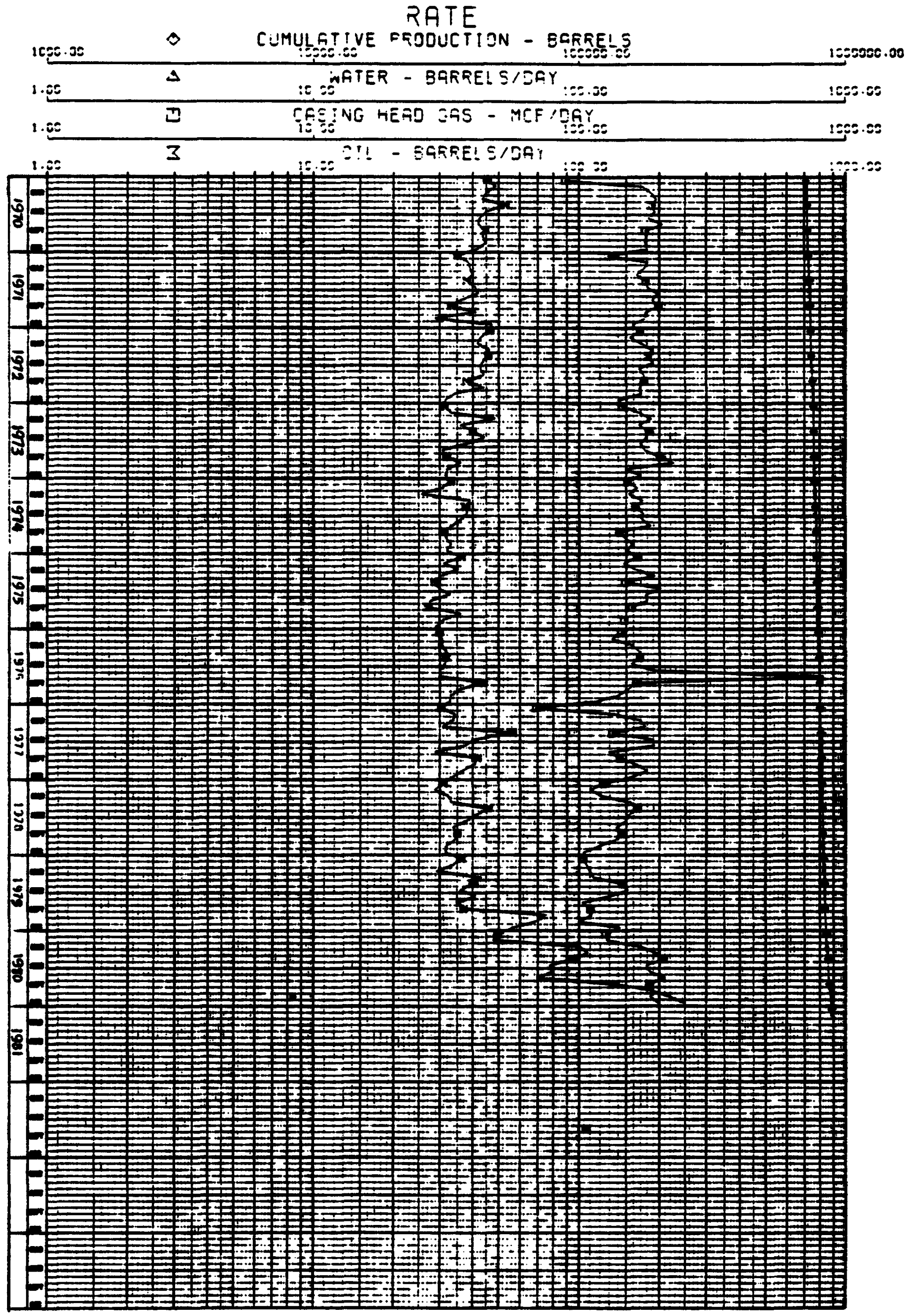

Figure 34: Production With Time (Pitts Lease)

WATER FLOOD PILOTS

The Cockrell area was selected for a pilot test to be representative of the entire area, because it was affected by primary recovery only. Twenty-eight active wells and one abandoned well exist in 318.8 acre surface area.

Two pilots were designed to determine the response of the Cockrell lease to water flood recovery prior to the investment of large sums of capital required to develop the full-scale project. Well Nos. 18, 21, 29 and 2 were selected as injection wells in Pilot No. 1 (Figure 16) and Well Nos. 16, 25, 24, 15, 26, 6, 17, 20, and 8 were selected as injection wells in Pilot No. 2 (Figure 17).

Maximum injection pressure was designed to be 2500 psi. The injection rate was calculated to be 807 bbls/day per injection well, using the following equation:

$$Q_i = \frac{0.00708\ K_{wi}\ h}{\mu w\ \ln \frac{rd}{rw}} (P_i - \bar{P})$$

where:

Q_i = water injection rate, bbls per day

K_{wi} = the effective water permeability, m.d

h = effective net pay thickness, feet

P_i = formation injection pressure, psi

$\bar{P}$ = average reservoir pressure, psi

μw = water viscosity, c.p

rd = 4re where re is the effective well radius, feet

rwf = borehole radius, feet

The pilot floods are unconfined and most of the materials in the literature were designed for confined reservoirs, therefore no literature can be used to calculate the swept area. The equipotential and stream lines were established for each pilot (Figures 18, 19) and Figures 35, 36). Because of high gas saturation, an oil bank is formed ahead of the water invaded region. Because of the zone with a high gas saturation, the injection water well does not know that the producing wells exist until the oil bank reaches the producing well.

Another set of equipotential lines and stream lines were established for each pilot after oil break-through at the producing wells (Figures 37, 38, 39 and 40). Areas swept by water were measured until the time of oil break-through for each pilot (Figures 41, 42, 43, and 44). Radius of the water front at the time of oil break-through was obtained assuming the swept area as a uniform circle (Appendix D). Since rwf is known, new oil production rates for those wells which have been contacted by the oil front have been obtained, and a new set of stream lines have been plotted (Appendices C and D).

Final swept area until water break-through was measured (Figures 45, 46, 47, 48 and 49). Time of oil break-through, water break-through and water injected for the two times were obtained using the following equations:

$$(Vi)_{BT} = (Vs)_{BT}\ \phi\ (1 - S_{wi} - S_{dr})$$

$$(T)_{BT} = \frac{(Vi)_{BT}}{q_i}$$

where:

$(Vi)_{BT}$ = total fluid injected at time of break-through, bbls

$(Vs)_{BT}$ = volume swept at the time of break-through, bbls

ϕ = average reservoir porosity, fraction

S_{wi} = connate water saturation, fraction

S_{dr} = final saturations in the displaced fluids, fraction

T = time of break-through in days

q_i = total injection rate bbls/day

Table 1A

Daily Oil Production in the Cockrell Lease

Well No.	Qo (bbls/day)
19	15
21	8
22	20
23	2.5
26	15
30	20
24	5
12	4
25	19
9	4
16	5
31	12
18	2.5
5	2
3	2.5
28	17
14	3
15	5
17	5
29	27
20	1.5
2	1
8	2.5
27	15
1	2.5
13	9.5
11	2
6	2

Table 1: Pressure Distribution (Pilot 1)

X	Y	P
0.000	0.000	139.882
187.200	0.000	149.869
374.400	0.000	151.455
561.600	0.000	144.214
748.800	0.000	128.726
936.000	0.000	106.841
1123.200	0.000	81.653
1310.400	0.000	55.775
1497.600	0.000	49.682
1684.800	0.000	50.183
1872.000	0.000	67.278
2059.200	0.000	91.726
2246.400	0.000	113.512
2433.600	0.000	130.556
2620.800	0.000	140.722
2808.000	0.000	142.369
2995.200	0.000	134.974
3182.400	0.000	120.883
3369.600	0.000	101.352
3556.800	0.000	78.255
3744.000	0.000	57.126
3931.200	0.000	57.742
0.000	187.200	193.977
187.200	187.200	205.326
374.400	187.200	207.875
561.600	187.200	197.930
748.800	187.200	176.204
936.000	187.200	146.221
1123.200	187.200	111.913
1310.400	187.200	80.784
1497.600	187.200	51.239
1684.800	187.200	66.022
1872.000	187.200	96.864
2059.200	187.200	127.492
2246.400	187.200	156.226
2433.600	187.200	179.676
2620.800	187.200	193.947
2808.000	187.200	195.704
2995.200	187.200	185.844
3182.400	187.200	166.363
3369.600	187.200	140.201
3556.800	187.200	112.654
3744.000	187.200	80.892
3931.200	187.200	57.154
0.000	374.400	251.374
187.200	374.400	273.156
374.400	374.400	276.892
561.600	374.400	263.238
748.800	374.400	231.614
936.000	374.400	189.969
1123.200	374.400	142.343
1310.400	374.400	106.221
1497.600	374.400	82.829
1684.800	374.400	89.958
1872.000	374.400	126.290
2059.200	374.400	164.332
2246.400	374.400	203.998
2433.600	374.400	238.170
2620.800	374.400	259.579
2808.000	374.400	261.636

Table 1 continued

X	Y	P
2995.200	374.400	246.210
3182.400	374.400	218.338
3369.600	374.400	182.298
3556.800	374.400	141.145
3744.000	374.400	107.743
3931.200	374.400	73.560
0.000	561.600	322.369
187.200	561.600	361.368
374.400	561.600	370.928
561.600	561.600	345.149
748.800	561.600	295.483
936.000	561.600	238.204
1123.200	561.600	182.561
1310.400	561.600	134.030
1497.600	561.600	120.232
1684.800	561.600	121.199
1872.000	561.600	154.[illegible]99
2059.200	561.600	194.133
2246.400	561.600	257.010
2433.600	561.600	309.139
2620.800	561.600	344.606
2808.000	561.600	349.018
2995.200	561.600	322.193
3182.400	561.600	277.346
3369.600	561.600	227.018
3556.800	561.600	178.44[illegible]
3744.000	561.600	133.443
3931.200	561.600	93.332
0.000	748.800	404.562
187.200	748.800	481.327
374.400	748.800	505.529
561.600	748.800	450.175
748.800	748.800	364.774
936.000	748.800	284.015
1123.200	748.800	214.923
1310.400	748.800	163.977
1497.600	748.800	151.241
1684.800	748.800	152.766
1872.000	748.800	181.646
2059.200	748.800	241.395
2246.400	748.800	315.133
2433.600	748.800	395.347
2620.800	748.800	461.866
2808.000	748.800	473.939
2995.200	748.800	416.078
3182.400	748.800	340.574
3369.600	748.800	269.343
3556.800	748.800	207.569
3744.000	748.800	154.872
3931.200	748.800	109.348
0.000	936.000	483.135
187.200	936.000	650.818
374.400	936.000	745.966
561.600	936.000	574.336
748.800	936.000	424.273
936.000	936.000	317.225
1123.200	936.000	235.937
1310.400	936.000	182.598
1497.600	936.000	173.891
1684.800	936.000	173.375

Table 1 continued

X	Y	P
1872.000	936.000	231.226
2059.200	936.000	272.224
2246.400	936.000	364.671
2433.600	936.000	493.429
2620.800	936.000	641.943
2808.000	936.000	669.278
2995.200	936.000	523.098
3182.400	936.000	396.353
3369.600	936.000	301.527
3556.800	936.000	227.485
3744.000	936.000	169.284
3931.200	936.000	119.894
0.000	1123.200	508.817
187.200	1123.200	747.376
374.400	1123.200	1072.476
561.600	1123.200	626.202
748.800	1123.200	442.022
936.000	1123.200	326.014
1123.200	1123.200	241.200
1310.400	1123.200	188.321
1497.600	1123.200	175.982
1684.800	1123.200	178.779
1872.000	1123.200	206.190
2059.200	1123.200	280.587
2246.400	1123.200	383.872
2433.600	1123.200	535.989
2620.800	1123.200	837.643
2808.000	1123.200	962.830
2995.200	1123.200	583.105
3182.400	1123.200	420.044
3369.600	1123.200	314.555
3556.800	1123.200	236.451
3744.000	1123.200	174.664
3931.200	1123.200	123.656
0.000	1310.400	454.524
187.200	1310.400	576.809
374.400	1310.400	627.421
561.600	1310.400	524.370
748.800	1310.400	403.499
936.000	1310.400	306.395
1123.200	1310.400	228.930
1310.400	1310.400	177.016
1497.600	1310.400	166.013
1684.800	1310.400	168.603
1872.000	1310.400	197.001
2059.200	1310.400	264.080
2246.400	1310.400	361.098
2433.600	1310.400	492.820
2620.800	1310.400	620.592
2808.000	1310.400	654.060
2995.200	1310.400	517.740
3182.400	1310.400	394.976
3369.600	1310.400	302.039
3556.800	1310.400	229.050
3744.000	1310.400	169.737
3931.200	1310.400	120.115
0.000	1497.600	370.717
187.200	1497.600	428.697
374.400	1497.600	444.988
561.600	1497.600	405.021

Table 1 continued

X	Y	P
748.800	1497.600	339.959
936.000	1497.600	274.248
1123.200	1497.600	209.928
1310.400	1497.600	152.947
1497.600	1497.600	142.389
1684.800	1497.600	144.555
1872.000	1497.600	178.194
2059.200	1497.600	239.302
2246.400	1497.600	311.616
2433.600	1497.600	391.266
2620.800	1497.600	455.360
2808.000	1497.600	463.037
2995.200	1497.600	411.573
3182.400	1497.600	339.151
3369.600	1497.600	269.309
3556.800	1497.600	207.816
3744.000	1497.600	155.273
3931.200	1497.600	109.720
0.000	1684.800	292.366
187.200	1684.800	323.002
374.400	1684.800	344.564
561.600	1684.800	341.222
748.800	1684.800	312.229
936.000	1684.800	268.531
1123.200	1684.800	215.941
1310.400	1684.800	163.912
1497.600	1684.800	138.206
1684.800	1684.800	121.948
1872.000	1684.800	157.228
2059.200	1684.800	225.178
2246.400	1684.800	290.758
2433.600	1684.800	346.942
2620.800	1684.800	381.580
2808.000	1684.800	383.999
2995.200	1684.800	344.441
3182.400	1684.800	285.116
3369.600	1684.800	227.081
3556.800	1684.800	178.174
3744.000	1684.800	133.914
3931.200	1684.800	93.691
0.000	1872.000	226.501
187.200	1872.000	271.124
374.400	1872.000	298.872
561.600	1872.000	308.308
748.800	1872.000	297.503
936.000	1872.000	270.091
1123.200	1872.000	229.578
1310.400	1872.000	183.291
1497.600	1872.000	139.936
1684.800	1872.000	152.781
1872.000	1872.000	186.400
2059.200	1872.000	225.813
2246.400	1872.000	280.813
2433.600	1872.000	323.249
2620.800	1872.000	345.107
2808.000	1872.000	342.832
2995.200	1872.000	311.073
3182.400	1872.000	262.910
3369.600	1872.000	204.324
3556.800	1872.000	145.221

Table 1 continued

X	Y	P
3744.000	1872.000	108.471
3931.200	1872.000	73.755
0.000	2059.200	197.631
187.200	2059.200	241.858
374.400	2059.200	275.450
561.600	2059.200	295.020
748.800	2059.200	298.375
936.000	2059.200	284.211
1123.200	2059.200	253.787
1310.400	2059.200	239.767
1497.600	2059.200	184.739
1684.800	2059.200	202.189
1872.000	2059.200	230.820
2059.200	2059.200	257.978
2246.400	2059.200	283.363
2433.600	2059.200	319.734
2620.800	2059.200	334.836
2808.000	2059.200	326.094
2995.200	2059.200	295.952
3182.400	2059.200	249.929
3369.600	2059.200	194.319
3556.800	2059.200	133.967
3744.000	2059.200	80.477
3931.200	2059.200	58.045
0.000	2246.400	176.014
187.200	2246.400	223.391
374.400	2246.400	264.927
561.600	2246.400	297.761
748.800	2246.400	316.449
936.000	2246.400	313.911
1123.200	2246.400	291.608
1310.400	2246.400	265.694
1497.600	2246.400	265.858
1684.800	2246.400	261.993
1872.000	2246.400	273.294
2059.200	2246.400	297.145
2246.400	2246.400	316.069
2433.600	2246.400	336.944
2620.800	2246.400	347.857
2808.000	2246.400	332.296
2995.200	2246.400	295.592
3182.400	2246.400	245.276
3369.600	2246.400	187.184
3556.800	2246.400	125.990
3744.000	2246.400	71.593
3931.200	2246.400	57.540
0.000	2433.600	158.177
187.200	2433.600	211.152
374.400	2433.600	263.629
561.600	2433.600	313.952
748.800	2433.600	354.856
936.000	2433.600	372.760
1123.200	2433.600	366.593
1310.400	2433.600	363.149
1497.600	2433.600	349.659
1684.800	2433.600	337.385
1872.000	2433.600	328.105
2059.200	2433.600	341.736
2246.400	2433.600	369.190
2433.600	2433.600	381.022

Table 1 continued

X	Y	P
2620.800	2433.600	389.262
2808.000	2433.600	360.119
2995.200	2433.600	308.032
3182.400	2433.600	246.218
3369.600	2433.600	181.874
3556.800	2433.600	133.620
3744.000	2433.600	90.167
3931.200	2433.600	56.944
0.000	2620.800	156.758
187.200	2620.800	210.285
374.400	2620.800	274.011
561.600	2620.800	349.924
748.800	2620.800	434.549
936.000	2620.800	503.299
1123.200	2620.800	506.235
1310.400	2620.800	471.375
1497.600	2620.800	430.198
1684.800	2620.800	405.893
1872.000	2620.800	402.335
2059.200	2620.800	421.768
2246.400	2620.800	457.225
2433.600	2620.800	482.275
2620.800	2620.800	475.674
2808.000	2620.800	413.504
2995.200	2620.800	335.480
3182.400	2620.800	263.968
3369.600	2620.800	202.643
3556.800	2620.800	150.127
3744.000	2620.800	104.685
3931.200	2620.800	64.911
0.000	2808.000	169.060
187.200	2808.000	228.071
374.400	2808.000	301.423
561.600	2808.000	399.528
748.800	2808.000	536.592
936.000	2808.000	725.966
1123.200	2808.000	722.016
1310.400	2808.000	575.368
1497.600	2808.000	490.912
1684.800	2808.000	453.387
1872.000	2808.000	452.050
2059.200	2808.000	486.847
2246.400	2808.000	565.762
2433.600	2808.000	635.465
2620.800	2808.000	672.000
2808.000	2808.000	511.627
2995.200	2808.000	385.259
3182.400	2808.000	291.910
3369.600	2808.000	219.328
3556.800	2808.000	161.355
3744.000	2808.000	113.421
3931.200	2808.000	71.474
0.000	2995.200	171.992
187.200	2995.200	232.422
374.400	2995.200	308.437
561.600	2995.200	412.498
748.800	2995.200	569.238
936.000	2995.200	889.021
1123.200	2995.200	856.914
1310.400	2995.200	607.521

Table 1 continued

X	Y	P
1497.600	2995.200	507.202
1684.800	2995.200	466.216
1872.000	2995.200	466.556
2059.200	2995.200	508.507
2246.400	2995.200	613.395
2433.600	2995.200	900.189
2620.800	2995.200	885.258
2808.000	2995.200	556.661
2995.200	2995.200	402.234
3182.400	2995.200	300.301
3369.600	2995.200	224.157
3556.800	2995.200	164.218
3744.000	2995.200	114.906
3931.200	2995.200	72.796
0.000	3182.400	165.141
187.200	3182.400	222.459
374.400	3182.400	292.198
561.600	3182.400	379.850
748.800	3182.400	490.021
936.000	3182.400	600.829
1123.200	3182.400	605.905
1310.400	3182.400	531.808
1497.600	3182.400	470.890
1684.800	3182.400	441.486
1872.000	3182.400	442.397
2059.200	3182.400	474.467
2246.400	3182.400	542.259
2433.600	3182.400	631.271
2620.800	3182.400	620.424
2808.000	3182.400	490.331
2995.200	3182.400	374.473
3182.400	3182.400	285.308
3369.600	3182.400	214.096
3556.800	3182.400	156.117
3744.000	3182.400	108.860
3931.200	3182.400	68.666
0.000	3369.600	149.530
187.200	3369.600	200.146
374.400	3369.600	257.789
561.600	3369.600	322.299
748.800	3369.600	388.222
936.000	3369.600	434.711
1123.200	3369.600	437.048
1310.400	3369.600	424.896
1497.600	3369.600	431.223
1684.800	3369.600	386.215
1872.000	3369.600	387.428
2059.200	3369.600	403.920
2246.400	3369.600	428.292
2433.600	3369.600	440.679
2620.800	3369.600	441.562
2808.000	3369.600	389.500
2995.200	3369.600	319.014
3182.400	3369.600	252.140
3369.600	3369.600	191.373
3556.800	3369.600	136.251
3744.000	3369.600	95.986
3931.200	3369.600	59.757
0.000	3556.800	127.586
187.200	3556.800	170.287

Table 1 continued

X	Y	P
374.400	3556.800	215.581
561.600	3556.800	261.122
748.800	3556.800	301.367
936.000	3556.800	326.379
1123.200	3556.800	323.579
1310.400	3556.800	325.245
1497.600	3556.800	320.693
1684.800	3556.800	311.332
1872.000	3556.800	316.337
2059.200	3556.800	322.143
2246.400	3556.800	324.026
2433.600	3556.800	322.031
2620.800	3556.800	327.781
2808.000	3556.800	302.388
2995.200	3556.800	259.391
3182.400	3556.800	211.250
3369.600	3556.800	162.950
3556.800	3556.800	117.265
3744.000	3556.800	80.591
3931.200	3556.800	53.458
0.000	3744.000	101.945
187.200	3744.000	137.107
374.400	3744.000	172.276
561.600	3744.000	205.115
748.800	3744.000	231.632
936.000	3744.000	246.479
1123.200	3744.000	244.535
1310.400	3744.000	237.383
1497.600	3744.000	241.629
1684.800	3744.000	241.755
1872.000	3744.000	242.488
2059.200	3744.000	242.327
2246.400	3744.000	235.962
2433.600	3744.000	246.271
2620.800	3744.000	247.603
2808.000	3744.000	232.121
2995.200	3744.000	204.120
3182.400	3744.000	169.527
3369.600	3744.000	132.461
3556.800	3744.000	96.384
3744.000	3744.000	63.332
3931.200	3744.000	54.602
0.000	3931.200	74.608
187.200	3931.200	103.373
374.400	3931.200	130.841
561.600	3931.200	155.085
748.800	3931.200	173.518
936.000	3931.200	183.260
1123.200	3931.200	181.817
1310.400	3931.200	169.579
1497.600	3931.200	166.665
1684.800	3931.200	170.030
1872.000	3931.200	170.122
2059.200	3931.200	166.634
2246.400	3931.200	173.732
2433.600	3931.200	184.496
2620.800	3931.200	194.812
2808.000	3931.200	174.334
2995.200	3931.200	154.832
3182.400	3931.200	129.471
3369.600	3931.200	100.881
3556.800	3931.200	71.588
3744.000	3931.200	54.725
3931.200	3931.200	55.848

Table 2: Pressure Distribution (Pilot 2)

X	Y	P
0.000	0.000	375.835
187.200	0.000	432.869
374.400	0.000	446.624
561.600	0.000	424.742
748.800	0.000	352.418
936.000	0.000	322.244
1123.200	0.000	303.340
1310.400	0.000	289.924
1497.600	0.000	274.317
1684.800	0.000	266.945
1872.000	0.000	280.355
2059.200	0.000	290.784
2246.400	0.000	306.464
2433.600	0.000	303.049
2620.800	0.000	287.644
2808.000	0.000	281.943
2995.200	0.000	272.088
3182.400	0.000	281.424
3369.600	0.000	303.256
3556.800	0.000	328.933
3744.000	0.000	333.851
3931.200	0.000	251.099
0.000	187.200	461.251
187.200	187.200	583.713
374.400	187.200	626.316
561.600	187.200	519.388
748.800	187.200	429.8[illegible]3
936.000	187.200	376.846
1123.200	187.200	333.259
1310.400	187.200	300.107
1497.600	187.200	292.089
1684.800	187.200	301.72[illegible]
1872.000	187.200	331.654
2059.200	187.200	354.841
2246.400	187.200	353.351
2433.600	187.200	308.217
2620.800	187.200	272.626
2808.000	187.200	257.793
2995.200	187.200	271.247
3182.400	187.200	306.103
3369.600	187.200	394.870
3556.800	187.200	489.020
3744.000	187.200	386.737
3931.200	187.200	266.031
0.000	374.400	526.453
187.200	374.400	782.445
374.400	374.400	1053.258
561.600	374.400	629.6[illegible]4
748.800	374.400	482.442
936.000	374.400	383.48[illegible]
1123.200	374.400	317.4[illegible]6
1310.400	374.400	293.299
1497.600	374.400	296.628
1684.800	374.400	339.081
1872.000	374.400	427.238
2059.200	374.400	496.635
2246.400	374.400	474.135
2433.600	374.400	299.411
2620.800	374.400	236.002
2808.000	374.400	213.5[illegible]7

Table 2 Continued

X	Y	P
2995.200	374.400	235.510
3182.400	374.400	302.986
3369.600	374.400	444.814
3556.800	374.400	1221.563
3744.000	374.400	436.705
3931.200	374.400	267.957
0.000	561.600	540.038
187.200	561.600	719.964
374.400	561.600	803.464
561.600	561.600	625.762
748.800	561.600	502.364
936.000	561.600	389.112
1123.200	561.600	318.141
1310.400	561.600	289.664
1497.600	561.600	300.184
1684.800	561.600	355.231
1872.000	561.600	530.963
2059.200	561.600	1084.518
2246.400	561.600	454.768
2433.600	561.600	271.538
2620.800	561.600	188.149
2808.000	561.600	167.221
2995.200	561.600	171.515
3182.400	561.600	196.201
3369.600	561.600	251.361
3556.800	561.600	390.988
3744.000	561.600	261.833
3931.200	561.600	202.770
0.000	748.800	505.241
187.200	748.800	594.175
374.400	748.800	618.274
561.600	748.800	554.302
748.800	748.800	468.647
936.000	748.800	395.078
1123.200	748.800	334.213
1310.400	748.800	286.275
1497.600	748.800	264.341
1684.800	748.800	283.[illegible]
1872.000	748.800	379.741
2059.200	748.800	455.849
2246.400	748.800	311.707
2433.600	748.800	202.113
2620.800	748.800	149.993
2808.000	748.800	113.387
2995.200	748.800	90.739
3182.400	748.800	54.793
3369.600	748.800	-33.662
3556.800	748.800	-77.161
3744.000	748.800	56.309
3931.200	748.800	119.013
0.000	936.000	464.564
187.200	936.000	514.279
374.400	936.000	526.292
561.600	936.000	494.249
748.800	936.000	447.807
936.000	936.000	396.736
1123.200	936.000	337.296
1310.400	936.000	278.638
1497.600	936.000	218.594
1684.800	936.000	169.457

Table 2 continued

X	Y	P
1872.000	936.000	154.453
2059.200	936.000	135.512
2246.400	936.000	97.915
2433.600	936.000	103.633
2620.800	936.000	97.466
2808.000	936.000	76.721
2995.200	936.000	39.538
3182.400	936.000	-28.715
3369.600	936.000	-249.021
3556.800	936.000	-492.795
3744.000	936.000	-41.028
3931.200	936.000	82.568
0.000	1123.200	409.828
187.200	1123.200	451.363
374.400	1123.200	461.850
561.600	1123.200	414.895
748.800	1123.200	403.558
936.000	1123.200	367.868
1123.200	1123.200	329.235
1310.400	1123.200	261.244
1497.600	1123.200	161.308
1684.800	1123.200	33.731
1872.000	1123.200	-113.887
2059.200	1123.200	-229.289
2246.400	1123.200	-112.730
2433.600	1123.200	-3.179
2620.800	1123.200	54.215
2808.000	1123.200	62.643
2995.200	1123.200	48.809
3182.400	1123.200	4.723
3369.600	1123.200	-56.322
3556.800	1123.200	-47.768
3744.000	1123.200	59.312
3931.200	1123.200	122.146
0.000	1310.400	370.282
187.200	1310.400	421.659
374.400	1310.400	438.661
561.600	1310.400	431.344
748.800	1310.400	369.315
936.000	1310.400	332.288
1123.200	1310.400	270.672
1310.400	1310.400	229.629
1497.600	1310.400	122.269
1684.800	1310.400	-4.363
1872.000	1310.400	-258.528
2059.200	1310.400	-640.340
2246.400	1310.400	-212.703
2433.600	1310.400	-78.651
2620.800	1310.400	4.820
2808.000	1310.400	60.331
2995.200	1310.400	93.665
3182.400	1310.400	105.422
3369.600	1310.400	163.788
3556.800	1310.400	241.265
3744.000	1310.400	241.178
3931.200	1310.400	213.474
0.000	1497.600	347.147
187.200	1497.600	443.630
374.400	1497.600	489.764
561.600	1497.600	462.079

Table 2 continued

X	Y	P
748.800	1497.600	363.160
936.000	1497.600	260.872
1123.200	1497.600	199.334
1310.400	1497.600	152.492
1497.600	1497.600	132.678
1684.800	1497.600	83.628
1872.000	1497.600	-48.376
2059.200	1497.600	-169.154
2246.400	1497.600	-130.961
2433.600	1497.600	-72.011
2620.800	1497.600	-20.224
2808.000	1497.600	47.480
2995.200	1497.600	131.730
3182.400	1497.600	217.951
3369.600	1497.600	391.251
3556.800	1497.600	626.488
3744.000	1497.600	448.999
3931.200	1497.600	298.582
0.000	1684.800	336.792
187.200	1684.800	519.527
374.400	1684.800	735.966
561.600	1684.800	522.094
748.800	1684.800	347.738
936.000	1684.800	214.769
1123.200	1684.800	136.890
1310.400	1684.800	136.233
1497.600	1684.800	179.087
1684.800	1684.800	288.773
1872.000	1684.800	305.012
2059.200	1684.800	56.671
2246.400	1684.800	-20.094
2433.600	1684.800	-38.398
2620.800	1684.800	5.824
2808.000	1684.800	73.658
2995.200	1684.800	166.890
3182.400	1684.800	312.173
3369.600	1684.800	512.628
3556.800	1684.800	837.473
3744.000	1684.800	551.664
3931.200	1684.800	355.442
0.000	1872.000	262.974
187.200	1872.000	422.546
374.400	1872.000	632.589
561.600	1872.000	428.977
748.800	1872.000	281.625
936.000	1872.000	204.771
1123.200	1872.000	153.099
1310.400	1872.000	126.612
1497.600	1872.000	164.552
1684.800	1872.000	315.349
1872.000	1872.000	422.116
2059.200	1872.000	174.013
2246.400	1872.000	9.947
2433.600	1872.000	25.154
2620.800	1872.000	58.996
2808.000	1872.000	117.450
2995.200	1872.000	226.277
3182.400	1872.000	349.884
3369.600	1872.000	492.215
3556.800	1872.000	542.990

Table 2 continued

X	Y	P
3744.000	1872.000	479.230
3931.200	1872.000	371.015
0.000	2059.200	160.757
187.200	2059.200	169.468
374.400	2059.200	183.735
561.600	2059.200	209.125
748.800	2059.200	223.761
936.000	2059.200	196.995
1123.200	2059.200	164.744
1310.400	2059.200	132.903
1497.600	2059.200	105.117
1684.800	2059.200	96.232
1872.000	2059.200	52.868
2059.200	2059.200	-27.993
2246.400	2059.200	-20.547
2433.600	2059.200	48.903
2620.800	2059.200	127.550
2808.000	2059.200	200.392
2995.200	2059.200	288.043
3182.400	2059.200	394.120
3369.600	2059.200	482.297
3556.800	2059.200	495.177
3744.000	2059.200	457.002
3931.200	2059.200	386.899
0.000	2246.400	67.786
187.200	2246.400	-82.653
374.400	2246.400	-244.964
561.600	2246.400	29.596
748.800	2246.400	154.364
936.000	2246.400	191.950
1123.200	2246.400	166.629
1310.400	2246.400	111.979
1497.600	2246.400	32.514
1684.800	2246.400	-93.420
1872.000	2246.400	-233.364
2059.200	2246.400	-199.727
2246.400	2246.400	-63.998
2433.600	2246.400	70.303
2620.800	2246.400	177.882
2808.000	2246.400	281.381
2995.200	2246.400	363.164
3182.400	2246.400	445.585
3369.600	2246.400	500.269
3556.800	2246.400	507.210
3744.000	2246.400	466.403
3931.200	2246.400	493.983
0.000	2433.600	68.101
187.200	2433.600	-82.605
374.400	2433.600	-244.572
561.600	2433.600	28.104
748.800	2433.600	152.091
936.000	2433.600	171.547
1123.200	2433.600	154.595
1310.400	2433.600	95.191
1497.600	2433.600	-0.463
1684.800	2433.600	-189.416
1872.000	2433.600	-723.144
2059.200	2433.600	-359.273
2246.400	2433.600	-90.304
2433.600	2433.600	71.061

Table 2 continued

X	Y	P
2620.800	2433.600	214.421
2808.000	2433.600	330.124
2995.200	2433.600	429.383
3182.400	2433.600	493.625
3369.600	2433.600	569.340
3556.800	2433.600	55[illegible].865
3744.000	2433.600	487.113
3931.200	2433.600	407.287
0.000	2620.800	161.994
187.200	2620.800	170.358
374.400	2620.800	191.115
561.600	2620.800	204.812
748.800	2620.800	194.437
936.000	2620.800	159.027
1123.200	2620.800	131.103
1310.400	2620.800	100.304
1497.600	2620.800	44.474
1684.800	2620.800	-52.019
1872.000	2620.800	-201.607
2059.200	2620.800	-162.719
2246.400	2620.800	-25.789
2433.600	2620.800	93.271
2620.800	2620.800	228.232
2808.000	2620.800	359.699
2995.200	2620.800	470.005
3182.400	2620.800	587.834
3369.600	2620.800	661.916
3556.800	2620.800	592.114
3744.000	2620.800	489.620
3931.200	2620.800	392.441
0.000	2808.000	265.223
187.200	2808.000	423.199
374.400	2808.000	632.098
561.600	2808.000	388.672
748.800	2808.000	225.473
936.000	2808.000	147.938
1123.200	2808.000	103.130
1310.400	2808.000	85.198
1497.600	2808.000	111.779
1684.800	2808.000	199.068
1872.000	2808.000	119.469
2059.200	2808.000	30.697
2246.400	2808.000	48.340
2433.600	2808.000	116.221
2620.800	2808.000	207.359
2808.000	2808.000	336.246
2995.200	2808.000	517.953
3182.400	2808.000	767.955
3369.600	2808.000	898.721
3556.800	2808.000	641.968
3744.000	2808.000	483.627
3931.200	2808.000	369.520
0.000	2995.200	320.965
187.200	2995.200	478.303
374.400	2995.200	686.397
561.600	2995.200	428.994
748.800	2995.200	240.747
936.000	2995.200	115.238
1123.200	2995.200	56.319
1310.400	2995.200	49.611

Table 2 continued

X	Y	P
1497.600	2995.200	119.811
1684.800	2995.200	417.094
1872.000	2995.200	273.262
2059.200	2995.200	68.909
2246.400	2995.200	50.433
2433.600	2995.200	100.401
2620.800	2995.200	185.022
2808.000	2995.200	309.876
2995.200	2995.200	487.861
3182.400	2995.200	743.893
3369.600	2995.200	853.822
3556.800	2995.200	596.021
3744.000	2995.200	438.753
3931.200	2995.200	327.662
0.000	3182.400	265.100
167.200	3182.400	349.8[illegible]4
374.400	3182.400	382.355
561.600	3182.400	317.215
748.800	3182.400	234.057
936.000	3182.400	98.591
1123.200	3182.400	23.360
1310.400	3182.400	-23.602
1497.600	3182.400	-22.796
1684.800	3182.400	3.840
1872.000	3182.400	-21.516
2059.200	3182.400	-34.991
2246.400	3182.400	-7.409
2433.600	3182.400	58.715
2620.800	3182.400	158.792
2808.000	3182.400	277.938
2995.200	3182.400	413.492
3182.400	3182.400	538.232
3369.600	3182.400	552.553
3556.800	3182.400	468.441
3744.000	3182.400	371.789
3931.200	3182.400	292.208
0.000	3369.600	235.775
187.200	3369.600	271.031
374.400	3369.600	258.385
561.600	3369.600	226.617
748.800	3369.600	174.690
936.000	3369.600	88.293
1123.200	3369.600	-0.661
1310.400	3369.600	-96.209
1497.600	3369.600	-224.305
1684.800	3369.600	-352.398
1872.000	3369.600	-299.719
2059.200	3369.600	-172.184
2246.400	3369.600	-78.721
2433.600	3369.600	23.297
2620.800	3369.600	125.783
2808.000	3369.600	228.452
2995.200	3369.600	329.156
3182.400	3369.600	394.367
3369.600	3369.600	396.137
3556.800	3369.600	358.659
3744.000	3369.600	346.349
3931.200	3369.600	249.864
0.000	3556.800	214.516
187.200	3556.800	232.541

Table 2 continued

X	Y	P
374.400	3556.800	199.234
561.600	3556.800	170.333
748.800	3556.800	128.538
936.000	3556.800	75.714
1123.200	3556.800	-19.765
1310.400	3556.800	-160.547
1497.600	3556.800	-395.271
1684.800	3556.800	-1113.698
1872.000	3556.800	-499.459
2059.200	3556.800	-260.522
2246.400	3556.800	-117.549
2433.600	3556.800	-11.756
2620.800	3556.800	89.664
2808.000	3556.800	180.672
2995.200	3556.800	246.461
3182.400	3556.800	292.143
3369.600	3556.800	297.563
3556.800	3556.800	276.327
3744.000	3556.800	244.162
3931.200	3556.800	205.175
0.000	3744.000	197.512
187.200	3744.000	[illegible]7.672
374.400	3744.000	174.470
561.600	3744.000	131.106
748.800	3744.000	94.253
936.000	3744.000	36.277
1123.200	3744.000	-49.113
1310.400	3744.000	-175.745
1497.600	3744.000	-357.710
1684.800	3744.000	-520.121
1872.000	3744.000	-412.397
2059.200	3744.000	-261.075
2246.400	3744.000	-130.305
2433.600	3744.000	-26.256
2620.800	3744.000	63.470
2808.000	3744.000	121.812
2995.200	3744.000	166.202
3182.400	3744.000	221.263
3369.600	3744.000	223.898
3556.800	3744.000	212.045
3744.000	3744.000	189.992
3931.200	3744.000	161.455
0.000	3931.200	155.236
187.200	3931.200	167.297
374.400	3931.200	143.319
561.600	3931.200	89.199
748.800	3931.200	39.370
936.000	3931.200	-15.389
1123.200	3931.200	-85.981
1310.400	3931.200	-172.566
1497.600	3931.200	-256.875
1684.800	3931.200	-295.436
1872.000	3931.200	-263.397
2059.200	3931.200	-193.242
2246.400	3931.200	-126.091
2433.600	3931.200	-50.031
2620.800	3931.200	12.212
2808.000	3931.200	62.350
2995.200	3931.200	116.491
3182.400	3931.200	163.276
3369.600	3931.200	165.171
3556.800	3931.200	157.534
3744.000	3931.200	142.018
3931.200	3931.200	120.558

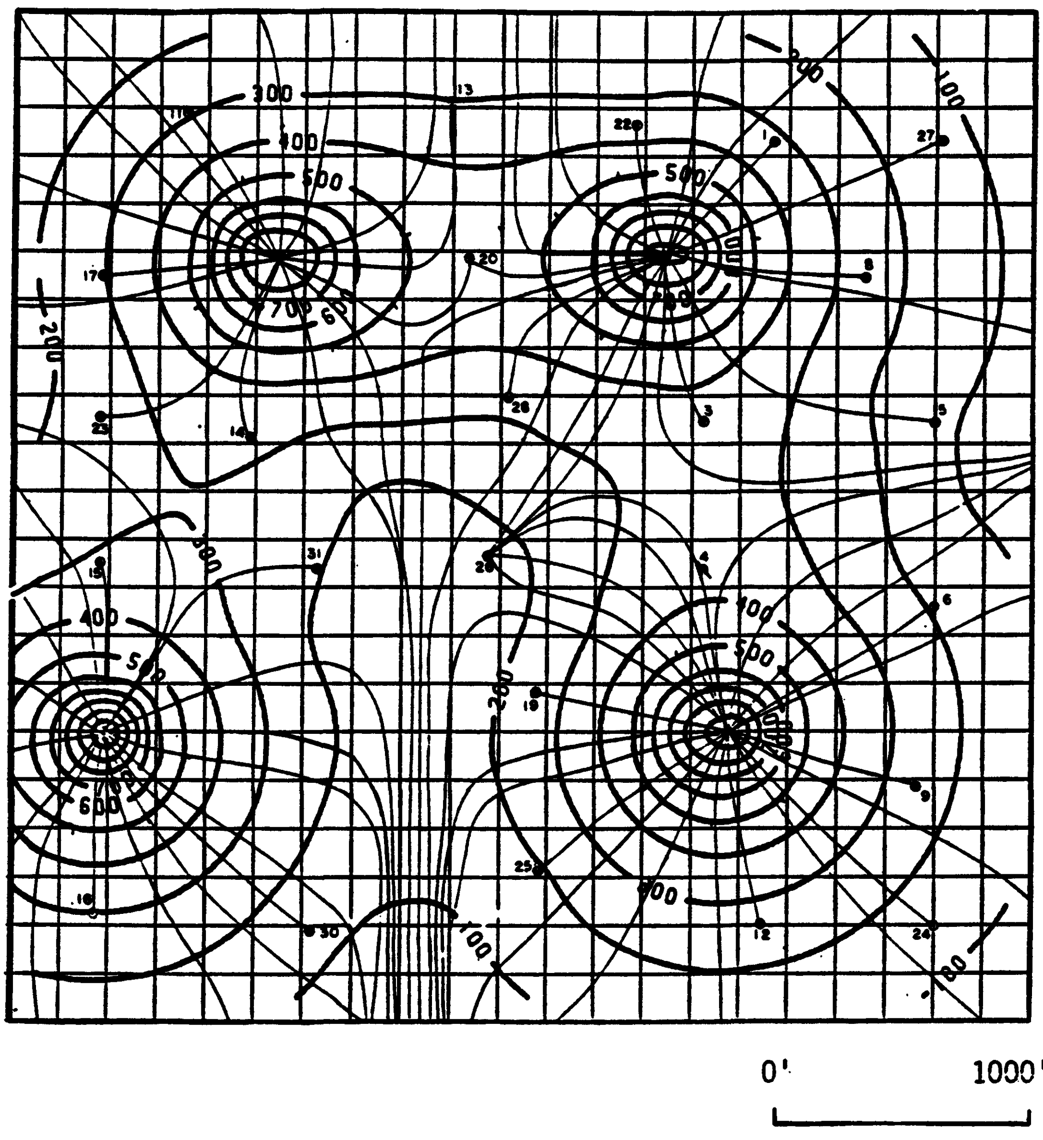

Figure 35: Pressure Distribution and Streamlines in Pilot No. 1

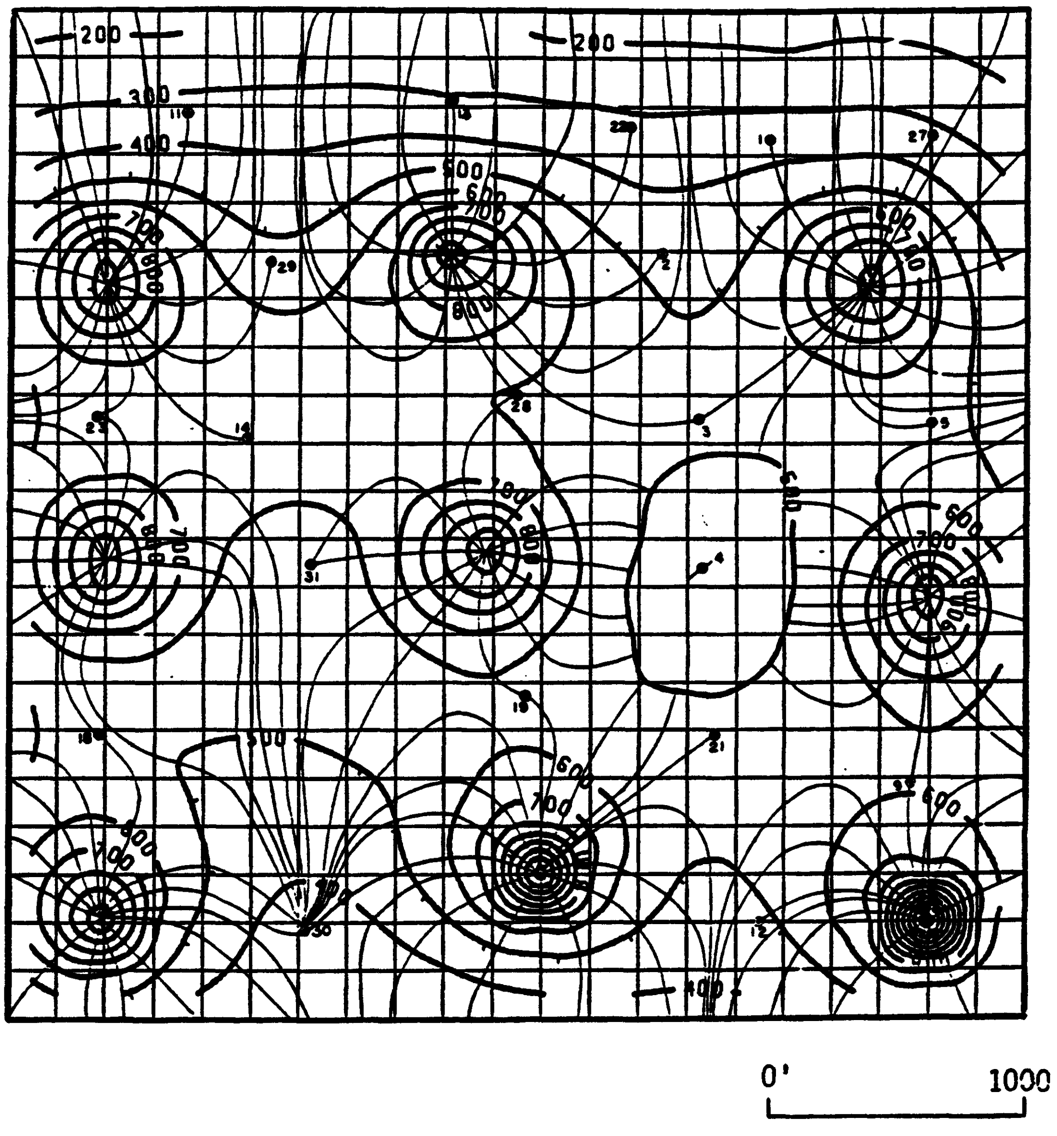

Figure 36: Pressure Distribution and Streamlines
in Pilot No. 2

Table 3: Pressure Distribution (Pilot 1) Stage 2

X	Y	P
0.000	0.000	139.815
187.200	0.000	149.794
374.400	0.000	151.378
561.600	0.000	144.142
748.800	0.000	128.665
936.000	0.000	106.796
1123.200	0.000	81.627
1310.400	0.000	55.773
1497.600	0.000	49.682
1684.800	0.000	50.183
1872.000	0.000	67.265
2059.200	0.000	91.694
2246.400	0.000	113.461
2433.600	0.000	130.494
2620.800	0.000	140.652
2808.000	0.000	141.999
2995.200	0.000	134.910
3182.400	0.000	120.751
3369.600	0.000	101.316
3556.800	0.000	78.238
3744.000	0.000	57.126
3931.200	0.000	57.740
0.000	187.200	190.869
187.200	187.200	225.206
374.400	187.200	227.752
561.600	187.200	197.813
748.800	187.200	176.103
936.000	187.200	146.142
1123.200	187.200	111.859
1310.400	187.200	80.755
1497.600	187.200	51.235
1684.800	187.200	66.077
1872.000	187.200	96.845
2059.200	187.200	127.428
2246.400	187.200	156.142
2433.600	187.200	179.573
2620.800	187.200	193.834
2808.000	187.200	195.598
2995.200	187.200	185.738
3182.400	187.200	166.274
3369.600	187.200	140.133
3556.800	187.200	110.609
3744.000	187.200	84.872
3931.200	187.200	57.154
0.000	374.400	250.917
187.200	374.400	272.981
374.400	374.400	276.711
561.600	374.400	263.068
748.800	374.400	231.469
936.000	374.400	189.654
1123.200	374.400	139.962
1310.400	374.400	106.169
1497.600	374.400	81.999
1684.800	374.400	89.922
1872.000	374.400	126.224
2059.200	374.400	164.235
2246.400	374.400	203.871
2433.600	374.400	238.018
2620.800	374.400	259.412
2808.000	374.400	261.467

Table 3 continued

X	Y	P
2995.200	374.400	246.054
3182.400	374.400	218.256
3369.600	374.400	182.195
3556.800	374.400	141.073
3744.000	374.400	107.700
3931.200	374.400	73.546
0.000	561.600	322.156
187.200	561.600	361.122
374.400	561.600	370.673
561.600	561.600	344.914
748.800	561.600	295.286
936.000	561.600	230.050
1123.200	561.600	182.450
1310.400	561.600	133.957
1497.600	561.600	120.170
1684.800	561.600	121.136
1872.000	561.600	154.077
2059.200	561.600	194.002
2246.400	561.600	256.838
2433.600	561.600	308.929
2620.800	561.600	344.370
2808.000	561.600	348.779
2995.200	561.600	321.976
3182.400	561.600	277.167
3369.600	561.600	226.879
3556.800	561.600	177.940
3744.000	561.600	133.381
3931.200	561.600	93.302
0.000	748.800	404.283
187.200	748.800	480.986
374.400	748.800	505.166
561.600	748.800	449.856
748.800	748.800	364.522
936.000	748.800	283.825
1123.200	748.800	214.788
1310.400	748.800	160.883
1497.600	748.800	151.154
1684.800	748.800	152.677
1872.000	748.800	181.533
2059.200	748.800	241.233
2246.400	748.800	314.885
2433.600	748.800	395.067
2620.800	748.800	461.535
2808.000	748.800	470.602
2995.200	748.800	415.716
3182.400	748.800	340.274
3369.600	748.800	269.170
3556.800	748.800	207.446
3744.000	748.800	154.792
3931.200	748.800	109.306
0.000	936.000	482.763
187.200	936.000	650.341
374.400	936.000	745.411
561.600	936.000	573.918
748.800	936.000	423.974
936.000	936.000	317.009
1123.200	936.000	235.785
1310.400	936.000	182.497
1497.600	936.000	170.788
1684.800	936.000	173.269

Table 3 continued

X	Y	P
1872.000	936.000	201.098
2059.200	936.000	272.039
2246.400	936.000	364.613
2433.600	936.000	498.075
2620.800	936.000	641.468
2808.000	936.000	668.783
2995.200	936.000	522.721
3182.400	936.000	396.078
3369.600	936.000	301.328
3556.800	936.000	227.346
3744.000	936.000	169.193
3931.200	936.000	119.843
0.000	1123.200	508.455
187.200	1123.200	746.821
374.400	1123.200	1071.660
561.600	1123.200	625.743
748.800	1123.200	441.709
936.000	1123.200	325.791
1123.200	1123.200	241.044
1310.400	1123.200	186.206
1497.600	1123.200	175.876
1684.800	1123.200	178.669
1872.000	1123.200	206.056
2059.200	1123.200	280.393
2246.400	1123.200	383.598
2433.600	1123.200	535.597
2620.800	1123.200	837.011
2808.000	1123.200	962.069
2995.200	1123.200	582.679
3182.400	1123.200	419.751
3369.600	1123.200	314.347
3556.800	1123.200	236.306
3744.000	1123.200	174.569
3931.200	1123.200	123.603
0.000	1310.400	454.205
187.200	1310.400	576.391
374.400	1310.400	626.961
561.600	1310.400	523.991
748.800	1310.400	403.216
936.000	1310.400	306.188
1123.200	1310.400	228.783
1310.400	1310.400	176.909
1497.600	1310.400	165.913
1684.800	1310.400	168.520
1872.000	1310.400	196.873
2059.200	1310.400	263.895
2246.400	1310.400	360.842
2433.600	1310.400	482.470
2620.800	1310.400	628.128
2808.000	1310.400	653.577
2995.200	1310.400	517.368
3182.400	1310.400	394.704
3369.600	1310.400	301.842
3556.800	1310.400	228.911
3744.000	1310.400	169.646
3931.200	1310.400	120.065
0.000	1497.600	370.465
187.200	1497.600	428.398
374.400	1497.600	444.674
561.600	1497.600	404.738

Table 3 continued

X	Y	P
748.800	1497.600	339.737
936.000	1497.600	274.067
1123.200	1497.600	209.796
1310.400	1497.600	152.858
1497.600	1497.600	142.308
1684.800	1497.600	144.471
1872.000	1497.600	178.082
2059.200	1497.600	239.140
2246.400	1497.600	311.401
2433.600	1497.600	390.992
2620.800	1497.600	455.034
2808.000	1497.600	462.707
2995.200	1497.600	411.286
3182.400	1497.600	338.924
3369.600	1497.600	269.139
3556.800	1497.600	207.695
3744.000	1497.600	155.199
3931.200	1497.600	109.678
0.000	1684.800	291.897
187.200	1684.800	322.786
374.400	1684.800	344.330
561.600	1684.800	343.990
748.800	1684.800	312.018
936.000	1684.800	268.353
1123.200	1684.800	215.801
1310.400	1684.800	163.813
1497.600	1684.800	138.127
1684.800	1684.800	121.880
1872.000	1684.800	157.131
2059.200	1684.800	225.030
2246.400	1684.800	290.560
2433.600	1684.800	346.702
2620.800	1684.800	331.314
2808.000	1684.800	330.736
2995.200	1684.800	344.209
3182.400	1684.800	284.932
3369.600	1684.800	226.944
3556.800	1684.800	178.077
3744.000	1684.800	133.853
3931.200	1684.800	93.662
0.000	1872.000	226.364
187.200	1872.000	270.949
374.400	1872.000	298.673
561.600	1872.000	308.102
748.800	1872.000	297.305
936.000	1872.000	269.912
1123.200	1872.000	229.428
1310.400	1872.000	183.177
1497.600	1872.000	139.856
1684.800	1872.000	152.689
1872.000	1872.000	186.279
2059.200	1872.000	224.865
2246.400	1872.000	282.624
2433.600	1872.000	323.028
2620.800	1872.000	344.871
2808.000	1872.000	342.671
2995.200	1872.000	312.865
3182.400	1872.000	262.744
3369.600	1872.000	204.206
3556.800	1872.000	145.151

Table 3 continued

X	Y	P
3744.000	1872.000	138.430
3931.200	1872.000	73.742
0.000	2059.200	197.517
187.200	2059.200	241.708
374.400	2059.200	275.272
561.600	2059.200	294.825
748.800	2059.200	298.175
936.000	2059.200	284.021
1123.200	2059.200	253.619
1310.400	2059.200	209.634
1497.600	2059.200	184.624
1684.800	2059.200	202.060
1872.000	2059.200	230.667
2059.200	2059.200	251.976
2246.400	2059.200	269.793
2433.600	2059.200	296.647
2620.800	2059.200	302.864
2808.000	2059.200	295.928
2995.200	2059.200	267.144
3182.400	2059.200	226.093
3369.600	2059.200	181.125
3556.800	2059.200	133.906
3744.000	2059.200	80.458
3931.200	2059.200	58.045
0.000	2246.400	175.917
187.200	2246.400	223.255
374.400	2246.400	264.757
561.600	2246.400	297.564
748.800	2246.400	316.235
936.000	2246.400	313.696
1123.200	2246.400	291.411
1310.400	2246.400	265.517
1497.600	2246.400	265.680
1684.800	2246.400	245.151
1872.000	2246.400	239.050
2059.200	2246.400	242.736
2246.400	2246.400	227.332
2433.600	2246.400	224.190
2620.800	2246.400	223.584
2808.000	2246.400	210.212
2995.200	2246.400	189.325
3182.400	2246.400	167.041
3369.600	2246.400	129.859
3556.800	2246.400	88.318
3744.000	2246.400	57.353
3931.200	2246.400	57.540
0.000	2433.600	158.095
187.200	2433.600	211.027
374.400	2433.600	263.460
561.600	2433.600	313.743
748.800	2433.600	354.612
936.000	2433.600	372.500
1123.200	2433.600	366.338
1310.400	2433.600	362.895
1497.600	2433.600	325.400
1684.800	2433.600	284.270
1872.000	2433.600	241.296
2059.200	2433.600	202.252
2246.400	2433.600	185.565
2433.600	2433.600	165.921

Table 3 continued

X	Y	P
2620.800	2433.600	158.758
2808.000	2433.600	132.259
2995.200	2433.600	102.845
3182.400	2433.600	75.546
3369.600	2433.600	59.619
3556.800	2433.600	49.422
3744.000	2433.600	38.760
3931.200	2433.600	36.872
0.000	2620.800	156.678
187.200	2620.800	210.160
374.400	2620.800	273.834
561.600	2620.800	349.686
748.800	2620.800	434.242
936.000	2620.800	502.936
1123.200	2620.800	505.869
1310.400	2620.800	448.546
1497.600	2620.800	371.488
1684.800	2620.800	310.977
1872.000	2620.800	236.654
2059.200	2620.800	188.687
2246.400	2620.800	165.907
2433.600	2620.800	148.454
2620.800	2620.800	120.557
2808.000	2620.800	61.456
2995.200	2620.800	11.210
3182.400	2620.800	-11.154
3369.600	2620.800	-8.715
3556.800	2620.800	9.721
3744.000	2620.800	14.707
3931.200	2620.800	13.525
0.000	2808.000	168.970
187.200	2808.000	227.932
374.400	2808.000	371.224
561.600	2808.000	399.250
748.800	2808.000	536.204
936.000	2808.000	725.425
1123.200	2808.000	712.056
1310.400	2808.000	525.651
1497.600	2808.000	398.239
1684.800	2808.000	293.905
1872.000	2808.000	204.432
2059.200	2808.000	151.185
2246.400	2808.000	150.799
2433.600	2808.000	211.232
2620.800	2808.000	167.447
2808.000	2808.000	12.076
2995.200	2808.000	-76.165
3182.400	2808.000	-102.394
3369.600	2808.000	-87.442
3556.800	2808.000	-53.678
3744.000	2808.000	-15.070
3931.200	2808.000	-9.677
0.000	2995.200	171.897
187.200	2995.200	232.280
374.400	2995.200	306.233
561.600	2995.200	412.211
748.800	2995.200	569.824
936.000	2995.200	888.351
1123.200	2995.200	828.563
1310.400	2995.200	534.214

Table 3 continued

X	Y	P
1497.600	2995.200	363.359
1684.800	2995.200	246.807
1872.000	2995.200	137.549
2059.200	2995.200	62.190
2246.400	2995.200	54.237
2433.600	2995.200	255.659
2620.800	2995.200	198.165
2808.000	2995.200	-130.916
2995.200	2995.200	-233.202
3182.400	2995.200	-230.867
3369.600	2995.200	-182.665
3556.800	2995.200	-122.686
3744.000	2995.200	-63.952
3931.200	2995.200	-34.268
0.000	3182.400	165.055
187.200	3182.400	222.326
374.400	3182.400	292.009
561.600	3182.400	379.589
748.800	3182.400	489.672
936.000	3182.400	600.391
1123.200	3182.400	564.129
1310.400	3182.400	440.475
1497.600	3182.400	315.726
1684.800	3182.400	173.458
1872.000	3182.400	41.214
2059.200	3182.400	-84.338
2246.400	3182.400	-190.012
2433.600	3182.400	-230.887
2620.800	3182.400	-266.009
2808.000	3182.400	-437.118
2995.200	3182.400	-494.368
3182.400	3182.400	-399.228
3369.600	3182.400	-284.771
3556.800	3182.400	-189.379
3744.000	3182.400	-110.019
3931.200	3182.400	-57.461
0.000	3369.600	149.457
187.200	3369.600	200.032
374.400	3369.600	257.628
561.600	3369.600	322.086
748.800	3369.600	387.956
936.000	3369.600	430.751
1123.200	3369.600	387.500
1310.400	3369.600	323.333
1497.600	3369.600	226.932
1684.800	3369.600	89.755
1872.000	3369.600	-64.296
2059.200	3369.600	-243.155
2246.400	3369.600	-507.612
2433.600	3369.600	-773.501
2620.800	3369.600	-675.411
2808.000	3369.600	-820.253
2995.200	3369.600	-964.967
3182.400	3369.600	-559.226
3369.600	3369.600	-364.133
3556.800	3369.600	-241.330
3744.000	3369.600	-143.605
3931.200	3369.600	-75.590
0.000	3556.800	127.530
187.200	3556.800	170.197

Table 3 continued

X	Y	P
374.400	3556.800	215.454
561.600	3556.800	262.958
748.800	3556.800	301.170
936.000	3556.800	321.965
1123.200	3556.800	273.713
1310.400	3556.800	222.792
1497.600	3556.800	146.182
1684.800	3556.800	14.192
1872.000	3556.800	-133.283
2059.200	3556.800	-332.970
2246.400	3556.800	-641.183
2433.600	3556.800	-1007.100
2620.800	3556.800	-790.226
2808.000	3556.800	-826.516
2995.200	3556.800	-832.346
3182.400	3556.800	-568.130
3369.600	3556.800	-381.802
3556.800	3556.800	-255.200
3744.000	3556.800	-156.171
3931.200	3556.800	-79.529
0.000	3744.000	101.911
187.200	3744.000	137.044
374.400	3744.000	172.185
561.600	3744.000	204.996
748.800	3744.000	231.491
936.000	3744.000	246.326
1123.200	3744.000	201.010
1310.400	3744.000	143.238
1497.600	3744.000	66.013
1684.800	3744.000	-27.738
1872.000	3744.000	-162.439
2059.200	3744.000	-326.043
2246.400	3744.000	-517.076
2433.600	3744.000	-638.851
2620.800	3744.000	-647.734
2808.000	3744.000	-636.444
2995.200	3744.000	-586.662
3182.400	3744.000	-469.308
3369.600	3744.000	-343.322
3556.800	3744.000	-236.345
3744.000	3744.000	-147.741
3931.200	3744.000	-64.913
0.000	3931.200	74.596
187.200	3931.200	103.338
374.400	3931.200	130.783
561.600	3931.200	155.007
748.800	3931.200	173.425
936.000	3931.200	183.159
1123.200	3931.200	150.866
1310.400	3931.200	92.424
1497.600	3931.200	37.482
1684.800	3931.200	-50.543
1872.000	3931.200	-161.662
2059.200	3931.200	-284.917
2246.400	3931.200	-392.330
2433.600	3931.200	-461.492
2620.800	3931.200	-487.266
2808.000	3931.200	-478.071
2995.200	3931.200	-437.935
3182.400	3931.200	-366.610
3369.600	3931.200	-282.017
3556.800	3931.200	-199.463
3744.000	3931.200	-113.507
3931.200	3931.200	-41.479

Table 4: Pressure Distribution (Pilot 2) Stage 2

X	Y	P
0.000	0.000	376.492
187.200	0.000	433.174
374.400	0.000	446.937
561.600	0.000	475.223
748.800	0.000	352.658
936.000	0.000	322.461
1123.200	0.000	333.542
1310.400	0.000	297.323
1497.600	0.000	334.965
1684.800	0.000	338.455
1872.000	0.000	332.604
2059.200	0.000	343.495
2246.400	0.000	354.273
2433.600	0.000	358.394
2620.800	0.000	360.166
2808.000	0.000	368.873
2995.200	0.000	390.103
3182.400	0.000	424.766
3369.600	0.000	462.234
3556.800	0.000	491.663
3744.000	0.000	454.537
3931.200	0.000	380.132
0.000	187.200	461.575
187.200	187.200	584.136
374.400	187.200	626.774
561.600	187.200	519.761
748.800	187.200	430.166
936.000	187.200	377.129
1123.200	187.200	349.101
1310.400	187.200	345.451
1497.600	187.200	363.121
1684.800	187.200	392.421
1872.000	187.200	434.627
2059.200	187.200	467.765
2246.400	187.200	461.269
2433.600	187.200	439.345
2620.800	187.200	422.762
2808.000	187.200	424.494
2995.200	187.200	451.642
3182.400	187.200	515.695
3369.600	187.200	628.298
3556.800	187.200	726.536
3744.000	187.200	687.648
3931.200	187.200	454.769
0.000	374.400	526.829
187.200	374.400	733.228
374.400	374.400	1054.989
561.600	374.400	637.266
748.800	374.400	462.765
936.000	374.400	427.368
1123.200	374.400	372.577
1310.400	374.400	378.297
1497.600	374.400	417.029
1684.800	374.400	485.494
1872.000	374.400	592.148
2059.200	374.400	665.695
2246.400	374.400	592.393
2433.600	374.400	512.333
2620.800	374.400	466.302
2808.000	374.400	463.744

Table 4 continued

X	Y	P
2995.200	374.400	578.136
3182.400	374.400	598.322
3369.600	374.400	773.148
3556.800	374.400	1558.276
3744.000	374.400	743.892
3931.200	374.400	524.457
0.000	561.600	542.425
187.200	561.600	720.497
374.400	561.600	634.265
561.600	561.600	626.221
748.800	561.600	530.633
936.000	561.600	435.525
1123.200	561.600	406.161
1310.400	561.600	421.261
1497.600	561.600	475.169
1684.800	561.600	568.961
1872.000	561.600	771.441
2059.200	561.600	1333.428
2246.400	561.600	731.186
2433.600	561.600	564.706
2620.800	561.600	496.736
2808.000	561.600	498.074
2995.200	561.600	536.592
3182.400	561.600	607.032
3369.600	561.600	709.079
3556.800	561.600	775.922
3744.000	561.600	676.652
3931.200	561.600	532.978
0.000	748.800	505.621
187.200	748.800	594.627
374.400	748.800	618.726
561.600	748.800	554.701
748.800	748.800	493.451
936.000	748.800	465.194
1123.200	748.800	454.644
1310.400	748.800	461.269
1497.600	748.800	499.788
1684.800	748.800	579.862
1872.000	748.800	716.391
2059.200	748.800	813.542
2246.400	748.800	657.608
2433.600	748.800	578.813
2620.800	748.800	529.983
2808.000	748.800	512.236
2995.200	748.800	534.361
3182.400	748.800	582.734
3369.600	748.800	625.787
3556.800	748.800	633.723
3744.000	748.800	596.579
3931.200	748.800	510.221
0.000	936.000	475.407
187.200	936.000	532.635
374.400	936.000	546.433
561.600	936.000	519.256
748.800	936.000	495.543
936.000	936.000	487.514
1123.200	936.000	484.718
1310.400	936.000	492.386
1497.600	936.000	510.381
1684.800	936.000	550.933

Table 4 continued

X	Y	P
1872.000	936.000	621.749
2059.200	936.000	641.699
2246.400	936.000	591.366
2433.600	936.000	559.695
2620.800	936.000	531.970
2808.000	936.000	521.333
2995.200	936.000	524.156
3182.400	936.000	556.689
3369.600	936.000	583.369
3556.800	936.000	586.984
3744.000	936.000	563.591
3931.200	936.000	497.242
0.000	1123.200	465.493
187.200	1123.200	516.906
374.400	1123.200	529.753
561.600	1123.200	512.357
748.800	1123.200	503.818
936.000	1123.200	582.332
1123.200	1123.200	573.464
1310.400	1123.200	511.624
1497.600	1123.200	524.388
1684.800	1123.200	533.611
1872.000	1123.200	531.415
2059.200	1123.200	577.728
2246.400	1123.200	544.562
2433.600	1123.200	533.723
2620.800	1123.200	510.658
2808.000	1123.200	512.455
2995.200	1123.200	523.416
3182.400	1123.200	543.253
3369.600	1123.200	533.379
3556.800	1123.200	631.681
3744.000	1123.200	574.746
3931.200	1123.200	562.741
0.000	1310.400	477.118
187.200	1310.400	542.349
374.400	1310.400	562.345
561.600	1310.400	554.127
748.800	1310.400	520.874
936.000	1310.400	513.446
1123.200	1310.400	513.759
1310.400	1310.400	524.966
1497.600	1310.400	543.521
1684.800	1310.400	578.381
1872.000	1310.400	593.955
2059.200	1310.400	567.512
2246.400	1310.400	538.195
2433.600	1310.400	583.340
2620.800	1310.400	493.995
2808.000	1310.400	496.356
2995.200	1310.400	510.169
3182.400	1310.400	550.664
3369.600	1310.400	622.459
3556.800	1310.400	633.415
3744.000	1310.400	632.464
3931.200	1310.400	524.233
0.000	1497.600	513.267
187.200	1497.600	629.441
374.400	1497.600	654.455
561.600	1497.600	644.477

Table 4 continued

X	Y	P
748.800	1497.600	565.817
936.000	1497.600	513.420
1123.200	1497.600	509.028
1310.400	1497.600	529.100
1497.600	1497.600	591.452
1684.800	1497.600	664.366
1872.000	1497.600	678.197
2059.200	1497.600	610.874
2246.400	1497.600	547.283
2433.600	1497.600	494.143
2620.800	1497.600	459.154
2808.000	1497.600	463.340
2995.200	1497.600	500.959
3182.400	1497.600	566.753
3369.600	1497.600	727.366
3556.800	1497.600	940.582
3744.000	1497.600	737.433
3931.200	1497.600	540.673
0.000	1684.800	572.523
187.200	1684.800	786.127
374.400	1684.800	1010.711
561.600	1684.800	778.630
748.800	1684.800	625.823
936.000	1684.800	534.106
1123.200	1684.800	503.656
1310.400	1684.800	500.574
1497.600	1684.800	669.768
1684.800	1684.800	848.036
1872.000	1684.800	944.171
2059.200	1684.800	739.900
2246.400	1684.800	571.783
2433.600	1684.800	433.132
2620.800	1684.800	452.092
2808.000	1684.800	452.192
2995.200	1684.800	486.141
3182.400	1684.800	576.060
3369.600	1684.800	743.547
3556.800	1684.800	1058.947
3744.000	1684.800	757.789
3931.200	1684.800	531.692
0.000	1872.000	580.568
187.200	1872.000	793.802
374.400	1872.000	1219.248
561.600	1872.000	786.597
748.800	1872.000	638.596
936.000	1872.000	583.322
1123.200	1872.000	566.228
1310.400	1872.000	588.516
1497.600	1872.000	684.516
1684.800	1872.000	885.570
1872.000	1872.000	1042.366
2059.200	1872.000	724.533
2246.400	1872.000	570.185
2433.600	1872.000	502.952
2620.800	1872.000	462.958
2808.000	1872.000	449.454
2995.200	1872.000	491.179
3182.400	1872.000	553.347
3369.600	1872.000	631.015
3556.800	1872.000	691.588

Table 4 continued

X	Y	P
3744.000	1872.000	617.632
3931.200	1872.000	489.1[illegible]
0.000	2059.200	569.78[illegible]
187.200	2059.200	685.789
374.400	2059.200	738.977
561.600	2059.200	713.584
748.800	2059.200	654.654
936.000	2059.200	620.524
1123.200	2059.200	609.[illegible]83
1310.400	2059.200	621.723
1497.600	2059.200	656.616
1684.800	2059.200	715.277
1872.000	2059.200	723.261
2059.200	2059.200	625.5[illegible]
2246.400	2059.200	547.116
2433.600	2059.200	506.731
2620.800	2059.200	485.66[illegible]
2808.000	2059.200	483.9[illegible]
2995.200	2059.200	495.348
3182.400	2059.200	532.282
3369.600	2059.200	569.387
3556.800	2059.200	584.[illegible]61
3744.000	2059.200	538.834
3931.200	2059.200	453.393
0.000	2246.400	552.483
187.200	2246.400	632.396
374.400	2246.400	655.427
561.600	2246.400	663.595
748.800	2246.400	652.694
936.000	2246.400	633.[illegible]6
1123.200	2246.400	627.396
1310.400	2246.400	632.396
1497.600	2246.400	641.547
1684.800	2246.400	632.419
1872.000	2246.400	624.23[illegible]
2059.200	2246.400	588.2[illegible]2
2246.400	2246.400	541.541
2433.600	2246.400	519.956
2620.800	2246.400	516.966
2808.000	2246.400	585.415
2995.200	2246.400	509.295
3182.400	2246.400	526.278
3369.600	2246.400	551.365
3556.800	2246.400	545.467
3744.000	2246.400	499.413
3931.200	2246.400	425.775
0.000	2433.600	552.798
187.200	2433.600	63[illegible].444
374.400	2433.600	655.639
561.600	2433.600	665.[illegible]55
748.800	2433.600	654.998
936.000	2433.600	639.184
1123.200	2433.600	631.591
1310.400	2433.600	636.17[illegible]
1497.600	2433.600	64[illegible].773
1684.800	2433.600	621.434
1872.000	2433.600	6[illegible].174
2059.200	2433.600	597.572
2246.400	2433.600	543.658
2433.600	2433.600	522.323

Table 4 continued

X	Y	P
2620.800	2433.600	516.121
2808.000	2433.600	523.458
2995.200	2433.600	535.163
3182.400	2433.600	549.115
3369.600	2433.600	572.671
3556.800	2433.600	551.262
3744.000	2433.600	467.459
3931.200	2433.600	407.568
0.000	2620.800	571.319
187.200	2620.800	685.581
374.400	2620.800	746.365
561.600	2620.800	708.735
748.800	2620.800	660.334
936.000	2620.800	629.365
1123.200	2620.800	622.544
1310.400	2620.800	636.523
1497.600	2620.800	662.254
1684.800	2620.800	693.037
1872.000	2620.800	657.237
2059.200	2620.800	618.965
2246.400	2620.800	564.604
2433.600	2620.800	518.548
2620.800	2620.800	511.562
2808.000	2620.800	532.277
2995.200	2620.800	574.936
3182.400	2620.800	639.768
3369.600	2620.800	655.561
3556.800	2620.800	592.545
3744.000	2620.800	489.968
3931.200	2620.800	592.711
0.000	2808.000	582.820
187.200	2808.000	794.456
374.400	2808.000	1010.759
561.600	2808.000	787.140
748.800	2808.000	646.996
936.000	2808.000	595.555
1123.200	2808.000	588.924
1310.400	2808.000	621.635
1497.600	2808.000	705.665
1684.800	2808.000	842.344
1872.000	2808.000	792.976
2059.200	2808.000	660.258
2246.400	2808.000	569.328
2433.600	2808.000	514.887
2620.800	2808.000	490.583
2808.000	2808.000	516.113
2995.200	2808.000	608.003
3182.400	2808.000	829.591
3369.600	2808.000	899.470
3556.800	2808.000	642.440
3744.000	2808.000	483.971
3931.200	2808.000	369.771
0.000	2995.200	536.666
187.200	2995.200	744.872
374.400	2995.200	970.139
561.600	2995.200	740.815
748.800	2995.200	632.453
936.000	2995.200	526.043
1123.200	2995.200	523.643
1310.400	2995.200	578.237

Table 4 continued

X	Y	P
1497.600	2995.200	7[illegible]4.433
1684.800	2995.200	1232.2[illegible]
1872.000	2995.200	932.514
2059.200	2995.200	647.221
2246.400	2995.200	53[illegible].[illegible]
2433.600	2995.200	431.531
2620.800	2995.200	46[illegible].[illegible]99
2808.000	2995.200	435.991
2995.200	2995.200	573.741
3182.400	2995.200	769.433
3369.600	2995.200	654.466
3556.800	2995.200	596.458
3744.000	2995.200	439.062
3931.200	2995.200	327.982
0.000	3182.400	431.155
187.200	3182.400	535.541
374.400	3182.400	597.179
561.600	3182.400	556.893
748.800	3182.400	595.172
936.000	3182.400	466.438
1123.200	3182.400	465.264
1310.400	3182.400	52[illegible].3[illegible]2
1497.600	3182.400	579.162
1684.800	3182.400	663.598
1872.000	3182.400	625.339
2059.200	3182.400	534.922
2246.400	3182.400	40[illegible].[illegible]52
2433.600	3182.400	422.155
2620.800	3182.400	417.075
2808.000	3182.400	441.339
2995.200	3182.400	459.494
3182.400	3182.400	543.417
3369.600	3182.400	552.955
3556.800	3182.400	456.776
3744.000	3182.400	372.[illegible]46
3931.200	3182.400	29[illegible].397
0.000	3369.600	342.583
187.200	3369.600	391.302
374.400	3369.600	416.170
561.600	3369.600	426.273
748.800	3369.600	414.818
936.000	3369.600	404.617
1123.200	3369.600	4[illegible]5.161
1310.400	3369.600	422.108
1497.600	3369.600	443.575
1684.800	3369.600	453.105
1872.000	3369.600	431.238
2059.200	3369.600	410.159
2246.400	3369.600	36[illegible].548
2433.600	3369.600	36[illegible].37[illegible]
2620.800	3369.600	36[illegible].[illegible]37
2808.000	3369.600	37[illegible].957
2995.200	3369.600	387.533
3182.400	3369.600	394.645
3369.600	3369.600	393.418
3556.800	3369.600	359.111
3744.000	3369.600	3[illegible]6.555
3931.200	3369.600	25[illegible].[illegible]22
0.000	3556.800	27[illegible].[illegible]22
187.200	3556.800	297.9[illegible]3

Table 4 continued

X	Y	P
374.400	3556.800	32[illegible].[illegible]72
561.600	3556.800	321.457
748.800	3556.800	326.954
936.000	3556.800	328.916
1123.200	3556.800	331.254
1310.400	3556.800	335.979
1497.600	3556.800	337.332
1684.800	3556.800	32[illegible].583
1872.000	3556.800	321.21[illegible]
2059.200	3556.800	3[illegible]9.752
2246.400	3556.800	3[illegible].036
2433.600	3556.800	289.296
2620.800	3556.800	291.239
2808.000	3556.800	293.932
2995.200	3556.800	294.349
3182.400	3556.800	294.816
3369.600	3556.800	297.753
3556.800	3556.800	276.511
3744.000	3556.800	244.313
3931.200	3556.800	265.227
0.000	3744.000	238.140
187.200	3744.000	225.782
374.400	3744.000	229.872
561.600	3744.000	232.195
748.800	3744.000	244.[illegible]86
936.000	3744.000	25[illegible].228
1123.200	3744.000	252.673
1310.400	3744.000	251.764
1497.600	3744.000	244.562
1684.800	3744.000	243.999
1872.000	3744.000	242.572
2059.200	3744.000	224.926
2246.400	3744.000	224.557
2433.600	3744.000	222.550
2620.800	3744.000	223.927
2808.000	3744.000	218.145
2995.200	3744.000	211.236
3182.400	3744.000	221.749
3369.600	3744.000	223.337
3556.800	3744.000	212.174
3744.000	3744.000	192.172
3931.200	3744.000	191.547
0.000	3931.200	158.313
187.200	3931.200	167.554
374.400	3931.200	172.732
561.600	3931.200	162.717
748.800	3931.200	166.475
936.000	3931.200	173.863
1123.200	3931.200	175.969
1310.400	3931.200	172.822
1497.600	3931.200	173.655
1684.800	3931.200	182.858
1872.000	3931.200	181.539
2059.200	3931.200	169.721
2246.400	3931.200	151.552
2433.600	3931.200	152.837
2620.800	3931.200	152.936
2808.000	3931.200	145.982
2995.200	3931.200	151.656
3182.400	3931.200	163.365
3369.600	3931.200	165.261
3556.800	3931.200	157.617
3744.000	3931.200	142.255
3931.200	3931.200	123.610

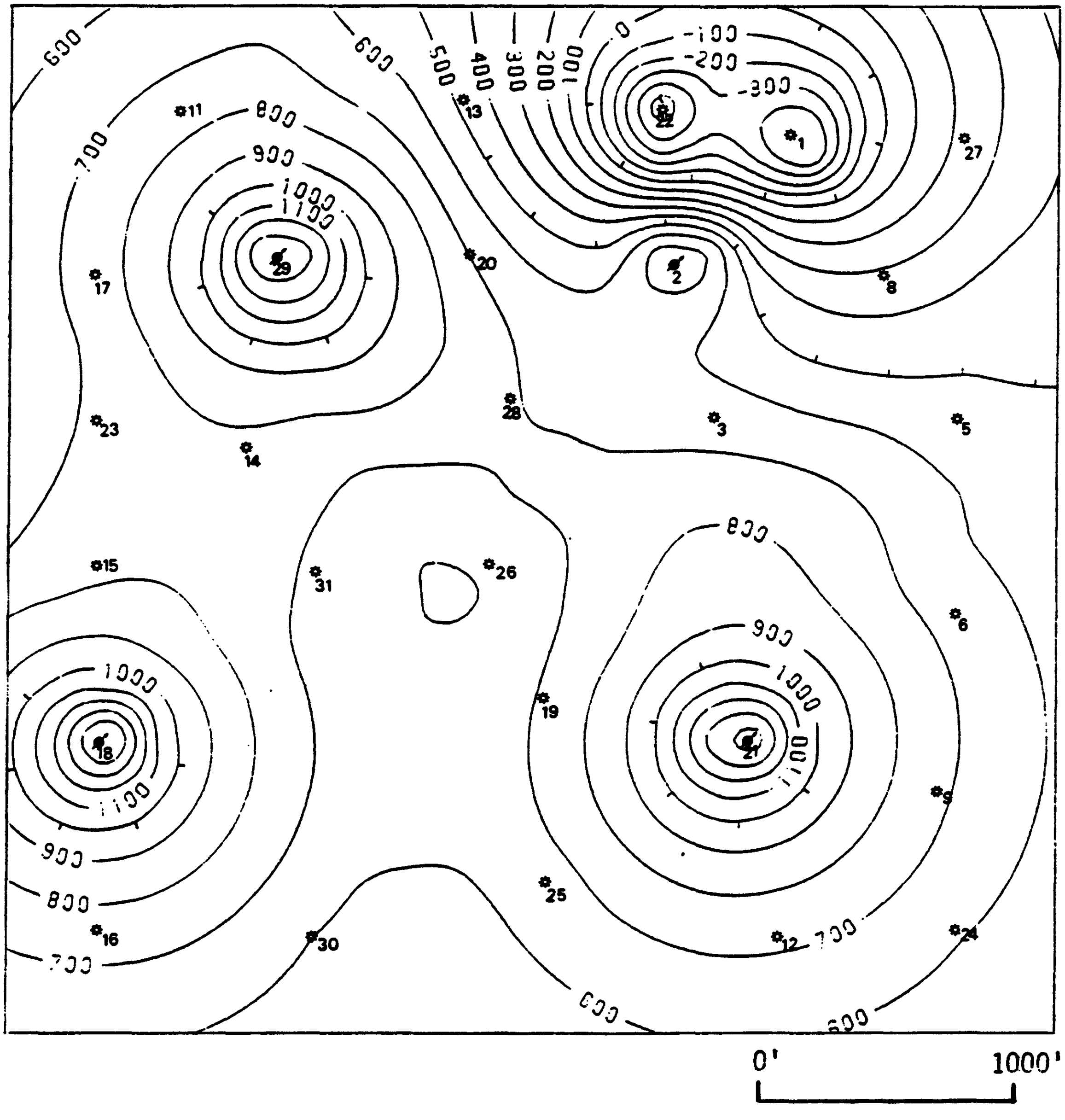

Figure 37: Pressure Distribution in Pilot No. 1
after Oil Breakthrough (Stage 2)

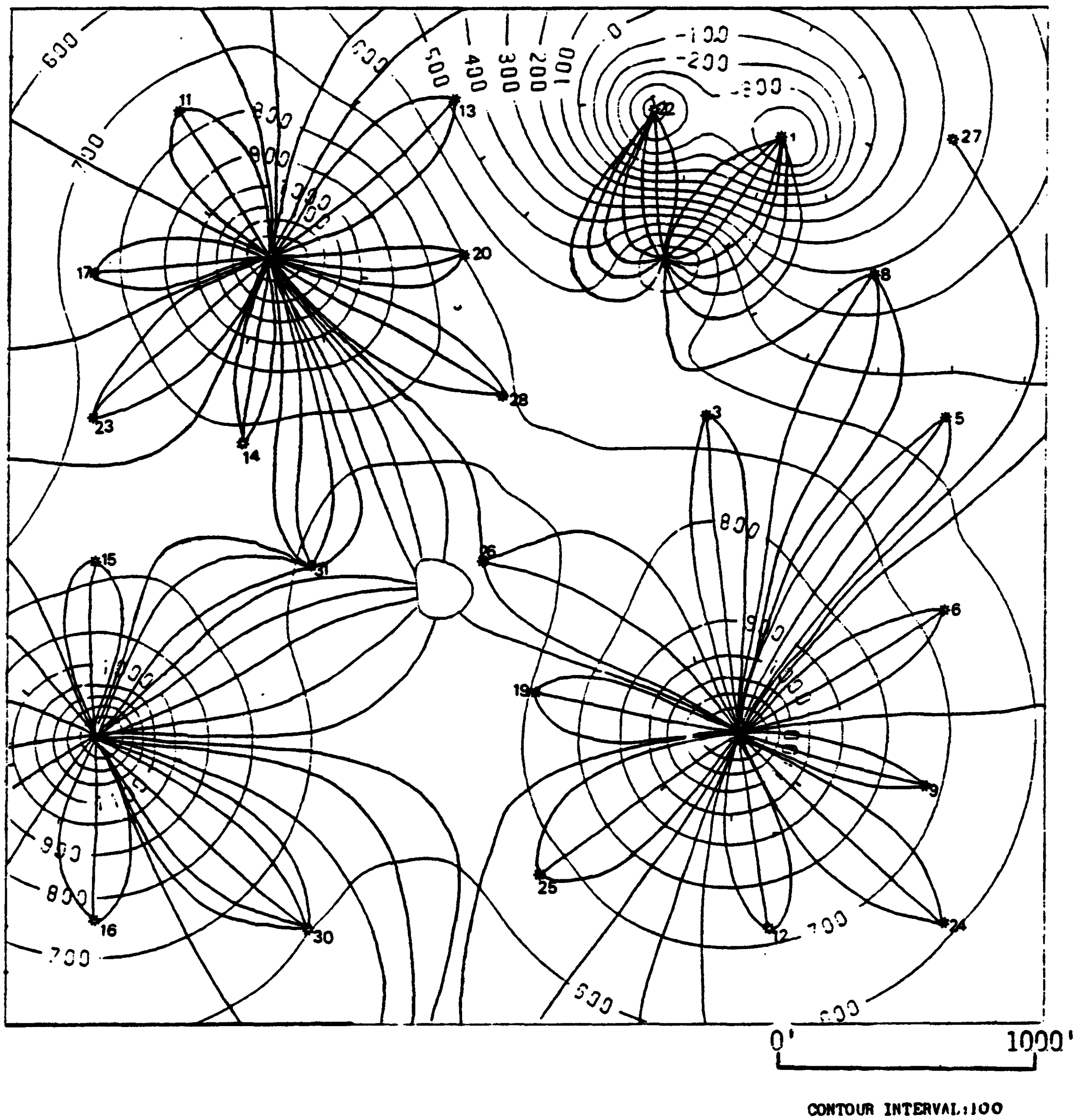

Figure 38: Pressure Distribution and Streamlines
after Oil Breakthrough (Stage 2)

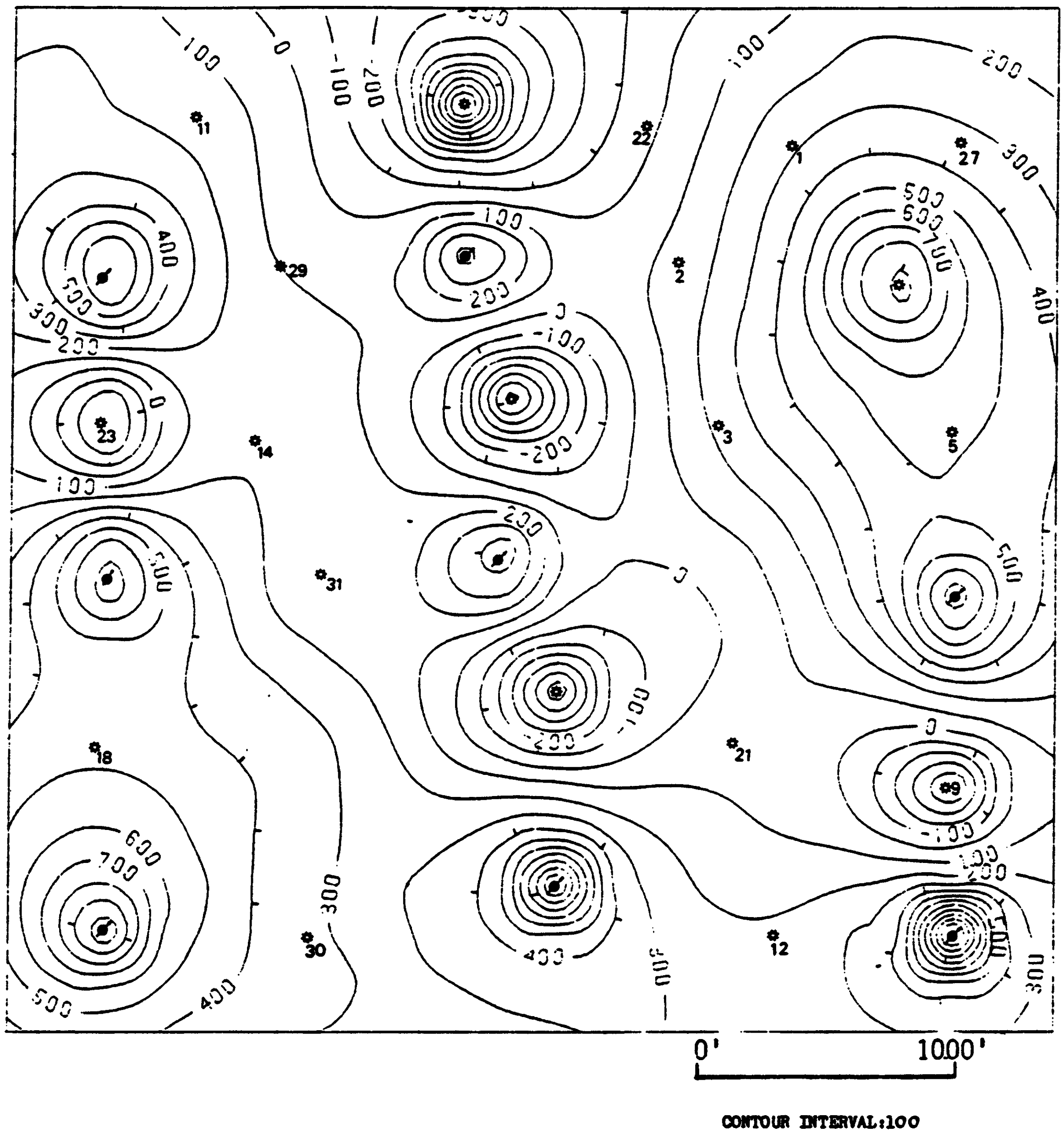

Figure 39: Pressure Distribution in Pilot No. 2
after Oil Breakthrough (Stage 2)

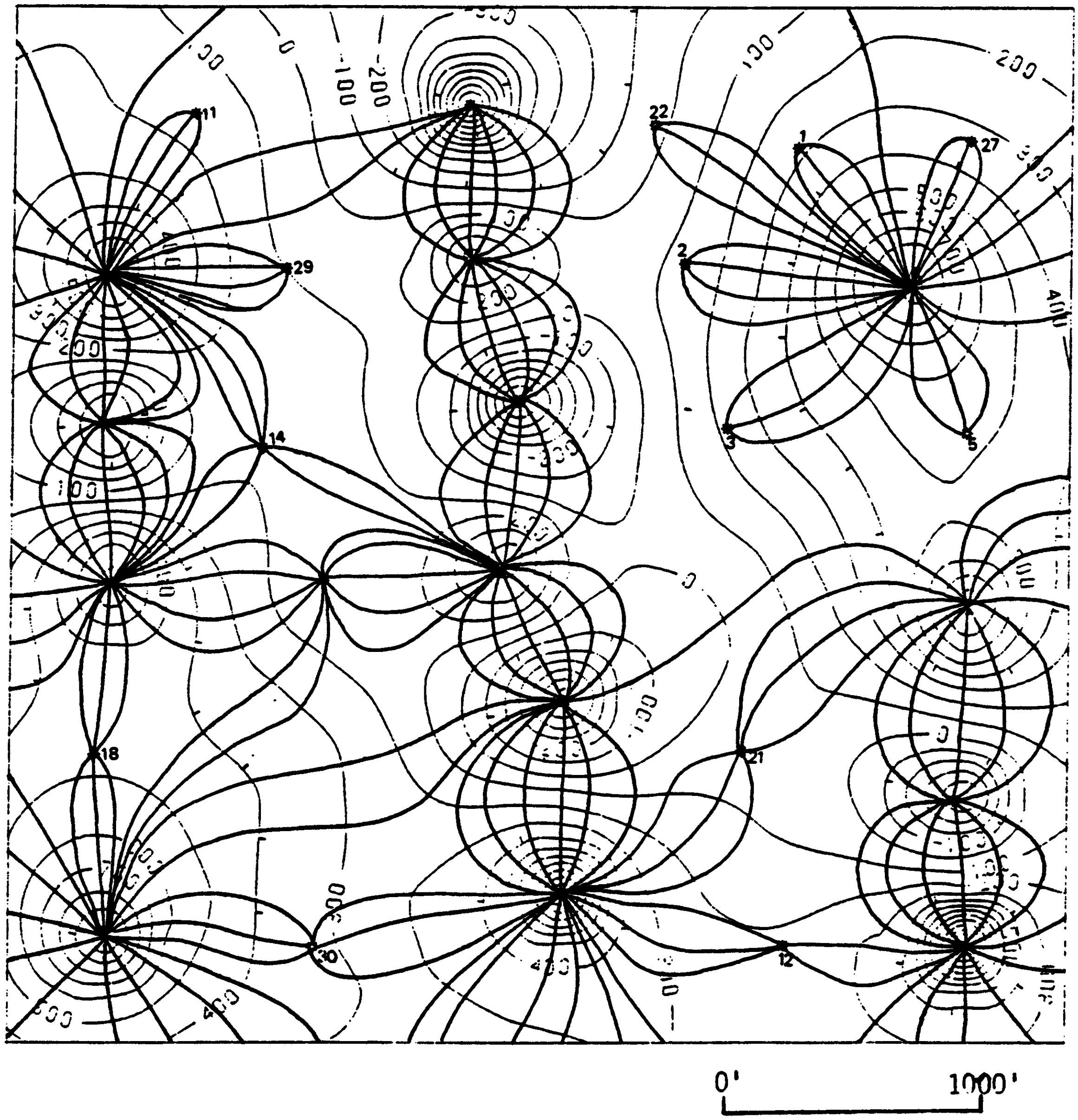

Figure 40: Pressure Distribution and Streamlines in Pilot No. 2 after Oil Breakthrough (Stage 2)

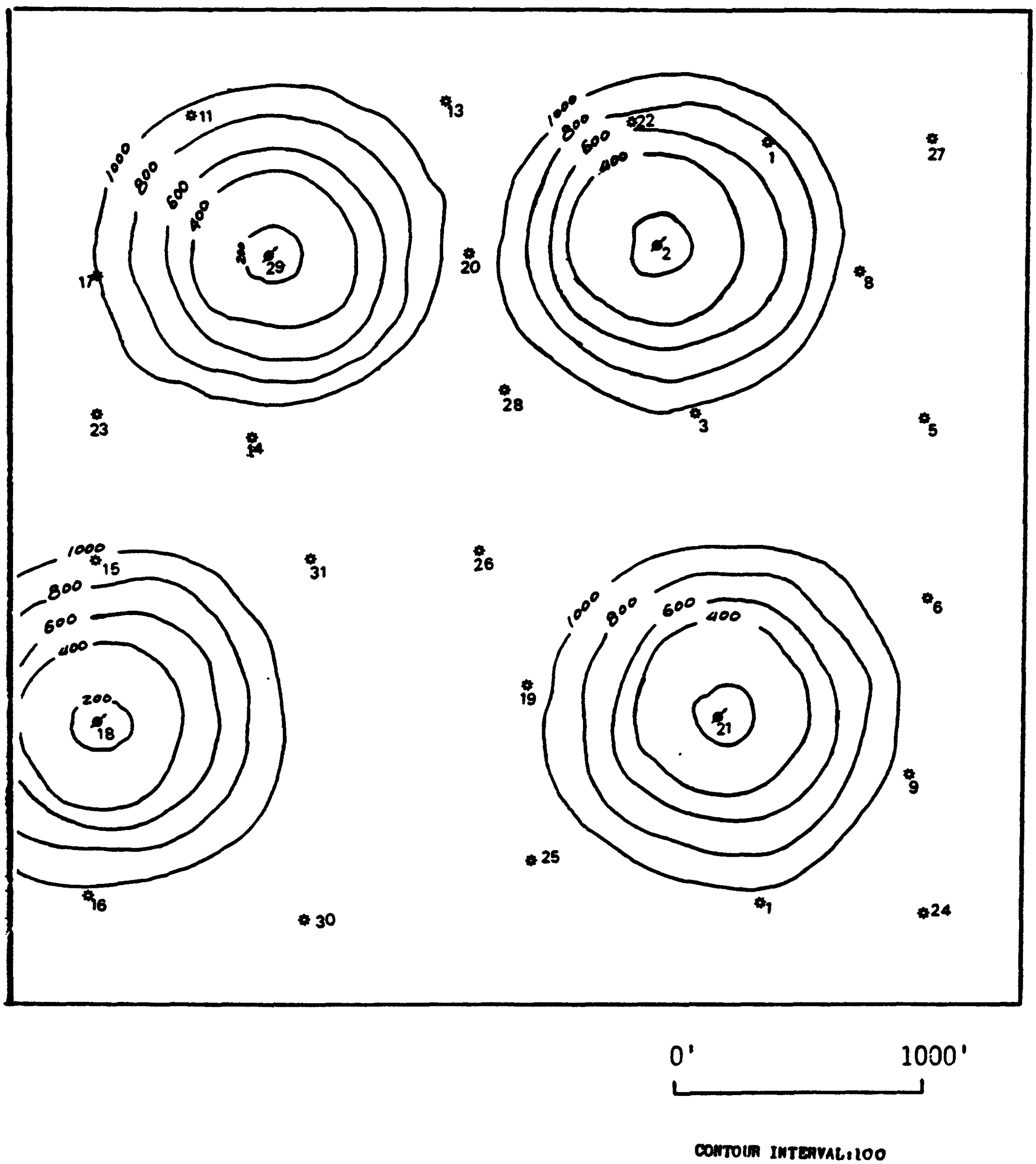

Figure 41: Water Front Positions in Pilot No. 1

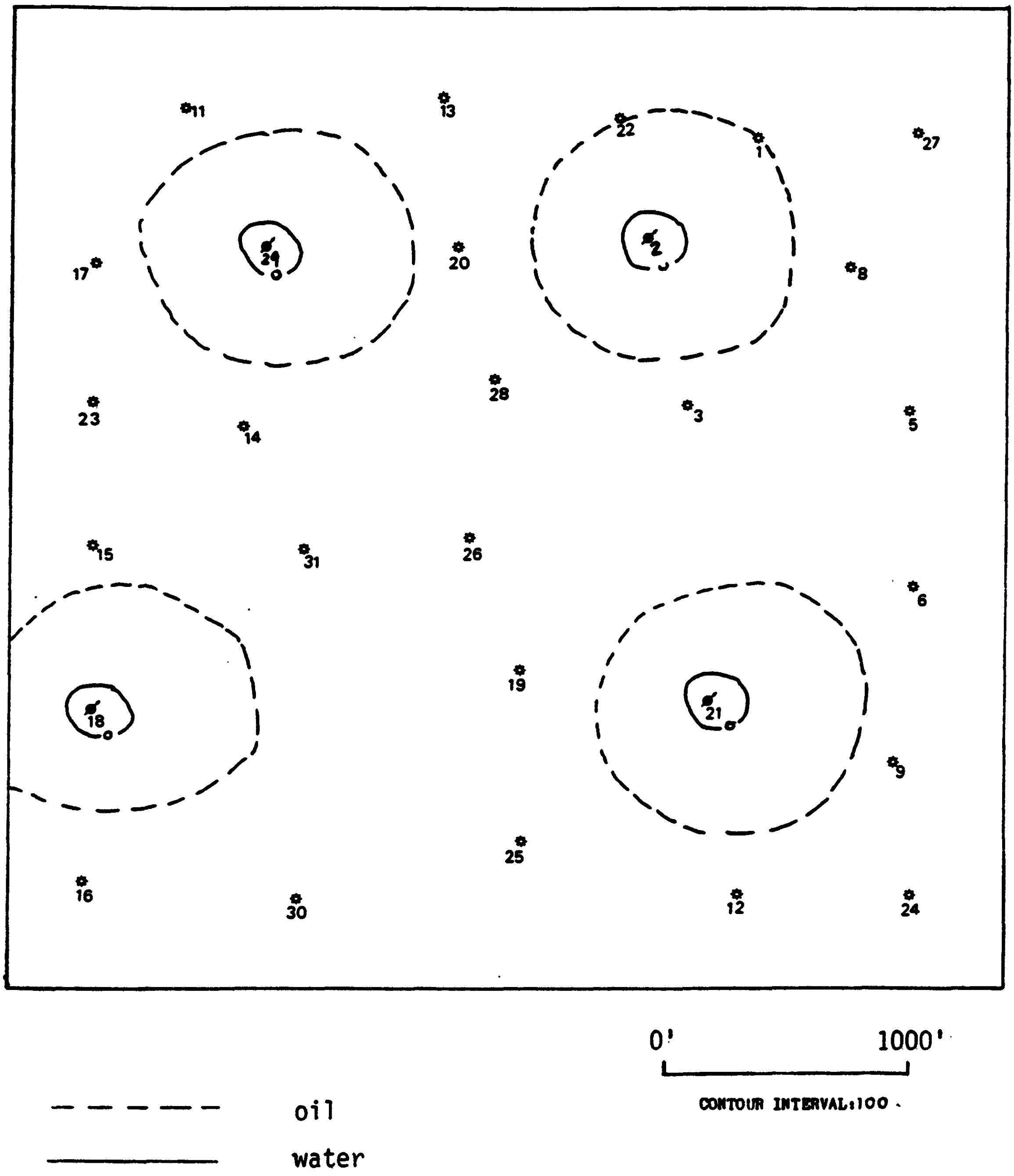

Figure 42: Oil Front Positions in Pilot No. 1

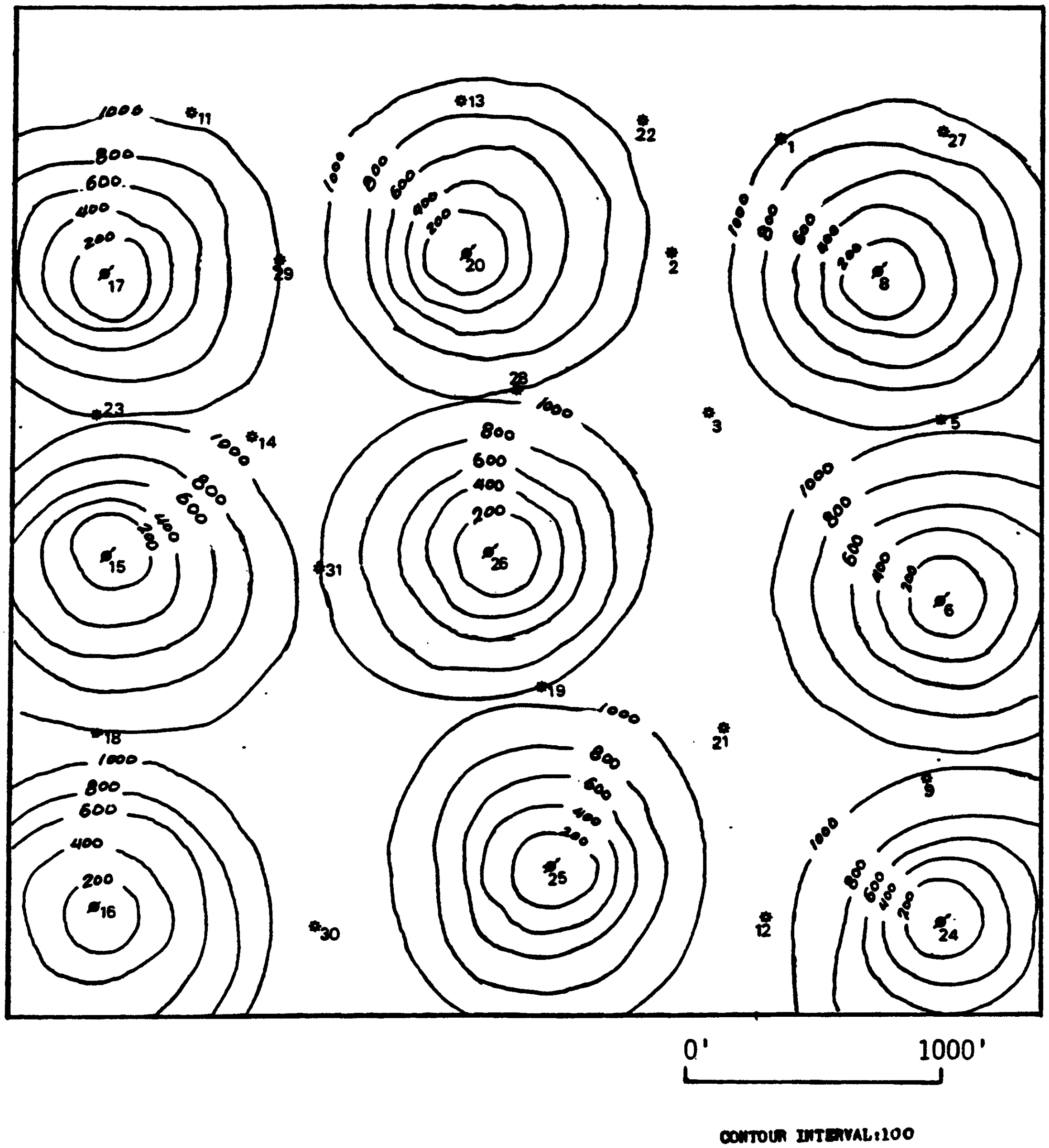

Figure 43: Water Front Positions in Pilot No. 2

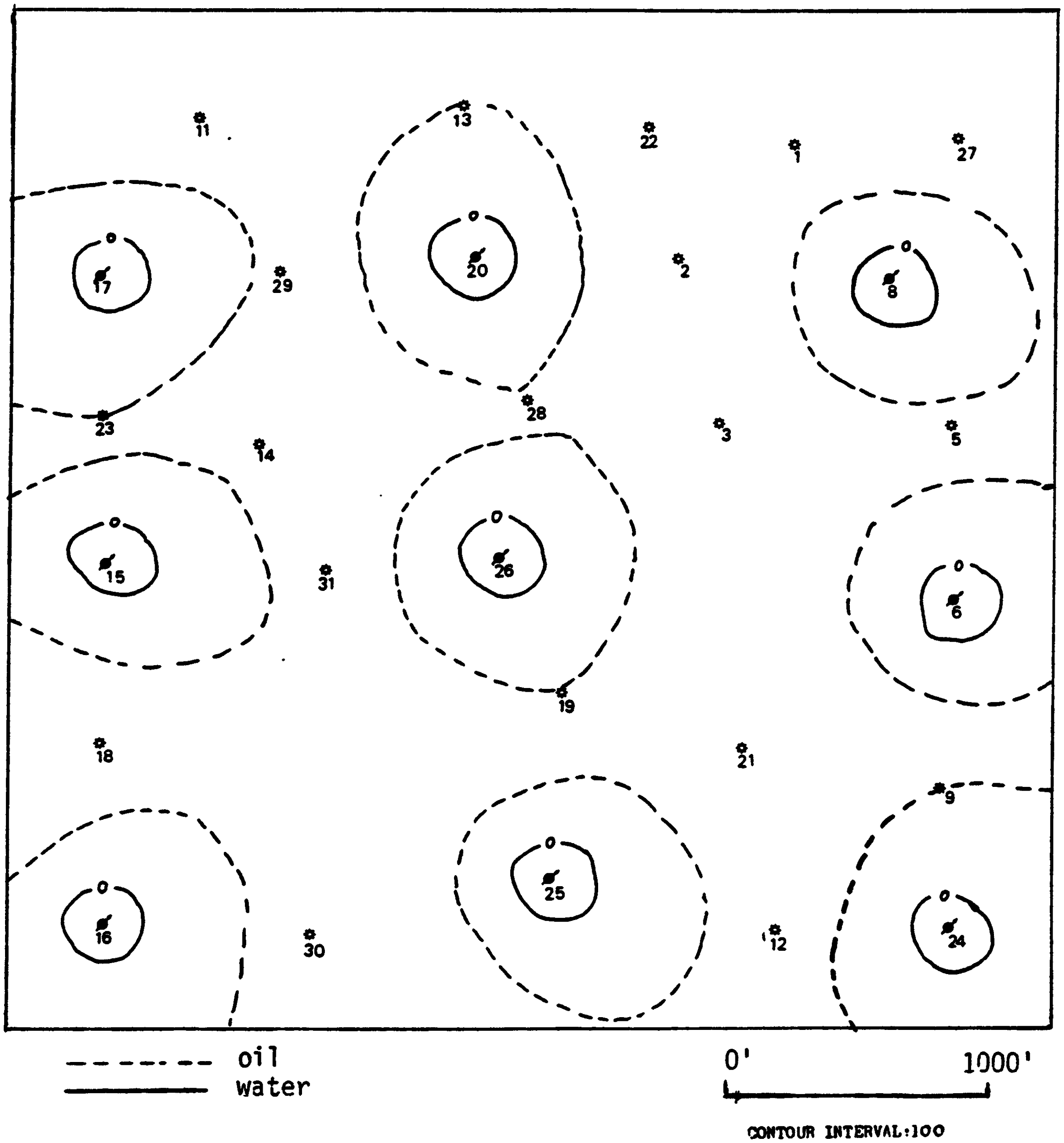

Figure 44: Oil Front Positions in Pilot No. 2

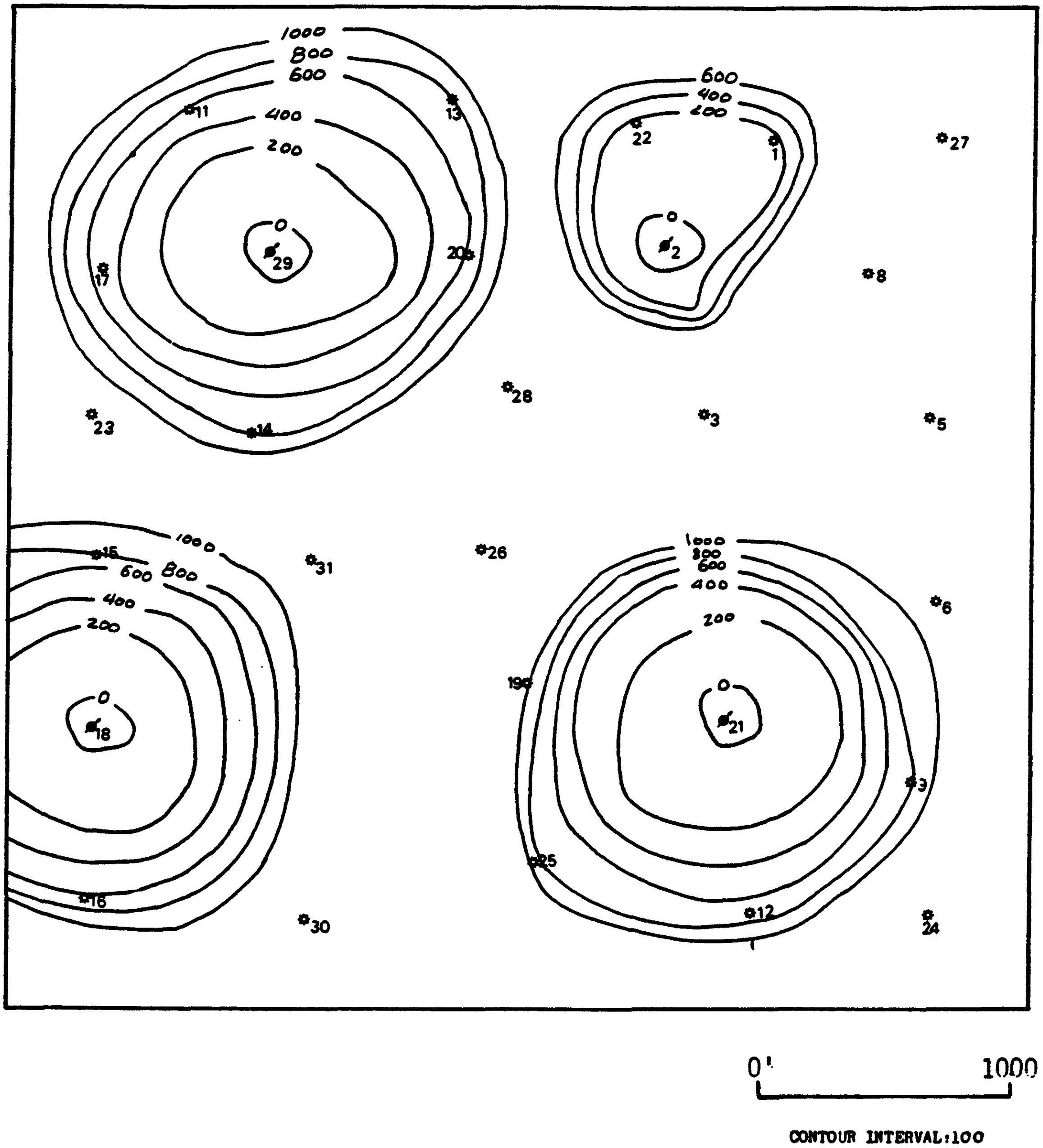

Figure 48: Water Front Position in Pilot 1 (Stage 2)

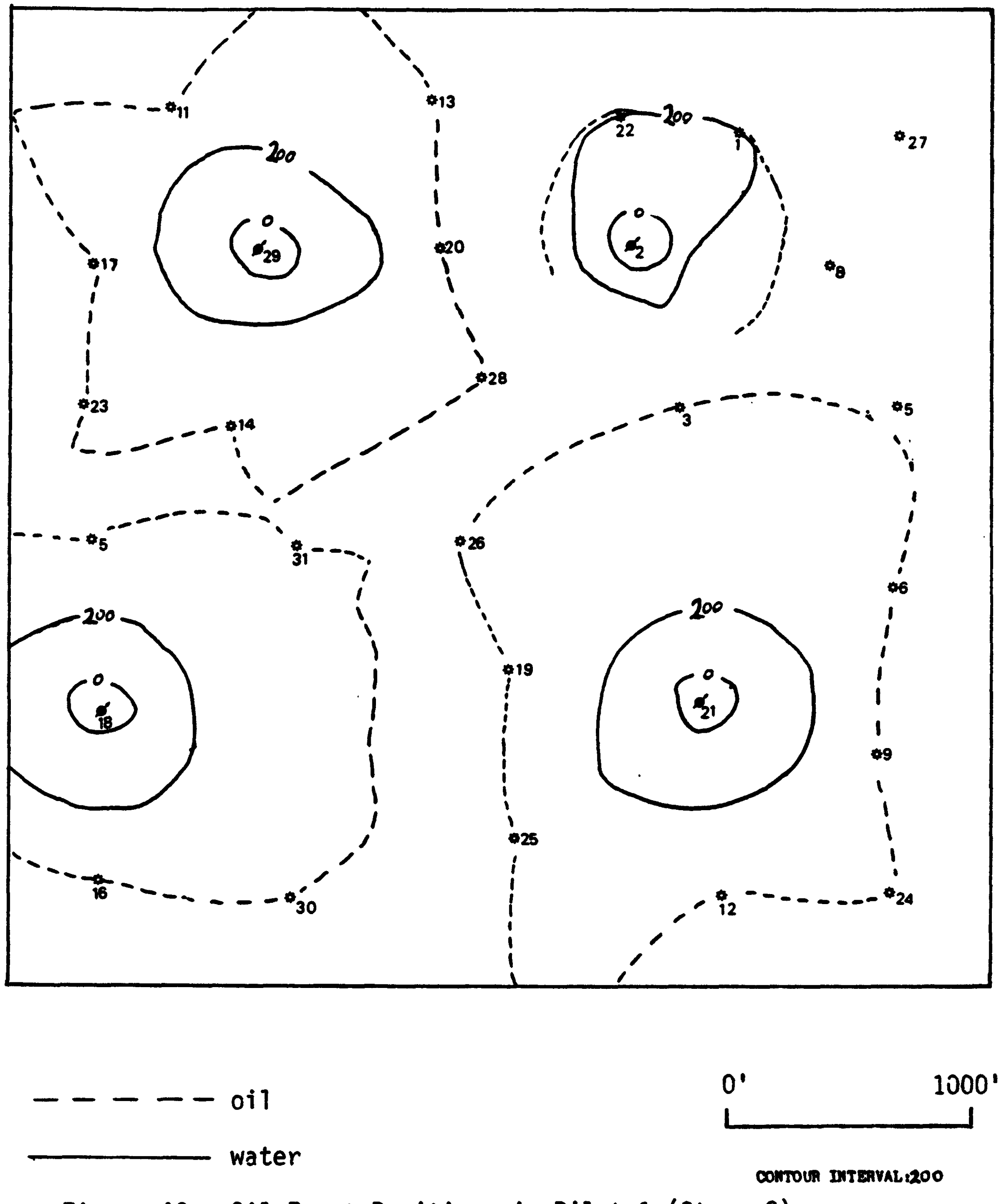

Figure 46: Oil Front Positions in Pilot 1 (Stage 2)

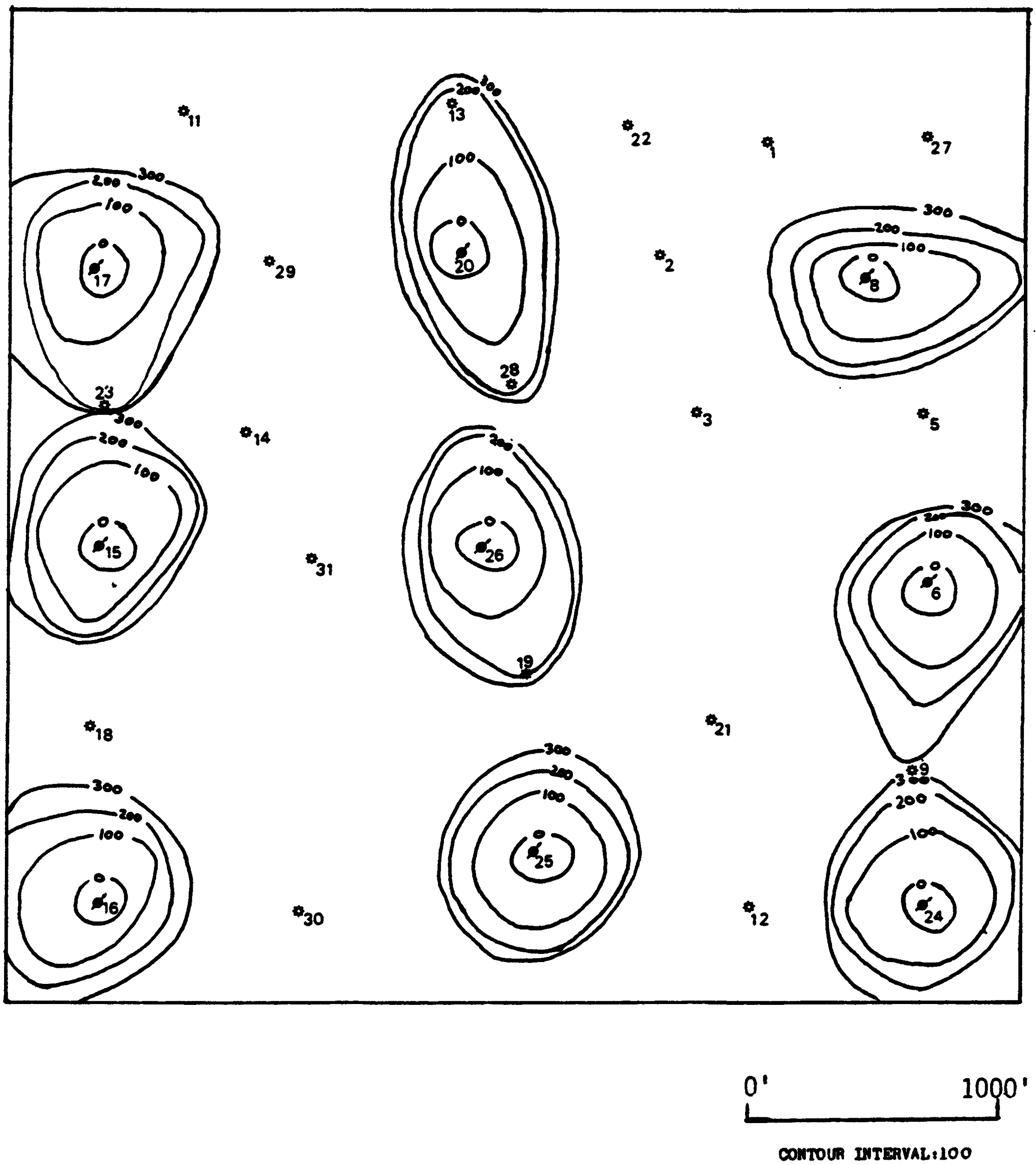

Figure 47: Water Front Positions in Pilot No. 2 (Stage 2)

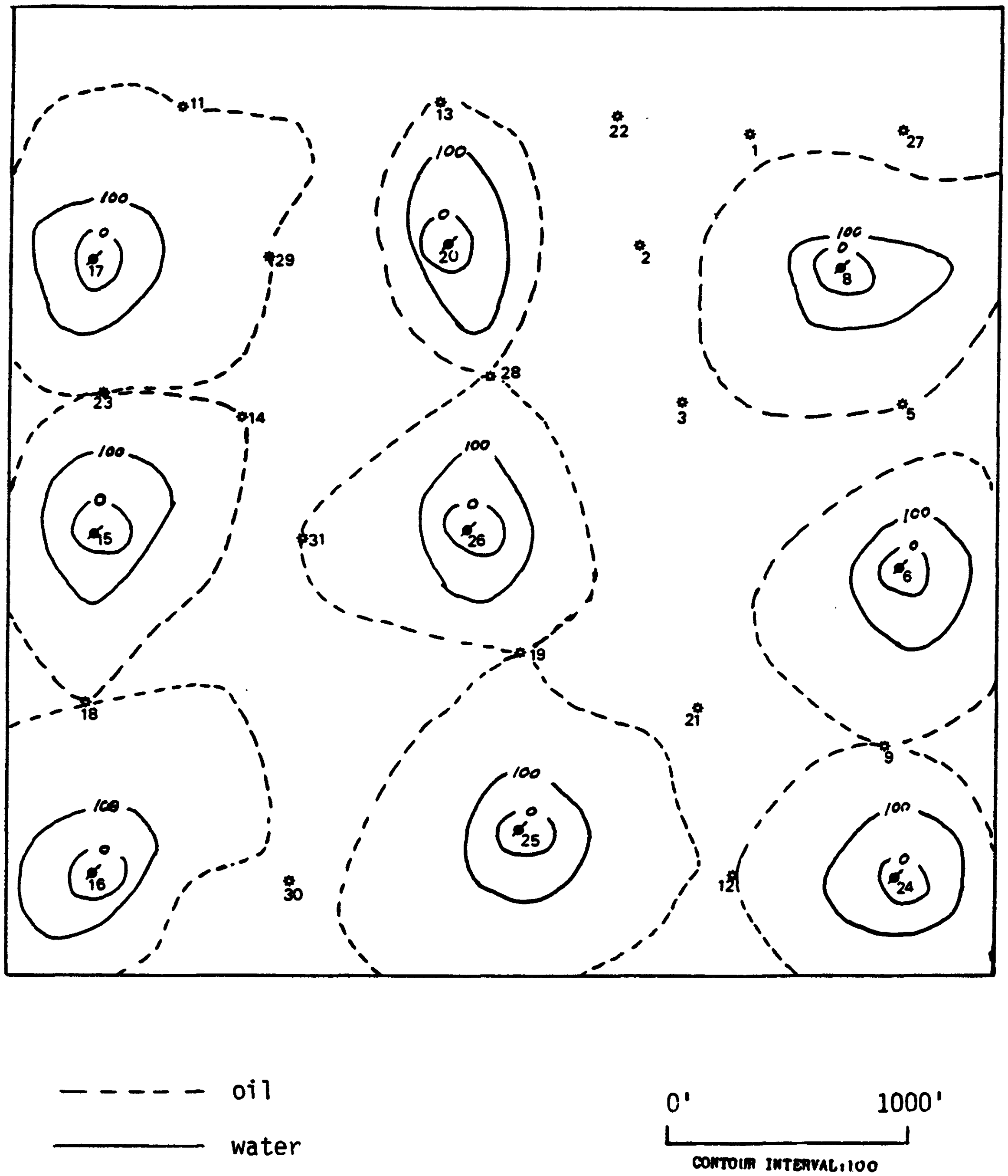

Figure 48: Oil Front Positions in Pilot No. 2 (Stage 2)

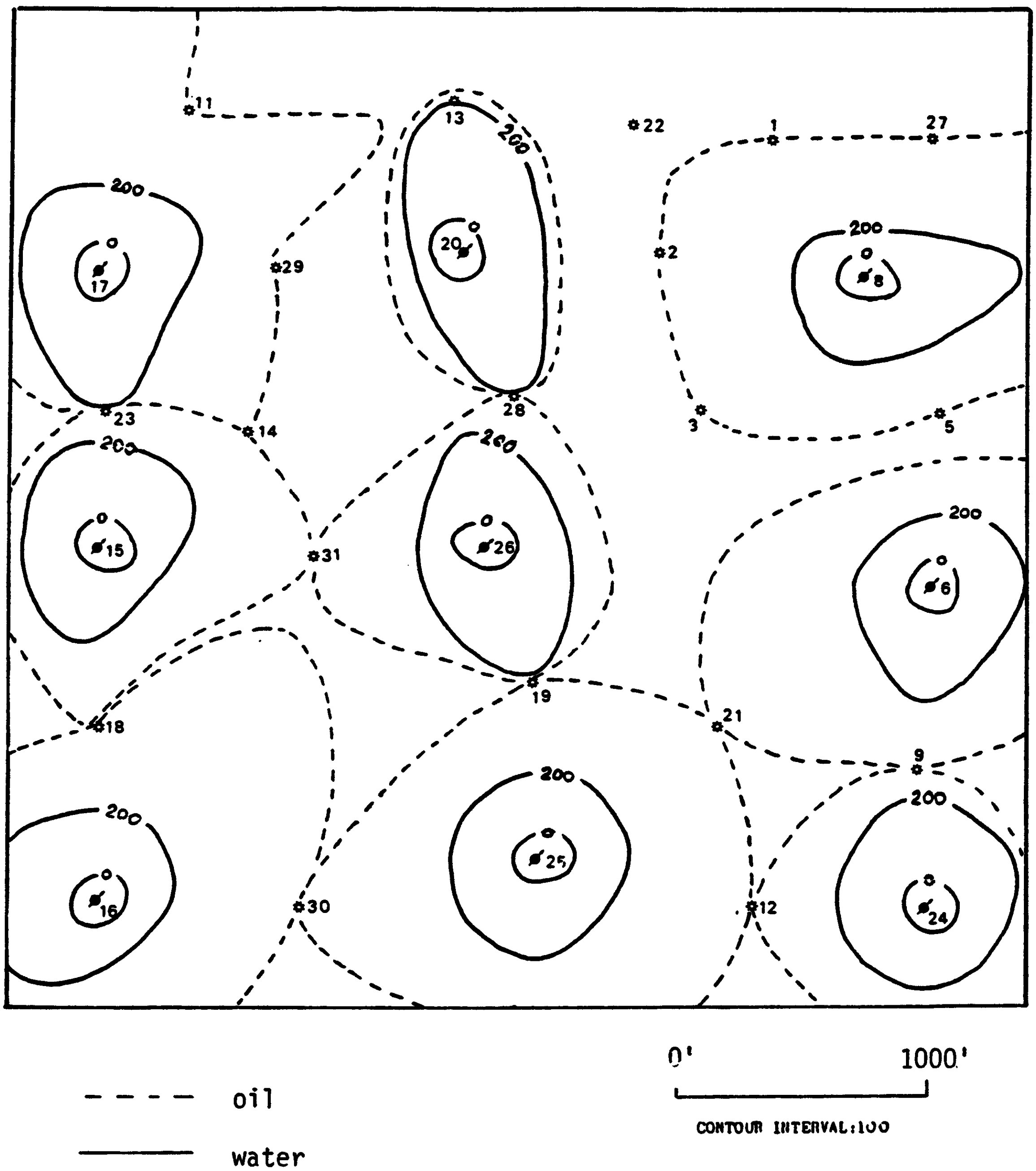

Figure 49: Oil Front Positions in Pilot No. 2 (Stage 2)
Water Front at 200 Pseudo Time Level

DISCUSSION

The results obtained from the water injection in the two pilots until the time of oil break-through are shown in Table 5 and 6. The area swept for each injection well in the two pilots and oil produced for each pilot until the time of water break-through are shown in Table 7 and 8. These results show:

1) The first oil break-through in Pilot No. 1 (Figure 42) occurred in Well No. 1 and Well No. 22, when the water front was 123 feet away from the injection wells;

2) The first water break-through in Pilot No. 1 (Figure 45) occurred in Well No. 1 and Well No. 22. At this time, 1.04 years after the start of water injection. The oil bank had reached Wells No. 1, 22, 17, 11, 13- 20, 28, 14, 15, 31, 16, 3, 6, 9, 24, 12, 25, 19 and 26, respectively in this length of time (Figure 46).

The only wells which did not have any responses from the water injection were Wells No. 27, 8 and 5 (Figure 46).

3) At the time of water break-through, 1.84 million square feet or 13.25% of the total area was invaded by the 1.1 million barrels of injected water, and 1 million barrels of oil were displaced into the oil bank or had been produced.

4) The oil bank had moved beyond the area of the pilot, as shown in Figure 46.

Table No. 5

The Results of Water Injection in Pilot No. 1 (4 Injection Wells) Before Oil Break-Through

Time of oil break-through:	35 days
Water injected from the start of water injection until the time of oil break-through:	114,400 barrels
Radius of water front from the injection wells at the time of oil break-through:	123 feet
Radius of oil bank from the injection wells at the time of oil break-through:	459 feet
The wells which had been effected by the oil bank:	Well No. 1 and 22
New oil production rate	
Well No. 1 new oil production rate:	1190 bbls/day
Well No. 22 new oil production rate:	1209 bbls/day

Table No. 6

The Results of Water Injection in
Pilot No. 2 (9 Injection Wells) Before
Oil Break-Through

Time of oil break-through:	35 days
Water injected from the start of water injection until the time of oil break-through:	253,232 barrels
Radius of water front from the injection wells at the time of oil break-through:	122 feet
Radius of oil bank from the injection wells at the time of oil break-through:	456 feet
The wells which had been effected by the oil bank:	Wells No. 9, 23, 19, 28 and 13
New oil production rates:	
Well No. 9 new oil production rate:	1191 bbls/day
Well No. 23 new oil production rate:	1190 bbls/day
Well No. 19 new oil production rate:	1203 bbls/day
Well No. 28 new oil production rate:	1205 bbls/day
Well No. 13 new oil production rate:	1197 bbls/day

Table No. 7

Waterflood Results in Pilot No. 1

At Initial Water Break-Through (Stage 2)

Area Swept MM Sq. Ft.	Total Water Injected MM Barrels	Total Oil Displaced MM Barrels	Time to Water Break-Through Years	Wells Which Had Water Break-Through
1.84	1.1	1	1.04	1 and 22

Table No. 8

Waterflood Results in Pilot No. 2

At Initial Water Break-Through (Stage 2)

Area Swept MM Sq. Ft.	Total Water Injected MM Barrels	Total Oil Displaced MM Barrels	Time to Water Break-Through Years	Wells Which Had Water Break-Through
2.91	1.75	1.6	0.77	23, 13, and 28

5) As the time of water injection goes on, more producing wells have water break-through, and the amount of oil displaced increases.

6) The first oil break-through in Pilot No. 2 (Figure 44) occurred in Wells No. 23, 13, 28, 19, and 9, when the water front was at 123 feet away from the injection wells;

7) The first water break-through in Pilot No. 2 (Figure 47) occurred in Wells No. 23, 13, and 28. At this time, 0.77 years after the start of water injection, the oil bank had reached Well Nos. 11, 29, 23, 13, 28, 5, 14, 18, 31, 19, 9, and 12. The wells which did not have any responses from the water injection were number 22, 2, 1, 27, 3, 21, and 30.

8) At the time of first water break-through, 2.91 million square feet or 21% of the total area was invaded by the 1.75 million barrels of injected water, and 1.6 million barrels of oil was displaced into the oil bank or had been produced.

9) The oil bank had moved beyond the area of the pilot as shown in Figure 48.

10) After the first oil break-through in the two pilots, new oil production rate was calculated for the producing wells which had the oil break-through. These oil production rate values were very high, because of the high ratio of the

effective permeability of oil to the effective permeability of water (30/4.4) which was reported in this report and was not compared to the saturation values used in this report.

CONCLUSIONS

The following conclusions were made on the basis of the results reviewed in the discussion:

1) Fast oil break-through occurred in the two pilots (35 days after the start of water injection).

2) Early water break-through occurred in both pilots.

3) At the time of initial water break-through a greater volume of oil had been displaced in Pilot No. 2 because of the larger volume of water injected.

4) The evaluation of the Pilots indicate that water-flooding appears feasible in the bottom member of the oil producing zone in the area.

RECOMMENDATIONS

1) Field testing should be undertaken to determine the hydraulic continuity within the area and if any directional permeability exists.

2) Using available cores, additional displacement tests should be done to refine the residual saturations used in this report.

3) A study should be undertaken to determine the availability of a suitable source of water.

4) Based on the acquisition of the recommended additional data, a comprehensive study should be performed to determine the optimum design and operational procedure for a full scale waterflood.

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Appendix A

Summary of the Results of the Secondary Recovery Projects

(Neslage, 1966)

Summary of Waterflood Projects

Name of the Project		Flooded Acre-Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
1.	Badger Cooperative	-	-	Failure
2.	Southwest Pampa	32,500	5.3	Partial*
3.	Meers C Lease	4,800	7.6	Partial
4.	Davidson Area	31,400	-	Partial
5.	Huber-Herring Burch	1.760	-	Failure
6.	Huber-State A & B	30,800	-	Partial
7a.	Kewanee-Chapman	17,700	-	Failure
b.	East Morse Flood Unit	40,200	25	Success*
c.	Gething	14,400	36	Success
d.	Johnson A	-	-	Failure
e.	KSAM Unit	13,000	27	Success*
f.	Morse Area	36,600	77	Success*
g.	Kewanee Morse	36,600	77	Success
h.	Phillips	-	-	Failure
i.	Short and Short A & B	8,400	29	Success
j.	Webb and Husely ABC	19,000	26	Success
k.	West Morse Group	17,400	45	Success
l.	West Webb	19,000	26	Success

* Results obtained from the decline curves

Name of the Project	Flooded Acre-Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
8. South Pampa Area	32,500	5	Partial
9. Stansberry	24,000	4	Partial
10. Little Seminole	87,000	27	Success*
11. R.E. Darsey	19,700	14	Success
12. Mobil Fee 227	135,400	14	Success
13. Mobil Fee 224	31,000	-	Failure
14. Mobil-Saunders "B"	18,500	13	Success
15. Mobil - SO & DC	16,000	-	Failure
16. Phillips-Finlly	14,400	12.5	Success*
17. Phillips-Pampa Unit	16,000	58	Success
18. Phillips-Supreme Lease	-	-	Success*
19. Phillips-West Stinnett Unit and Bret Q & R	11,800	-	Failure
20. Sinclair-East Pampa	14,400	16	Success
21. Skelly-Schafer Ranch	108,000	19	Success
22. Skelly-Webb Batteries #1, #3, and #5	19,000	26	Success
23. Sunray DX-Brown Dolomite Unit	6,400	47	Success

* Results obtained from the decline curves

Name of the Project	Flooded Acre-Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
24. Combs Lease	14,850	-	Failure
25. Chapman	17,700	-	Failure
26. Saunders	35,650	-	Failure
27. J.C.Short	-	-	Failure

WOC Gas Injection Projects

Name of the Project	Flooded Acre-Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
1. Alexander	5,600	12.4	Success
2. Cities Service Drillex	4,480	16	Success
3. Creslenn			
a. Moore A & B	3,360	10.7	Partial
b. Moore C	5,600	7.7	Partial
c. Moore D	3,360	5.8	Partial
4. Gulf			
a. Cockrell B	1,120	7.7	Partial
b. Cockrell C NCT.B	7,840	7.3	Partial
c. Pitcher	8,960	5.0	Partial
5. Kerr-McGee			
a. Cockrell	17,853	6	Partial
b. Pitts	71,680	5.4	Partial
6. Kewanee			
a. Haile	8,960	5	Partial
b. Haile A	6,720	6.6	Partial
c. Haile B	8,960	7.3	Partial
d. Haile C	4,480	7.3	Partial
e. Haile D	8,960	4.3	Partial
f. Haile F	6,720	7.3	Partial
g. Watkins B	8,960	6.6	Partial

Name of the Project	Flooded Acre-Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
7. Martex	7,840	6	Partial
8. Phillips			
a. Black	1,120	9.4	Partial
b. Cockrell Ranch	6.312	6.5	Partial
c. E-Cockrell	1,680	5.6	Partial
d. W.B. Haile	9,464	6.5	Partial
e. Harvey Unit	40,320	4.7	Partial
f. D. Jordan	16,240	5.0	Partial
g. Kent A	2,800	5.0	Partial
h. Kent B	19,152	4.3	Partial
i. Lone Star	1,680	9.4	Partial
j. Terr & Terr B	3,920	5.8	Partial
k. Timms	4,480	8	Partial
l. Turner-Whittenburg	3,920	3.8	Partial
m. Whittenburg Btg #1	10,752	12.4	Success
9. S & M	8,960	7.7	Partial
10. Skelly			
a. Watkins A	8,960	3.9	Partial
b. Watkins B	9,520	10	Partial
11. Dale Smith	2,800	17.6	Success
12. Spradling Longstar	1,680	16.3	Success

Name of the Project	Flooded Acre-Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
13. Texaco			
a. Garner A NCT-Y	8,960	3	Partial
b. Lewis NCT-4	29,736	3.2	Partial
c. EJ Moore NCT-1	8,960	8	Partial
d. EJ Moore NCT-2	8,960	5.5	Partial
e. J.W. Moore	8,960	4.3	Partial
f. Pond	34,720	6.4	Partial
14. Amoco			
a. Haile A	9,184	7	Partial
b. Haile B	15,120	2	Partial
c. EJ Moore	8,960	7	Partial
d. Pitcher A	8,960	5	Partial
e. Pitcher B	4,480	6.5	Partial
f. Terry	17,920	2	Partial
g. Ware A	8,960	6	Partial
h. Ware B	8,960	4.5	Partial
i. Ware C	8,960	3.5	Partial
j. Watkins AR/AA	8,960	7	Partial
k. Watkins AR/AB	8,960	4	Partial
l. Watkins B	11,200	5.5	Partial
15. Chase	4,480	4	Partial

Name of the Project	Flooded Acre Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
16. Detra			
a. McCarty	7,280	3	Partial
b. Panl	2,240	5	Partial
17. Dunigen	4,480	6	Partial
18. Harman	6,720	22.5	Success
19. Hawks	8,960	3	Success
20. Panhandle Haile	9,184	5	Partial
21. Hanover			
a. Coleman	24,136	2.5	Partial
b. Watkins	9,520	5.5	Partial
22. Superior	4,480	4.6	Partial

West Pampa Repressuring Associations

Name of the Project	Flooded Acre Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
1. Amoco			
a. Cobb	24,920	3	Partial
b. Culler	4,480	9.85	Partial
c. Kinzer	8,960	6	Partial
d. Wagoner	8,960	8	Partial
2. Atlantic Richfield	6,160	5.4	Partial
3. Bruce (Jackson)	2,800	4	Partial
4. Chase	3,360	3	Partial
5. Chisam Phillips A	8,400	3.3	Partial
6. Cities Service			
a. Archer	8,960	6	Partial
b. Bender	8,960	2.7	Partial
c. Culler	12,320	5.5	Partial
d. Noel	8,960	2.7	Partial
e. Sailor Unit	8,960	4	Partial
f. Shields	12,208	5.3	Partial
g. Smith	8,960	4.8	Partial
7. Crabtree Haggard	8,960	6.6	Partial
8. Federer Skidmore	5,600	4.2	Partial
9. Gulf			
a. Hughey	4,480	3.6	Partial

Name of the Project	Flooded Acre Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
9. b. Smith	4,480	3.6	Partial
c. Thompson	8,960	4.3	Partial
10. Kewanee			
a. Arnold	8,960	4.3	Partial
b. Cobb	2,800	3.2	Partial
c. Culler	4,480	9.2	Partial
d. Harrah	8,960	6.5	Partial
e. Morgan	8,960	12	Success
f. Rest	13,440	8.6	Partial
g. S. Pampa Unit	22,400	2.5	Partial
11. Mobil			
a. M. Sailor	1,680	5.4	Partial
12. Oil Well Operator			
a. Harrah	8,960	6	Partial
13. Petroluem Int.			
a. Arnold	4,480	13.5	Success
b. R.W. Harrah	2,240	7.6	Partial
c. W.W. Harrah	6,720	12.5	Success
d. Pope	8,960	4	Partial
e. Sackett	8,960	5.6	Partial
14. Phillips			
a. Castleberry B	4,480	7.7	Partial
b. Hughey	3,920	3.4	Partial

Name of the Project	Flooded Acre Ft.	Incremental Sec. Rec. bbls/Acre-Ft.	Note Success Status
14. c. Leopold	4,480	4.6	Partial
d. Leopold	2,800	5.8	Partial
e. Pampa Unit Balance	109,592	7.8	Partial
f. Sin-Harrah	4,480	12.4	Success
g. Sin-Pope	4,480	4.5	Partial
15. Pringle			
a. Jackson	6,160	5	Partial
b. Vollmert	8,960	5.7	Partial
16. Texaco			
a. Barrett	6,720	1.4	Partial
b. Harrah	8,960	5.8	Partial
17. Wefco			
a. Baird	4,480	5.7	Partial
b. Noel	4,480	6.3	Partial
c. Vaughn	8,960	8.9	Partial

Appendix B

Review of Two Waterflood Projects Nearby the Area of Interest

(Wilson, 1982)

Appendix B

Review of Two Waterflood Projects Conducted Near to Pitts and Cockrell Leases

1. Badger Cooperative Waterflood

The Badger Cooperative Waterflood project is located in the south portion of the Watkins Operator Committee approximately 3½ miles south of the area of interest (Pitts and Cockrell Leases), and include a sum of 2,840 surface acres. The oil production data is plotted separately on the three attached performance curves as the Sunray-Lewis lease, the Kewanee Badger Lease, and the Texaco-Lewis NCT-1.

The only significant production kick was on the Sunray-Lewis in September 1963. This occurred shortly after the Stage II expansion, when 39 additional water injection wells were converted. This waterflood attempt was considered to be partially successful (Figure 50).

2. The Huber State A & B Waterflood Project

This project is located approximately 3 miles north of the Pitts and Cockrell Leases, Hutchinson County. Water injection began February 1962 into four wells with a fifth well being converted in January 1963.

Approximately 5MM bbls of water was injected into these wells through 1966. During this time the oil production data indicated a leveling out shortly after the start of injection (Figure 51) and a subsequent decline roughly parallel to the prior decline trend.

The incremental oil attributed to secondary recovery was estimated by the operator at 110,000 bbls. In February 1966, an expansion of the injection operation commenced with the conversion of 3 WIW. In July 1966, two of the original input wells were put on production and 10 additional wells were converted to input status. This project was considered to be a partial success at the time.

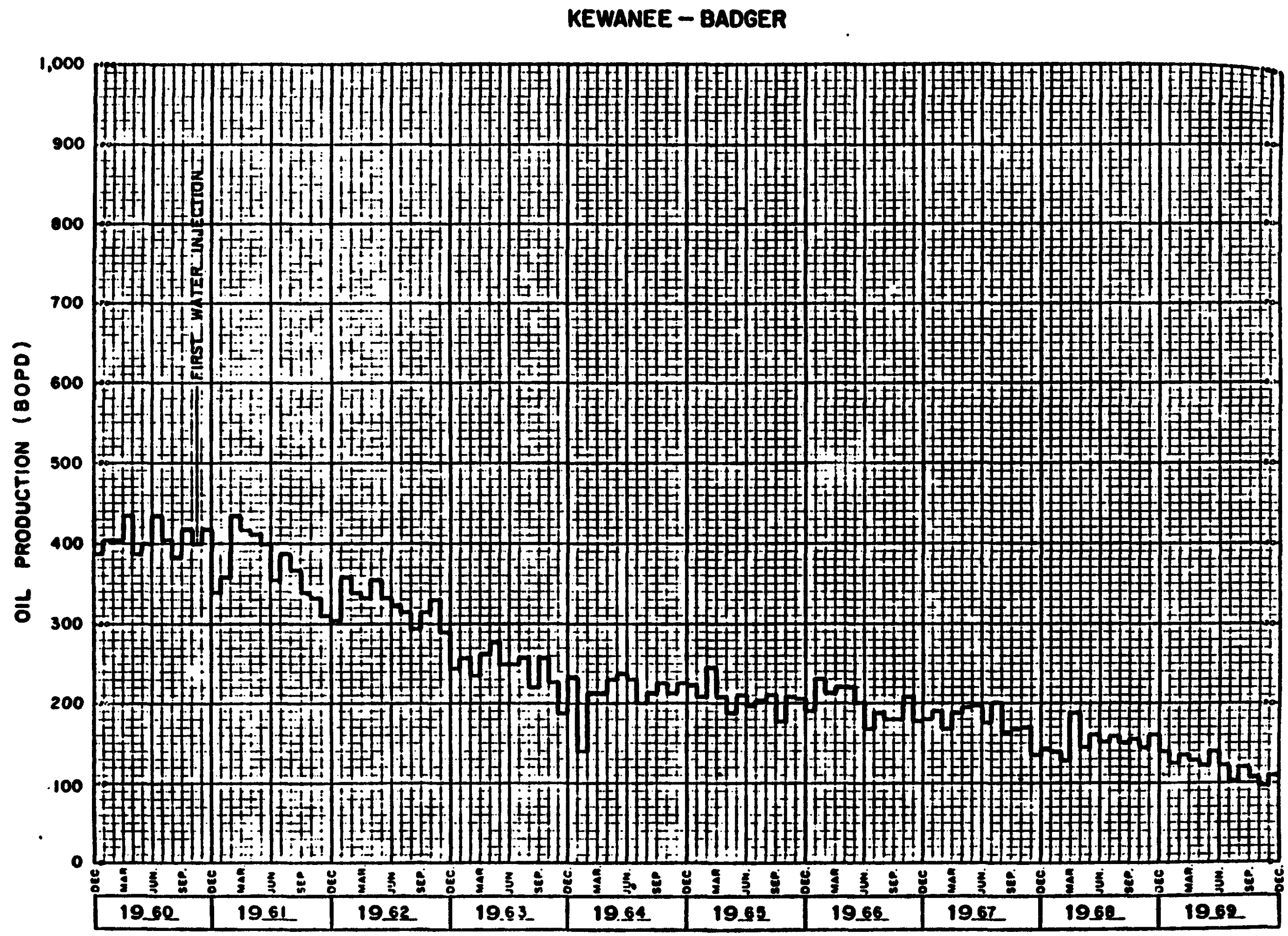

Figure 50: **Water Flood Evaluation in Kewanee Badger (Gray County).** (After Wilson, 1982)

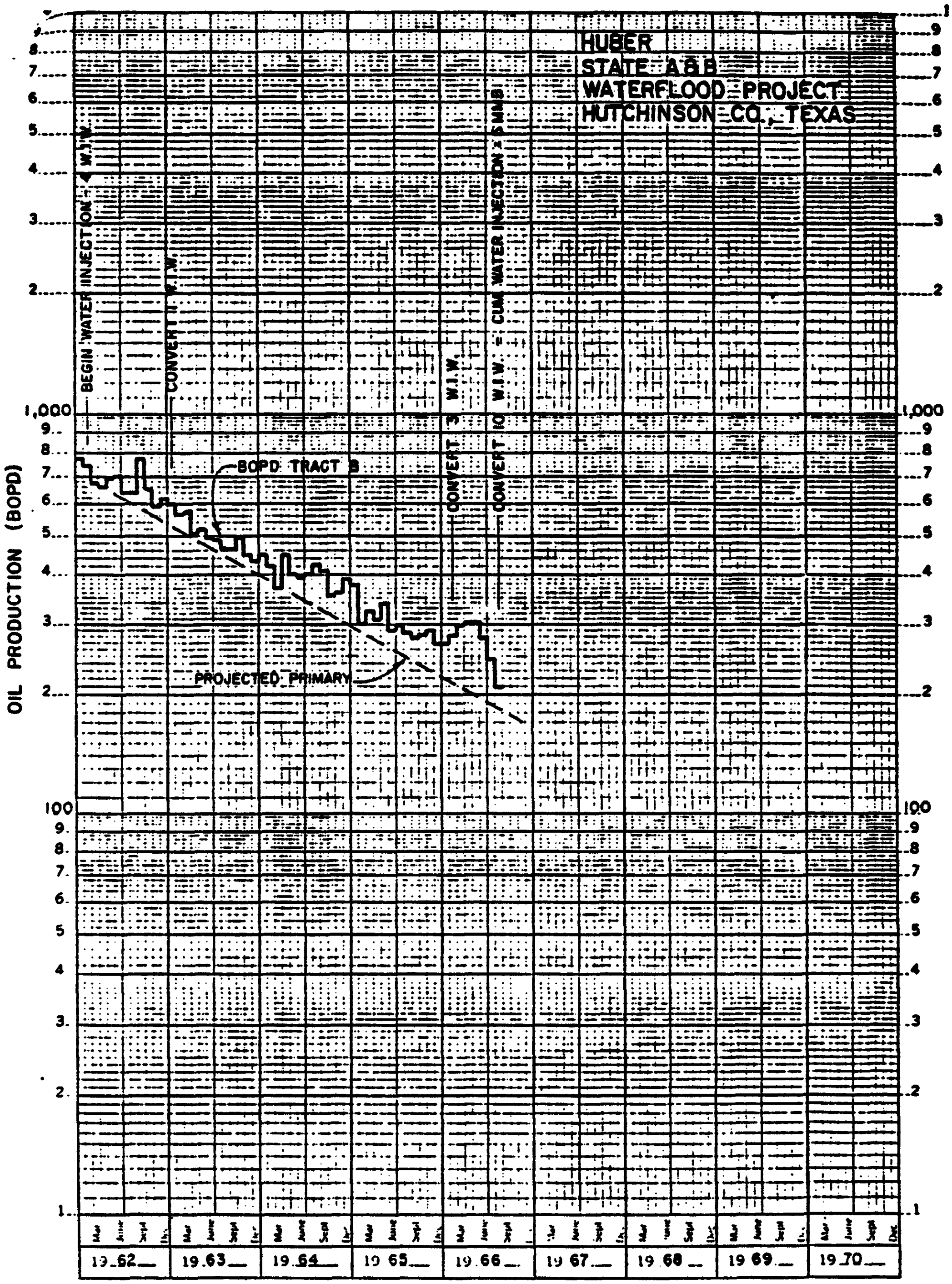

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Figure 51 : Water Flood Evaluation in Huber State A&B (Hutchinson County). (After Wilson, 1982)

Appendix C

Procedure of Evaluating the Waterflood Projects

Appendix C

Procedure of Evaluating the Two Waterflood Pilots

1. The pilot area had been divided into 484 grid points (22 x 22).
2. Reservoir pressures were calculated at each point by using these equations (Table 1):

$$P = \frac{Qo\ \mu o}{0.00708\ koh} \ln \frac{r}{rw} + Po$$

and:

$$P = \frac{-Qi\ \mu i}{0.00708\ Kwih} \ln \frac{r}{rw} + Pi$$

where:

P = reservoir pressure at each grid point in psi

Qo = oil production rate in bbls per day

μo = oil viscosity in centipoises

Ko = oil effective permeability in millidarcies

h = effective pay thickness in feet

r = distance from the grid point to the injection or producing well in feet

r_{wf} = well bore radius in feet

P_o = producing bottom hole pressure in psi

Q_i = water injection rate in bbls per day

μi = water viscosity, centipoises

K_{wi} = water effective permeability, millidarcy

P_i = injection bottom hole pressure, psi

3. Equipotential lines for each pilot were plotted (Figures 18 and 19).
4. Stream lines for each pilot were drawn perpendicularly to the equipotential lines from the injection wells to the producing wells (Figures 35 and 36).
5. Water front positions for each pilot were determined (Figures 41 and 43). The method used to determine the positions of the waterfront is discussed in Appendix D.
6. The oil front positions were drawn (Figure 42 and 44). The method used to determine the positions of the oil front is explained in Appendix D.
7. New oil production rates were calculated for the producing wells which have the first oil break-through. The new oil production rate was calculated using the following equation:

$$Q_o = \frac{0.00708\ Koh}{\ln \frac{rd}{rw}} (Pi - Po)$$

where:

Q_o = the new oil production rate, bbl per day

K_o = the oil effective permeability, millidarcy

h = the effective pay thickness, feet

P_i = the injection bottom hole pressure, psi

P_o = the producing bottom hole pressure, psi

r_d = equal to 2re where re is the effective well radius, feet

r_w = the well bore radius, feet

8. At the time of oil break-through in some wells, new pressure distributions were simulated for each Pilot (Table 3 and 4) and new stream lines were plotted for each Pilot following Step No. 4.
9. New water front positions and oil front positions were plotted (Figures 45, 46, 47, 48 and 49). The procedure followed is discussed in Appendix D.

Appendix D

Determination of Water Front and Oil Front

Appendix D
Procedure of Determination of Water Front and Oil Front (Bass, 1982)

All that needs to be noted is that the front is determined by a line of constant time. The fluids move along the stream lines, and the locus of the points giving the distance of advance on each stream line for a given time form a curve. This curve is a curve of a constant time. The family of all the constant time curves gives all possible positions of the fronts.

An expression for the constant time curves will now be derived. Let L represent the distance along any stream line.

The velocity of movement of the fluid along the stream lines is then given by:

$$q = -\frac{k}{\mu}\frac{dp}{dL} \tag{1}$$

and:

$$q = \frac{dL}{dt} \tag{2}$$

Thus:

$$\frac{dL}{dt} = -\frac{k}{\mu}\frac{dp}{dL} \tag{3}$$

or:

$$dt = - \frac{\mu}{k} \frac{dL}{dP/dL} \tag{4}$$

The time of travel along any stream line is then:

$$t = - \frac{\mu}{k} \int \frac{dL}{(\frac{dP}{dL})} \tag{5}$$

The integral is the line integral along the stream line. To find (t) as a function of x and y is the next step.

Now the vectors given by ∇p are perpendicular to the lines of constant P, hence:

$$\frac{dP}{dL} = |\nabla P| \tag{6}$$

and:

$$dL = \sqrt{\overset{2}{dx} + \overset{2}{dy}} = \sqrt{1 + (\frac{dy}{dx})^2}\ dx \tag{7}$$

$\frac{dy}{dx}$ being the slope of the stream line. However,

$$\frac{dy}{dx} = - (\frac{\delta\phi}{\delta x} / \frac{\delta\phi}{\delta y}) \tag{8}$$

Thus:

$$t = - \frac{\mu}{k} \int \frac{\sqrt{1 + (\frac{\phi x}{\phi y})^2}}{|\nabla P|}\ dx \tag{9}$$

Analytically evaluating the integral would give the lines of constant t.

A simple numerical procedure can be used; however, to find the lines of constant (t), using Equation (4):

$$dt \times \frac{(dL)^2}{dP}$$

or in terms of finite differences:

$$\Delta t \; \alpha \frac{(\Delta L)^2}{\Delta P}$$

ΔL is the distance on any particular stream line between two successive equipressure lines. ΔP is the pressure difference between the two successive equipressure lines, and Δt is the time consumed as the fluid moves along the stream line from the higher equipotential line to the lower one.

Thus, if the stream line and constant pressure lines are plotted, it is possible to calculate numerically $(\Delta L)^2/\Delta P$, which is proportional to t, and on each stream line to mark off numbers at the given distances representing $\frac{(\Delta L)^2}{\Delta P}$.

Actual times are not computed since these depend on K and μ. The relative times given up by $\frac{(\Delta L)^2}{\Delta P}$ determine the front, just as well as actual times.

These computations were carried out to determine the shapes of the water front in the first and the second stage as shown in Figures 41, 43, 45, 47.

For each time level, the area encountered by the water front was measured by planimeter and assumed to be like a circule; then r_{wf}, which is the radius of the water front from the injection well was calculated by using this formula:

$$A = \pi r_{wf}^2$$

where:

A is the area in square feet

r_{wf} is the radius in feet

The radius to the oil front then was calculated by using this equation:

$$r_{oB}^2 = r_{wf}^2 \left(\frac{(S_{oi} - S_{or} + S_{gi} - S_{gr})}{(S_{gi} - S_{gr})}\right)$$

where:

r_{oB} is the radius to the oil front, feet

S_{oi} is the initial oil saturation, fraction

S_{or} is the residual oil saturation, fraction

S_{gi} is the initial gas saturation, fraction

S_{gr} is the residual gas saturation, fraction

The oil bank front was plotted ahead of the water front along the same stream lines. For the first oil break-through, the area countered by water front is taken as a zero level to start calculating the new water and oil fronts for the second stage.