Case History Of A Multiple Zone Peripheral Water Flood

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INTRODUCTION

This paper is a discussion of the background and performance of a water flood operation which has been in operation in the Oscar field, located in Jefferson County, Oklahoma. The operator of the project is the J. B. Stoddard Estate, who is a joint working interest owner with Continental Oil Company. The oil reservoirs affected by this water flood program involve 3 members of the Hoxbar sand of Middle Pennsylvanian Age which is found at depths of 1100 to 1200 ft subsurface. The individual sand members are designated locally as the "A", "B" and "D" sands. Figure 2 contained herein is a composite log which identifies all sands that are present in the area to a depth of approximately 1750 ft subsurface and shows both productive and non-productive zones.

At the time of the initiation of water injection, the "A", "B" and "D" sands had exhibited water encroachment, the configuration of the limit of water-free production varying with each sand member. The interpretation of water-free areas as of the time of the original study in 1953 are outlined on the isopachous maps of gross sand intervals included as Figure 3, 4 and 5. The purpose of this paper is to present basic data concerning each reservoir, review the data which was available for study and note its significance, to outline operating procedures and resulting performance of the reservoirs under a peripheral water injection type program.

DEVELOPMENT

The J. B. Stoddard Estate - Continental Oil Company - W. D. Seay lease is located in Jefferson County, Oklahoma, immediately north of the Red River and approximately 15 mi northeast of Nocona. It is in the Oscar (Oklahoma) area of the old Nocona or Montague County, Texas, pool. The Hoxbar sands are productive over a considerable area in this region extending under the Red River into Oklahoma from the Montague County, Texas, area.

The first productive well drilled on the lease was located on a sand spit in the middle of the Red River and was completed in July, 1930. This well was drilled to a total depth of 1265 ft and completed in the "D" sand reservoir. The "B" sand was also present in this well at approximately 1100 ft, and in August, 1930, the No 2 well was drilled on the same spit at a location 300 ft north of No. 1 and completed in this 1100 ft zone. Beginning in 1933, an intensive development program was commenced and by 1935 there were 30 producing wells on the lease. Again in 1937, active drilling was undertaken and by January, 1938 a total of 62 wells had been drilled, 59 of which were oil productive, one gas well having been completed in an 800 ft Cisco sand zone, and 2 wells had been abandoned.

Operations were assumed by J. B. Stoddard in 1944 as the result of the acquisition of a portion of the working interest, and additional development was initiated in 1946 and continued periodically through 1956, until a total of 83 producing wells, 1 dry hole, 1 gas well and 11 abandoned wells were on the lease. The lease encompasses a total of 287 acres, of which approximately 200 acres were found to be oil productive.

PRODUCTION HISTORY

Figure 1 illustrates graphically the production history from all productive sands, and by virtue of the fluctuations in producing rate, shows the period in which drilling took place. At the time that the initial study of this reservoir was made during 1953, cumulative production from all reservoirs had amounted to 3,857,243 bbl. Cumulative production at the initiation of the full-scale water flood program in September, 1957 was 4,427,000 bbl; and as of January 1, 1963, cumulative production was 5,638,460 bbl.

BASIC DATA ON THE RESERVOIRS

In order to map the individual sand members present under the lease, a total of 8 cross-sections were constructed, utilizing all available electric logs, gamma ray logs and drillers logs. From these sections, sand continuity was established according to the designations shown on the composite type log, Figure 2.

The 1100 ft zone was separated into the "A", "B" and "C" sand members. The "A" and "B" sands were found to have different original oil-water contacts, indicating that they were separate accumulations of oil with no natural communication existing. The "A" sand shaled out in the eastern portion of the Seay lease as shown on Figure 3, and the "B" sand had a shale-out condition in the southern portion of the lease as shown on Figure 4. The "C" sand, considered for geologic purposes to be a part of the 1100 ft zone, is water productive where present and was not exposed for production in any well.

The "D" sand member of the 1200 ft zone is the most widespread and probably has been the most prolific producing zone of those underlying the lease. Except for 2 small shale-out areas on the interior of the lease, as shown on Figure 5, this sand member had no limitations in extent so far as the lease was concerned. The "E" and "F" sands of the 1200 ft zone were very erratic in their development and contributed only minor amounts of production where they were encountered.

The "G" through "K" sands were all water productive and erratic in their development across this lease.

The 1600 ft zone consists of 2 members known as the "L" and "M" sands which were first discovered

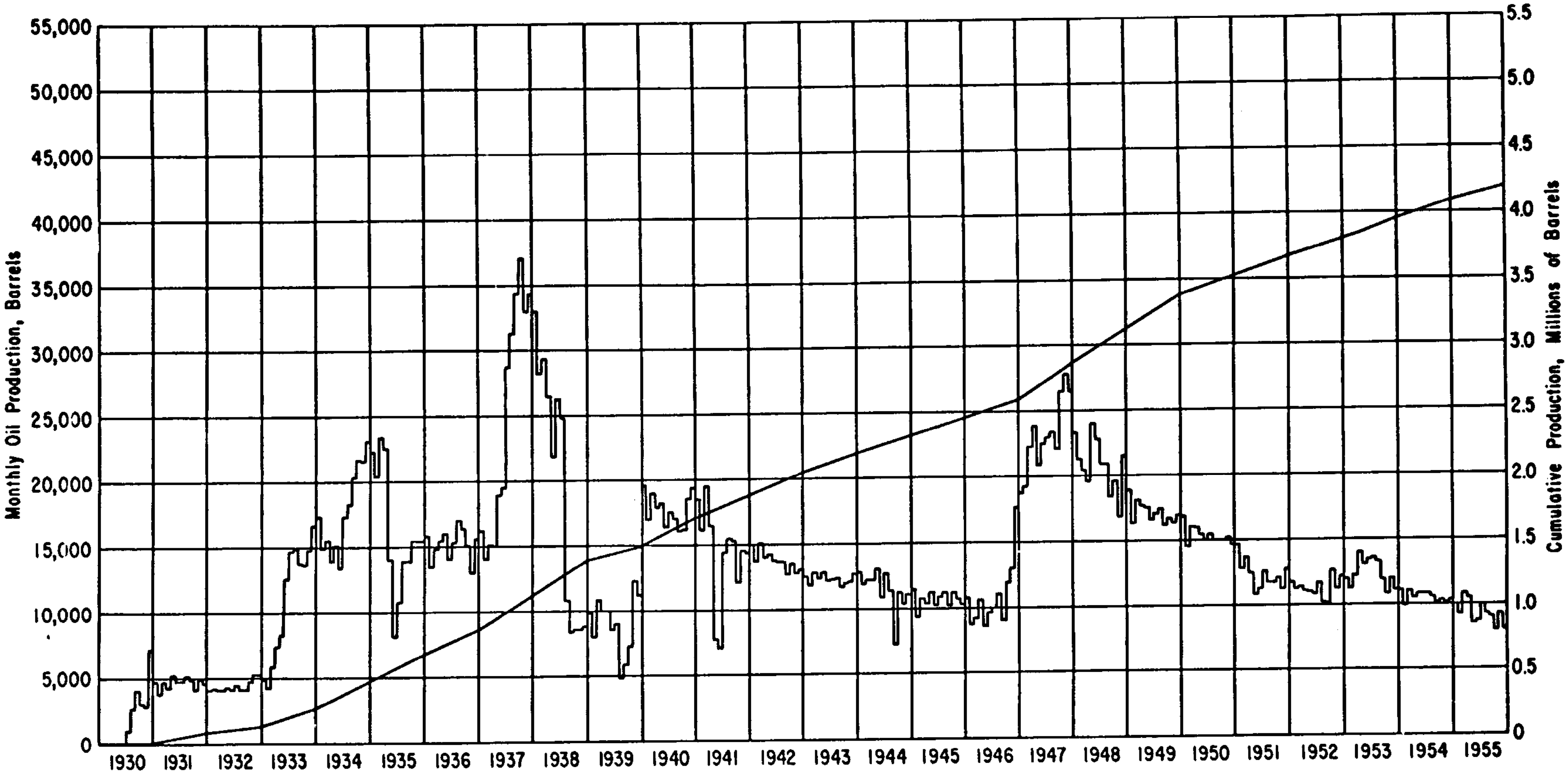


FIGURE I

PRODUCTION HISTORY

DISCOVERY THRU 12-31-55

OSCAR FIELD

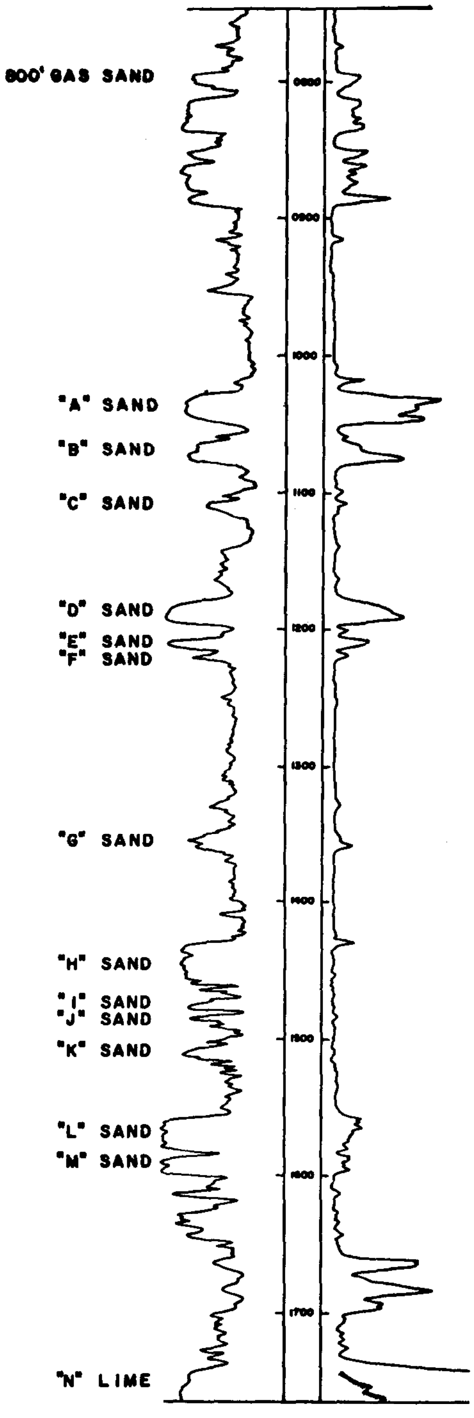
JEFFERSON COUNTY, OKLAHOMA

FIGURE 2

COMPOSITE TYPE LOG

OSCAR FIELD

JEFFERSON COUNTY, OKLAHOMA



in 1946, at which time 18 wells were drilled and completed in both sands with 4 other wells being deepened to these intervals.

The Ellenburger-Dolomite has been tested in several wells and found to be predominately water productive. This is the deepest zone penetrated to date on the Seay lease.

Isopachous maps of those zones concerned with the water flood program are the only ones included herein.

In studying this field to establish the secondary recovery potential by water flooding, first impressions were that water production was widespread throughout the field and that natural water encroachment has been efficient mechanism. It could easily have been concluded that the field was not a candidate for water flooding had it not been for an excellent set of individual well test records which the operator kept.

After a careful geologic study, it was concluded that the "A" sand had original oil-water contact at minus 360 ft subsea, that the lower structurally "B" sand had a contact at minus 345 ft subsea and the "D" sand a contact at minus 546 ft subsea. As previously stated, these data indicated that the "A" and "B" sands were separate reservoirs even though there is only minor separation vertically.

Through the use of this geologic study and the resulting isopachous maps and well test data applied where appropriate to wells which had individual sand completions, it was possible to develop in each sand member, areas of essentially water-free production. These areas are outlined on the isopachous maps, Figures 3, 4 and 5. They illustrate graphically the varying areas of encroachment by sands, and because of field practice of multi-sand completions where present, the erroneous interpretations which could have resulted without having had adequate well test available. Figure 6 shows the estimated total water-free area of the 3 sands combined. This area represents a total of 56.5 acres.

Core analyses were available on 6 wells. The average permeability in the "A" and "B" sands is 698 millidarcys and the average porosity is 25.9%. The average permeability and porosity values determined from core analyses for the "D" sand are 530 millidarcys and 25.2%, respectively.

Porous plate capillary pressure measurements were obtained and results of these measures indicated an average connate water saturation for these reservoirs of 26.3 % of the pore volume. Flood tests were made on nine samples and the average residual oil saturation was found to be 17.5% of pore volume and the average relative permeability to water was 46.4% of the specific permeability to water. The magnitude of residual oil saturation was confirmed by routine core analysis date from water base cores.

The gravity of the oil present in the "A" and "B" zones averaged approximately 30 API at 60°F., and 34° from the "D" zone, while the viscosity in centipoise at 95°F was 20.5 in the "A" and "B" zones and 7.5 in the "D" zone.

WATER FLOOD RESERVES

In determining which sands contained potential water flood reserves, the areas within the mapped water-free productive areas for each sand were planimetered to obtain reservoir volumes. From this it was established that the "L" and "M" sands did not

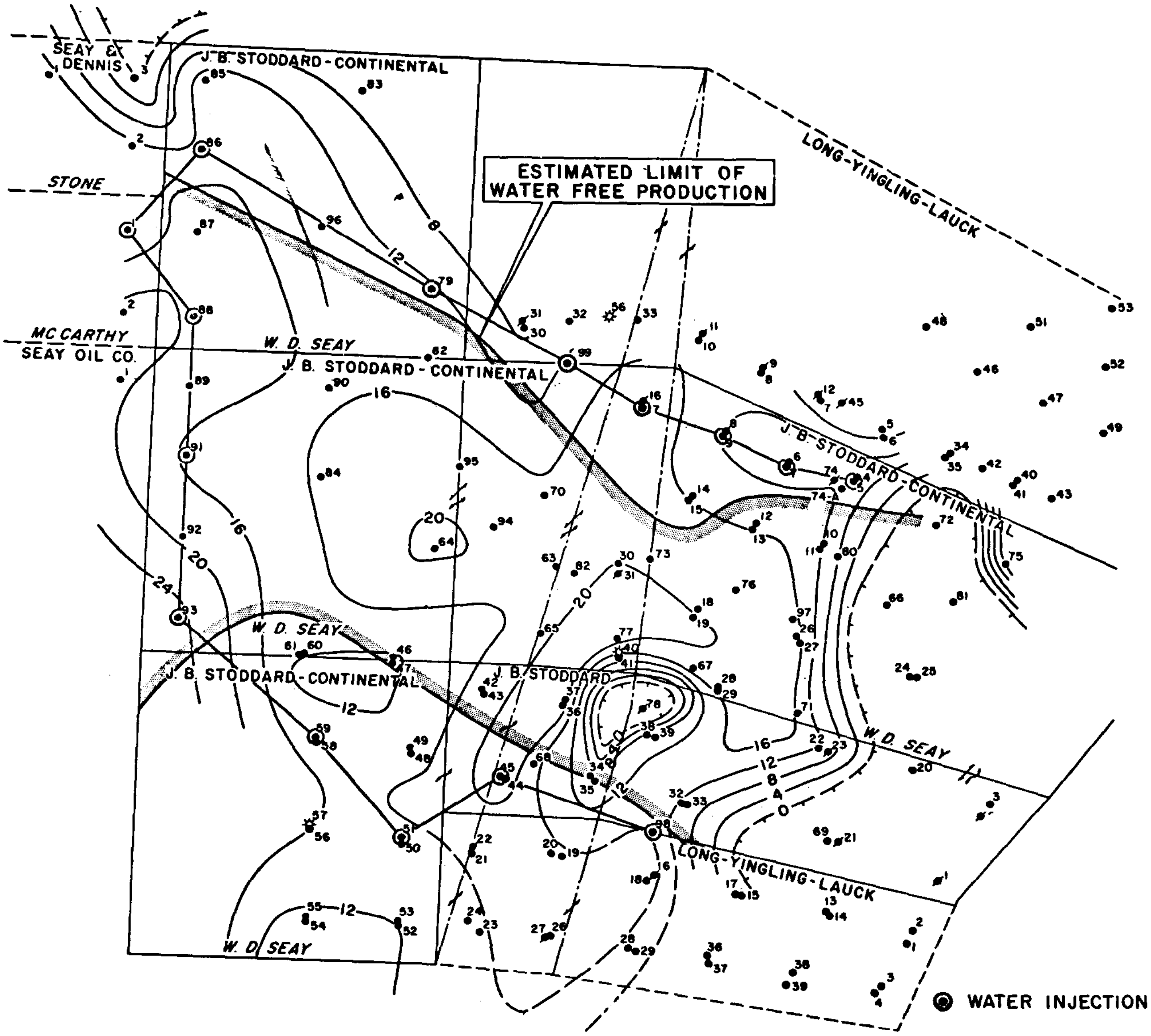


FIGURE 3

GROSS SAND ISOPACH & WATER INJECTION PATTERN

"A" SAND

OSCAR FIELD

JEFFERSON COUNTY, OKLAHOMA

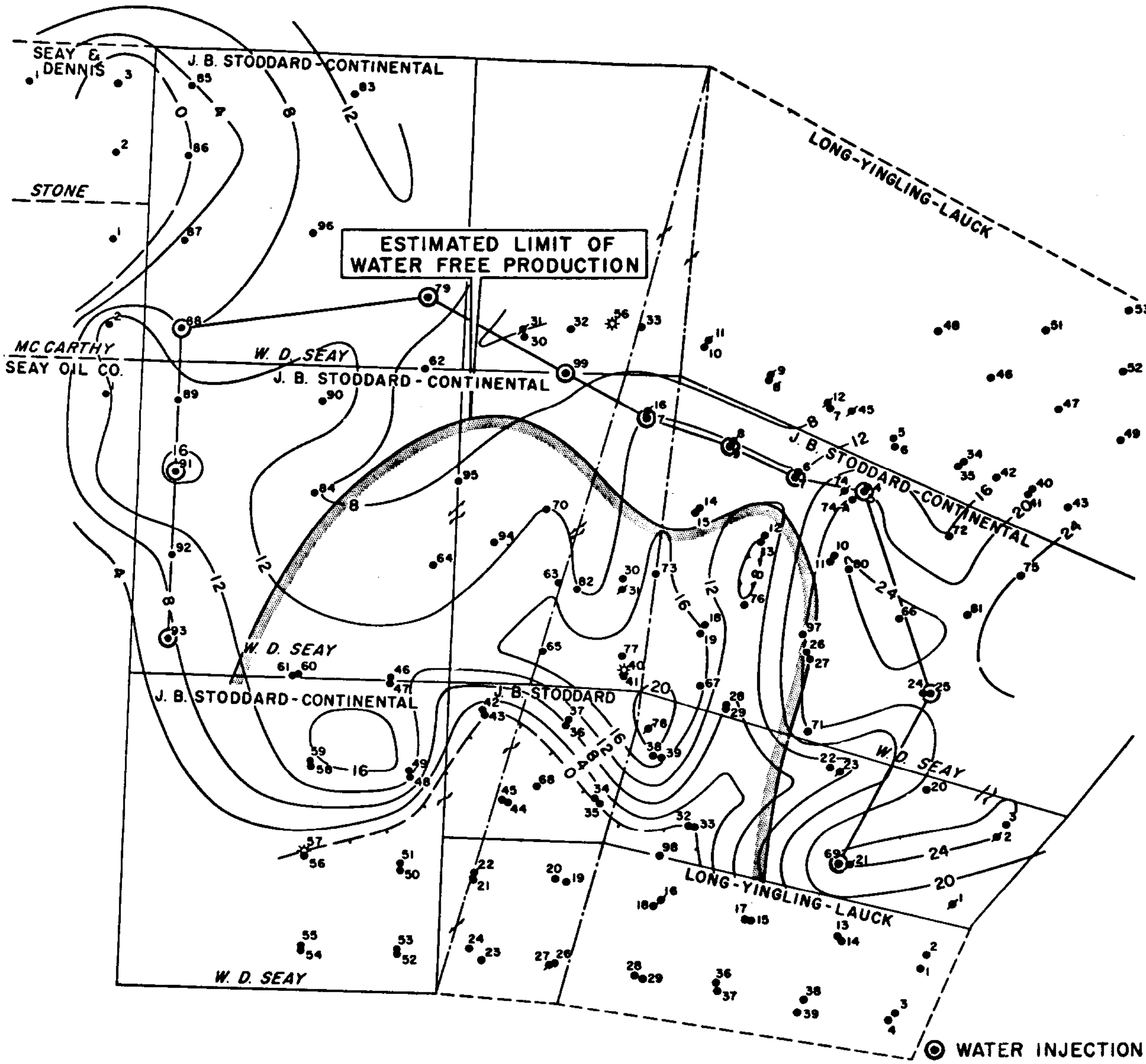


FIGURE 4

GROSS SAND ISOPACH & WATER INJECTION PATTERN

"B" SAND

OSCAR FIELD

JEFFERSON COUNTY, OKLAHOMA

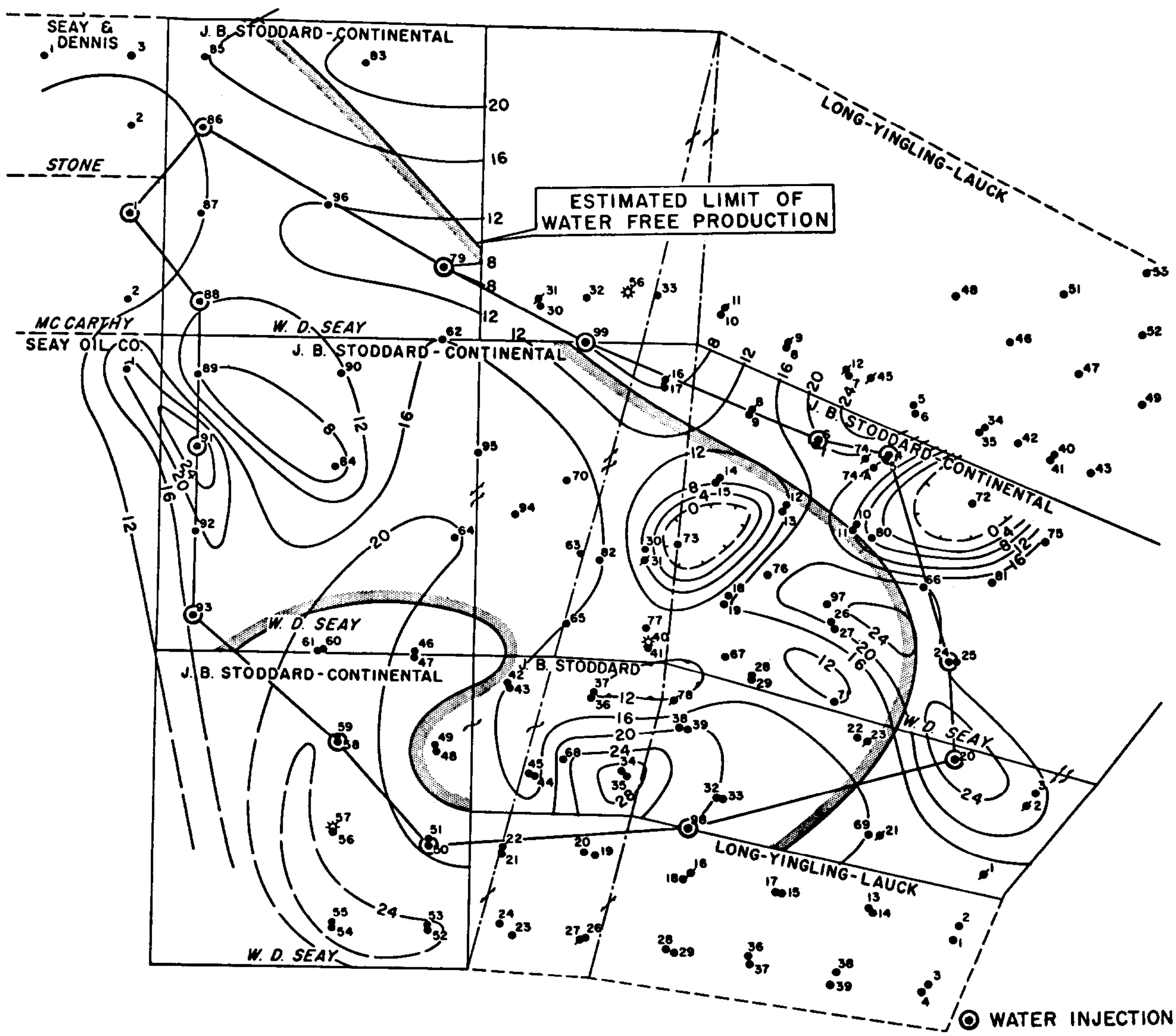


FIGURE 5

GROSS SAND ISOPACH & WATER INJECTION PATTERN

"D" SAND

OSCAR FIELD

JEFFERSON COUNTY, OKLAHOMA

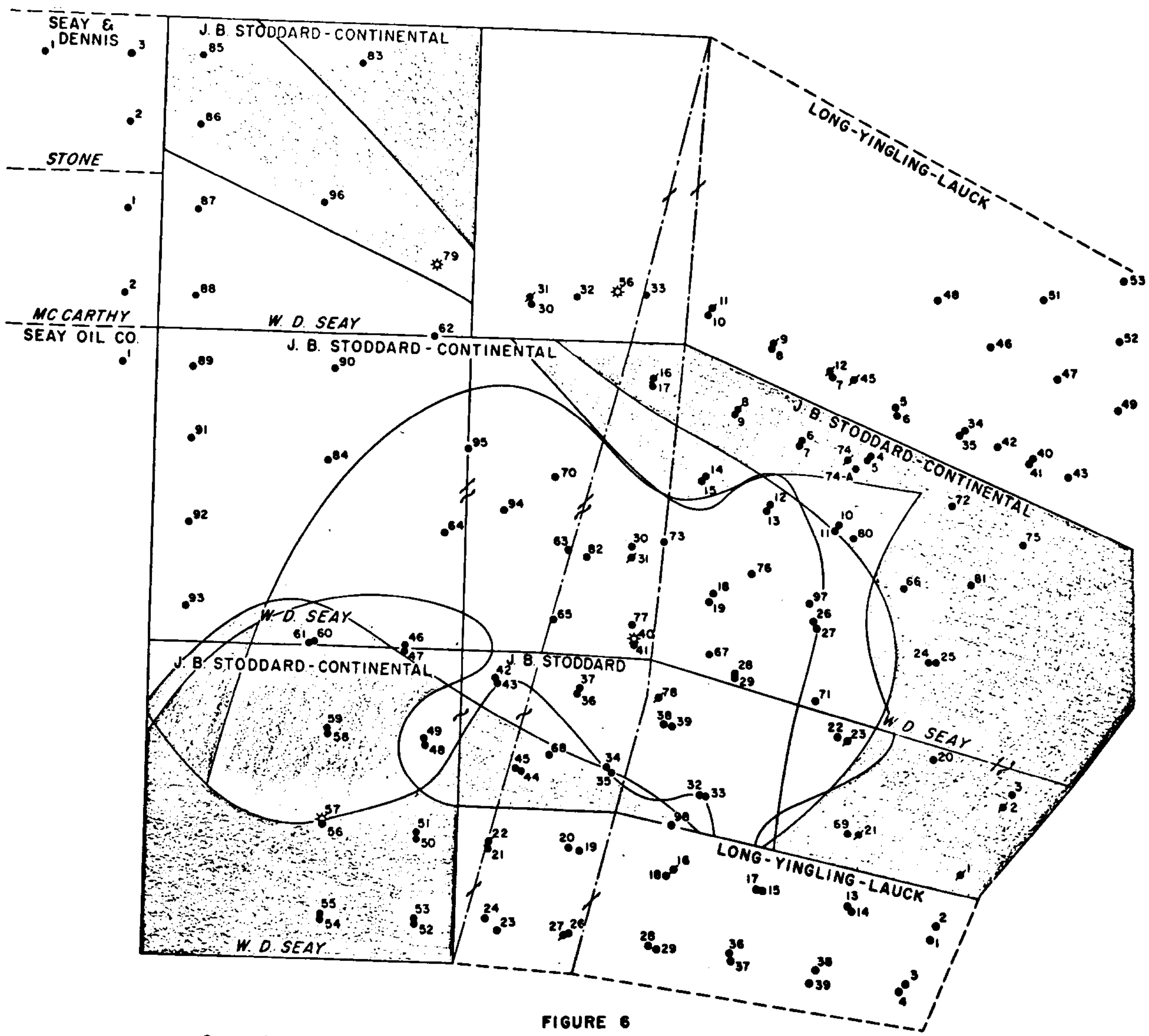


FIGURE 6

ESTIMATED TOTAL WATER FREE AREA - ALL SANDS

OSCAR FIELD
JEFFERSON COUNTY, OKLAHOMA

contain sufficient potential secondary oil to warrant further consideration; however, the "A", "B" and "D" sands were very good prospects.

From a total surface area of approximately 120 acres, reservoir volumes determined were as follows:

"A" Sand	1564 acre ft
"B" Sand	773 acre ft
"D" Sand	1795 acre ft

Utilizing the average core properties previously listed, together with an estimated gas saturation in the water-free areas of 10% of pore space, and a formation volume factor of 1.05 reservoir barrels per stock tank barrels, it was calculated that the in-place oil at the time of the study was 866.2 bbl per acre ft for the "A" and "B" sands and 860.2 bbl per acre ft for the "D" sand.

From permeability and capacity distribution relationships and water cut recovery calculations, it was estimated that to a 97% water cut, recovery efficiencies would be 54% for the "A" and "B" sands and 57% for the "D" sand.

When the original study of the Oscar field was made, it was anticipated that water flood operations would be initiated early in 1954; however, because of circumstances beyond the control of the operator, full scale operations were not initiated until September, 1957. During this intervening period, 2 additional wells were drilled and a pilot flood program was conducted during 1956 in the "A" and "B" sands. Both of the wells were cored and analyzed. Well No. 95 revealed the existence of gravity segregation in the "D" sand, as illustrated in Figure 7. Attention is directed to the sharp increase in oil saturation at 1230 ft in depth. This condition was not observed in other cores of the "D" sand and was probably a condition confined only to local areas, but required an arbitrary down-grading of reserve potential.

The pilot water flood was carried out utilizing wells No. 63, 64, 70 and 95 for water injection simultaneously into the "A" and "B" sands, and No. 94 as the enclosed producing well. The enclosed area was 3.4 acres, and the reservoir volume was 108.2 acre ft. Initially the center producing well produced no oil and 11 BWPD, but as will be noted from Figure 8, a

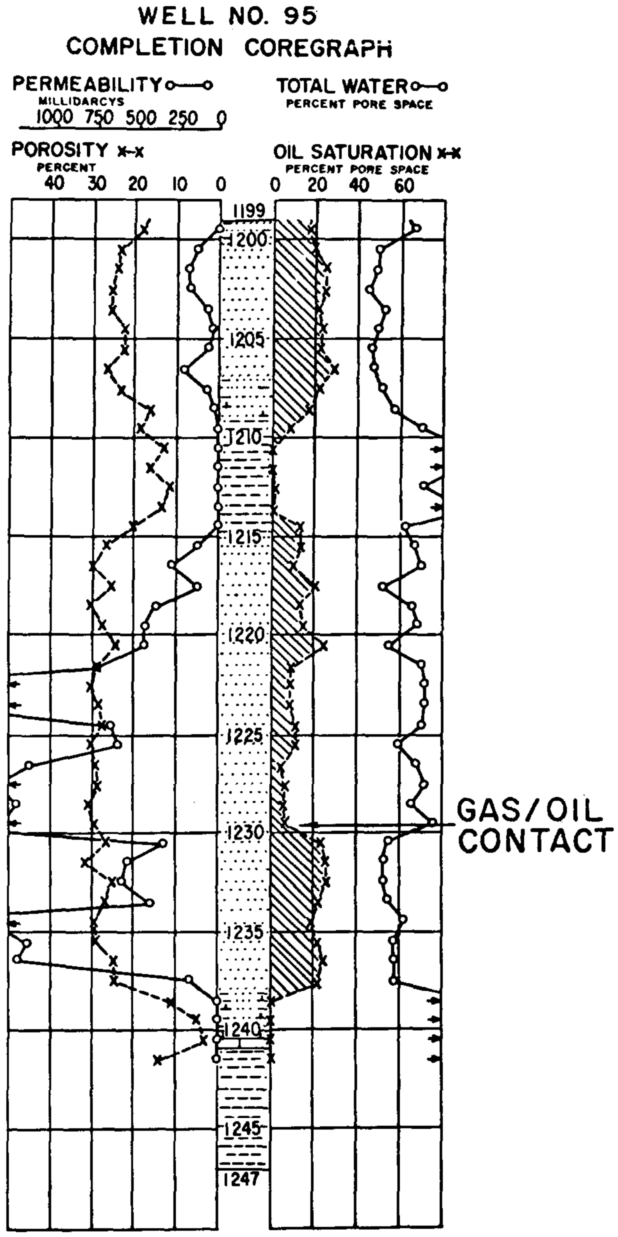


FIGURE 7

CORE ANALYSIS GRAPH "D" SAND

OSCAR FIELD
JEFFERSON COUNTY, OKLAHOMA

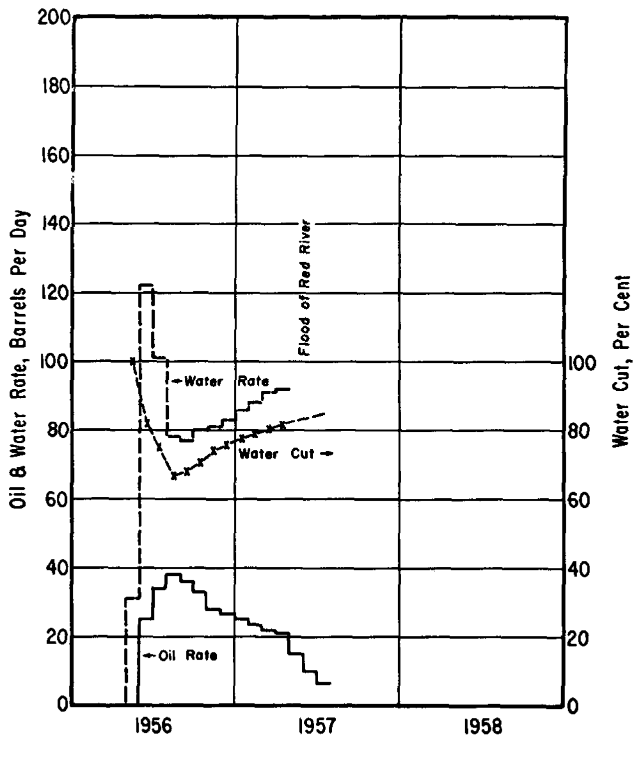


FIGURE 8

PILOT WATER FLOOD PERFORMANCE A&B SANDS

OSCAR FIELD
JEFFERSON COUNTY, OKLAHOMA

peak oil rate of 38 BPD with 78 BWPD was attained in June, 1956. A total of 10,387 bbl of oil was produced in 14 months time, equivalent to a recovery of 96.2 barrels per acre ft to a water cut of 82%. The initial, and to a large extent the continuing, high percentage of water production from this pilot area was thought to be due to water invasion of the "A" and "B" sands from a bad cement job. Deterioration of performance in the last 3 months of the operation was largely because of flooding conditions on the Red River which required moving in and out 6 times over a 2 month period.

Well No. 94 was originally drilled in October, 1953 and completed in the "D" sand, producing from open hole. When recompleted in the "A" and "B" sands through perforations, it produced only water at a rate of 70 BPD, which was the capacity of the equipment on the well. It became apparent that the water was coming from a water sand above the "D" sand, and this was confirmed after a diesel-cement squeeze reduced the volume to 11 BPD. There had undoubtedly been a high degree of water invasion into the "A" and "B" sands during the 2-1/2 yr this condition was in existence, and this water produced during the pilot operation.

Wells surrounding the 5 spot which also responded very favorably to the pilot water injection program were Nos. 30, 47 and 84. After 15 months in operation of this pilot flood, it became feasible to proceed with the full scale flooding program, and at this time the pilot program was terminated.

When the full scale flood operation was initiated, it was estimated that the future gross oil reserves to be obtained from the lease by primary depletion of the "L" and "M" sands and water injection into the "A", "B" and "D" sands would be 1,220,000 bbl.

DEVELOPMENT PROGRAM

Due to the configuration of sand development and natural water encroachment, the lease line well development and the lack of cooperation from the west and north by offset operators, a peripheral type injection pattern for the "A" and "B" and "D" sands was adopted. These patterns are shown on Figures 3, 4 and 5 superimposed on the isophachous maps.

Since the practice of completing the "A" and "B" sands together in open hole had been followed in most development wells, it became mandatory to carry out simultaneously water injection into these 2 sands. Injection into the "D" sand is segregated and metered separately.

WATER INJECTION SYSTEM

The main surface feature of the lease is the fact that the eastern portion of the lease lies in the Red River and all but the extreme northwest corner of the lease is subject to flooding during periods of high water. Floods of major consequence occurred in 1940, 1941 and 1951, and to a lesser extent in 1957. The 1941 and 1951 floods caused all but the northwest corner of the lease to be overlain by 10 to 15 ft of water. A plant was, therefore, constructed in this corner of the lease on high ground. A water supply was obtained from 3 shallow sand wells and commingled with produced water in a closed system with no chemical treatment.

Initially the supply and produced waters were compatible and were commingled for injection but changing water quality has required the waters now to be handled separately. The peripheral injection pattern wells are supplied through one injection line that loops the lease. This line was easily adaptable to the problem; it can be separated at any chosen well, with produced water supplying a portion of the wells and supply water the others. As produced water volume increases, additional wells were added to this leg of the system. Both water systems are closed, and until recently, the waters have required no treatment other than to provide filtration. Corrosion problems have been controlled by cement lining of produced water injection lines, plastic coating of water storage tanks, addition of small amounts of chemical to retard bacteria growth in make-up water during warm weather and to reduce corrosion of tubing wells utilizing produced water.

WATER FLOOD PERFORMANCE

Figure 9 shows graphically the performance of the lease from the inception of the pilot water flood to the present time. Injection was initiated at a rate of 5200 BPD, with a rapid response in producing rate from 260 to 566 BPD in a 4 month period. Total field water cut at this time was 74%. As can be seen by referring to the performance graph, injection rates have been progressively increased during the 52 months of operation. This increased injection is largely a result of the steady increase in produced water volumes, since the 3 water wells have consistently been operated at a capacity. A peak oil rate of 755 BPD was attained in April, 1959.

In order to maintain a maximum possible effective injection rate, perimeter high water cut wells have been closely observed and either abandoned or converted to injection when they reached an economic limit or 2 BPD of oil production.

In May, 1961, 3 up-structure wells in the "A" and "B" sands and 3 in the "D" sand were converted to injection in order to obtain increased effectiveness from the water, and concurrent with this program, rates into other wells were increased so that total injection is now 11,400 BPD of which 10,250 bbl are injected by the operator. The difference is accounted for by noting that several injection wells have been turned over to the offset operator for continued operation. It will be noted that production has increased from a low 514 BPD in May, 1961 to 528 BPD in December, 1961, with water cuts remaining level at 92.6%. Another revision in the injection program is currently being made which should again improve water flood efficiencies.

Response to the water injection program in the "A" and "B" sands has generally been good where anticipated over the entire lease, while the "D" sand response has been much more erratic. This is most likely a reflection of the effects of gravity segregation previously referred to as being present in the "D" sand.

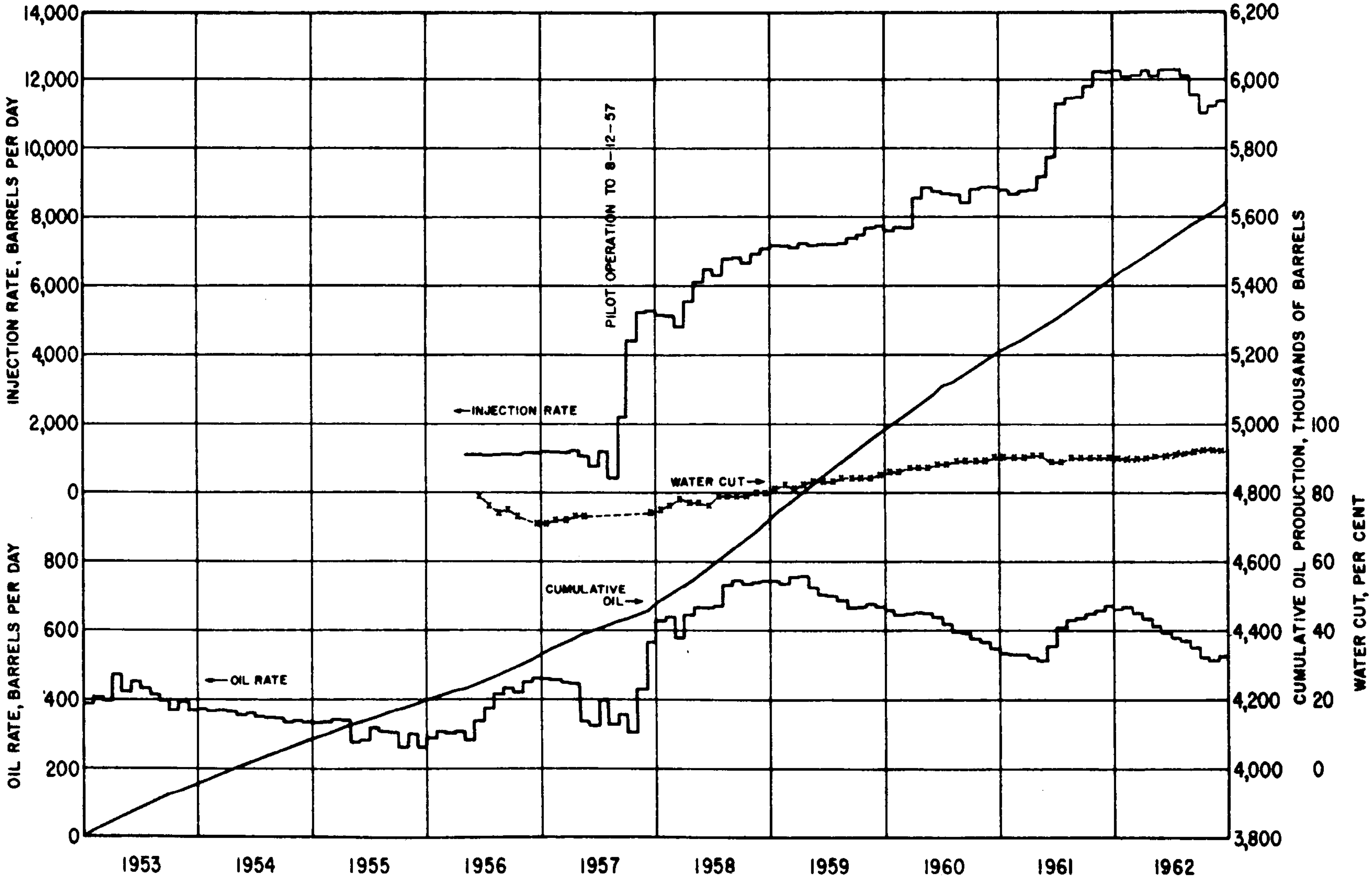


FIGURE 9

WATER FLOOD PERFORMANCE
TOTAL SEAY LEASE

OSCAR FIELD
JEFFERSON COUNTY, OKLAHOMA

CONCLUSIONS

Oil recovery from the lease under the water flood program will probably exceed early estimates.

1. Estimated future recovery

Estimated future recovery (1957 Est.) from 9-1-57	1,220.00 bbl
Actual Recovery, 9-1-57 to 1-1-63	1,211,460 bbl
Anticipated Future Recovery	143,540 bbl
Total Recovery Now Estimated	1,355,000 bbl

2. Increase in recovery is probably a combination of the following factors:

   (A) Higher degree of in-place oil saturation than originally estimated.
   (a) Peripheral injection has resulted in better coverage than anticipated.
   (C) Effects of gravity segregation not as widespread as anticipated.

3. The physical operation of the lease has been such that corrosion has been closely observed and controlled, required remedial work has been performed with a minimum of delay and large production equipment has been employed where required.

4. Control of operating costs has resulted in wells being produced to a higher water cut than originally anticipated.

5. The successful water injection program into three zones in the Oscar field illustrates the necessity for close inspection of all wells in any field being considered for secondary recovery operations, and the value of good records and data. This is an illustration of a portion of a field which, upon examination of all data, provided a small area which has been successfully water flooded.

ACKNOWLEDGEMENT

Permission given by Continental Oil Company to submit this paper is gratefully acknowledged.