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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

WATER FLOODING OF OIL SANDS IN ILLINOIS

BY

D. B. TALIAFERRO, C. M. KEITHLY, AND THOMAS JENNINGS

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By D. B. Taliaferro[2], C. M. Keithly[3] and Thomas Jennings[4]

CONTENTS

ILLUSTRATIONS

1/ The Bureau of Mines will welcome reprinting of this paper provided the following acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3778."

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ILLUSTRATIONS (Cont'd)

TABLES

INTRODUCTION

This report describes the methods of development and operation and gives the results of controlled water injection into oil sands in Illinois. It is the third of a group relating to water-flooding operations in various States; previous reports have covered projects in Oklahoma[5] and Kansas.[6] Systematic water flooding has been in progress, in these States, for more than 10 years. In Illinois the Tide Water Associated Oil Co. has been injecting water into one or two wells on each of five leases in the Robinson

5/ Taliaferro, D. B., and Logan, David M., History of Water Flooding of Oil Sands in Oklahoma: Bureau of Mines Rept. of Investigations 3728, 1943, 182 pp.

6/ Grandone, Peter, History of Water Flooding of Oil Sands in Kansas: Bureau of Mines Rept. of Investigations 3761, 1944, 144 pp.

field for several years; the oldest dates back to 1933. These operations are considered as exploratory, however, and the results obtained could not be expected to equal those obtained from systematic developments in which injection wells are arranged in patterns so as to drive oil toward each producing well from several directions. The possibility of increasing recovery of oil from the older fields of Illinois by systematic water flooding has been seriously considered only recently.

Many shallow fields in southeastern Illinois appear well-suited to water flooding. Squires and Bell7/ have shown that in may places accidental water floods (floods in which the water entered the oil-bearing formation through leaky casing or in some similar accidental method) have resulted in phenomenal increases in the rate of oil production. An example of the results obtained is an accidental flood in the Kirkwood sand in Lawrence County. According to Squires and Bell:

> The Oscar Smith and T. C. Combs farms, sec. 20, T. 4 N., R. 12 W., Lawrence County, experienced an impressive accidental flood. The flood involved three pumping wells, covered an estimated 10 acres, lasted for 7 years on the Smith farm and 11 years on the Combs farm, and increased normal production by 36,689 and 60,606 barrels, respectively, which is a recovery of 7,338 and 12,121 barrels per acre for the whole flood period and 1,048 and 1,102 barrels per acre for each year the property was flooded.

Fields producing from the Casey sand in Clark and Cumberland Counties and from the Robinson sand in Crawford County are attracting attention at this time because of the shallow depth of the sands. Most of the newer fields (discovered since 1937), located principally in the south central part of the State, are producing from greater depths than the older fields, therefore water flooding in this area probably will be more costly. Water injection has been started, however, in the Patoka field in Marian County and in the Clay City field in Clay County.

On July 1, 1943, no applied systematic flood in Illinois had been in operation long enough to permit predicting its outcome. The most outstanding of the few projects then in operation were the two "floods" of the Forest Oil Corporation; one had produced oil for only 4 months and the other had produced no oil. Although the operations are few in number they are being watched with keen interest. Several operators are making preparations to initiate water-flooding projects when the economic considerations involved in this type of undertaking promise more financial success.

7/ Squires, Fredrick, and Bell, Alfred H., Water Flooding of Oil Sands in Illinois: State Geol. Survey Rept. of Investigations 89, 1943, 101 pp.

Acknowledgments

This study was made under the general supervision of R. A. Cattell, chief engineer, and H. C. Fowler, assistant chief engineer, Petroleum and Natural Gas Division, Bureau of Mines, Washington, D. C., and N. A. C. Smith, supervising engineer, Petroleum Experiment Station, Bureau of Mines, Bartlesville, Okla., and under the direct supervision of Ludwig Schmidt, senior petroleum engineer, Bureau of Mines, Bartlesville, Okla.

The cooperation of the operators who are conducting water-flooding projects and who have made this report possible by furnishing data on their operations is gratefully acknowledged. The writers are grateful also to the following members of the Bureau of Mines for assistance in preparation and criticism of the manuscript: C. J. Wilhelm, Franklin, Pa.; and Gustav Wade, R. E. Heithecker, and Peter Grandone, Bartlesville, Okla. The illustrations were prepared by Helen Cramer, Petroleum Experiment Station, Bureau of Mines, Bartlesville, Okla.

Water for Flooding

Obtaining an adequate supply of water is one of the major problems facing the water-flood operator in Illinois. The Wabash and Embarrass Rivers and the North Fork of the Embarrass flow through the oil-producing areas in the eastern part of the State and will provide, throughout the year, a supply of water adequate for water-flooding projects along their banks. Elsewhere in the older Illinois fields the operator of a water-flood must look to shallow wells for fresh water or to wells completed in the deeper-seated formations for brine as a flooding medium. Most of the projects in operation July 1, 1943, were using fresh water from shallow wells; however, the available supply from these wells usually was small. Some operators were forced to drill a number of water wells to obtain an adequate supply for flooding.

Many operators in Oklahoma and Kansas are using brine successfully as a flooding medium, and this medium may prove practical in many places in Illinois. If brine is used the treatment required to condition it for injection remains the same, whereas the treatment of river water must be varied from time to time, depending on the quantity of suspended matter and salts in solution in the water. The Felmont Corporation and Adams Oil & Gas Co. plan to use brine in a project being developed in the Patoka field in Marion County, Ill. Where available, fresh water taken from shallow wells has been used without chemical treatment or filtering, and there has been no evidence of the plugging of injection wells. The mineral analyses of waters used on some of the Illinois water-flooding projects are shown in table 1.

TABLE 1. - Analyses of waters used for flooding in Illinois

Radical, p.p.m.	Source						
	C. K. Antonopulos flood (spring)	Cokey Oil Co. "flood" (shallow well)	Forest Oil Corporation "floods" (shallow well)	Kewanee Oil & Gas Co. "flood" (shallow well)	The Ohio Oil Co., C. E. Siles "flood" (spring)	Pure Oil Co. Clay City field "flood" (river)	Tide Water Assoc. Oil Co. Drake #1 "flood" (shallow well)
Calcium (Ca)	72	49	84	42	54	42	54
Magnesium (Mg)	3	24	32	1	10	4	20
Sodium (Na)	40	506	43	194	56	66	241
Carbonate (CO_3)	12	36		24		6	
Bicarbonate (HCO_3)	244	421	415	561	183	146	592
Sulfate (SO_4)	48	6	56	5	107	82	5
Chloride (Cl)	7	645	25	18	25	35	177
Total solids	426	1,687	655	845	435	381	1,089
Sp. gr. at 60° F.	1.000	1.000	1.000	1.000	1.000	1.000	1.000

DISCUSSION OF INDIVIDUAL WATER-FLOODING PROJECTS IN ILLINOIS

Felmont Corporation and Adams Oil & Gas Co.

The Felmont Corporation and Adams Oil & Gas Co. on July 1, 1943 were developing jointly a pilot water-flooding project in sec. 21, T. 4 N., R. 1 E., 3 P. M. in the Patoka field, Marion County, Ill., to determine the feasibility of water flooding in this field. Nine new wells had been drilled to serve as water-intake wells, and the injection of water was started in October, 1943. The pilot project, covering 60 acres, was developed on a five-spot pattern, with 660-foot spacing between like wells.

The above operators[8/] own, jointly, most the productive area of the Patoka field, which covers about 700 acres, and if the pilot flood is successful they plan to water-flood the entire field. Tentative plans call for drilling a total of 44 water-intake wells if the project is extended. From core analyses, recovery records, and past experience, the operators estimate that the production by means of water-flooding may approximate the quantity of oil that this field has produced to date. From the date of discovery (1937) to January 1, 1943, the field produced 2,325,000 barrels of oil.

Production is from the Benoist sand, which is at an average depth of 1,420 feet and has an average thickness of 25 feet. The formation temperature and pressure were 80° F. and 30 pounds per square inch, respectively, at the time water injection was started. It is reported that under these conditions of temperature and pressure the oil has an absolute viscosity of 5.35 centipoises. The gravity of the oil is 38.6° A.P.I. at 60° F.

From study cores the sand was found to have an average porosity between 19 and 20 percent and to have an average oil saturation ranging from 50 to 55 percent. The permeability of the sand averaged 150 millidaroys, and in streaks it is as high as 400 millidarcys. Wells in the center of the field have produced no water, but some wells in a town-lot area on the south end of the field and some on the northwest edge are producing water.

Water for flooding will be taken from a well completed in the Tar Springs sandstone. The water must be treated before it is injected into the Benoist sandstone. Treatment consists of aeration, the addition of alum and lime, and then filtration. There is some evidence that chemicals will be required to prevent organic growth.

C. K. Antonopulos

C. K. Antonopulos started a small water-flooding project in sec. 34, T. 14 N., R. 14 W., and sec. 3, T. 13 N., R. 14 W., 2d P. M. in the Warrenton field, Edgar County, in January 1943. The Benoist sand, which is only 150 feet deep and ranges in thickness from 31 to 61 feet in this area, is being flooded. Six water-intake wells and two oil wells have been drilled to form 2 five-spot patterns, with like wells spaced 330 feet apart. The

8/ Since this manuscript was prepared the Sohio Oil & Gas Co. has purchased the Adams Oil & Gas Co.

operator plans to produce the oil by flowing rather than pumping the oil-producing wells. A map of the project is shown in figure 1.

This property was first drilled about 34 years ago, so when the water-flood development was started the casing in the old wells was in poor condition and permitted considerable quantities of surface water to enter the wells. The 40-acre lease on which the flood is located has produced about 39,000 barrels of oil. Both oil and water wells were completed alike, as the operator plans to flow the production from the oil wells. All wells were drilled through the sand, and each was shot with 25 quarts of nitroglycerin. A string of 1½-inch tubing was set on the top of the sand with a packer and cemented in place with 10 to 14 sacks of cement mixed with sand in a ratio of about 3:1. It is estimated that there is about 70 feet of cement above the packer. All casing used while the wells were drilled was removed after the tubing had been cemented.

Figure 2 shows the analysis of a core of the oil sand from a well drilled on the property. It will be noted that the porosity of the sand averages about 20 percent and that its permeability varies widely, ranging from 0 to 80 millidarcys.

Water for flooding is obtained from springs on the lease and is injected without chemical treatment or filtration. Two fresh-water wells (84 feet deep) have been drilled to serve as a standby water supply. A mineral analysis of the flood water is shown in table 1. Water injection was started January 17, 1943, and on February 1, 1943, the injection pressure at the wellhead was 60 pounds per square inch. Since that date the pressure has been increased steadily to 210 pounds per square inch on July 1, 1943. On that date the volume of water that had been injected into the six individual wells ranged from 912 to 6,911 barrels per well; the total volume injected was 13,200 barrels. On that date the fluid level in the oil wells was 59 feet below the surface and rising steadily. The operator expected them to begin flowing in the near future.

Cokey Oil Co.

The Cokey Oil Co. is developing a small water-flooding project on its R. O. and L. Cochonour farms in sec. 25, T. 10 N., R. 10 E., 2d P. M., Crawford County. The project is being started with two newly drilled oil wells, three newly drilled water-intake wells, and one old oil well converted to a water-intake well. The four water-intake wells, located approximately in a rectangle 400 feet long in a north-south direction and 330 feet in an east-west direction. One oil well is in the center of the rectangle and the other is about 400 feet north of it.

Production is obtained from the Siggins sand, which is about 30 feet thick and found at a depth of 630 feet. An analysis of the core of sand from one of the wells is shown in figure 3. The average porosity of the core from this well was about 20 percent and the average permeability 419 millidarcys. The measured temperature of the producing horizon was 68° F. No sample of freshly produced oil was available for analysis at the time the writers visited the property.

Both oil and water wells were completed without shooting. The water-intake wells are equipped with 2-inch tubing set at the top of the sand with a burlap packer, and enough cement was placed above the packer to fill the annular space for about 40 feet. The oil wells are cased and will be pumped through 2-inch tubing.

Water for flooding is obtained from a fresh-water well about 1¼ miles south of the project. The water will be injected, without treatment, by a triplex pump installed at the water-well location. On May 28, 1943, injection of water by gravity was started into the converted oil well. About 1,200 barrels of water had been admitted to this well to July 1, 1943. The other intake wells were ready for service at this date, and it was expected that the injection of water under pressure into all four wells would be started in the near future. The oil wells had not been pumped since water injection was begun, and the operator planned to postpone operating them until enough water to "bank" the oil around the producing wells had been injected.

Forest Oil Corporation

Flood No. 1. - The Forest Oil Corporation No. 1 flood, covering 40 acres, is in the Westfield pool in Clark County and in the center of the SW¼ sec. 21, T. 11 N., R. 14 W., 2d P. M. It has as its objective the recovery of oil by water-flooding the Upper Casey sand, which is at an average depth of 300 feet and ranges in thickness from 30 to 50 feet. The project is being developed on a five-spot pattern, with like wells spaced 660 feet. Nine water-intake wells and four oil-producing wells, making up 4 five-spot patterns, were drilled during the summer of 1942 and the injection of water was started on August 10, 1942. The oil wells, although drilled at the same time as the input wells, were capped. A map of the project showing the locations of the water-intake and oil-producing wells is shown in figure 4.

The intake wells were shot with an average of 21 quarts of nitroglycerin each. Usually the wells were not cased (except about 20 feet of 8-inch surface pipe), but in a few holes which caved badly, about 100 feet of 6¼-inch casing were used. They are equipped with a string of 1½-inch, cement-lined tubing set on top of the sand and cemented in place with 10 sacks of cement. The oil wells were completed in the same manner and equipped to produce by flowing.

A shallow, fresh-water well about 6 miles from this project furnishes enough water for both Forest Oil Corporation flooding projects. The water is of excellent quality and requires no chemical treatment or filtration. Sand filters, installed and used for a few months, were found to be unnecessary and were removed. A mineral analysis of the water is shown in table 1. The injection pressure at the surface was maintained at about 100 pounds per square inch until November 30, 1942, when a booster pump was installed and the injection pressure was increased. On July 1, 1943, the injection pressure was 295 pounds per square inch.

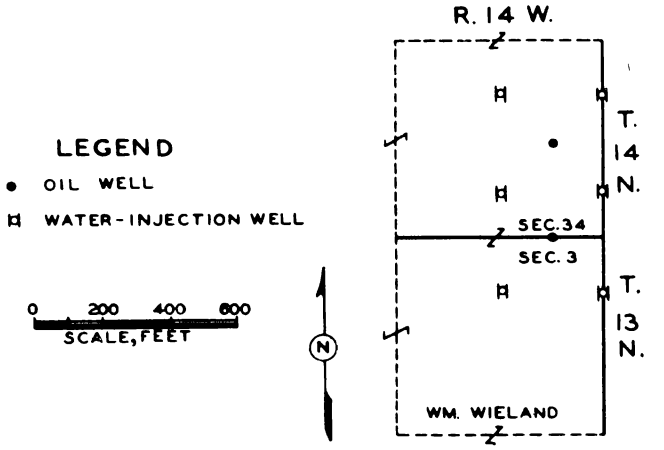


FIGURE 1 - MAP OF C. K. ANTONOPULOS WATER-FLOODING PROJECT, EDGAR COUNTY, ILL., JULY 1, 1943.

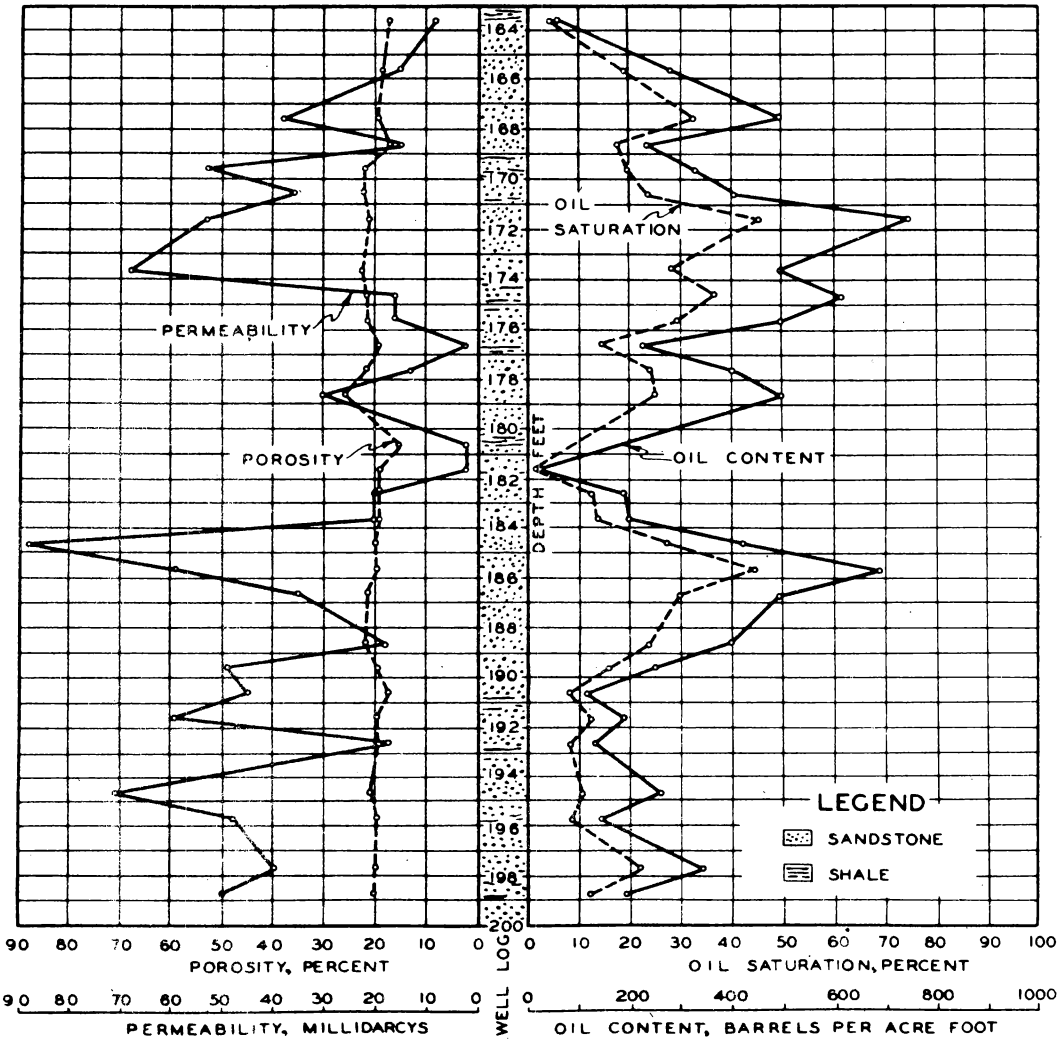


FIGURE 2 - ANALYSIS OF A CORE OF BENOIST SAND FROM C. K. ANTONOPULOS WATER-FLOODING PROJECT, EDGAR COUNTY, ILL.

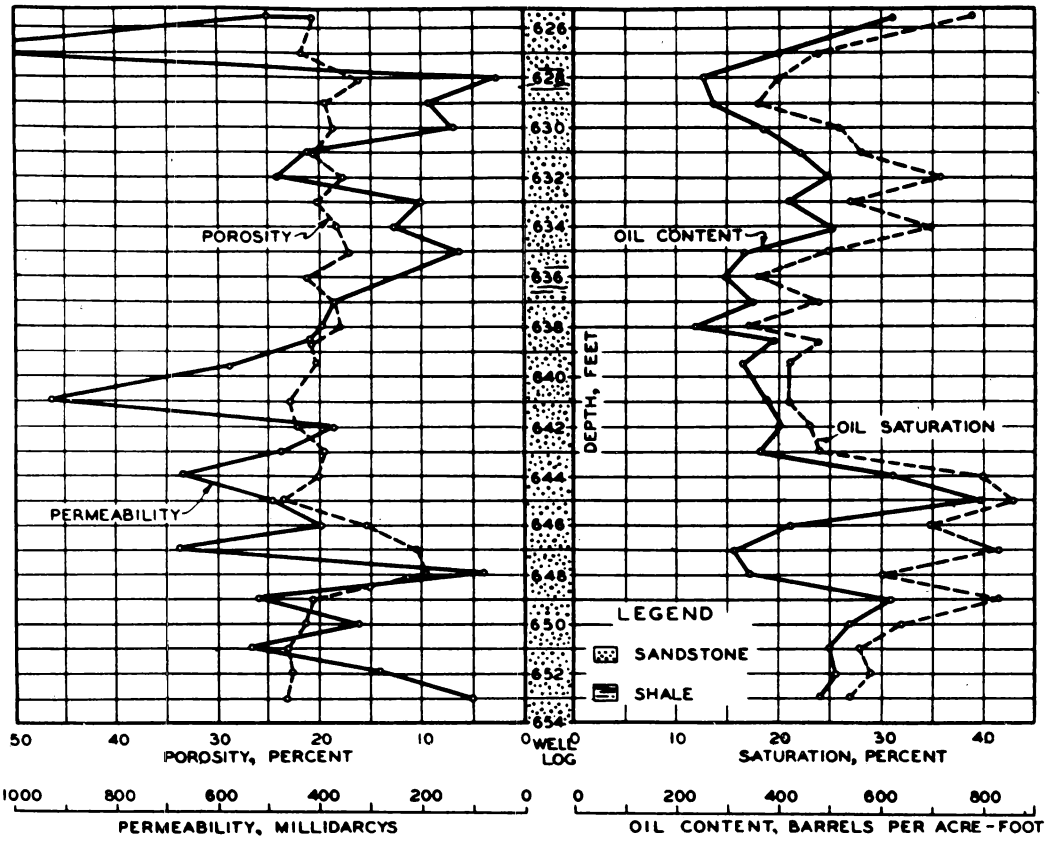


FIGURE 3 - ANALYSIS OF A CORE OF SIGGINS SAND FROM COKEY OIL CO. WATER-FLOODING PROJECT, CRAWFORD COUNTY, ILL.

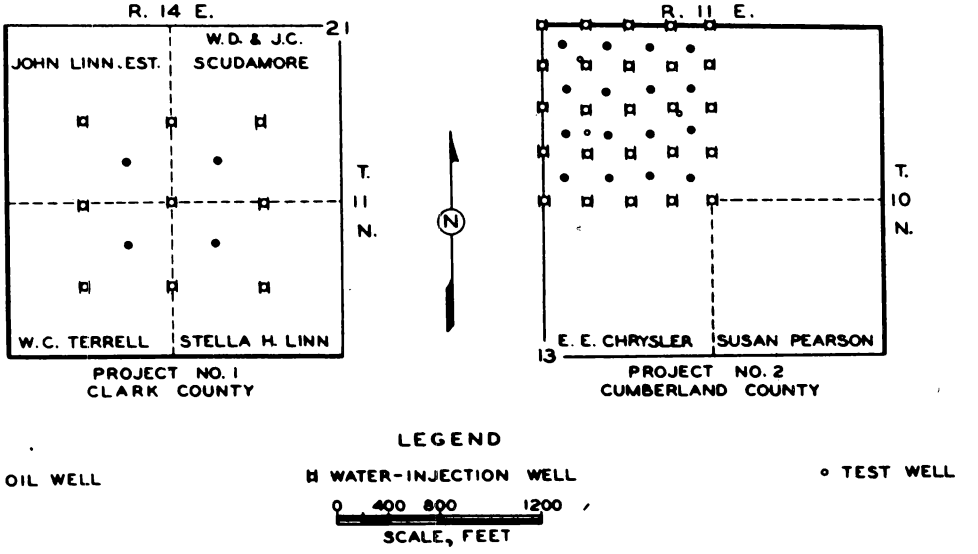


FIGURE 4 - MAPS OF FOREST OIL CORPORATION WATER-FLOODING PROJECTS, CLARK AND CUMBERLAND COUNTIES, ILL., JULY 1, 1943.

The sand thickness ranges from 30 to 50 feet, and the average permeability is about 100 millidarcys. The permeability, however, varies widely - from only a few millidarcys to more than 500 millidarcys, so that it is possible that channeling will occur in the more permeable strata and that much of the sand will not be flooded effectively. The profiles of the permeability and oil content, as determined from a representative core from this project, are shown in figure 5.

A sample of the oil produced from this property was not available for analysis but is believed to be similar to that produced on nearby flood No. 2. The temperature of the Upper Casey sand was found to be 60° F. at a depth of 320 feet in the Siggins field and at this temperature the oil produced on the No. 2 flood had a viscosity of 8.8 centipoises and a gravity of 36.6° A.P.I.

From date of first water injection to July 1, 1943, 235,860 barrels of water had been injected into the nine intake wells. The volumes of water injected each month are shown in the following Summary of Operations.

Summary of operations
Forest Oil Corporation water-flooding project 1
Clark County, Ill.

Well pattern	5-spot 660' x 660'	Location	(Sec. 21, T. 11 N., (R. 14 W., 2d P.M.
First injection	Aug. 10, 1942	Sand flooded	Casey
First oil increase	Delayed flood	Top of sand	300 ft.
Date discontinued	Active	Sand thickness	30 to 50 ft.
Formation temp.	60°F. 1/	Gravity of oil	36.6°A.P.I. (60°/60° F.) 1/

Viscosity of oil at 60°F. - 8.8 centipoises. 1/

Date	Acres flooded	Injection wells	Oil wells	Cumulative oil production, bbl. per acre	Cumulative water:oil ratio
Jan. 1, 1943	40	9	4	Not produced to July 1, 1943	
July 1, 1943	40	9	4		

Monthly record of water injected and oil produced

	1942		1943	
	Water injected, bbl.	Oil produced, bbl.	Water injected, bbl.	Oil produced bbl.
January			28,816	
February			24,073	
March			26,568	
April			25,565	
May			28,036	
June				

1/ Formation temperature and crude oil sample obtained in Siggins pool (flood No. 2). See text.

Monthly record of water injected and oil produced (Cont'd)

	1942		1943	
	Water injected, bbl.	Oil produced, bbl.	Water injected, bbl.	Oil produced, bbl.
July				
August	21,550			
September	22,497			
October	21,684			
November	9,956			
December	27,115			
Total	102,802	Nil	133,058	Nil

Cumulative water injected to July 1, 1943 - 235,860 bbl.
Cumulative oil produced to July 1, 1943 - 0 bbl.

Flood No. 2. - The Forest Oil Corporation No. 2 "flood" is in the Siggins field in Cumberland County and covers 40 acres, comprising the NW¼ NE¼ sec. 13, T. 10 N., R. 11 E., 3d P. M. The oil-producing horizon is the Upper Casey sand, at an average depth of 290 feet and an average thickness of 30 feet. The temperature of the producing horizon, measured at a depth of 320 feet in a test well, was found to be 60° F. At this temperature the oil produced has a viscosity of 8.8 centipoises and a gravity of 36.6° A.P.I.

This project has been developed on a five-spot pattern, with like wells spaced 330 feet, so there are 25 water-intake wells and 16 oil-producing wells on the 40-acre block. If the project is expanded the management has indicated that the new development probably will be on a similar pattern with a spacing of 440 feet between like wells. Figure 4 includes a map of the development to July 1, 1943, showing the locations of all wells. The injection of water into all intake wells was started on June 20, 1942. Oil wells were drilled at the same time as the input wells but were capped until March 2, 1943, when about 375,000 barrels of water had been injected into the sand. The injection pressure is controlled by valves at each wellhead, so that the rate of advance of water through the sand from the various injection wells will not vary widely. The average, controlled injection pressure has been varied from 130 to 400 pounds per square inch. All oil wells are flowed; thereby the cost of rods, pumping jacks, powers and other equipment and energy chargeable to the cost of lifting the oil has been eliminated.

Both the oil-producing wells and water-intake wells were shot with an average of 20 quarts of nitroglycerin each and were completed without casing. All wells were equipped with 1½-inch cement-lined tubing and a packer set at the top of the sand and cemented in place with about 10 sacks of cement.

The average permeability of the Upper Casey sand is about 75 millidarcys on this project, and core analyses indicate that the sand contains about 700 barrels of oil per acre-foot, of which about 275 or 300 barrels

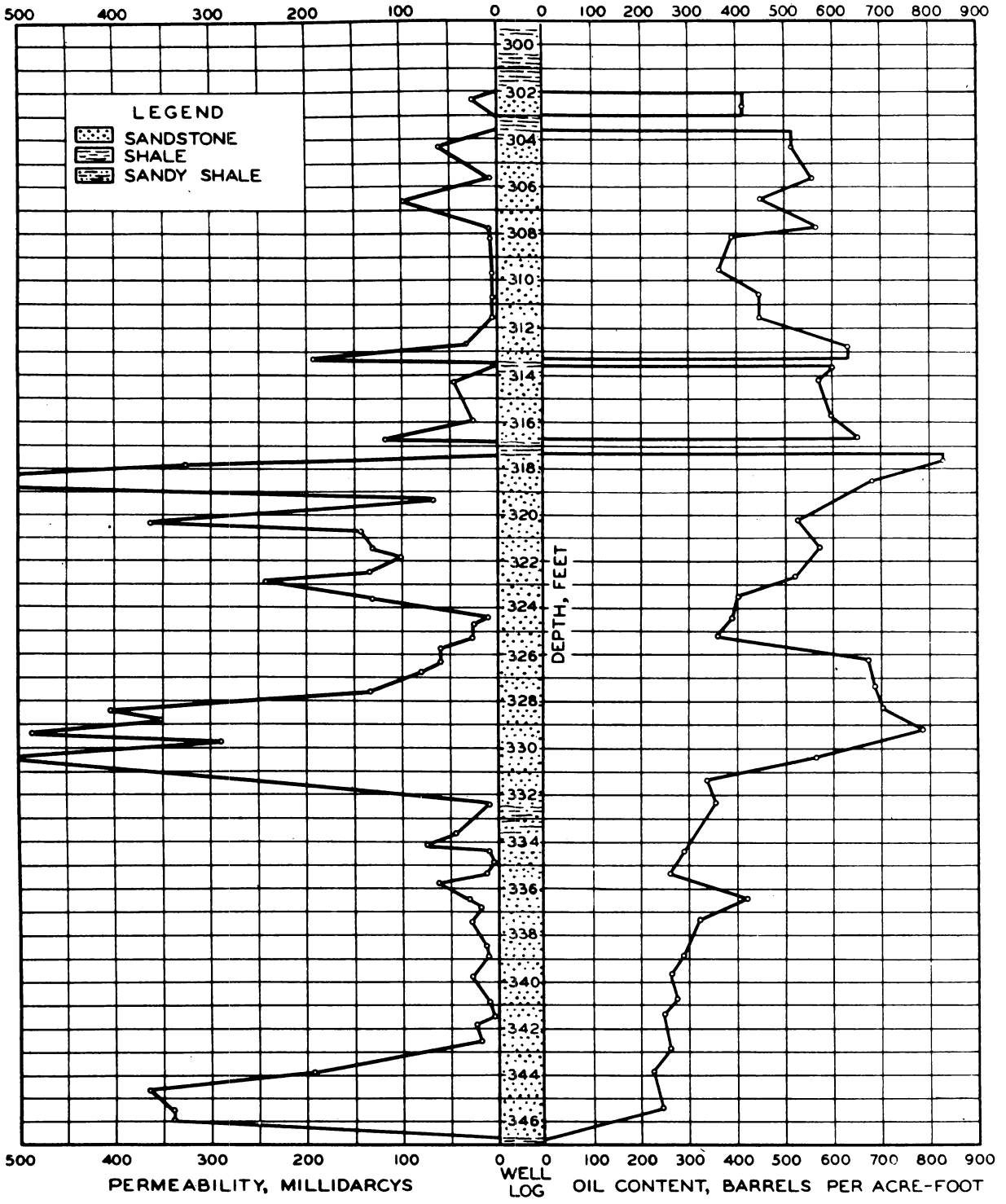


FIGURE 5-ANALYSIS OF A CORE OF CASEY SAND FROM FOREST OIL CORPORATION NO. 1 WATER-FLOODING PROJECT, CLARK COUNTY, ILL.

are estimated by laboratory tests to be recoverable. Figure 6 shows a graph of the permeability and oil content determined on a typical core from this property.

When the production of oil from the project was started, it was presumed that the oil had been "banked" in the center of the five-spot patterns by the water injected during the preceding 8½-month period (375,000 barrels) and that the wells would flow a large amount of oil before water would appear. Most of the wells, however, produced large quantities of water from the date they were first opened and much less oil than was expected.

The large quantities of water and relatively small quantities of oil produced were originally ascribed to the possible presence of "mud veins" or soft streaks in the formation. It is reported that some success in reducing channeling has been attained in Oklahoma by the injection of aquagel and fibrotex. Numerous injection wells on this project were treated by injecting aquagel alone, or aquagel and fibrotex together, under high pressure, and then washing the excess material out of the hole. Temporary plugging of channels was sometimes attained. No permanent good effects resulted, however, and in some instances the channeling was increased. Three test wells were drilled on the project to determine the location of the channeling, but these wells were not cored and no useful information was obtained.

A careful study of water-input histories was made in the fall of 1943, and input-decline curves of many wells indicated that the channeling began when, upon completion of the pressure plant, the pressure was raised to over 300 pounds per square inch. Several wells were tested by determingin the water-input rate at several pressures. These tests revealed that wells that probably had not channeled previously showed a sharp increase in injectivity index (barrels of water injected per day per pound per square inch differential) at 375 pounds per square inch, indicating that a rupture in the formation occurred at the pressure. The input-decline curves showed that rupture took place at a somewhat lower pressure early in the life of the "flood", possibly as low as 275 pounds per square inch. After the test the excessive input rate did not recede to its former value, showing that the rupture was permanent.

Tests with fluorescein dye tracer showed that the water passed from one input well to a producer in less than 24 hours. Electrical conductivity tests on an untubed test well showed that the water was channeling near the top of the sand and could be sealed off by a packer. The company now believes that the channeling was principally caused by excessive initial pressures.

It will probably be impossible to remedy the situation in this development, for the following reasons. All of the wells are tubed with cement packers, so remedial work on the wells is impossible. The producing wells were open to the sand but capped at the surface, so that the channeled water doubtless entered the sand in the vicinity of the producing wells,

seriously injuring their productivity. The old wells were plugged with permeable gravel at the bottom of the hole, so that water probably entered the sand surrounding them.

The failure of this project to yield results expected can be ascribed principally to the operators' unfamiliarity with local conditions and does not necessarily condemn the water-flooding method for use in this pool.

To July 1, 1943, 5,021 barrels of oil had been recovered from the project by the injection of 480,812 barrels of water, a ratio of 1 barrel of oil produced to 95.8 barrels of water injected. During the month of June 1943 the ratio of water injected to oil produced was 21.3. The oil produced by flooding amounted to 126 barrels per acre. The volumes of oil produced and water injected each month are shown in the following Summary of Operations.

Summary of operations
Forest Oil Corporation water-flooding project 2
Cumberland County, Ill.

Well pattern	5-spot 330' x 330'	Location	Sec. 13, T. 10 N., R. 11 E. 3d P. M.
First injection	June 20, 1942	Sand flooded	Casey
First oil increase	March 2, 1943	Top of sand	290 ft.
Date discontinued	Active	Sand thickness	30 to 50 ft.
Formation temp.	60°F.	Gravity of oil	36.6°A.P.I. (60°F.)

Viscosity of oil at 60°F. - 8.8 centipoises

Date	Acres flooded	Injection wells	Oil wells	Cumulative oil production, bbl. per acre	Cumulative water:oil ratio
Jan. 1, 1943	40	25	16		
July 1, 1943	40	25	16	126	95.8

Monthly record of water injected and oil produced

	1942		1943	
	Water injected, bbl.	Oil produced, bbl.	Water injected, bbl.	Oil produced, bbl.
January			45,375	
February			28,104	
March			38,711	811
April			36,711	1,060
May			36,211	1,562
June	10,574		33,865	1,588
July	27,487			
August	35,830			
September	43,451			
October	44,062			
November	51,139			
December	49,292			
Total	261,835	0	218,977	5,021

Cumulative oil production to July 1, 1943 - 5,021 bbl.
Cumulative water injected to July 1, 1943 - 480,812 bbl.

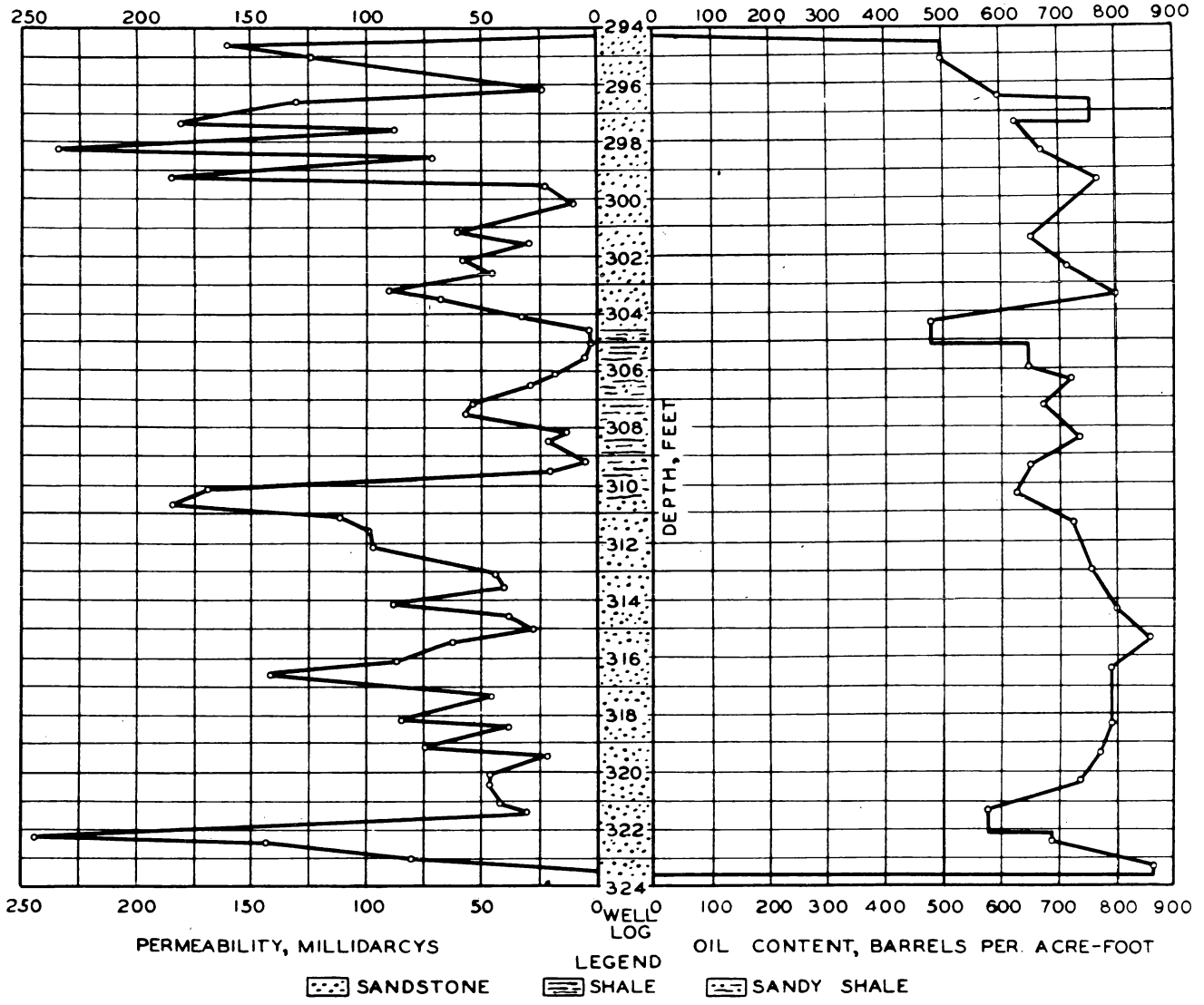


FIGURE 6 - ANALYSIS OF A CORE OF CASEY SAND FROM FOREST OIL CORPORATION NO. 2 WATER-FLOODING PROJECT, SEC. 13, T. 10 N., R. 11 E., CUMBERLAND COUNTY, ILL.

Kewanee Oil & Gas Co.

The Kewanee Oil & Gas Co. started the injection of water by gravity into the Baldwin No. 5 well in the Robinson field, Crawford County, sec. 17, T. 7 N., R. 14 W. 2d P. M., on March 24, 1943. The well formerly was used as an air-input well, but as no beneficial results were obtained from the injection of air it was converted to a water-input well.

The well was completed in the Robinson sand, which occurs here in two lenses, one at a depth of 927 to 937 feet and the other at a depth of 958 to 966 feet. This well, penetrating both sands, has a total depth of 977 feet, and both sand sections have been shot with nitroglycerin. The casing in the well is not cemented, and the tubing was removed before water injection was started.

Water for flooding is obtained from a shallow, fresh-water well but the supply is small. As no adequate, cheap water supply is available the operator is planning no further water-flooding development. A mineral analysis of the water being used is shown in table 1.

The quantity of water that the input well has taken by gravity has been small and has had no effect on the oil production. It is estimated that about 30 barrels of water a day entered the well to May 4, 1943, and from that date to July 1, 1943, the volume has approximated 10 barrels daily. The total volume of water to enter the well to July 1, 1943, is approximately 1,800 barrels.

Niagara Oil Corporation

The Niagara Oil Corporation has been introducing water into the Robinson sand on the P. Dennis Heirs lease in secs. 29 and 30, T. 7 N., R. 13 W., Crawford County, since July 1936. The lease was developed in 1906, and for several years before the injection of water, air was injected into a few wells. Production is from what is known locally as the 800- to 1,000-foot Robinson zone, and the productive sand section ranges in thickness from 20 to 40 feet. Water is being introduced into the P. Dennis Heirs No. 2 and No. 23 wells (see fig. 7). The No. 2 well was completed November 26, 1906. The oil sand was found at a depth of 827 to 944 feet, and the well was completed by shooting with 140 quarts of nitroglycerin. Six and one-quarter-inch casing was set with a packer at a depth of 796 feet. Well No. 23 was completed March 11, 1909, the oil sand being logged at a depth of 865 to 953 feet. This well was shot with 170 quarts of nitroglycerin, and $6\frac{1}{4}$-inch casing was set with a packer at a depth of 780 feet. Water was introduced into well No. 23 beginning about 1932, and in 1936 it was converted to an air-injection well until approximately 1939, when the well was reconverted to a water-injection well. Since then the quantity of water injected has been metered, but due to incomplete knowledge of recompletion data there is some doubt that water is entering the pay sand. Water was introduced into well No. 2 about 1941, but no records were kept.

Water for flooding is obtained form four shallow fresh-water wells on the P. Dennis Heirs lease and two on the adjacent E. F. Frazier lease. These wells are completed in a shallow sand at depths ranging from 60 to 80 feet, known locally as "quicksand." Three of these wells were completed with $6\frac{1}{4}$-inch casing and three with 10-inch casing. They are pumped by means of a central power, as are all the oil-producing wells. Water for injection into well No. 2 is pumped into a 250-barrel elevated tank, where suspended matter settles out. The water from the tank enters the well without chemical treatment or filtration. Although the casing fills with water (there is no tubing in this well) the only additional pressure that can be applied at the wellhead by the system is that due to the elevation of the tank. Water for injection into well No. 23 is produced into a pit, where it is picked up by a small pump and injected into the well. This well has never filled with water at any injection rate used to July 1, 1943.

The available records on this project are incomplete, and as the oil from many wells that are unaffected by the injection of water is pumped into the same tank with oil from the affected wells, the data available do not permit drawing any conclusions regarding the benefits obtained by flooding. No records of the oil produced before August 1940 are available. An increase in the rate of oil production from P. Dennis Heirs No. 1 and from E. F. Frazier wells Nos. 1, 2, and 3 has been reported.

The Ohio Oil Co.

C. E. Siler Flood

Late in 1942, The Ohio Oil Co. was about to abandon an old well on its C. E. Siler A/C 2 lease in the Robinson field, sec. 5, T. 5 N., R. 12 W., 2d P. M., Crawford County, Ill. As a supply of good water was available from a nearby spring and could be injected into the well at little or no expense, the engineer in charge decided to see if water injection would have any beneficial effect on the rate of oil production, before plugging the well. The rods and tubing were removed from the well, and the water without being treated or filtered was allowed to flow into the well by gravity.

By the time 1,000 barrels of water had entered the well, the nearest offset well had shown a material increase in its rate of production, and within a few months the rate of production of wells on The Ohio Oil Co. G. H. Allison lease and the Kewanee Oil & Gas Co. W. H. Allison lease had increased also (see fig. 8). When the injection of water was started in September 1942 and three leases were producing an average of 9.14 barrels of oil daily. In April 1943 the average daily production of the three leases reached a peak of 22.28 barrels, and in June 1943 their average daily production was 21.14 barrels. The wells on these leases had not produced water previously, and water was just beginning to appear in some of the wells on July 1, 1943, at which date 13,972 barrels of water had been injected. Water injection was continuing at the rate of 80 barrels of water daily. The following Summary of Operations shows the volume of oil produced by each of the three leases affected and the volume of water injected each month that the project has been in operation.

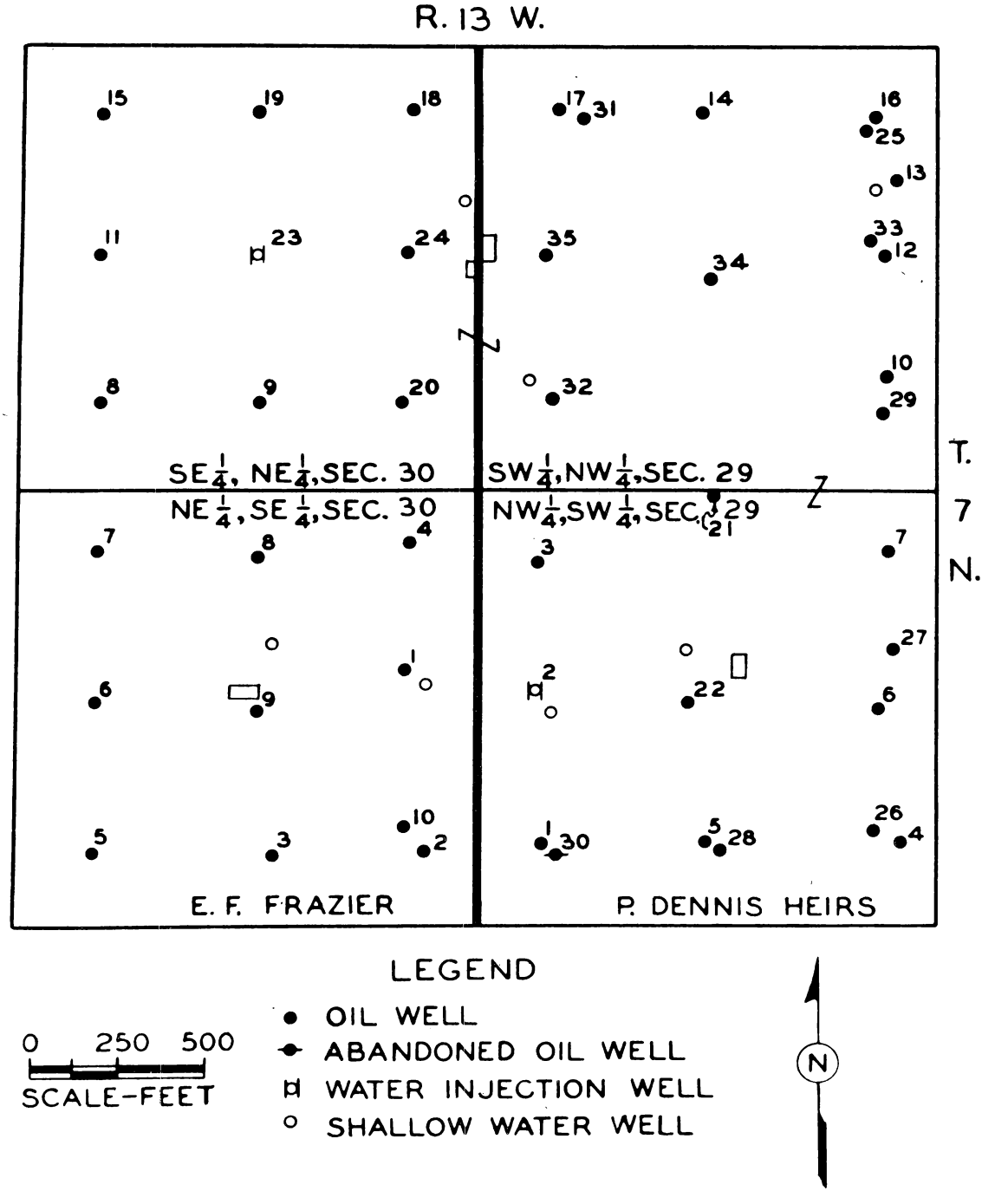
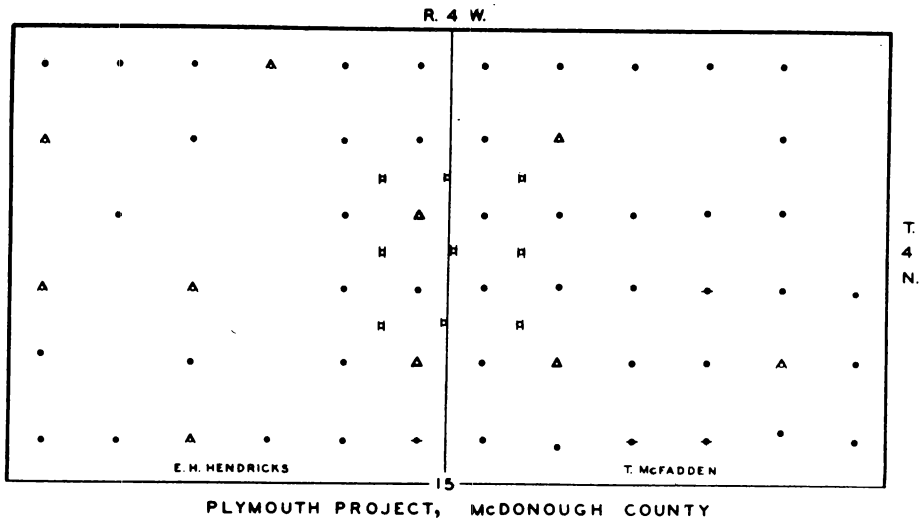
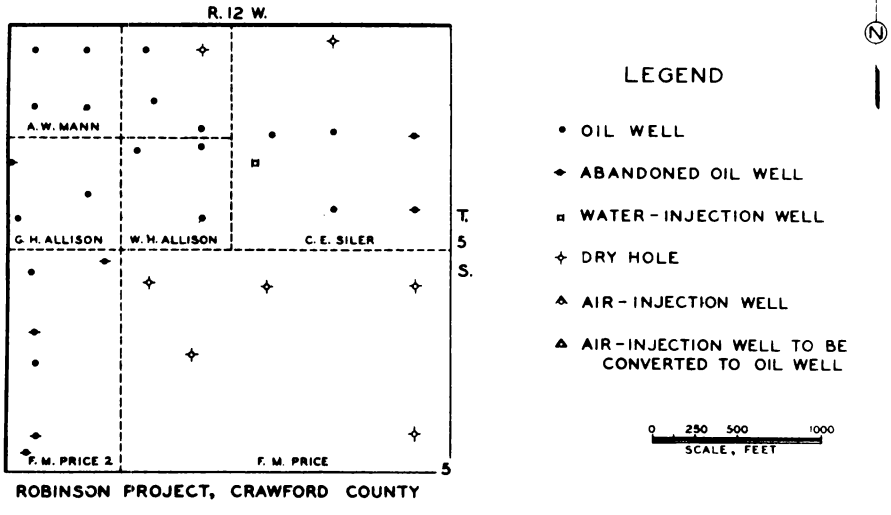


FIGURE 7-MAP OF NIAGARA OIL CORPORATION WATER-FLOODING PROJECT, CRAWFORD COUNTY, ILL., JULY 1, 1943.



PLYMOUTH PROJECT, McDONOUGH COUNTY



ROBINSON PROJECT, CRAWFORD COUNTY

FIGURE 8 - MAPS OF THE OHIO OIL CO. WATER-FLOODING PROJECTS, Mc DONOUGH AND CRAWFORD COUNTIES, JULY 1, 1943.

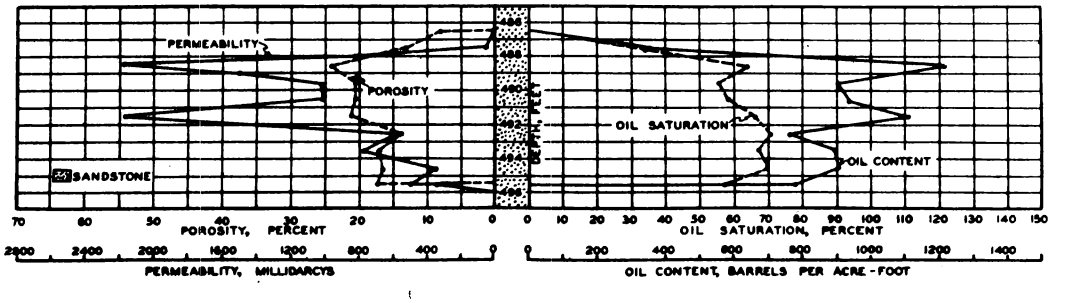


FIGURE 9 - ANALYSIS OF A CORE OF HOING SAND FROM THE OHIO OIL CO. PLYMOUTH WATER-FLOODING PROJECT, SEC. 15, T. 4 N., R. 4 W., Mc DONOUGH COUNTY, ILL.

The production is from the Robinson sand which, in the water-input well, is found at a depth of 908 feet and is 35 feet thick. The input well was completed with 875 feet of $6\frac{1}{4}$-inch casing (not cemented). The operator believes that it was shot rather heavily, although no record of the size of the shot is available. The temperature of the Robinson sand was measured in the well that offsets the intake well on the north and found to be 84° F. At that temperature the oil produced has a viscosity of 6.6 centipoises and a gravity of 34° A.P.I. A mineral analysis of the water injected is shown in table 1.

As an increase of more than 2,000 barrels of oil has been obtained in the past few months from this simple, inexpensive project, it appears that a systematic water-flooding development in this locality would be profitable. It suggests also the possibility of profitable water-flooding operations in other parts of the rather extensive area underlain by productive sand. The ratio of water injected to oil increase by water flooding is only 10.2:1.0.

Summary of operations
The Ohio Oil Co., C. E. Siler water-flooding project
Crawford County, Ill.

Well pattern	Irregular	Location	Sec. 5, T. 5 N., R. 12 W.
First injection	Sept. 21, 1942	Sand flooded	Robinson
First oil increase	Dec. 1942 (?)	Top of sand	908 ft.
Date discontinued	Active	Sand thickness	35 ft.

Date	Acres flooded	Injection wells	Oil wells	Cumulative oil production, bbl. per acre	Cumulative water:oil ratio
Jan. 1, 1943	10	1	5		
July 1, 1943	10	1	5		

Monthly record of water injected, oil produced and increased oil production due to flooding

1942	Water injected	C. E. Siler A/c 2 Production	C. E. Siler A/c 2 Increase[1]	W. H. Allison Production	W. H. Allison Increase[1]	G. H. Allison Production	G. H. Allison Increase[1]
Sept.)		150				64	
Oct.)	1,200	155				150[2]	
Nov.	2,512	150				214[2]	
Dec.	3,773	155		186	124	212	156
Total	7,485	610	0	186	124	640	156
1943							
Jan.	3,269	217	62	186	124	212	156
Feb.	3,219	200	66	182	126	196	130
March	2,897	221	66	217	155	217	151
April	2,072	240	90	214	154	214	150
May	2,753	248	93	212	150	212	155
June	2,431	240	90	180	120	214	150
Total	16,641	1,366	467	1,191	829	1,265	892

Cumulative oil production to July 1, 1943 - 5,258 bbl.
Cumulative oil increase to July 1, 1943 - 2,368 bbl.
Cumulative water injected to July 1, 1943 - 24,125 bbl.

1/ These figures obtained by extrapolating the production decline curve for the lease before water injection was started, reading the indicated production and subtracting this figure from the actual production.

2/ Estimated

Hendricks-McFadden Flood

The Ohio Oil Co., on July 1, 1943, was developing a 40-acre water-flooding project in the East Plymouth pool, McDonough County, in the center of N½ sec. 15, T. 4 N., R. 4 W., 4th P. M. This property was first drilled during 1914 and 1915, was produced normally to 1926, and was subjected to vacuum from 1926 to 1935. Gas injection was started in 1935 and was continued until recently. To date the two leases involved in the project have produced between 1,400 and 1,500 barrels of oil an acre or about 110 barrels of oil per acre-foot of sand. At the time water flooding was started the Hendricks lease (160 acres) was producing about 7 barrels of oil daily and the McFadden lease (160 acres) was producing about 5½ barrels daily.

The water-flooding development is on a five-spot well pattern, with like wells spaced 440 feet apart, so there are 16 water-intake wells and 9 oil wells on the 40-acre block. (See map, fig. 8.) The oil wells are old, but new wells have been drilled for the water injection. The development was completed in June 1943, and the injection of water was started on June 29.

Production is from the Hoing sand, which occurs at a depth of approximately 485 feet and is about 14 feet thick, with no shale breaks in it. The sand is much more permeable than most sands that are being water-flooded successfully in Pennsylvania and the Mid-Continent areas; permeability probably

will average nearly 1 darcy. The success obtained in flooding this type of sand will be of interest. Figure 9 shows the porosity, permeability, and oil content of one of the cores taken on this project. While the core was cut, oil was used as a drilling fluid to avert contamination. The temperature of the Hoing sand, measured on the McFadden lease, was 68° F. At this temperature the oil produced has a viscosity of 8.6 centipoises and a gravity of 36.6° A.P.I. Water for flooding will be obtained from shallow fresh-water wells on the leases.

Pure Oil Co.

The Pure Oil Co. is conducting a water-flooding experiment in the Clay City field in Clay County, Ill., that is unusual in that it is the first project in the State, and one of a few in the Nation, in which a limestone reservoir is being water-flooded. Natural water drives common to many limestone reservoirs furnish all the energy needed to produce the oil, but in the Clay City field only small volumes of water are produced with the oil, therefore the operator is experimenting with the injection of large volumes of fresh water into a few flank wells.

The Clay City field was discovered in 1937, and its development continued through 1938 and the first half of 1939. Production is from a porous zone of Fredonia limestone. Although the limestone is 50 to 100 feet thick, the section from which oil is produced usually ranges from 6 to 12 feet in thickness. The zone of porosity is known generally as the "McClosky limestone." The oil-productive section has not been electrically logged in most wells, but the section of greatest uplift appears to run through the field from northeast to southwest and to occur at an average depth of 3,000 feet.

Satisfactory cores of the oil-productive section of the limestone could not be obtained so no core-analysis data are available. Most of the wells flowed naturally at first but were soon put on the pump. Many of the best wells have produced more than 100,000 barrels of oil each, and a few have produced over 200,000 barrels of oil. The well spacing throughout most of the field is one well to 20 acres, as is shown by the map in figure 10.

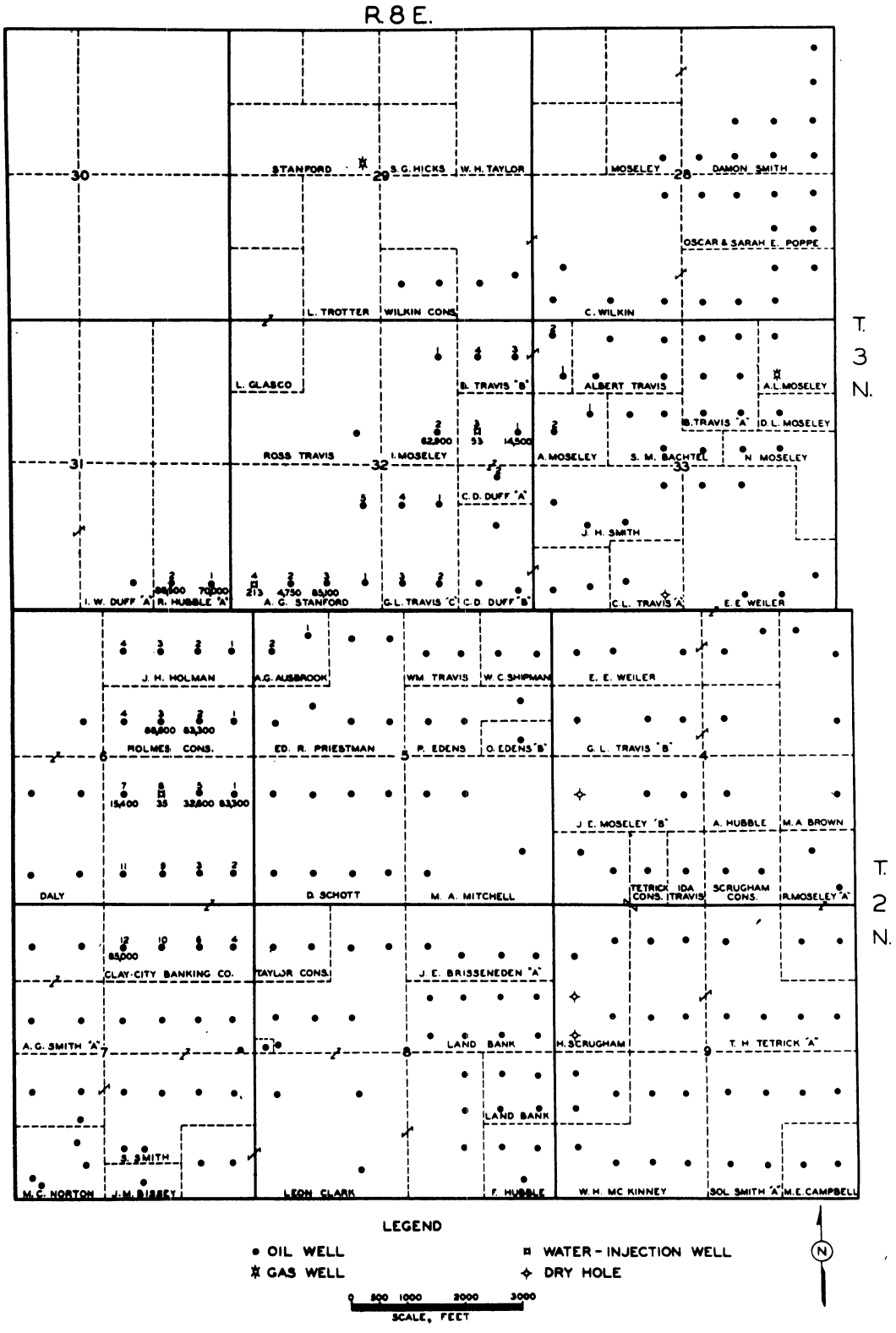
The reservoir temperature is 95° F., and at this temperature the stock-tank oil has a viscosity of 4 centipoises. The gravity of the oil produced is 39° A.P.I. at 60° F. On July 1, 1942, the gas:oil ratio for most of the wells in the field was estimated to be between 1,000 and 1,500 cubic feet per barrel. Very little water has been produced.

The wells were completed with 5½-inch casing run to the top of the McClosky and cemented. Usually about 225 feet or 8-5/8- or 9-5/8-inch casing is run as a surface string. None of the wells were shot, but each was treated with 5,000 gallons of acid. The wells are pumped through 2-inch tubing, usually by large central powers serving several leases, however, a few wells have individual pumping units.

The Pure Oil Co. owns most of the field, and in the fall of 1942 the company management decided to experiment with the injection of water into wells on the flanks of the field to augment the natural production. Three wells on the west flank of the field (Clay City Banking Co. A No. 8, A. G. Stanford No. 4, and C. D. Duff A No. 3), as shown on the map in figure 10, were selected to serve as water-intake wells. Water injection was started into Clay City Banking Co. A well No. 8 on September 19, 1942, and during the period to July 1, 1943, a total of 393,358 barrels of water had been injected into this well, at an average rate of about 1,400 barrels a day. Injection into the C. D. Duff A well No. 3 was started September 30, 1942, and to July 1, 1943, a total of 275,266 barrels of water had been injected, at an average rate of about 1,000 barrels daily. Injection of water into the A. G. Stanford No. 4 well started on October 16, 1942, and to July 1, 1943, a total of 225, 776 barrels of water had entered this well, or at an average rate of about 900 barrels daily.

The Little Wabash River flows along the edge of the field and serves as a source for "flood" water. The river water is pumped into a settling pond and from there is pumped to the injection wells, where it passes through a tubular carborundum filter and then enters the well by gravity. The water is given no chemical treatment and probably is turbid when it enters the injection wells, as the river water contains large amounts of suspended matter during wet weather. It is believed that the filters alone are inadequate for the large volumes of river water passed through them. The pumper in charge of one of the injection wells reported that the filter on that well had been back-washed only twice during a 60-day period. This has had no apparent injurious effect on the wells, as they continue to take water by gravity.

The movement of the water front from the intake wells has been very erratic, as might be expected in a limestone reservoir. Complete records of the water produced by the wells surrounding the intake wells are not available. Samples of the water produced from several of the wells were taken on June 12, 1943, and analyzed. The chloride-ion concentration in these samples, in parts per million, is shown on the map in figure 10 by small figures in parentheses next to the wells from which the samples were taken. As the interstitial water contains about 85,000 parts per million of chloride and fresh water is being injected, the approximate movement of the injected water is indicated by the reduction in the chloride concentration of the water produced with the oil. The erratic movement of the water is best-shown by the chloride saturation of the samples of water taken from the wells surrounding the injection well on the Clay City Banking Co. A lease. One of the first wells on this lease to be affected by the injection of water was the No. 11 well, although several other wells are closer to the water-injection well. The monthly oil production from the No. 11 well increased from 299 barrels during December 1942 to 1,498 barrels during the following month, but by the end of February 1943 the well was producing only water. The chloride content of water from the No. 11 well after oil production had ceased was found to be 6,400 p.p.m., whereas the chloride content of water produced from Clay City Banking Co. 1, 3, and 9 wells and from Holmes Consolidated 3 well (all of which are closer to, or the same distance from the injection well) had not varied appreciably from the chloride content of the connate water.



NOTE: FIGURE BELOW WELL SYMBOL INDICATES THE CHLORIDE CONTENT OF THE WATER PRODUCED FROM, OR INJECTED INTO, THE WELL, MEASURED IN PARTS PER MILLION.

FIGURE 10 - MAP OF PURE OIL CO. WATER-FLOODING PROJECT, CLAY COUNTY, ILL., JULY 1, 1943.

Table 2 shows the monthly oil production for each of the wells that have shown an increase in oil production as a result of water injection. The table covers the period from July 1, 1942, to July 1, 1943, and the total production of each well before July 1, 1942, as well. It will be noted that some of the wells affected showed a rapid increase in the rate of oil production, and after a peak was reached the decline in the rate of production was rapid. Each injection well has affected one or two producing wells in its vicinity in this manner. Other affected wells have shown a more gradual increase in the rate of oil production, and - although insufficient time has elapsed to obtain conclusive evidence - it is believed the increased rate of production will be sustained over a longer period.

As many of the wells affected had not reached their peak production to July 1, 1943, it is difficult to predict the success of the project. Figure 11 shows the composite monthly production of all of the wells surrounding each of the intake wells for 3 years before July 1, 1943. From these production-decline curves the increased production resulting from water injection has been estimated. It is estimated that 7,400 barrels of additional oil have been recovered to July 1, 1943, by the injection of water into the Clay City Banking Co. A No. 8 well and that this is equivalent to the production that would have been obtained from the well for the next 5 months, or to December 1, 1943, by primary methods. During June 1943 these wells produced 1, 982 barrels, and it is estimated that without the effect of water injection, they would be producing at the rate of 1,480 barrels monthly on December 1, 1943.

Similarly, it is estimated that the wells surrounding the C. D. Duff injection well had produced 9,000 barrels more oil to July 1, 1943, than would have been obtained by primary production. This is equivalent to the production that would have been obtained for 8 months following July 1, 1943, or to March 1, 1944, without water injection. During June 1943 these wells produced 2,997 barrels of oil, whereas the normal decline curve indicates that they would be producing at the rate of 1,100 barrels per month on March 1, 1944.

The injection of water into the A. G. Stanford No. 4 well has had less effect on the surrounding wells, measured in barrels of oil, but the percentage increase in the rate of oil production is outstanding. The estimated increased recovery as a result of water injected to July 1, 1943, amounted to only 6,600 barrels of oil, but this is equal to the production that would have been obtained for 19 months following this date or to February 1, 1945. This group of wells produced 731 barrels of oil during June 1943, whereas their estimated rate of production would have declined to 300 barrels per month by February 1, 1945.

TABLE 2. - Oil produced by wells affected by water injection in the Clay City field

Well	To July 1942	July 1942	August 1942	September 1942	October 1942	November 1942	December 1942	January 1943	February 1943	March 1943	April 1943	May 1943	June 1943
Wells affected by injection of water into Clay City Banking Co. A No. 8	Oil production, bbl.												
Clay City Banking Co. A No. 8	84,026	181	170	88	Converted to water-injection well September 19, 1942								
Clay City Banking Co. A No. 1	107,412	136	147	148	129	134	197	258	258	315	281	303	259
Clay City Banking Co. A No. 5	79,060	175	180	173	178	183	238	354	933	1,321	1,000	1,067	887
Clay City Banking Co. A No. 7	95,213	179	189	180	187	191	830	1,649	821	239	121	107	107
Clay City Banking Co. A No. 11	84,176	397	397	389	349	299	349	1,498	494	Went to water.		Not operated after Feb.	
Clay City Banking Co. A No. 12	55,982	344	339	351	223	223	239	238	303	431	403	339	363
Holmes Consolidated No. 4	68,070	361	298	310	328	347	356	432	384	427	379	400	366
Total for Group	573,939	1,773	1,720	1,639	1,394	1,377	2,209	4,429	3,193	2,733	2,184	2,216	1,982
Wells affected by injection of water into C. D. Duff A No. 3	Oil production, bbl.												
C. D. Duff A No. 3	44,611	59	66	65	Converted to water-injection well September 29, 1942								
C. D. Duff A No. 1	64,595	105	93	114	124	120	124	116	169	468	340	7	573
C. D. Duff A No. 2	91,224	94	98	116	124	120	124	117	108	151	170	164	180
Geo. L. Travis No. 1	205,339	240	188	180	172	172	160	179	162	138	159	152	194
Geo. L. Travis No. 2	56,536	149	125	120	118	116	119	118	108	103	113	105	159
Geo. L. Travis No. 3	51,518	240	190	179	172	172	156	179	161	137	159	163	196
Geo. L. Travis No. 4	12,013	120	124	120	118	118	119	121	106	104	110	106	158
Zoa Mosely No. 1	66,557	152	157	148	155	150	70	151	121	373	188	305	373
Zoa Mosely No. 2	9,726	72	60	45	48	32	18	43	41	215	212	243	431
Bunyan Travis No. 3	118,529	213	217	208	216	203	206	310	661	422	216	329	394
Bunyan Travis No. 4	74,294	184	186	178	187	176	176	1,502	2,499	502	162	199	339
Total for Group	794,942	1,628	1,504	1,473	1,434	1,379	1,272	2,836	4,136	2,613	1,829	1,773	2,997
Wells affected by injection of water into A. G. Stanford No. 4	Oil production, bbl.												
A. G. Stanford No. 4	34,941	99	87	85	50	Converted to water-injection well October 16, 1942							
A. G. Stanford No. 2	78,831	76	66	90	61	60	61	2,599	1,769	100	204	22	95
A. G. Stanford No. 3	41,378	96	81	60	61	30	31	64	246	434	171	148	154
J. H. Holman No. 3	54,545	184	185	179	184	177	208	228	215	244	220	218	226
J. H. Holman No. 4	19,412	152	150	150	153	150	172	187	187	214	170	183	190
R. C. Hubble No. 1	11,170	62	62	60	61	34	35	69	177	338	97	71	39
R. C. Hubble No. 2	7,813	65	62	60	62	34	35	57	71	99	51	49	27
Total for Group	248,090	734	693	684	632	485	542	3,204	2,665	1,429	913	691	

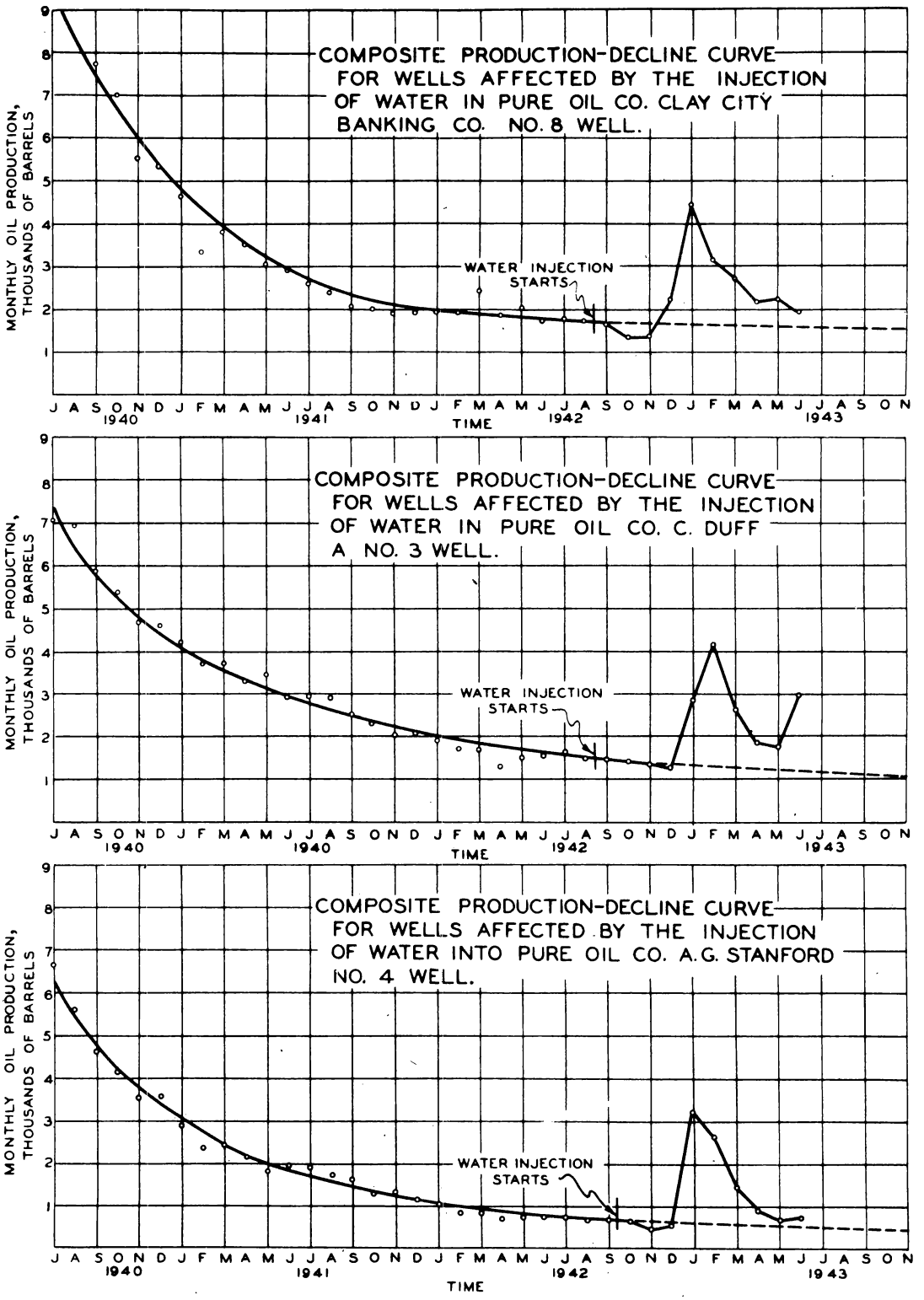


FIGURE 11 -COMPOSITE PRODUCTION-DECLINE CURVES FOR EACH GROUP OF WELLS IN THE CLAY CITY FIELD, CLAY COUNTY, ILL., THAT HAS BEEN AFFECTED BY WATER INJECTION.

Tide Water Associated Oil Co.

The Tide Water Asscciated Oil Co. is injecting water into one or two wells on each of five different leases, all in the Robinson field. All of the leases are producing from the Robinson sand in Crawford and Lawrence Counties. The first of these operations was started in 1933 and the most recent in May 1941. Figure 12 shows a map of these leases, with the location of all oil-producing wells and water-intake wells indicated. The projects have been inexpensive, as old oil wells have been converted to water-intake wells in every case and fresh water from shallow wells or salt water produced with the oil has been injected without chemical treatment.

The old wells were shot and usually are completed with $6\frac{1}{4}$-inch casing set on or near the top of the sand and are pumped through 2-inch tubing. When they are converted to water-intake wells, the rods and tubing are removed and a string of 2-inch tubing, with a 2- to 3- or 4-inch swage nipple on the lower end, is rerun to the top of the sand. Several feet of gravel is placed on top of the swage nipple, and the gravel is covered with a cap of cement.

The mineral analyses of the waters used for flooding are shown in table 1.

Table 3 shows monthly figures for the volumes of water injected into each well, the total volume of water injected on each lease, and the volume of oil produced by each lease. The production from the wells immediately surrounding the water-intake wells was not measured separately; and, as there were only one or two water-intake wells on each lease (varied in size from 70 to 350 acres), the effect of water injection on the rate of oil production from the lease as a whole was not always pronounced; it is evident, however, that the water has had some beneficial effects.

Information regarding the individual projects follows:

Drake No. 2. - This lease, which includes 70 acres with seven oil wells and one water-intake well, is in sec. 12, T. 7 N., R. 14 W. The lease was drilled in 1908, and the Robinson sand was found in the well being used as a water-intake well, at a depth of 932 feet. The sand is 15 feet thick. Water injection was started in August 1933, when the lease was producing only 1.75 barrels of oil daily. An increase in the rate of oil production was evident 3 months after water injection was started, and about 2 years later (October 1935) production reached a peak of 7.04 barrels daily. On July 1, 1943, the average rate of oil production had declined to about 3.0 barrels daily. A total of 218,685 barrels of water had been injected into the one well to July 1, 1943, and the lease had produced 17,322 barrels of oil during this period. The oil recovered from the time of the first development to July 1, 1943, amounted to about 1,200 barrels per acre.

TABLE 3. - Water injected and oil produced on Tide Water Associated Oil Co. leases subjected to water flooding

Month and Year	M. DRAKE NO. 2 FARM: Water injected, bbl.: Well No.4	Cumulative	Oil produced, bbl.	COCHRAN FARM: Water injected, bbl.: Well No.9 1/	Cumulative	Oil produced, bbl.	M. DRAKE NO. 1 FARM: Water injected, bbl.: Well No. 15	Cumulative	Well No.16	Cumulative	Total monthly	Cumulative total	Oil produced, bbl.	RESERVE FARM: Water injected, bbl.: Well No.14	Cumulative	Well No.26	Cumulative	Total monthly	Cumulative total	Oil produced, bbl.	AMES FARM: Water injected, bbl.: Well No.28	Cumulative	Oil produced, bbl.
1933																							
August			42																				
September			45																				
October			46																				
November			79																				
December			129																				
Total			341																				
1934																							
January			109																				
February			106																				
March			157																				
April			142																				
May			136																				
June			134																				
July			161																				
August			141																				
September			164																				
October			177																				
November			172																				
December			156																				
Total			1,755																				
1935																							
January		82,323	173																				
February			155																				
March			191																				
April			176																				
May			199																				
June			208			30																	
July			190			32																	
August			195			54																	
September			196			39																	
October			218			40	4,050	4,050			4,050	4,050	279										
November			197			41																	
December			208		44,400*	34																	
Total			2,306			270	4,050						279										
1936																							
January			198			25																	
February			153			20	2,700	6,750			2,700	6,750											
March			186			34																	
April			204			41																	
May			182			49	1,940	8,690			1,940	8,690											
June			190			50							1,087										
July	2,143	84,466	205	3,720	48,120	51	1,705	10,395			1,705	10,395											
August	3,150	87,616	204	3,720	51,840	51	1,085	11,480			1,085	11,480											
September	2,520	90,136	199	3,600	55,440	40	1,950	13,430			1,950	13,430											
October	2,810	92,946	191	3,720	59,160	43																	
November	2,440	95,386	162	3,600	62,760	52																	
December	2,620	98,006	195	3,720	66,480	54																	
Total	15,683		2,269	22,080		510							1,087										
1937																							
January	2,520	100,526	171	3,720	70,200	44	14,700	28,130			14,700	28,130											
February	2,275	102,801	179	3,360	73,560	39																	
March	2,900	105,701	183	3,720	77,280	53																	
April	2,010	107,711	208	3,600	80,880	59	0				0	28,130											
May	2,160	109,871	192	3,720	84,600	63	0				0	28,130											
June	2,120	111,991	196	3,600	88,200	68	420	28,550			420	28,550	1,128										
July	1,545	113,536	202	3,720	91,920	58	686	29,236			686	29,236											
August	1,385	114,921	152	3,720	95,640	57	0	29,236			0	29,236											
September	2,400	117,321	159	3,600	99,240	42	0	29,236			0	29,236											
October	2,405	119,726	152	3,720	102,960	64	0	29,236			0	29,236											
November	2,876	122,602	177	3,600	106,560	65	0	29,236			0	29,236											
December	2,676	125,278	158	3,720	110,280	64	0	29,236			0	29,236											
Total	27,272		2,129	43,800		676							1,128										
1938																							
January	2,772	128,050	168	3,720	114,000	56	0	29,236			0	29,236											
February	2,887	130,937	155	3,360	117,360	61	0	29,236			0	29,236											
March	2,802	133,739	172	3,720	121,080	70	0	29,236			0	29,236											
April	3,307	137,046	174	3,600	124,680	75	0	29,236			0	29,236											
May	2,801	139,847	165	3,720	128,400	69	0	29,236			0	29,236											
June	2,700	142,547	147	3,600	132,000	84	0	29,236			0	29,236	960										
July	3,150	145,697	178	3,720	135,720	80	0	29,236			0	29,236											
August	2,766	148,463	183	3,720	139,440	84	710	29,946			710	29,946											
September	1,915	150,378	167	3,600	143,040	68	927	30,873			927	30,873											
October	2,304	152,682	163	3,720	146,760	71	482	31,355			482	31,355											
November	2,088	154,770	182	3,600	150,360	59	375	31,730			375	31,730											
December	1,731	156,501	183	3,720	154,080	68	502	32,232			502	32,232											
Total	31,223		2,037	43,800		845	2,996						960										
1939																							
January	2,001	158,502	139	3,720	157,800	48					0	32,232	68										
February	1,525	160,027	126	3,360	161,160	41					0	32,232	52										
March	1,900	161,927	139	3,720	164,880	48					0	32,232	58										
April	1,530	163,457	137	0	164,880	72					0	32,232	64										
May	1,550	165,007	147	0	164,880	91					0	32,232	77										
June	1,560	166,567	162	0	164,880	79					0	32,232	69	963	963			963	963	599			
July	1,589	168,156	158	0	164,880	74			800	800	800	33,032	71	1,332	2,295	2,395	2,395	3,727	4,690	588			
August	1,427	169,583	158	0	164,880	68			1,910	2,710	1,910	34,942	73	1,500	3,795	1,704	4,099	3,204	7,894	580			
September	1,510	171,093	162	0	164,880	69			1,902	4,612	1,902	36,844	64	936	4,731	1,344	5,443	2,280	10,174	516			
October	1,825	172,918	153	0	164,880	64			3,290	7,902	3,290	40,134	63	1,008	5,739	1,092	6,535	2,100	12,274	622			
November	1,725	174,643	145	0	164,880	34			3,980	11,882	3,980	44,114	51	756	6,495	840	7,375	1,596	13,870	548			
December	1,570	176,213	139	3,720	168,600	65			3,185	15,067	3,185	47,299	53	672	7,167	588	7,963	1,260	15,130	572			
Total	19,712		1,765	14,520		753			15,067				763	7,167		7,963		15,130		4,025			
1940																							
January	789	177,002	90	3,720	172,320	35			0	15,067		47,299	27	504	7,671	336	8,299	840	15,970	369			
February	Frozen	177,002	125	3,480	175,800	56			2,140	17,207	2,140	49,439	57	672	8,343	2/	8,299	672	16,642	400			
March	971	177,973	146	3,720	179,520	53			2,465	19,672	2,465	51,904	60	672	9,015	2/	8,299	672	17,314	455			
April	1,680	179,653	122	3,600	183,120	69			3,520	23,192	3,520	55,424	59	672	9,687	1,962	10,261	2,634	19,948	426			
May	1,890	181,543	137	3,720	186,840	67			3,550	26,742	3,550	58,974	73	840	10,527	1,764	12,025	2,604	22,552	468			
June	1,890	183,433	171	3,600	190,440	75			2,960	29,702	2,960	61,934	62	672	11,199	1,344	13,369	2,016	24,568	457			
July	705	184,138	129	3,720	194,160	69			2,650	32,352	2,650	64,584	76	672	11,871	1,092	14,461	1,764	26,332	516			
August	1,890	186,028	154	3,720	197,880	59			3,300	35,652	3,300	67,884	65	672	12,543	756	15,217	1,428	27,760	459			
September	1,535	187,563	141	3,600	201,480	64			2,680	38,332	2,680	70,564	67	840	13,383	672	15,889	1,512	29,272	501			
October	1,440	189,003	125	3,720	205,200	73			2,890	41,222	2,890	73,454	61	672	14,055	672	16,561	1,344	30,616	521			
November	1,760	190,763	113	3,600	208,800	70			2,435	43,657	2,435	75,889	65	672	14,727	840	17,401	1,512	32,128	499			
December	1,410	192,173	118	3,720	212,520	77			3,530	47,187	3,530	79,419	69	672	15,399	672	18,073	1,344	33,472	492			
Total	15,960		1,571	43,920		767			32,120				741	8,232		10,110		18,342		5,563			
1941																							
January	1,457	193,630	125	3,720	216,240	74			2,480	49,667	2,480	81,899	70	840	16,239	840	18,913	1,680	35,152	509			
February	1,275	194,905	111	3,360	219,600	65			2,730	52,397	2,730	84,629	71	672	16,911	504	19,417	1,176	36,328	458			
March	1,035	195,940	128	3,720	223,320	79			1,580	53,977	1,580	86,209	86	672	17,583	672	20,089	1,344	37,672	502			
April	1,255	197,195	126	3,600	226,920	72			3,014	56,991	3,014	89,223	132	672	18,255	672	20,761	1,344	39,016	488			
May	915	198,110	131	3,720	230,640	80			3,090	60,081	3,090	92,313	115	672	18,927	672	21,433	1,344	40,360	519	1,940	1,940	167
June	815	198,925	107	3,600	234,240	86			2,490	62,571	2,490	94,803	83	840	19,767	840	22,273	1,680	42,040	464	2,630	4,570	287
July	780	199,705	122	3,720	237,960	81			3,140	65,711	3,140	97,943	104	672	20,439	672	22,945	1,344	43,384	498	3,268	7,838	299
August	940	200,645	119	3,720	241,680	79			2,830	68,541	2,830	100,773	113	672	21,111	672	23,617	1,344	44,728	449	2,612	10,450	276
September	735	201,380	112	3,600	245,280	75			2,720	71,261	2,720	103,493	81	672	21,783	672	24,289	1,344	46,072	444	2,794	13,244	287
October	805	202,185	115	3,720	249,000	74			2,965	74,226	2,965	106,458	93	672	22,455	672	24,961	1,344	47,416	494	2,734	15,978	304
November	1,295	203,480	111	3,600	252,600	74			2,630	76,856	2,630	109,088	88	672	23,127	840	25,801	1,512	48,928	463	2,857	18,835	285
December	1,010	204,490	114	3,720	256,320	89			2,890	79,746	2,890	111,978	85	840	23,967	672	26,473	1,512	50,440	443	2,290	21,125	244
Total	12,317		1,421	43,800		928			32,559				1,121	8,568		8,400		16,968		5,731	21,125		2,149
1942																							
January	825	205,315	106	3,720	260,040	56			1,330	81,076	1,330	113,308	53	672	24,639	672	27,145	1,344	51,784	433	310	21,435	266
February	765	206,080	105	3,360	263,400	67			510	81,586	510	113,818	76	672	25,311	672	27,817	1,344	53,128	407	1,700	23,135	243
March	854	206,934	108	3,720	267,120	81			1,375	82,961	1,375	115,193	74	744	26,055	744	28,561	1,488	54,616	422	1,995	25,130	286
April	837	207,771	103	3,600	270,720	86			2,516	85,477	2,516	117,709	87	720	26,775	720	29,281	1,440	56,056	430	1,485	26,615	252
May	842	208,613	114	3,720	274,440	89			2,929	88,406	2,929	120,638	84	744	27,519	744	30,025	1,488	57,544	438	2,795	29,410	304
June	780	209,393	101	3,600	278,040	83			2,814	91,220	2,814	123,452	81	720	28,239	720	30,745	1,440	58,984	437	2,437	31,847	271
July	710	210,103	101	3,720	281,760	82			2,526	93,746	2,526	125,978	74	744	28,983	744	31,489	1,488	60,472	445	2,573	34,420	234
August	791	210,894	99	3,720	285,480	77			2,258	96,004	2,258	128,236	73	0	28,983	744	32,233	744	61,216	520	2,475	36,895	247
September	797	211,691	95	3,600	289,080	79			2,617	98,621	2,617	130,853	73	756	29,739	828	33,061	1,584	62,800	505	2,430	39,325	271
October	817	212,508	84	3,720	292,800	81			2,800	101,421	2,800	133,653	70	1,116	30,855	1,860	34,921	2,976	65,776	521	1,970	41,295	252
November	812	213,320	93	3,600	296,400	63			2,650	104,071	2,650	136,303	67	1,080	31,935	1,800	36,721	2,880	68,656	484	2,498	43,793	285
December	743	214,063	93	3,720	300,120	52			0	104,071	0	136,303	38	1,116	33,051	1,860	38,581	2,976	71,632	515	2,217	46,010	244
Total	9,573		1,202	43,800		896			24,325				850	9,084		12,108		21,192		5,557	24,885		3,155
1943																							
January	760	214,823	77	3,720	303,840	84			1,840	105,911	1,840	138,143	64	1,116	34,167	1,860	40,441	2,976	74,608	421	2,170	48,180	273
February	645	215,468	69	3,360	307,200	76			1,460	107,371	1,460	139,603	50	1,638	35,805	1,680	42,121	3,318	77,926	453	1,800	49,980	219
March	742	216,210	95	3,720	310,920	100			2,424	109,795	2,424	142,027	77	1,056	36,861	1,824	43,945	2,880	80,806	435	810	50,790	266
April	801	217,011	99	3,600	314,520	70			2,561	112,356	2,561	144,588	89	990	37,851	1,440	45,385	2,430	83,236	458	2,395	53,185	251
May	785	217,796	92	3,720	318,240	94			865	113,221	865	145,453	59	900	38,751	1,392	46,777	2,292	85,528	448	2,010	55,195	248
June	889	218,685	94	0	318,240	70			530	113,751	530	145,983	38	933	39,684	1,296	48,073	2,229	87,757	376	2,550	57,745	243
Total	4,622		526	18,120		494			9,680				377	6,633		9,492		16,125		2,591	11,735		1,500
Grand Total	218,685		17,322	318,240		6,139	32,232		113,751				7,306	39,684		48,073		87,757		23,467	57,745		6,804

1/ Estimated at 120 barrels daily.
2/ Lines frozen.

*Monthly figures not available.

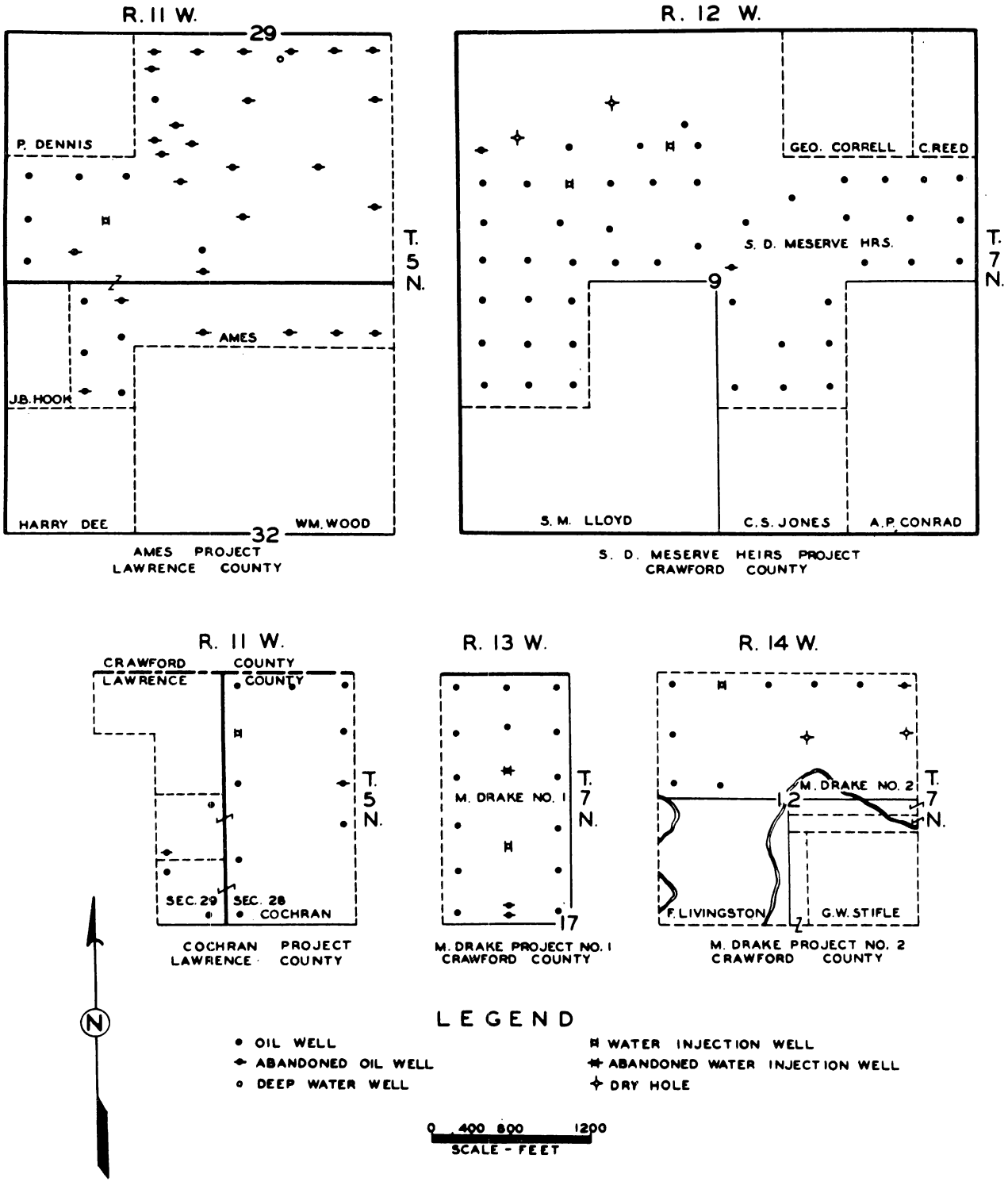


FIGURE 12-MAP OF TIDE WATER ASSOCIATED OIL CO. WATER-FLOODING PROJECTS, CRAWFORD AND LAWRENCE COUNTIES, ILL., JULY 1, 1943.

Cochran. - This lease, in secs. 28 and 29, T. 5 N., R. 11 W., includes 100 acres with 11 oil wells and 1 water-intake well. The producing horizon is found at a depth of 940 to 961 feet in the single well serving as a water-intake well. Water injection was started June 25, 1935, and although the water is not metered, the rate of input has been estimated to be 120 barrels daily. On this basis the total volume injected to July 1, 1943, is estimated to be 318,000 barrels. The rate of oil production from the lease was about 1 barrel of oil per day when water injection was started. Since that date the rate of production has shown a very gradual increase, and during the first 6 months of 1943 it averaged 2.75 barrels of oil daily.

Drake No. 1. - This lease includes 14 active oil wells and 1 active water-intake well on 80 acres in sec. 17, T. 7 N., R. 13 W., 2d P. M., Crawford County. On September 23, 1935, the injection of water was started into a well which had served as an air-injection well from December 1929 to that date. Water injection continued at pressures ranging from 150 to 300 pounds per square inch at the wellhead until December 27, 1938, but it had very little effect on the rate of oil production. (See table 3.) A total of 32,232 barrels of water had been injected during this time. During 1939 no pressure was applied at the wellhead, but water continued to enter the well by gravity until July, when the well was plugged and abandoned. On July 20, 1939, the injection of water was started into a second well on the lease, and to July 1, 1943, 113,000 barrels of water had been injected into this well. At the time this well was converted to a water-intake well the lease production was about 2.25 barrels of oil a day, and by the middle of 1941 it had increased to 3.50 barrels a day. During the first 6 months of 1943 the average rate of oil production from the lease was about 2 barrels a day. Production on the lease is from three sandstone sections found in the now active water-injection well at depths of 890 to 905 feet, 920 to 935 feet, and 948 to 968 feet. This lease has produced 108,265 barrels of oil or 1,353 barrels per acre to July 1, 1943.

S. D. Meserve. - This lease, in sec. 9, T. 7 N., R. 12 W., Crawford County, covers 350 acres and has 46 active oil wells and 2 active water-intake wells. The injection of water into 2 old oil wells was started July 1939, and to July 1, 1943, 87,664 barrels of water had entered these 2 wells. The ratio of oil wells to water-intake wells is so large, however, that it is difficult to determine what effect, if any, the injection of water has had on the rate of oil production. When water injection was begun the lease was producing oil at the rate of about 19 barrels of oil daily, whereas the average daily rate of production had declined to 14.34 barrels during the first 6 months of 1943. In the water-intake wells the oil sand is found at depths of 1,050 to 1,080 feet.

Ames. - This lease, in secs. 29 and 32, T. 5 N., R. 11 W., covers about 280 acres. A total of 38 wells has been drilled on the lease, but only 11 oil-producing wells and 1 water-intake well remained on July 1, 1943. Water injection was started in May 1941, when the lease was producing about 8.50 barrels of oil daily. During the following October the average rate of oil production reached a peak of 9.79 barrels daily, and on July 1, 1943, the lease was producing at the rate of about 8 barrels daily. A total of 57,745 barrels of water had been injected into the single intake well to this date.