A RESERVOIR ANALYZER STUDY OF THE WOODBINE BASIN

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ABSTRACT

This paper presents a reservoir analyzer study of the performance of the Woodbine formation in the East Texas basin. The study was made possible by the compilation of available information on the configuration, thickness and the pressure drawdown of the formation. The investigation was made of the pressure variations in the basin incident to production from the several Woodbine reservoirs. In addition, the apparent compressibility of Woodbine water was evaluated so that the potential water yield of the formation could be determined. The distribution of permeability of the Woodbine sand and the interference between producing areas were also investigated. In conjunction with this basic study of the Woodbine sand, an acceptable match of the production-pressure relationship in the East Texas Field was established on the analyzer.

INTRODUCTION

When production is taken from a reservoir contiguous to an aquifer, the resultant pressure gradient causes a water influx into the reservoir. For some years it has been the practice to predict the performance of water drive reservoirs with mathematical equations that relate the water influx into reservoirs to their pressure behavior. A rigorous solution of these equations is quite complex; hence, the conventional method requires the simplifying assumptions that the formation have constant thickness, permeability and porosity, and that it have a known and regular shape. It is necessary to use performance records of the reservoir in question to determine the equation constants that make the results of the mathematical calculations duplicate the reservoir history. The values of the constants determined in this manner sometimes differ so greatly from theoretical or measured values that the constants appear unreasonable. The equation constants comprise such factors as the thickness, porosity and permeability of the formation, and the viscosity and compressibility of water. Usually the thickness, porosity and viscosity are known within a reasonable degree of certainty, whereas the formation permeability and the water compressibility are known with considerably less certainty. Hence, permeability and compressibility values are arbitrarily selected that will make the mathematical equations duplicate the reservoir behavior. In many reservoir studies the value of the compressibility of water thus selected has exceeded the reported value by a factor of from severalfold to manyfold. Whether this excessive value results from the inadequacy of the mathematical approach to take into account the shape irregularities and the heterogeneities of the aquifer, or is due to some type of formation compaction and decrease of porosity has not been established. Because of the significance of the potential water yield of formations with reference not only to oil reservoirs but to water resources as well, it is very important that a representative value for the effective water compressibility be determined.

One of the best known examples of a field for which it has been possible in the past to predict the future reservoir pressure is the East Texas Field. Until about 1943 it was possible by means of mathematical equations to duplicate past pressure behavior and to predict with a high degree of accuracy the reservoir pressure of the field. Since 1943, however, the calculated pressures have deviated progressively from the observed pressures to such a degree that in recent years, it has

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[1] References given at end of paper.

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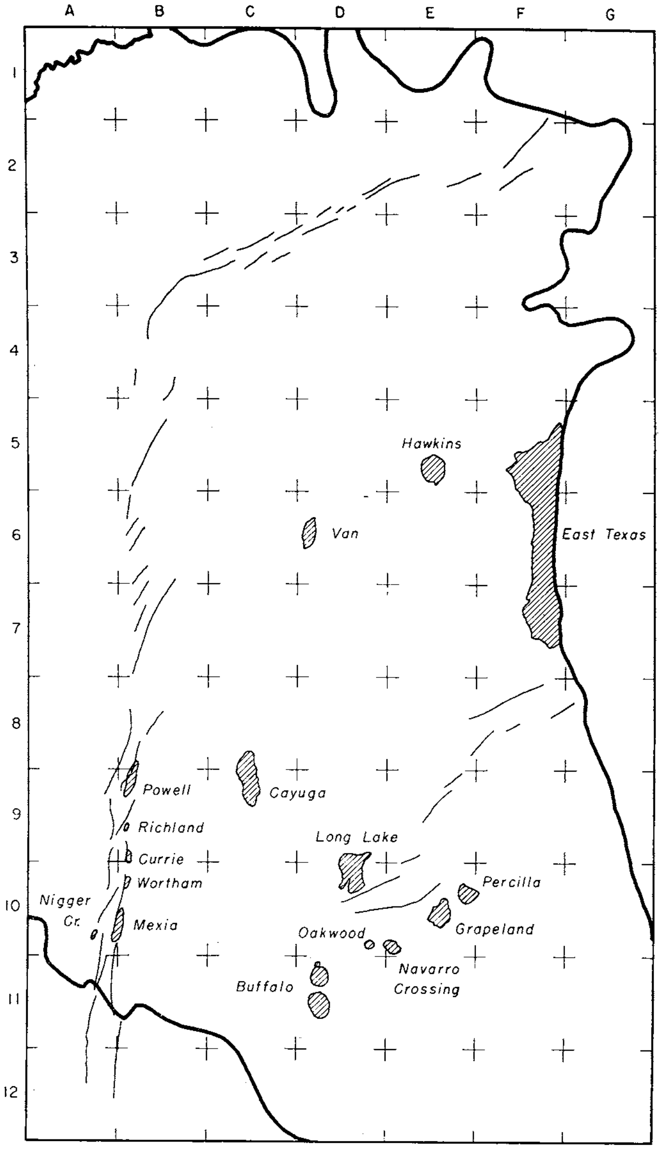

FIG. 1 — SUBDIVISION OF WOODBINE BASIN.

not been possible to predict accurately the future pressure of the field using the equation constants that were employed in the past. The geometric configuration and the permeability variation of the Woodbine aquifer, which is the source of the water drive for the field, and the production from other Woodbine fields were thought to be causing the discrepancy between the observed and calculated pressures.

As an approach to these problems, a detailed study of the Woodbine basin was made with an electric reservoir analyzer to determine the apparent compressibility of the formation water and the permeability variation throughout the basin, and to obtain a reliable means of predicting the pressure of the East Texas Field. In this study the aquifer was represented by an electric analogy in which variations in the geometry and the permeability of the sand were included. The apparent water compressibility and the permeability variations were determined from the analyzer constants and network condenser and resistor values that gave a basin pressure distribution consistent with the observed pressure history of the East Texas Field and the known pressure drawdown in the basin as of Jan. 1, 1947. The pressure pattern throughout the basin during the entire history of production from the Woodbine formation was derived simultaneously with this study.

In addition, the study provided a satisfactory means of determining the pressure history of the East Texas Field. From the electric characteristics of the analog, the influence of production from other fields on the pressure of the East Texas Field was determined, and predictions of the future pressure-production behavior of this field were made.

Insofar as is known by the authors, the Woodbine basin is the only producing formation about which sufficient data have been compiled to permit a quantitative study of an entire aquifer. Basic information available for this study included Woodbine formation pressures derived both from field measurements and from drill stem tests throughout the basin. The configuration of the Woodbine formation and the distribution of the net sand thickness were also known.

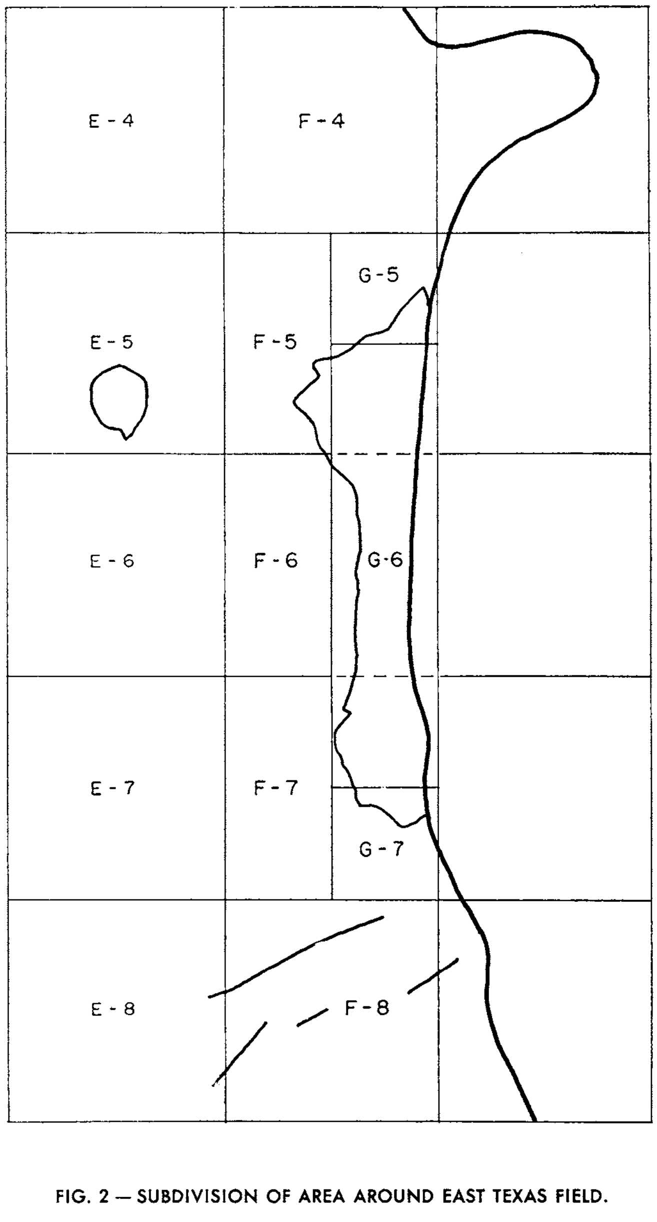

FIG. 2 — SUBDIVISION OF AREA AROUND EAST TEXAS FIELD.

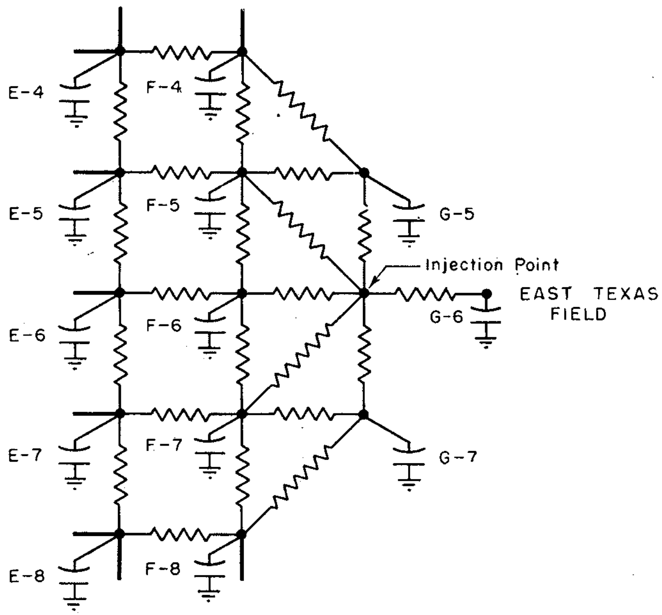

FIG. 3 — RESISTOR NETWORK.

STUDY OF THE BASIN

Electric Representation of the Woodbine Basin

To represent the Woodbine basin electrically on the pool unit of the reservoir analyzer, the area of the basin was divided into a number of squares 15.42 miles on the side as shown by the grid map on Fig. 1. On this map are shown the location of the Woodbine reservoirs that were considered in this study. The three squares enclosing the East Texas Field were subdivided further as shown on Fig. 2 so that the subdivision in which the field lay approximated closely the areal extent of the field. For each of the integral formation volumes corresponding to these area subdivisions, the fluid capacitance, which is defined as the product of the interstitial fluid volume and the appropriate fluid compressibility, was represented by an electric condenser. The equation for arriving at the relative condenser values is shown below:

$$C_E = M\,c\,ab\,\phi \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

where,

C_E = electric capacity of condenser, microfarads

M = analyzer proportionality constant between fluid and electric units, $\dfrac{\text{microfarads}}{\text{bbl/psi}}$

c = compressibility of interstitial fluid, vol/vol/psi

ab = volume of formation sand within each square, bbl

ϕ = porosity of sand, fraction of total sand volume

The compressibility of the water and the porosity of the sand were assumed to be constant everywhere in the aquifer, whereas the sand volume corresponding to each areal subdivision was determined from the average clean sand thickness for each subdivision as indicated by electric logs of the wells drilled throughout the basin.

The condensers representing the fluid capacitance of the Woodbine formation were arranged in the same pattern as the corresponding areas. The resistance to fluid flow between the centers of adjacent formation subdivisions was represented by a variable resistor, so that for each boundary common to two areal units there was a resistor connecting the corresponding condensers. The resistors representing paths of flow from the aquifer across the East Texas Field boundary were tied together to form a common point to which was attached a single resistor terminated by the condenser representing the East Texas Field. Each resistor bears the inverse relationship to the corresponding formation permeability shown by the following equation:

$$R_E = \frac{N\,\mu}{0.001127\,K\,b} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

where,

R_E = electric resistance, megohms

N = analyzer constant, $\dfrac{\dfrac{\text{megohms}}{\text{psi}}}{\text{B/D}}$

μ = viscosity of Woodbine water, centipoises

0.001127 = proportionality constant to change millidarcys to $\dfrac{(\text{bbl})\ (\text{sq in.})\ (\text{cps})}{(\text{lb})\ (\text{day})\ (\text{ft})}$

K = permeability, md

b = clean sand thickness on side of formation subdivision, ft

In order to simulate production from the fields producing from the Woodbine sand, current was withdrawn from the charged resistor-condensor network at the appropriate mesh points. To simulate injection of water along the western edge of the East Texas Field, current proportional to the volume of water injected into the field was introduced at the junction of the resistor leading to the field and the resistors leading to the aquifer as is shown on Fig. 3.

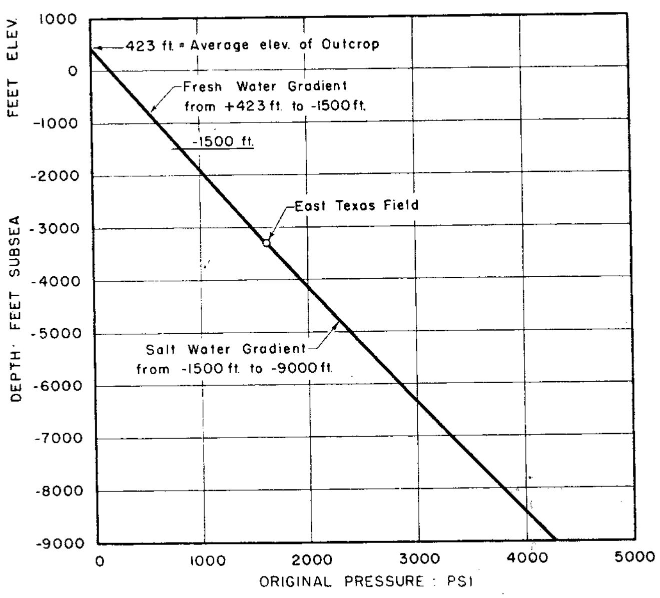

FIG. 4 — WOODBINE BASIN — PRESSURE VS DEPTH.

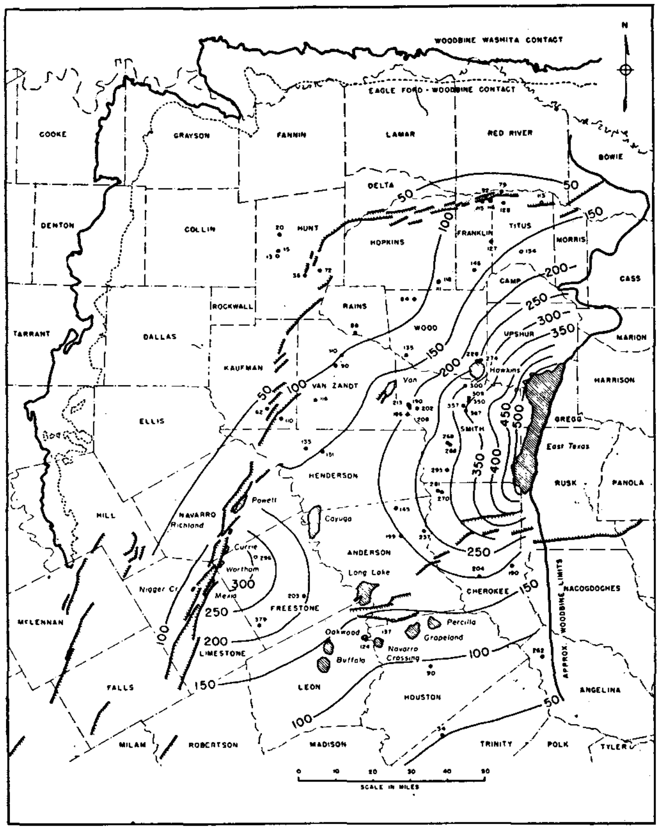

FIG. 5 — PRESSURE LOSS IN WOODBINE BASIN ON JAN. 1, 1947.

Pressure Loss in the Basin

During the last decade, drill stem tests were made on many of the wells drilled into the Woodbine formation. In conjunction with these tests, pressures were measured in the Woodbine formation, and water samples were taken.[1] From the density and chloride content of these samples, and the depths at which they were taken, the relationship between original pressure in the Woodbine sand and subsea depth was established. This relationship is shown on Fig. 4. By means of this relationship and the measured pressures, the change from original pressure was determined for each of the different well locations as of the date on which the pressure measurement was made. A preliminary analyzer study of these pressure changes provided an indication of the approximate rates of change in pressure in the various parts of the basin. These were used to adjust observed pressures to an arbitrary date of Jan. 1, 1947.

In an analyzer study of the performance of a reservoir, a charged condenser of an arbitrary capacity is used to express the product of the volume of a compressed fluid and its compressibility. The original voltage across the condenser is analogous to the original formation pressure. In such an analogy the drop in voltage across the condenser remains proportional to the volume-weighted pressure decline in the formation. Therefore, volume-weighted pressures were used in this study.

The pressure drawdown of the Woodbine basin, contoured at 50 psi intervals by the use of adjusted pressure losses, is shown on Fig. 5. Volume weighted pressure losses for the squares into which the basin had been sub-divided were determined from this map of pressure drawdown in the basin in conjunction with an isopach map of the clean sand thickness in the basin and are presented on Fig. 6.

Match of Pressure Loss in the Basin

The reservoirs that had produced or were producing from the Woodbine formation were surveyed to determine which of them had production of sufficient magnitude to cause water efflux from the basin into the reservoirs in such quantities as to affect appreciably the pressure pattern of the basin. The water efflux from the basin was expressed in terms of the rates of water influx into the various reservoirs considered. The water influx rates of each of these reservoirs were calculated for their producing histories where the necessary data existed and were carefully estimated for the fault line fields where water production data were not available. The effects

Table I — Daily Average Water Influx Rates

Year	Prod. Contr. No. 1 Sq.: F-5a* East Texas B/D	Prod. Contr. No. 2 Sq.: E-5 East and West Hawkins B/D	Prod. Contr. No. 3 Sq.: D-6 Van B/D	Prod. Contr. No. 4 Sq.: C-9 Cayuga B/D	Prod. Contr. No. 5 Sq.: D-10 Long Lake B/D	Production Controller No. 6 Sq.: E-10					Production Controller No. 7 Sq.: B-9				Production Controller No. 8 Sq.: B-10			
						Navarro Crossing B/D	Buffalo B/D	Grapeland B/D	Percilla B/D	Group Total B/D	Powell B/D	Richland B/D	Currie B/D	Group Total B/D	Wortham B/D	Nigger Creek B/D	Mexia B/D	Group Total B/D
1921																	17,000	17,000
1922													7,000	7,000			137,000	137,000
1923											103,000		9,000	112,000			103,000	103,000
1924											189,000	17,000	8,000	214,000			81,000	81,000
1925											142,000	25,000	5,000	172,000	11,000		67,000	78,000
1926											119,000	22,000	4,000	145,000	57,000	8,000	64,000	129,000
1927											112,000	23,000	4,000	139,000	39,000	35,000	64,000	138,000
1928											98,000	25,000	4,000	127,000	31,000	22,000	57,000	110,000
1929											95,000	24,000	5,000	124,000	24,000	15,000	53,000	92,000
1930			13,000								93,000	18,000	4,000	115,000	19,000	10,000	48,000	77,000
1931	379,000		39,000								76,000	7,000	4,000	87,000	9,000	4,000	43,000	56,000
1932	504,000		56,000								63,000	4,000	3,000	70,000	4,000		36,000	40,000
1933	725,000		53,000								77,000	4,000	3,000	84,000	3,000		36,000	39,000
1934	646,000		14,000								71,000	4,000	3,000	78,000	3,000		36,000	39,000
1935	621,000		76,000								72,000	3,000	3,000	78,000	3,000		40,000	43,000
1936	603,000		25,000								75,000	2,000	3,000	80,000	2,000		40,000	42,000
1937	666,000		33,000		12,000			1,000		1,000	82,000	1,000	4,000	87,000	2,000		40,000	42,000
1938	629,000		11,000		34,000		2,000	—		2,000	78,000	2,000	3,000	83,000	2,000		39,000	41,000
1939	637,000		15,000		27,000		2,000	—		2,000	74,000	2,000	4,000	80,000	2,000		38,000	40,000
1940	624,000		12,000		16,000	8,000	1,000	4,000		13,000	71,000	2,000	4,000	77,000	4,000		36,000	40,000
1941	724,000		11,000		11,000	—	—	14,000		14,000	69,000	4,000	4,000	77,000	13,000		38,000	51,000
1942	697,000		2,000	4,000	28,000	6,000	—	14,000		20,000	62,000	3,000	5,000	70,000	13,000		40,000	53,000
1943	609,000		—	42,000	54,000	1,000	3,000	17,000		21,000	54,000	2,000	6,000	62,000	11,000		37,000	48,000
1944	559,000		11,000	70,000	48,000	—	1,000	33,000		34,000	54,000	2,000	5,000	61,000	8,000		37,000	45,000
1945	545,000	7,000	23,000	124,000	61,000	4,000	3,000	22,000		29,000	49,000	2,000	5,000	56,000	7,000		36,000	43,000
1946	489,000	13,000	21,000	134,000	46,000	6,000	2,000	24,000	1,000	33,000	60,000	3,000	5,000	68,000	6,000		36,000	42,000
1947	467,000	12,000	19,000	70,000	60,000	9,000	12,000	21,000	1,000	43,000	60,000	3,000	5,000	68,000	6,000		36,000	42,000
1948	443,000	15,000	32,000	69,000	82,000	7,000	8,000	18,000	3,000	36,000	60,000	3,000	5,000	68,000	6,000		32,000	38,000
1949	368,000	16,000	33,000	55,000	73,000	5,000	2,000	14,000	2,000	23,000	64,000	3,000	4,000	71,000	7,000		28,000	35,000
1950	372,000	14,000	25,000	52,000	63,000	8,000	2,000	3,000	2,000	15,000	63,000	3,000	4,000	70,000	6,000		28,000	34,000

*Note: The squares in which East Texas Field lay were subdivided into smaller divisions so that one condenser represented just the fluid capacitance of East Texas Field.

of production from the various reservoirs were reproduced on the analyzer by the withdrawal of currents proportional to the rates of water influx from the condensers corresponding to the areas in which the reservoirs lay. Since the analyzer used in this study has only eight current controller units, some of the reservoirs were grouped together. The water influx rates, reservoir groups, and squares from which current withdrawals were made are presented in Table I.

By a trial-and-error procedure of adjusting the resistor values representing the resistance to flow and the magnitude of the currents proportional to the water influx rates, the change in voltage across the condenser representing each square was made proportional to the volume-weighted pressure drop calculated for the square as of Jan. 1, 1947. In order to obtain a more nearly unique match of the whole basin, the voltage decline of the condenser representing the East Texas Field was made to simulate the volume weighted pressure decline of the field. The resultant voltage declines of the two condensers representing the Van Field and the Oakwood Field were then found to be reasonably consistent with the observed pressure declines in the two fields. Since these two comparisons appeared reasonable, it was felt that a fairly accurate solution of the pressure distribution had been obtained. Fig. 7 shows the distribution of the pressure drawdown in the basin as of Jan. 1, 1947, obtained with the analyzer. The agreement of these pressure changes with those shown on Fig. 6 is indicative of the accuracy of the analogy used.

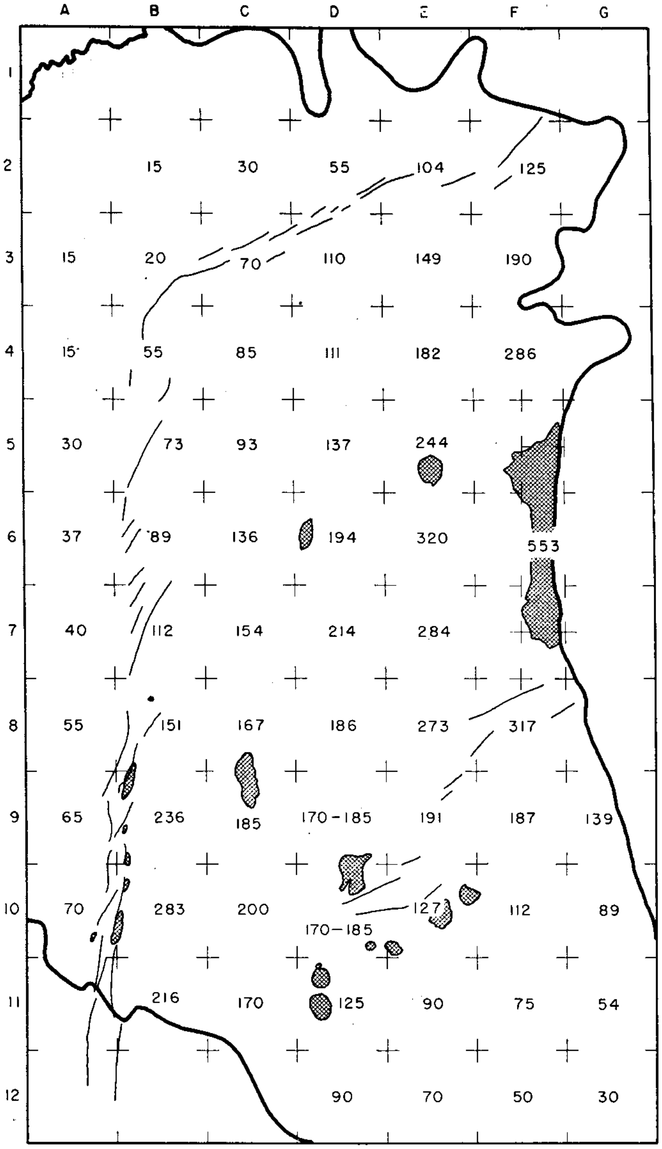

FIG. 6 — VOLUME-WEIGHTED PRESSURE LOSS AS OF JAN. 1, 1947 — OBSERVED.

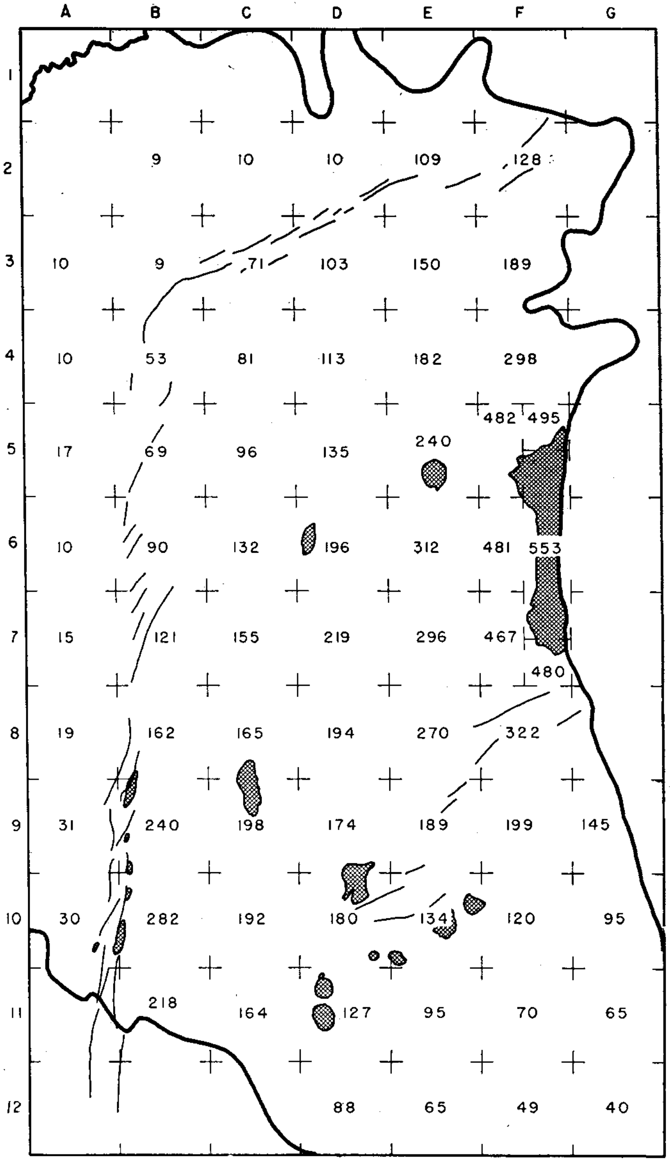

FIG. 7 — PRESSURE LOSS AS OF JAN. 7, 1947 — ANALYZER.

Compressibility of Water

The proportionality constants, or analyzer constants, between fluid units and electrical units determined from the study of the basin distribution of pressure are presented in Table II. One of these constants, "M," which was found to be 3.28×10^{-6} microfarads/bbl/psi, was used in Equation (1) with the values of the condensers representing the basin to compute the apparent compressibility of the water in the Woodbine basin. The porosity of this formation throughout the basin was assumed to be constant at 25 per cent. This computed value for the apparent compressibility, 5.3×10^{-8} vol/vol/lb/sq ft, is somewhat higher than the value of 1.85×10^{-8} vol/vol/lb/sq ft that was measured on samples of Woodbine water taken during drill stem tests. A study of the production-pressure relationship in the East Texas Field reported in the literature in 1938 indicated an apparent compressibility of 1.11×10^{-7} vol/vol/lb/sq ft for Woodbine water.[2] Earlier investigators reported values as high as 12 times the compressibility of pure water.[3,4]

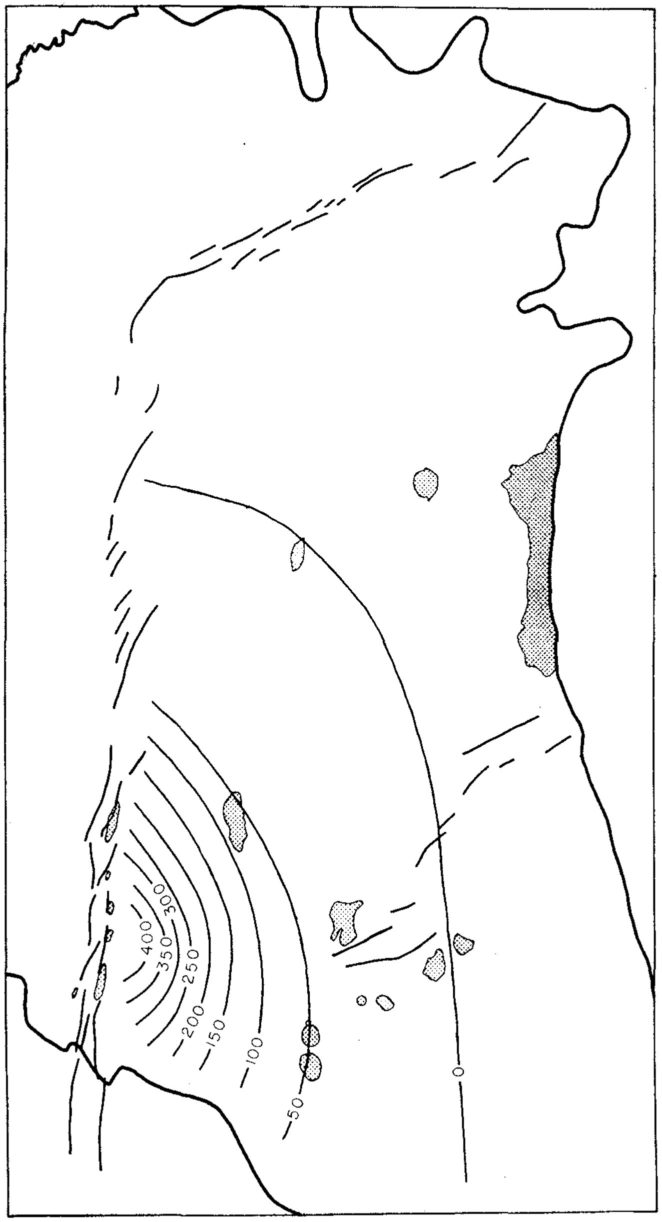

FIG. 8 — PRESSURE LOSS — JAN. 1, 1930.

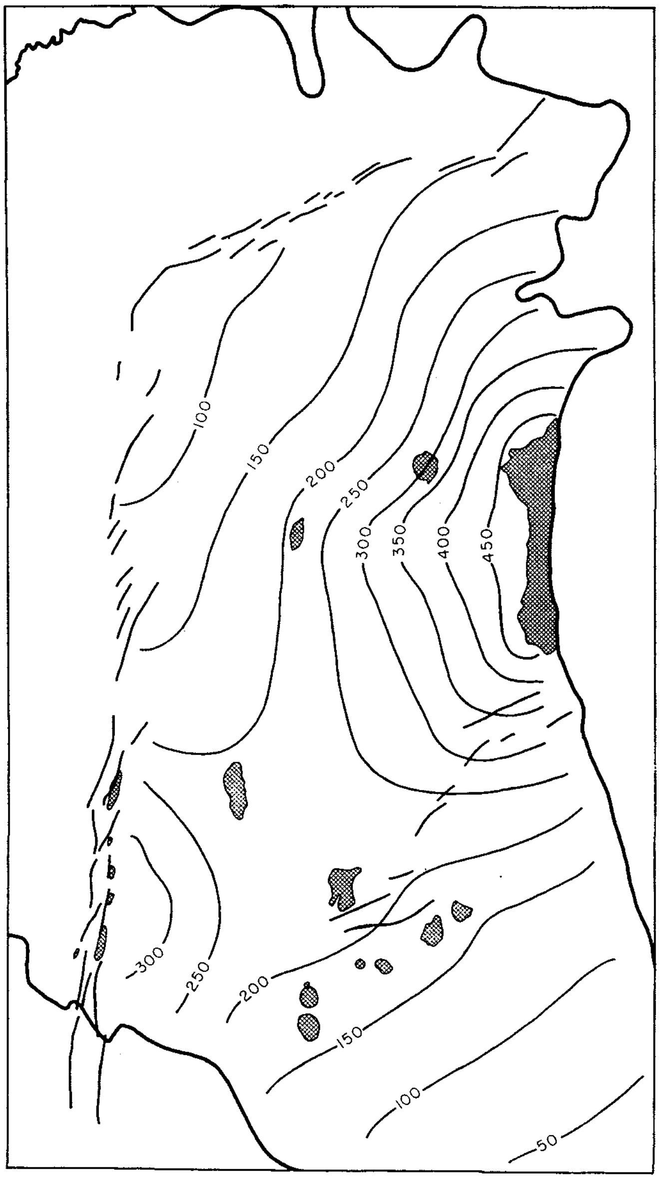

FIG. 9 — PRESSURE LOSS — JAN. 1, 1950.

A Bureau of Mines publication on the compressibility of consolidated sandstones presented information from which the effect of pressure on the pore volume could be computed.[5] The measured effect of pressure loss on Woodbine sand was to reduce the size of the pore volume by an amount equal to 2.85×10^{-8} vol/vol/lb/sq ft. On the assumption that this effect would be additive with the compressibility of the Woodbine water, the effective compressibility in the Woodbine aquifer would be 4.7×10^{-8} vol/vol/lb/sq ft. The agreement between this value and that experimentally determined with the analyzer is rather close and is well within the over-all accuracy of the analyzer study. However, the difference between the two might be accounted for by some other phenomenon which would result in a reduction of the volume of the pore space or by the intrusion of extraneous water into the Woodbine formation.

Table II — Analyzer Constants

Constant	Units	Pool Unit	Water-Drive Unit
L	volts/psi	0.300	0.3261
L/N	$\frac{\text{microamps}}{\text{B/D}}$	1.44×10^{-4}	1.246×10^{-4}
MN	sec/D	6.849×10^{-3}	8.219×10^{-2}
N	$\frac{\text{megohms}}{\text{psi/B/D}}$	2088	2617
M	$\frac{\text{microfarads}}{\text{B/psi}}$	3.28×10^{-6}	3.141×10^{-5}

As in independent approach, the apparent compressibility of Woodbine water was determined from the ratio of cumulative water yielded by the formation to the integrated product of the volume of Woodbine water and its observed loss in pressure to Jan. 1, 1947. For this purpose the water yielded was considered to be the sum of the volume of water influx into all fields producing from the Woodbine formation. This procedure gave a value of 5.6×10^{-8} vol/vol/lb/sq ft. The difference between this value and that obtained with the analyzer indicates the accuracy with which the basin pressure behavior was simulated on the analyzer.

Permeability Distribution

From another analyzer constant, "N," which was found to be 2,088 megohms/psi/B/D, Equation (2), and the values of the various resistors, the effective permeabilities at various locations in the basin were determined. In general, the permeability was found to be in the range of 1,000 to 1,500 md around the East Texas Field and to decrease to values from 100 to 700 md as the Mexia-Talco fault line is approached. Continuity across the fault block appeared to be very limited.

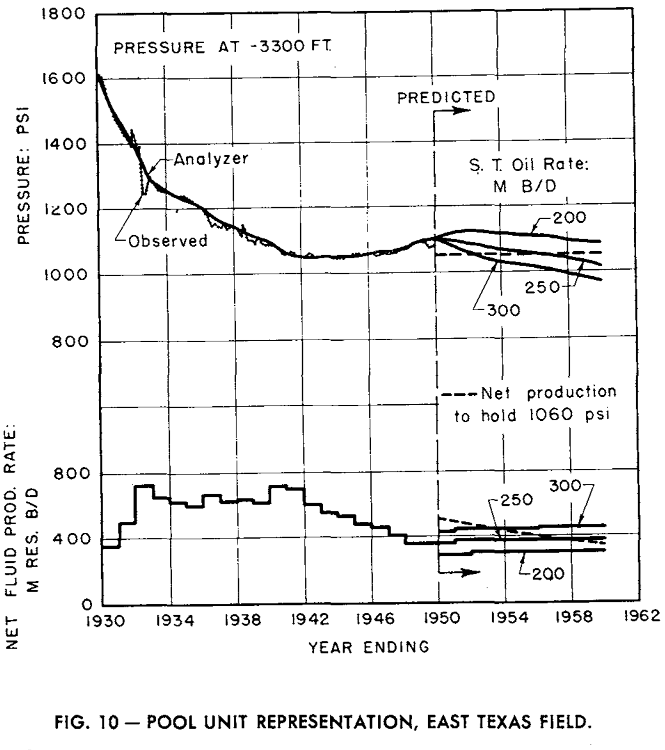

FIG. 10 — POOL UNIT REPRESENTATION, EAST TEXAS FIELD.

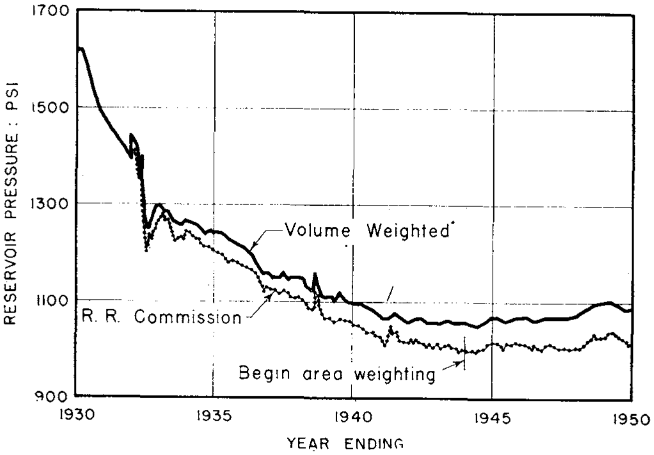

FIG. 11 — COMPARISON OF VOLUME-WEIGHTED AND AREA-WEIGHTED PRESSURES, EAST TEXAS FIELD.

Basin Pressure Behavior

The analyzer study indicated the manner in which the pressure drawdown throughout the basin has developed since production of the Woodbine fields began. Figs. 8 and 9 show the pressure drawdown of the basin in 1930 and 1950. Major production from the basin began in 1921 with production from the Mexia-Powell fault-line fields, and by 1930 a pressure sink of some 400 psi was established around the Mexia-Powell area with a perceptible drawdown occurring as far east and north as 60 to 70 miles. The East Texas Field was discovered and began producing from the east edge of the basin late in 1930. Between this date and 1950 the production from the fault line fields declined, and the production from the East Texas Field became the dominant influence on the pressure of the basin. By 1950 marked interference existed between these two producing areas as is evident by the distortion of the pressure distribution about them, and their effects caused a pressure drawdown in all of the basin east and south of the Mexia-Talco fault.

STUDY OF THE EAST TEXAS FIELD

Pressure Predictions with the Pool Unit

One of the major controls in obtaining a match of the pressure distribution of the Woodbine basin on the reservoir analyzer was the duplication by the analyzer of the pressure history of the East Texas Field. This match of the pressure-production history of East Texas with the pool unit is shown on Fig. 10. The observed pressures in this illustration are the average pressures obtained by volume weighting. This

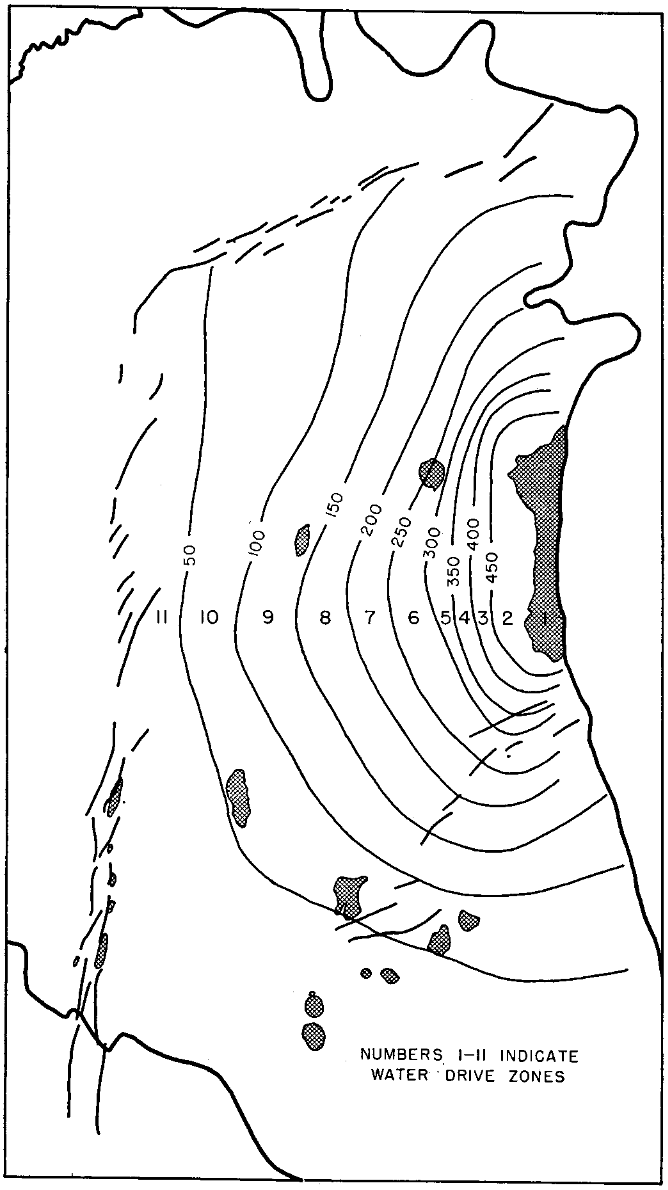

FIG. 12 — PRESSURE DRAWDOWN OF WOODBINE BASIN DUE TO EAST TEXAS FIELD PRODUCTION.

Table III — Estimates of Water Production

Oil Rate S.T. B/D	Date	Water Rates Production B/D	Water Rates Injection B/D
200,000	1-1-51 to 9-1-52	502,200	452,000
	9-1-52 to 9-1-59	637,400	573,700
	9-1-59 to 1-1-61	688,100	619,300
250,000	1-1-51 to 4-1-52	532,300	479,000
	4-1-52 to 10-1-57	707,600	636,800
	10-1-57 to 1-1-61	769,000	692,100
300,000	1-1-51 to 1-1-52	563,100	506,760
	1-1-52 to 7-1-56	777,700	700,000
	7-1-56 to 1-1-61	851,750	766,600

method of obtaining an average pressure for the field was used in place of the customary procedure of area-weighting, since the pressure obtained from the analyzer is a volume-weighted pressure. A comparison of the pressures derived from the two methods of averaging is presented on Fig. 11.

The pool unit representation of the East Texas Field was used to make predictions of the pressure in the field for the period Jan. 1, 1951, to Jan. 1, 1961, using oil production rates of 200,000, 250,000, and 300,000 bbl of stock-tank oil per day. The estimates of water production presented in Table III were based on the following assumptions:

1. The number of marginal wells will remain constant.
2. The rate of oil production from the marginal wells will remain at 20,419 bbl of stock-tank oil per day, the rate existing on Jan. 1, 1950.
3. The other wells will produce at a rate of 20 bbl of stock-tank oil per producing day.
4. Ninety per cent of the produced water will be returned to the Woodbine formation.
5. The rate of fluid production from the other fields producing from the Woodbine will be maintained at their 1950 rates.

Fig. 10 shows the predicted pressure behavior of the East Texas Field for the above rates of oil production. The 200,000 bbl of stock-tank oil per day rate resulted in a pressure rise from 1,100 to 1,130 psi by 1953, followed by a gradual decline to 1.095 psi by Jan. 1, 1961. The 250,000 bbl of stock-tank oil per day and the 300,000 bbl of stock-tank oil per day rates caused the reservoir pressure to decline over the 10-year period to 1,060 and 970 psi, respectively.

In addition to these predictions, the rate of net reservoir withdrawal that would be required to hold the volume-weighted pressure constant at 1,060 psi was determined for the period 1951 to 1961. A volume-weighted pressure of 1,060 psi during this period corresponds to an area-weighted pressure of approximately 990 psi. This rate was found to decrease gradually from the initial net fluid withdrawal rate of 500,000 reservoir B/D to 360,000 reservoir B/D. These rates are equivalent to 320,000 and 230,000 bbl of stock-tank oil per day, respectively. This study indicated that, even though the basin is considerable in expanse, the portion readily available for the water drive under which the East Texas Field is producing is bounded on the north and west by the Mexia-Talco fault, across which there is limited continuity. This should have a significant effect on future field behavior, and should necessitate the return to the formation of nearly all produced water and a gradual decrease in production rate to maintain an area-weighted pressure of 990 psi.

Determination of Available Water

In order to determine whether the water yield will be sufficient from the Woodbine basin to produce by water drive the two and a half billion bbl of recoverable oil remaining in the East Texas field, the effects of maintaining the pressure at two different levels were investigated by means of the pool unit representation of the basin. It was determined that if the volume-weighted pressure in the reservoir is maintained at 1,020 psi, six billion bbl of water will enter the East

Table IV — Average Permeability in the Water-Drive Zones

Zone	Permeability millidarcys	Zone	Permeability millidarcys
1-2	1,644	6-7	723
2-3	1,866	7-8	699
3-4	755	8-9	722
4-5	761	9-10	351
5-6	655	10-11	294

Texas reservoir from the Woodbine basin. Similarly, if the reservoir pressure is maintained at 820 psi, ten billion bbl of Woodbine water will enter the reservoir. Hence, it appears that there will be more than sufficient water yield from the Woodbine aquifer to produce by water drive the remaining two and a half billion bbl of stock-tank oil from the East Texas Field if the present practice of returning 90 per cent or more of the produced water to the Woodbine formation is continued.

Representation on the Water-Drive Unit

The detailed variations in reservoir pressure caused by abrupt changes in the production rate were not duplicated on the pool unit of the analyzer, since the field was assumed to have an average rate of withdrawal for each year. To match the month-to-month fluctuations in pressure, it was desirable that the water-drive unit be employed because the greater number of time periods available on that unit permitted a breakdown of the production history into smaller increments. To transfer the problem from the pool unit to the water-drive unit, it was desirable to determine the pressure distribution in the Woodbine basin due to production from the East Texas Field alone. With the same pool-unit network used to obtain the match of the volume-weighted pressure decline of the East Texas Field, the basin pressure drawdown due solely to the production from the East Texas Field was determined as of Jan. 1, 1947, and is shown on Fig. 12.

In the transfer of the problem from the pool unit to the water-drive unit of the analyzer, the Woodbine aquifer was divided into 11 approximately semi-circular, concentric zones about the East Texas Field with zone boundaries corresponding to the pressure contours shown on Fig. 12. Each of these zones was represented by an electrical capacitance, the value of which was computed from the water compressibility determined on the pool unit to be 5.3×10^{-8} vol/vol/lb/sq ft and from data regarding the size and thickness of the aquifer.

Table V — Water-Drive Resistor and Condenser Values

Zones	Resistor megohms	Condenser microfarads
1	0.280	8
2	.200	10
3	.200	15
4	.300	19
5	.200	15
6	.300	45
7	.300	81
8	.300	103
9	.800	155
10	1.600	250
11	off	310

To arrive at apparent permeabilities for each of the zones, the zone boundaries were superimposed on a map showing the apparent permeabilities that were obtained from the pool unit. An average value was then estimated for the permeability between adjacent concentric zones. These values are presented in Table IV and were used in calculating the values of the water-drive resistors. The representation of the East Texas Field and its aquifer on the water-drive unit, then, was consistent with the pool-unit representation insofar as compressibility of the Woodbine water and the apparent permeability distribution of the aquifer were concerned. The constants for both the pool-unit and water-drive unit studies are presented in Table II. Table V presents the values of the water-drive resistors and condensers.

In an ideal aquifer for any finite time, the pressure drawdown at a point a given distance from a production point is theoretically a linear function of the rate of production. This fact, in conjunction with the principle of superposition, indicates that the pressure drawdown resulting from production a given distance away is always independent of the number of production points. This would indicate that the effect of any basin production on the pressure in the East Texas Field might be closely approximated in the water-drive unit study by the withdrawal of a proportional current from the zone condenser corresponding to the area in which the point of production lay.

A satisfactory match of the volume-weighted pressure behavior of the East Texas Field was obtained on the analyzer by the withdrawal of appropriate production from the zones in which producing fields lay. This match is shown on Fig. 13. As a further check on the validity of this method of representing the problem, predictions of the pressure behavior of the East Texas Field were made at the same rates of produc-

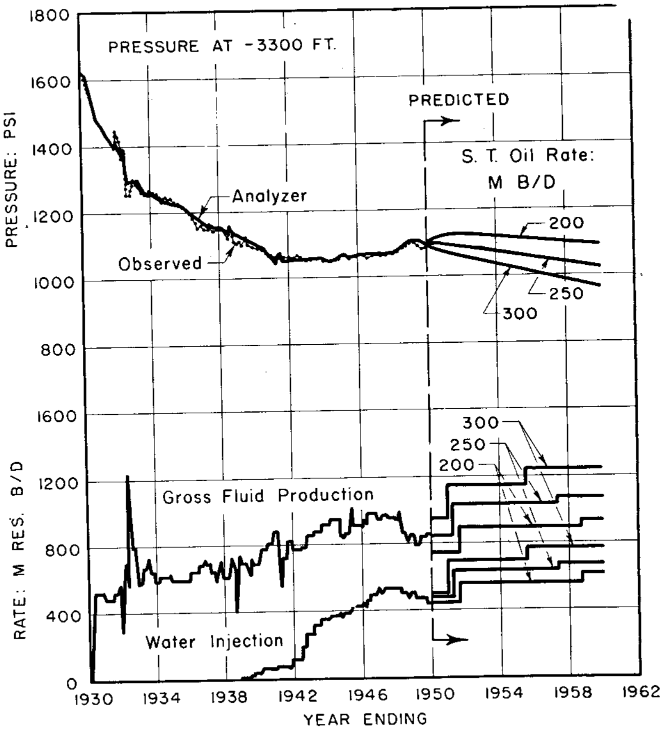

FIG. 13 — WATER DRIVE UNIT REPRESENTATION, EAST TEXAS FIELD.

tion as were used in the pool-unit study. The predictions with the water-drive unit are presented on Fig. 13. These predictions check closely with those obtained in the pool-unit study. The close agreement between the two methods indicates that even though there is interference between fields, reservoir studies can be made of those fields with the water-drive unit.

CONCLUSIONS

The analyzer study of the Woodbine basin indicates that the value of the effective compressibility of water used in conventional mathematical reservoir studies should be higher than that of the water alone. The agreement between the value, 5.3×10^{-8} vol/vol/lb/sq ft, obtained for the apparent compressibility of the Woodbine water and the sum, 4.7×10^{-8} vol-vol/lb/sq ft, of the measured compressibilities of the water and sand indicates that these may be the major components of the apparent compressibility.

The study indicated that the apparent permeability of the Woodbine sand is 1,000 to 1,500 md in the vicinity of the East Texas Field, and decreases to 100 to 700 md near the Mexia-Talco fault line. The data on the pressure drawdown west of the Mexia-Talco fault line were too meager to determine accurately the long range effect of the fault on the pressure distribution in the Woodbine basin; however, there appears to be little effective communication across the fault line.

The presentation of the Woodbine basin on the analyzer provides a satisfactory match of the pressure performance in the East Texas Field, and should therefore furnish a convenient means of predicting future pressures. However, the pressure behavior of the field should still be predictable with the use of the mathematical equations if the proper boundary conditions are applied. The magnitude of the effects of the Mexia-Talco fault line and the production from other fields on the pressure of the East Texas Field are of sufficient magnitude that they must now be accounted for in any computation of the performance of the field. This study of the performance of the East Texas Field and of the associated Woodbine aquifer on the reservoir analyzer indicated that if the present practice of returning 90 per cent or more of the produced water to the Woodbine formation is continued, an area-weighted pressure of 990 psi can be maintained provided there is also a gradual decrease in the rate of production. The study further indicated that with the current practice of return of produced water, there will be sufficient water yield from the aquifer to produce the East Texas Field to depletion under the water-drive mechanism.

REFERENCES

1. Bell, John S., and Shepherd, J. M.: "Pressure Behavior in the Woodbine Sand," *Trans.* AIME (1951) **192,** 19.
2. Buckley, S. E.: "The Pressure-Production Relationship in the East Texas Field," API *Drill. and Prod. Prac.* (1938), 140.
3. Schilthuis, R. J., and Hurst, W.: "Variations in Reservoir Pressure in the East Texas Field," *Trans.* AIME (1935) **114,** 164.
4. Muskat, M.: "Flow of Compressible Fluids Through Porous Media and Some Problems in Heat Conduction," *Physics* (1934) **5,** 71.
5. Carpenter, C. B., and Spencer, G. B.: "Measurements of Compressibility of Consolidated Oil-Bearing Sandstones," *Bureau of Mines RI 3540* (October, 1940).

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