Geol Survey

STATE OF ILLINOIS

DEPARTMENT OF REGISTRATION AND EDUCATION

AN ESTIMATE OF FUTURE CRUDE OIL PRODUCTION IN ILLINOIS

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ILLINOIS PETROLEUM 91

ILLINOIS STATE GEOLOGICAL SURVEY

1969

URBANA, ILLINOIS

AN ESTIMATE OF FUTURE CRUDE OIL PRODUCTION IN ILLINOIS

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ABSTRACT

Future oil production in Illinois for the period 1970-1989 is estimated at 533 million barrels. This prediction is based on regression analysis of primary and secondary (waterflood) oil production data. Of the total, 109 million barrels will be produced by primary methods and 424 million barrels by secondary methods.

INTRODUCTION

Oil producers, economists, financiers, and government planning agencies are but a few of the many interested in knowing how oil production will change in the future. An estimate of this production in Illinois, based on the extrapolation of both primary and secondary oil production decline curves, is presented.

Acknowledgments

The writer wishes to express his gratitude to Hubert M. Bristol, T. F. Lawry, and J. Van Den Berg, of the Illinois State Geological Survey, who supplied data and gave valuable suggestions during discussions of the problems of predicting future oil production.

REVIEW OF PAST PRODUCTION HISTORY

Figure 1 is a graph of the history of oil production in Illinois since 1904. As can be seen, Illinois oil production reached an all-time peak of approximately 148 million barrels in 1940. In 1951, waterflooding became an important source of oil production in Illinois, when over 9 million barrels were produced by secondary recovery methods. In 1961, waterflodd production in the state reached a peak of 52.7 million barrels, and since that time, has steadily declined.

The influence of secondary production (almost 100 percent of which is from waterfloods) on the state's total oil production can be seen in figure 1. During 1955-1962, increasing waterflood production essentially offset the decline in primary production so that the state's total oil production remained fairly constant at about 80 million barrels. In 1963, the state's total oil production began to decline because both primary and secondary oil production were declining.

SOURCE OF PRODUCTION DATA

In the past, the Illinois State Geological Survey has accumulated oil production data on an annual basis. The state's total oil production generally has been derived from reports of pipeline runs, which have been published by oil industry scouting services. Where pipeline data is inadequate, major oil company sources have been used. Since 1949, data on secondary oil production in the state have been gathered and published annually by the Geological Survey from the individual waterflood operators.

The annual oil production decline data used in this report for the projections of future oil production are given in table 1. Total oil production data were taken directly from Van Den Berg, Lawry, and Mast (1968, table 14, p. 118). Secondary oil production in table 1 is the sum of oil production from controlled waterfloods, estimated dump floods, and pressure maintenance operations.

Data for controlled waterflood production and estimated dump flood production can be found in table 18 of Van Den Berg, Lawry, and Maat (1968). Data for production from pressure maintenance operations were taken from the Survey's annual reports for each year (see Selected Bibliography). The primary oil production figures in table 1 are simply the difference between total oil production and secondary oil production data given in table 1.

QUALITY OF PRODUCTION DATA

Total oil production data have been accumulated in the same way for many years, though changes have occurred in the company preparing the pipeline report and in the method of handling the data. These changes occasionally have caused some minor unexplained variations in reported production over the years; however, in general, the data available are of good quality.

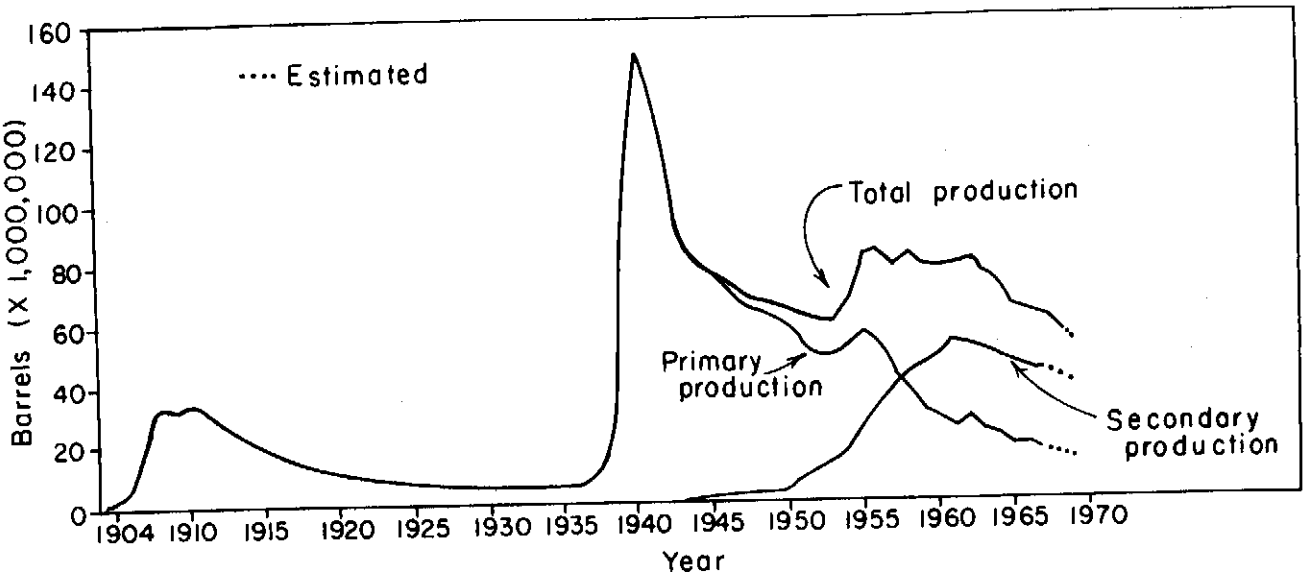

Fig. 1 - Annual oil production in Illinois.

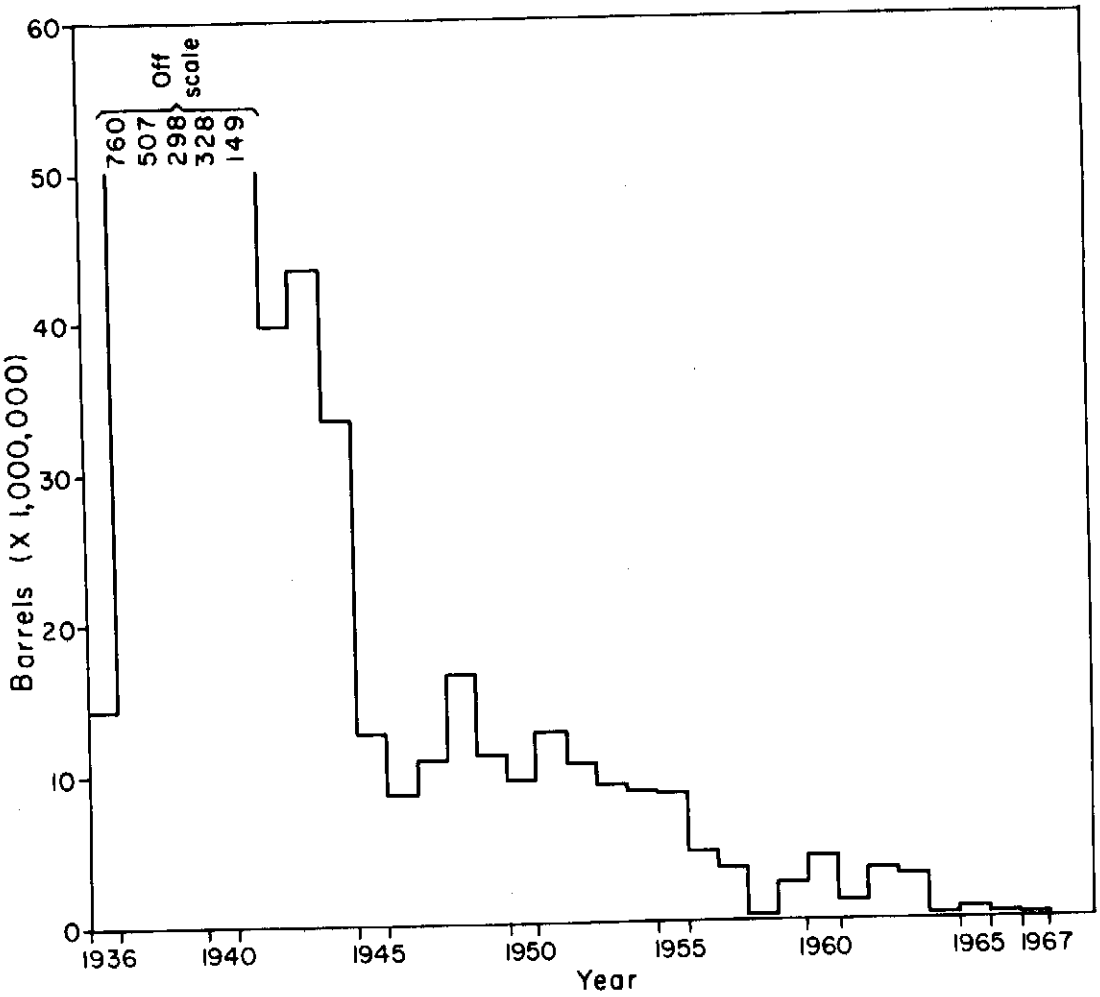

Fig. 2 - 1967 estimate of ultimate recovery from fields discovered in Illinois from 1936-1967. Source: A.G.A., A.P.I., and C.P.I. (1968).

TABLE 1 - ILLINOIS OIL PRODUCTION DATA

Year	Total oil	Primary oil	Secondary oil
1955		53,484,000	
1956		49,886,000	
1957		39,661,000	
1958		36,606,000	
1959		31,809,000	
1960		29,764,000	
1961		24,759,000	52,719,000
1962	78,796,000	27,430,000	51,366,000
1963	74,796,000	23,802,000	50,994,000
1964	70,168,000	20,645,000	49,523,000
1965	63,708,000	18,702,000	45,006,000
1966	61,982,000	18,331,000	43,651,000
1967	60,115,000	16,181,000	43,934,000
1968	56,391,000		41,891,000†
1969	51,720,000*		38,720,000†

*Last 7 months estimated.
†Total oil minus estimated primary.

Data on secondary recovery in the state have been collected by sending questionnaires annually to the individual waterflood operators. Although the response to these requests over the years has been excellent, data on some waterflood operations have not been reported. Generally, these missing production figures represent only a small part of the total secondary oil produced in the state and are partially compensated for the fact that some of the reported waterflood production probably includes some primary oil. It is my opinion that the reported secondary oil production data closely correspond to the actual secondary production in the state.

REGRESSION ANALYSIS OF PRODUCTION DATA

Oil production decline curves are widely used in the petroleum industry to predict future performance of oil reservoirs. Curves are fitted to production data by the method of least squares. Different curves (i.e., exponential or hyperbolic) usually can be correlated with the rock type and the production mechanism of a given reservoir.

Very little information exists regarding methods for predicting the future oil production of an entire state (essentially a large group of reservoirs). Production from already discovered reservoirs is continually declining while new reservoirs are being discovered. In addition, production mechanisms are continually changing as primary solution gas drive reservoirs are converted to secondary water drive reservoirs by waterflooding.

In order to find the most reasonable solution to this problem, both linear and exponential curves have been fitted to Illinois total, primary, and secondary oil production data given in table 1. The results of this analysis and the general form of the equations that were determined are presented in table 2. Table 3 summarizes the projected cumulative oil production for 1970-1979, 1980-1989, and 1970-1989 using the curves computed from the least squares regression analysis. The data in tables 2 and 3 were used to determine the best method of extrapolating Illinois future oil production.

TABLE 2 - OIL PRODUCTION REGRESSION DATA AND GENERAL EQUATIONS

Type regression line	Slope (m_1)	Decay factor (m_2)	y Intercept (b_1)	Original amplitude (b_2)	Correlation coefficient
Illinois Total Oil Production					
Linear	-3,731,067		309,094,148		-.9892
Exponential		-0.02506		2.8110×10^9	-.9867
Illinois Primary Oil Production					
Linear	-2,919,936		208,193,727		-.9551
Exponential		-0.04192		1.0135×10^{10}	-.9871
Illinois Secondary Oil Production					
Linear	-1,740,738		159,570,543		-.9771
Exponential		-0.01641		5.3874×10^8	-.9663
Pennsylvania Secondary Oil Production					
Linear	-419,798		30,336,287		-.9841
Exponential		-0.02335		1.2517×10^8	-.9741

General Equations

Linear

$$y_1 = m_1 x_1 + b_1$$

y_1 = Annual production
x_1 = (Year-1900)
m_1 = Slope
b_1 = y Intercept

Exponential

$$y_2 = b_2 10^{m_2 x_2}$$

y_2 = Annual production
x_2 = (Year-1900)
m_2 = Decay factor
b_2 = Original amplitude

TABLE 3 - PROJECTED CUMULATIVE PRODUCTION IN BARRELS, BASED ON REGRESSION DATA

Production	Type regression	Cumulative oil production		
		1970-1979	1980-1989	1970-1989
Total oil	Linear	311,000,000	24,000,000*	335,000,000*
	Exponential	387,000,000	217,000,000	604,000,000
Primary oil	Linear	6,000,000†	-	6,000,000†
	Exponential	79,000,000	30,000,000	109,000,000
Secondary oil	Linear	299,000,000	125,000,000	424,000,000
	Exponential	325,000,000	222,000,000	547,000,000
Primary oil + Secondary oil	Exponential + Linear	378,000,000	155,000,000	533,000,000

* Reaches zero in 1983
† Reaches zero in 1972

Total Production

Both the linear and exponential curves fitted to the total oil production data had very high correlation coefficients (-0.9892 and -0.9867, respectively). Because these coefficients are nearly equal, it is difficult to decide which of the curves would best describe the future oil production for Illinois. Integration of the exponential curve for 1970-1989 results in a cumulative production of 604 million barrels, (table 3). In contrast, integration of the linear extrapolation for the same period yields a cumulative production of only 335 million barrels. Consequently, it was concluded that the total oil production decline data were insufficient to predict future oil production with the relatively simple mathematical expressions that were employed.

Primary Production

Primary oil production in the state began declining in 1940; however, a significant reversal of this trend occurred in 1954 and 1955 (fig. 1), which has been attributed by Whiting and Oros (1957) to the widespread use of hydraulic fracture treatment of wells. As seen in figure 1, the post-1955 decline rate in primary production is greater than the decline rate from 1945-1954. This change well reflects the drop in annual crude oil discoveries in Illinois (fig. 2) that was experienced after 1955. Basically, then, the extrapolation of the curve fitted to the 1955-1967 primary decline data assumes that the future discovery of oil will continue to decline at approximately the same rate as in the 1956-1967 period.

Analysis of the data given in table 2 indicates that the exponential curve best fits the 1955-1967 primary oil production data. Assuming that the economics of oil production in future years remains comparable to that of the past 15 years, extrapolation of this curve (fig. 3) should give reliable estimates of future primary oil production in Illinois.

Secondary Production

Secondary oil production began to decline in 1961. Because the Survey collects data during the year following the actual production year, at the time these projections were made, no data on secondary oil production were available for 1968 and 1969. However, data on total oil production were available through May 1969. Total oil production for the entire year was estimated by taking the ratio of oil production for the first five months of 1969 to the oil production during the same period in 1968 times the total oil production in 1968. Secondary oil production figures for 1968 and 1969 were estimated by subtracting the extrapolated value of the primary production decline curve for these years from the total oil production. As a result, secondary oil production decline data were available for curve fitting for the nine-year period from 1961 through 1969.

Analysis of the data in table 2 indicates that a straight line best fits the secondary oil production data. In order to gain some confidence in applying a linear decline to forecast Illinois secondary production, linear and exponential curves were fitted to the secondary production data for Pennsylvania from 1937 to 1966. These data were taken from Lytle, Heyman, and Wagner (1967, fig. 4, p. 11). The results of this analysis are shown in table 2. The correlation coefficient for the linear curve (-0.9841) is better than that for the exponential curve (-0.9741). Therefore, it was concluded that a linear extrapolation of Illinois secondary oil production data should provide the best forecast of future secondary production.

Sherman, in 1961, estimated future oil production in Illinois. His extrapolation of future primary production based on primary decline data from 1955-1960 is essentially the same as the one presented in this paper. In 1961, waterflood production was still increasing, so that no decline data were available upon which to base future estimates. His forecast of future secondary production, however, was too conservative, primarily because an exponential curve with a large decay factor was employed to estimate future secondary production.

A major factor in estimating secondary production is the rate of future development of waterflood projects. Unfortunately, this is difficult to predict with certainty, as improvements in technology are continually adding reservoirs to the list of those that can be profitably developed for waterflood. Table 4, taken from Mast (1967), gives Illinois reservoir data on the rock and fluid properties, total reservoir pore volume, and percentage of these reservoirs that already have been developed for waterflood as of January 1, 1966, based on pore volume. Study of the information indicates that large reservoir volumes are

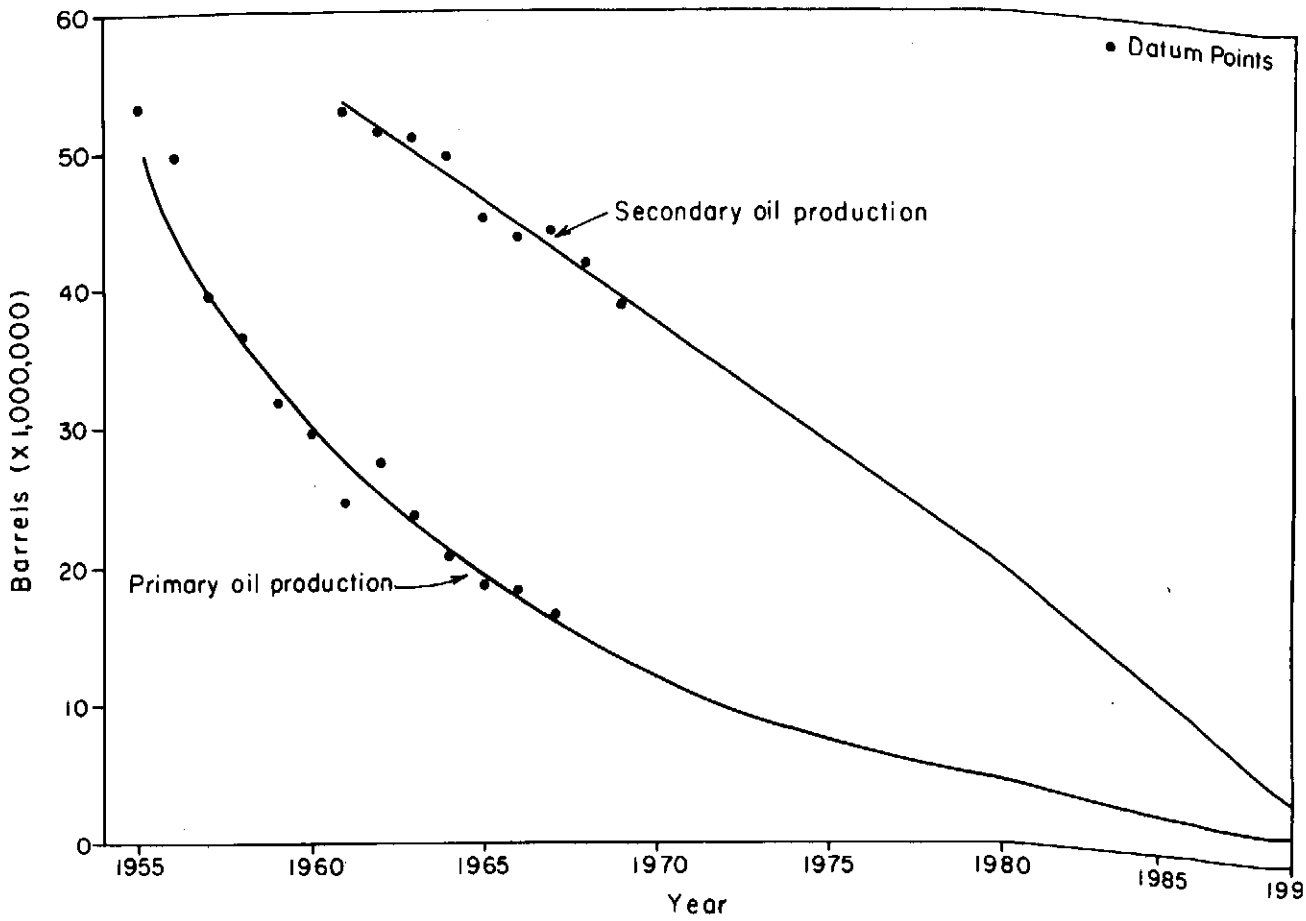

Fig. 3 - Primary and secondary oil production decline curves for Illinois.

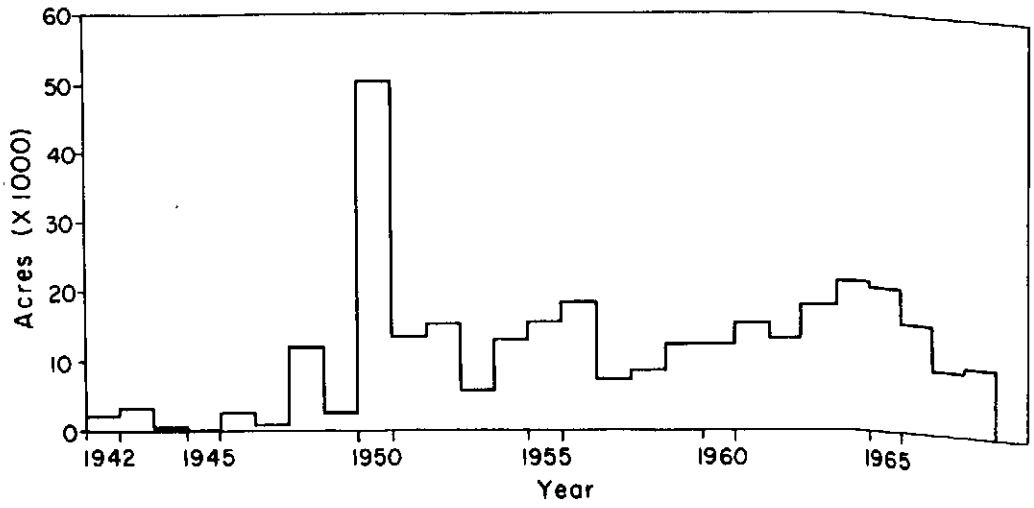

Fig. 4 - Acres developed for waterflood each year in Illinois.

TABLE 4 - VOLUME, DEVELOPMENT, AND PROPERTIES OF ILLINOIS PETROLEUM RESERVOIRS, AS OF JANUARY 1, 1967

Unit	Depth interval	Total reservoir pore volume (bbls x 1 million)	Under flood (%)	Reservoir properties						Fluid properties			
				Pore volume per acre (bbls)		Porosity (%)		Permeability (md)		Gravity (API)		Viscosity (cp)	
				M*	SD†	M	SD	M	SD	M	SD	M	SD
SANDSTONES													
Pennsylvanian	250-499	528	59	48,000	16,000	19	1	180	108	32	4	20	19
	500-2,250	3,140	46	37,000	6,800	19	1	110	59	36	2	8	7
Chesterian	0-1,999	3,280	73	30,000	8,500	18	1	110	47	37	2	7	3
	2,000-3,500	2,500	43	23,100	8,000	18	1	90	57	36	2	7	4
Aux Vases	500-2,649	482	65	24,300	8,100	16	2	46	28	37	1	6	1
	2,750-3,500	2,100	55	22,800	4,500	18	1	97	39	38	1	6	1
All other	500-5,500	304	35	14,500	3,000	15	2	200	235	37	2	6	3
SILTSTONES	500-4,250	180	30	38,600	12,300	14	2	19	20	37	1	7	2
OOLITIC LIMESTONE													
Ste. Genevieve	0-2,499	237	62	16,800	3,300	15	1	258	81	37	1	6	1
	2,500-4,500	1,898	30	14,400	3,300	16	1	168	109	38	1	5	1
LIMESTONE AND DOLOMITES													
Devonian, Silurian, and Ordovician	0-5,000	1,033	36	36,600	20,800	13	2	48	61	38	4	8	8
All other	250-4,500	446	18	15,400	5,800	17	3	206	265	37	2	7	3

*M=Mean

†SD=Standard deviation

still available for future waterflood development. In general, these undeveloped reservoirs tend to be deeper and thinner than those that are now more extensively developed. It is anticipated that because of improving technology and the availability of these reservoirs, Illinois oil operators will continue to develop waterfloods for several years. However, significant changes in technology and the economics of waterflood production could quickly alter this picture.

Figure 4 shows the total number of acres developed annually for waterflood in Illinois from 1942 to 1968. As can be seen, waterflood development in the state has declined since 1964. It is estimated that waterflood development for the next 10 years will probably bring an average of 5000 acres per year under flood and that this development rate should be enough to sustain the present linear decline rate of 1.74 million barrels per year.

RESULTS OF THE FORECAST

Table 3 gives the cumulative oil production resulting from the extrapolation of the exponential primary production curve and the linear secondary production curve. During 1970-1989, it is estimated that 533 million barrels of oil will be produced in Illinois. Of the total, 109 million barrels will be produced by primary methods and 424 million by secondary methods. A production schedule for 1970-1989 as well as the specific equations used to determine this schedule are in table 5. A graph of the data and the projections are shown in figure 3.

The above estimates are neither optimistic nor conservative. Curve-fitting techniques are empirical and, in essence, estimates derived from them depend on how well a given process can be characterized by the past performance data. In one sense, the complexities of the state's oil industry make it difficult to evaluate these projections. On the other hand, most of the controlling factors should be well represented in the past performance data and the projections should prove to be reasonable estimates of future performance. These estimates are based on the following assumptions:

(1) Discoveries of new oil accumulations will continue to decline at the same rate as in the 1956-1968 period.

(2) Waterflood development will continue at a rate of 5000 acres per year for the next 10 years.

(3) Factors affecting the economics of oil production in Illinois will remain constant or improve somewhat in future years. Some of these factors are:

   a. technology
   b. price of crude oil
   c. government regulation
   d. taxation.

TABLE 5 - PROJECTED ANNUAL OIL PRODUCTION FOR ILLINOIS, 1970-1989, IN THOUSANDS OF BARRELS*

Year	Primary	Secondary	Total	Cumulative
1970	11,800	37,700	49,500	49,500
1971	10,700	36,000	46,700	96,200
1972	9,720	34,240	43,960	140,160
1973	8,820	32,500	41,320	181,480
1974	8,010	30,760	38,770	220,250
1975	7,270	29,020	39,290	256,540
1976	6,600	27,270	33,870	290,410
1977	6,000	25,530	31,530	321,940
1978	5,440	23,790	29,230	351,170
1979	4,940	22,050	26,990	378,160
1980	4,490	20,310	24,800	402,960
1981	4,080	18,570	22,650	425,610
1982	3,700	16,830	20,530	446,140
1983	3,360	15,090	18,450	464,590
1984	3,050	13,350	16,400	480,990
1985	2,770	11,610	14,380	495,370
1986	2,510	9,870	12,380	507,750
1987	2,180	8,130	10,310	518,060
1988	2,070	6,390	8,460	526,520
1989	1,880	4,640	6,520	533,040

*Equations used for projection:

$$\text{Annual primary production} = \left[1.0135 \times 10^{10}\right]\left[10^{(-0.04192)\ (1900\text{-year})}\right]$$

$$\text{Annual secondary production} = \left[-1{,}740{,}738\right]\left[1900\text{-year}\right] + \left[159{,}570{,}543\right]$$

These assumptions, which are made in extrapolating the production trends, in all likelihood will be most closely approximated during the early years of the forecast. Therefore, more confidence can be placed in the forecast for 1970-1979 than 1980-1989.

Any analysis of the future of an industry as large as the oil industry in the state of Illinois must include a discussion of the factors that could significantly alter its future. Economists and social scientists have predicted large population growth and even larger expansions in the industrial base required to support our growing society. By 1980, this expansion could increase the demand for petroleum and natural gas in the United States an estimated 50 percent above the 1965 level (United States Dept. of Interior, 1968).

As a result of this increased demand, active exploration for deep, potentially productive oil reservoirs in Illinois (Bell et al., 1964) could be realized before 1990. In addition, research continues on

new methods for recovering more oil from the already known accumulations. Processes have been developed that can recover additional large quantities of oil from reservoirs that have been waterflooded. However, these processes have not as yet proved to be economically feasible. It is estimated that if a new recovery process is proved economical during the next 10 to 15 years, it could add 500 million to 1 billion barrels of oil to Illinois recoverable reserves.

In addition to these possibilities, the need for more energy could require a basic change in its source. Risser (1968) discusses the potential of Illinois coal reserves as a source of manufactured coal gas. In the event that gas is produced from Illinois coal, Illinois oil reservoirs are well located to serve as storage reservoirs for this gas. This could result in some increased oil recovery, as a result of gas injection. Oil recovery and gas storage have been profitably applied in several instances in the underground storage of natural gas (Elenbaas, Buck, and Vary, 1968; Oil and Gas Journal, 1967). In fact, two projects in which oil is being produced from gas storage reservoirs are now active in Illinois.

Risser (1962) has also pointed out that the Illinois-Missouri mineral resource complex can provide an excellent base for future industrial development. As our industrial complex expands, so will the problem of industrial liquid waste disposal. The Illinois-Missouri area, as described by Risser, contains most of the Illinois oil reservoirs, which could be used as future sites for industrial waste disposal. Much of the geologic and engineering information concerning the suitability of these reservoirs for such disposal is already available. This includes information regarding salinity of the brines, rock porosity and permeability, fluid injection, and adequacy of cap rocks. In addition, the oil industry can provide much of the equipment and "know-how" that is required to inject large volumes of fluid underground.

Disposal projects might also be designed to recover petroleum from unflooded reservoirs. The economics of such operations would depend on the future requirements of the Illinois industrial complex for waste disposal.

CONCLUSIONS

Estimates of future oil production in Illinois indicate that approximately 533 million barrels of oil will be produced from 1970 to 1989. At the present price of crude oil of $3.35 per barrel, the 533 million barrels would have a total value of 1.8 billion dollars.

Future demand for crude oil and natural gas could bring active exploration of Illinois deep sediments in the next 20 years and also help make economically attractive new recovery processes. In addition, the expansion of industry within the state could lead to the further utilization of Illinois oil reservoirs for gas storage and waste disposal.

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