Empirical Oil Recovery Forecast Models for Waterflood Infill Drilling in West Texas Carbonate Reservoirs

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ABSTRACT

Empirical oil recovery forecast models were developed for waterflood infill drillings in San Andres and Clearfork carbonate reservoirs of Permian Basin. The models were developed using field waterflood databases and the geographical distributions of the ultimate recovery efficiencies. The study evaluated the incremental oil recovery by infill drilling without acceleration of expected oil recovery. Results of testing the empirical oil recovery forecast models indicated an average error of less than six per cent. The forecast models are applicable to a wide range of unit sizes. They are useful for initial evaluations of waterflood infill drilling performance and for property evaluation.

The dominant factors affecting the infill drilling ultimate recovery are found to be primary ultimate recovery (geology, pay connectivity, rock properties, etc.), well spacing and development strategies. When the well spacing is to be reduced to below 20 acres, a targeted infill drilling based on reservoir geology, reservoir properties and past production performance should be contemplated instead of a blanket pattern infill drilling.

INTRODUCTION

Infill drilling is a viable incremental oil recovery strategy for waterflooding heterogeneous carbonate reservoirs[1-12]. The carbonate reservoirs are complex and heterogeneous, thereby, responsive to infill development. San Andres and Clearfork are two of the prolific oil producing carbonate formations in west Texas. Much of the oil remains in the ground unrecoverable when the well spacing is over 35 acres/well.

Infill drilling can enhance both areal and vertical sweep efficiencies to improve the oil recovery. Driscoll[1] described the advantages of infill drilling in low permeability waterfloods. He illustrated nine factors affecting recoveries including pattern modification and improved sweep efficiencies.

Many articles reported that improving the pay continuity between wells is a primary reason for the success of infill drilling. Barbe et al.[7] reported that West Texas carbonate reservoirs are more discontinuous than originally believed.

San Andres and Clearfork databases[11,12] are established to study the impact of infill drilling on the oil recovery and economics. They are also useful for developing empirical oil recovery forecasting models for waterflood infill drillings. The databases developed in this program provide a statistical inference of the impact of infill drilling on the waterflood recovery. However, the database analysis does not provide detailed information on the effect of geological, reservoir, process, and operational factors on the recovery efficiency. Therefore, Monahans Clearfork unit study is used to provide detailed unit reservoir and production data that may clarify some of the uncertainties inherent in the database study.

IMPACT OF INFILL DRILLING ON OIL RECOVERY

Infill Drilling and Well Spacing

Infill drilling is defined as drilling additional wells in an existing producing unit to optimize the oil recovery. As a result of infill drilling the inter-well connectivity of heterogeneous flow units is increased. An increase in inter-well connectivity should increase the oil recovery, especially for waterflooding and other improved oil recovery processes. Since most producing units are developed on varying well spacings for pattern development, it is difficult to determine the well spacing for the entire unit. We define the average well spacing as the number of acres per well regardless wether the well is a producer or an injector. Or, it is defined as the ratio of the total productive area to the total number of wells. For convenience, the average well spacing and well spacing are considered synonymous in this paper.

The well spacing is often chosen based on the recovery strategy, reservoir characteristics, individual operator's operating policy, crude oil market and economics. Traditional waterflood well spacing is over 40 acres although it has been reduced to 20 acres and some even lower than 10 acres.

The practice of infill drilling has been very controversial. The controversy may stem from the uncertainty associated with the complexity and adversity of reservoir characteristics, variability of operations schemes, and differences in technical and economic analysis. Some may argue that the additional oil recovery due to infill drilling is either accelerated recovery or incremental recovery or both. Our data indicated that infill drilling provides incremental oil recovery, not just acceleration of the oil recovery. The question is how much is the incremental oil recovery per infill well? And what is the economic impact of the infill drilling on the recovery project?

Field Case Study - Monahans Clearfork Unit

This case study shows how the basic reservoir data can be used to examine the impact of infill drilling on the ultimate oil recovery. Monahans Clearfork Unit is located on the western portion of the Central Basin Platform in the Permian Basin of West Texas (Fig. 1). Henning and Wilson[13] discussed the geological settings for Monahans Clearfork Unit.

Monahans Clearfork Unit is a northwest-southeast trending anticline with gently sloping flanks (Fig. 2)[14]. The entire unit covers a productive area of about 4,700 acres. Oil production is from the interval between 4,700 ft to 5,400 ft with an average net pay of 70 feet[15]. From discovery to 1990, about 250 wells were drilled with an average well spacing of 20 acres. The oil recovery efficiency by primary depletion and waterflood up to April 1990 is 18.2 %OOIP.

In addition to the entire unit study, Section 37, which is located at the center of the unit (Fig. 2), is selected for a detailed infill drilling study. This selected section has a productive area of 690 acres. There are 37 wells in this section including 19 production wells, 13 water injection wells, and 5 abandoned wells (Fig. 3). Twenty one wells in Section 37 have modern log suites. Two cored wells provide core analysis data. These data were used to characterize reservoir rock properties and estimate the original oil in place.

Unit Production Performance Analysis

The unit production performance is shown in Fig. 4. The primary oil production in Monahans Clearfork Unit started in July 1945. As more wells were drilled, the oil production increased very rapidly. By May 1948, the unit oil production first reached its maximum rate of 70,000 BOPM. Since solution gas was the main driving mechanism for primary production, reservoir pressure declined very rapidly, which resulted in sharp decline in oil production. By mid 1952, the unit monthly oil production dropped to about 13,000 BOPM. During the period from 1952 to 1957, additional 27 wells were completed. The addition of these new wells resulted in a substantial incremental oil recovery.

Waterflood in Monahans Clearfork Unit started in 1962. The initial waterflood was peripheral which included 20 injection wells. Response of oil production to the initial waterflood was a significant increase in oil production rate from about 10,000 BOPM at the end of 1962 to about 15,000 BOPM at the early 1965. After that, the unit oil production rate remained constant for about 6 years, followed by a decline to about 10,000 BOPM at early 1974. The production could not be further increased because the peripheral waterflood had a limited sweep efficiency.

In 1974, a large-scale field development was initiated which included infill drilling, pattern modification of waterflood, well re-completion and well treatments. The impact of well spacing reduction on oil production was very significant. There was a sharp increase in oil production from 10,000 BOPM at early 1974 to about 40,000 BOPM at late 1975, four time increase in production rate. Then the unit production fluctuated for several years and began to decline again. The average well spacing at that time was about 40 acres. Further well spacing reduction to 20 acres resulted in another substantial increase in oil production.

The ultimate oil recovery for different well spacings was estimated from decline curve analysis. The economic limit was 3 STB per well per day. Both exponential and hyperbolic decline curve were analyzed and the results were compared. Results from hyperbolic decline analysis only is reported. Table 1 summarizes the results from the unit production performance analysis. As the well spacing decreases from 75 acres to 36 acres, the ultimate oil recovery efficiency increases from 8.5 to 15.0 %OOIP. As the well spacing is further reduced to 19 acres, the ultimate recovery efficiency increases from 15.0 to 23.3%OOIP.

Section 37 Production Performance Analysis

The oil production performance of Section 37 is shown in Fig. 5. The effect of well spacing on oil recovery can be clearly seen in the plot. We identified 3 well spacing cases for Section 37: 63 acres, 46 acres, and 19 acres. The 46-acre case includes waterflood without changing the well spacing. The results are shown in Fig. 5 and summarized in Table 2.

As it is shown in the table, when the well spacing is reduced from 63 acres to 46 acres, the ultimate recovery efficiency increases from 6.4% to 9.3% of OOIP. For waterflood infill drilling, well spacing reduction from 46 acres to 19 acres increases the ultimate recovery efficiency by about 12% of OOIP.

In order to better evaluate the impact of well spacing reduction on the ultimate oil recovery, we combined the results obtained from both the unit and Section 37. Fig. 6 shows the ultimate recovery efficiency distribution. As it can be seen, the impact of well spacing reduction on the ultimate oil recovery for waterflood infill drilling is greater than that for primary production. The combination of unit study and section study provides a more detailed and clear picture of how well spacing reduction affect the ultimate recovery efficiency. Estimated ultimate recovery efficiencies from the primary production at the average well spacing of 130, 75, 45 acres are 3.4, 6.4, and 9.3% of OOIP, respectively. Estimated ultimate recovery efficiencies from waterflood infill drilling at the average well spacing of 75, 46, and 19 acres are 8.5, 12.2, and 23.9% of OOIP, respectively. The result from the analysis of well spacing reduction versus ultimate recovery may provide important information for future recovery projection and further development of improved oil recovery process.

EMPIRICAL OIL RECOVERY FORECAST MODELS

Database

Two databases are developed for San Andres and Clearfork units in West Texas for waterflood infill drilling analysis. San Andres database has twenty-one units (Table 3) and Clearfork database has twenty-three units (Table 4). Results of database analysis indicate that the average waterflood incremental recovery per infill well in the carbonate reservoirs ranged from 25,000 to 380,000 stock tank barrels. The majority of the units in our databases has an incremental recovery greater than 40,000 STB/infill well. A large percentage of the units studied indicates a reasonably good economic return for waterflood infill drilling when the well spacing decreases from approximately 40 acres to approximately 20 acres.

Major Factors Affecting Infill Drilling Recovery

It is interesting to note from the infill drilling study that the initial waterflood ultimate recovery efficiency is, to a certain extent, a function of the primary ultimate recovery efficiency; and the infill drilling on the initial waterflood ultimate recovery efficiency. Also noted is that the initial waterflood ultimate recovery appears to be inversely proportional to the initial waterflood well spacing (WWS), and the infill drilling ultimate waterflood recovery is proportional to well spacing reduction (WSR) from the initial waterflood well spacing to infill drilling well spacing (IWS).

The primary and waterflood ultimate recovery efficiencies appear to be geographically controlled and appear to be dependent on the geological setting. Fig. 7 and 8 show the geographical distribution of the primary ultimate recovery. Based on the geographical distribution the San Andres units are grouped into five regions and Clearfork units into six regions. The effect of infill drilling on the ultimate recovery efficiency is investigated for the eleven groups.

Figs. 9 through 11 show the ultimate oil recovery efficiency as a function of well spacing for the regions. The average slope of the ultimate oil recovery efficiency versus well spacing represents the impact of well spacing reduction. The high impact level has a slope greater than 1.00. The slope of moderate impact level is between 0.400 to 1.00. The slope of the low impact level is less than 0.400.

It is interesting to note that the well spacing reduction is more effective for San Andres units than for Clearfork units. It is also of interest to note that in both San Andres and Clearfork units, the well spacing reduction is more effective for the units located in Northern Shelf than those located in Central Basin Platform. Results from the geographical distribution and the impact of well spacing reduction may indicate the effect of depositional environments and relative location from the basins and platform margins.

Development of Empirical Oil Recovery Model

The following empirical oil recovery forecast models were developed based on the above observations for the San Andres and Clearfork units in the databases. These models were developed using multi-variable regression analysis. The models may be used to provide an initial estimate of the ultimate recovery as a reference point for further infill drilling evaluation. The results obtained from the use of the models should be carefully assessed with a sound geological and engineering evaluation.

For the San Andres units, the initial waterflood ultimate recovery (1000's STB) may be expressed as[12]:

$$IWUR = 8.517(PRUR)^{0.971}(WWS)^{-0.347} \quad (1)$$

IWUR = the initial waterflood ultimate recovery in 1000's STB.
PRUR = the primary ultimate recovery in 1000's STB.
WWS = the initial waterflood well spacing in acres per well.

The infill drilling ultimate recovery may be expressed as[12]:

$$IDUR = 1.098(IWUR)^{1.036}(WSR)^{0.178} \quad (2)$$

IDUR = the infill drilling ultimate recovery in 1000's STB.
WSR = (WWS-IWS)/WWS.
IWS = the infill drilling well spacing in acres per well.

For the Clearfork units, the initial waterflood ultimate recovery (1000's STB) may be expressed as[12]:

$$IWUR = 14.538(PRUR)^{0.958}(WWS)^{-0.507} \tag{3}$$

The infill drilling ultimate recovery may be expressed as[12]:

$$IDUR = 1.607(IWUR)^{1.016}(WSR)^{0.282} \tag{4}$$

The empirical oil forecast models are improved using infill drilling recovery index (IDRI). The infill drilling recovery index (IDRI) is defined as,

$$IDRI = \frac{((IR - WR)/WR)}{((WWS - IWS)/WWS)} \tag{5}$$

The IDRI is correlated with the reservoir, process and operational parameters for the units in each geographical region. The correlation models for IDRI are tabulated in Tables 5 and 6. For a particular unit in a geographical region, IDRI is a constant because it is only dependent upon reservoir properties, operating parameters and production data of the unit in the region. Once the value of IDRI for a unit is determined from the correlation model, it is used to calculate the infill drilling ultimate oil recovery efficiency using the following correlation,

$$IR = (IDRI + 1)*WR - \frac{IDRI*WR*IWS}{WWS} \tag{6}$$

The projected infill drilling ultimate recovery efficiency, IR, is a function of the expected infill drilling well spacing, IWS.

Depending on the selection of WR and WWS we have two extrapolation techniques to project the expected infill drilling ultimate recovery efficiency. One approach uses the initial waterflood WR and WWS which is designated as "straight-line extrapolation." The other approach uses current infill drilling WR and WWS which is designated as "stage-by-stage extrapolation." It is recommended to use the average of the projected future ultimate infill drilling recoveries by the two approaches as the expected future ultimate infill drilling recovery.

We have compared the performance of the IDUR and IDRI infill drilling oil recovery forecast models. Result are presented in Fig. 12 and Fig. 13, respectively. As can be observed, the IDRI models are superior.

APPLICATION

Johnson JL AB, Dollarhide AB and Monahans units are selected to test the accuracy of the IDRI forecast models. Results are shown in Fig. 14 through 16. The forecasted ultimate recovery efficiencies agree well with actual field value. The maximal absolute average relative error is less than 8.78%.

It is of interest to note that the results from the stage-by-stage extrapolation are greater than the actual value. However, the values from the straight-line extrapolation are less than the actual value. These two approaches appear to provide a range of forecasted infill drilling ultimate recovery efficiency at a particular infill well spacing. The average value appears to give the best recovery estimate as listed in Table 7.

Let us use Johnson JL "AB" unit as an example to illustrate the application of the IDRI empirical forecast model. The unit is located San Andres region #1 in Central Basin Platform. The IDRI is calculated using the following correlation,

$$\text{IDRI} = 1.7828 - 0.0000387\ \text{AREA} - 0.4788\ \text{HNG} - 1.6432\ \text{DP} - 0.001759\ \text{SW}$$

where AREA is the area of the unit in acres; HNG is the ratio of net to gross thickness; DP is the pressure gradient in psi/ft; and Sw is the initial saturation of water in percentage. The IDRI calculated is 0.50146. The initial waterflooding well spacing is 40 acres and ultimate recovery efficiency is 13.30 %OOIP. The well spacing of two subsequent infill drilling stages is 22 and 9 acres, respectively.

For the straight-line approach,the calculated infill drilling ultimate recovery efficiency is 16.30 %OOIP for 22-acre well spacing and 18.47 %OOIP for 9-acre well spacing. For the stage-by-stage extrapolation approach, the ultimate recovery efficiency is 16.30 %OOIP for 22-acre well spacing and 21.13 %OOIP for 9-acre well spacing. The field data indicated that the ultimate recovery efficiency of 9-acre infill drilling is 19.40 %OOIP. The relative error is -4.79 and 8.92%, respectively. If we use the average value of these two methods, the recovery efficiency is 19.8 %OOIP and the relative error is 2.06%.

CONCLUSIONS

1. A field example is used to illustrate an useful approach to evaluate the impact of well spacing reduction on the ultimate infill drilling recovery. Infill drilling provides incremental oil recovery from primary depletion and waterflooding.

2. Empirical oil recovery forecast models for waterflood infill drilling are presented. The models using infill drilling recovery index (IDRI) is recommended.

3. Based on primary recovery efficiency, San Andres and Clearfork units in the database are grouped into five and six geographical regions, respectively. Infill drilling ultimate recovery efficiency appears to be dependent on geological setting.

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NOMENCLATURE

API: API gravity of oil
AREA: Overall unit area (acres)
DEPTH: Formation depth (feet)
DP: The geological pressure gradient (psi/ft)
DRR: (IR-WR)/WR
FVF: Formation volume factor (RB/STB)
GPN: GROSS/(NET*(PERM**0.5))
GROSS: Gross thickness of pay zone (feet)
HNG: NET/GROSS
IDRI: DRR/WSR
IDUR: The infill drilling ultimate recovery in 1000's STB.
IR: Infill drilling ultimate recovery efficiency (% OOIP)
IWS: The infill drilling well spacing in acres per well.
IWUR: The initial waterflood ultimate recovery in 1000's STB.
KH: PERM * NET (md.ft)
NET: Net thickness of pay zone (feet)
PERM: Permeability (md)
POR: Porosity (%)
PRUR: The primary ultimate recovery in 1000's STB.
PR: Primary ultimate recovery efficiency (% OOIP)
PRESS: Formation pressure (psi)
SOP: (100-SW) * POR
SW: Initial water saturation (%)
TRAN: POR*VIS/PERM (cp/md)
VIS: Viscosity of oil (cp)
WR: Waterflood ultimate recovery efficiency (% OOIP)
WSR: (WWS-IWS)/WWS.
WWS: The initial waterflood well spacing in acres per well.

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Table 1
Summary of Unit Production
Performance Analysis

	Well Spacing (Acres/Well)	UOR* (MMSTB)	URF** (% OOIP)
Primary Production:	130	2.85	3.4
	75	5.35	6.4
Waterflooding:	75	7.08	8.5
	36	12.52	15.0
	19	19.47	23.3

Table 2
Summary of Section 37 Production
Performance Analysis

	Well Spacing (Acres/Well)	UOR (MMSTB)	URF (% OOIP)
Primary Production:	63	1.41	6.4
	46	2.06	9.3
Waterflooding:	46	2.71	12.2
	19	5.42	24.4

* UOR: Estimated Ultimate Oil Recovery.
** URF: Estimated Ultimate Recovery Efficiency

Table 3
San Andres Data

Name of Field/Unit	WSP acre/well	PR % OOIP	WSW acre/well	WR % OOIP	WSI acre/well	IR % OOIP
ADAIR "SA"	49.00	15.63	41.00	25.57	30.00	37.30
FUHRMAN MASCHO/BL10 "GBSA"	57.00	10.37	52.00	11.94	46.00	13.02
FUHRMAN MASCHO/BL9 "GBSA"	51.00	11.63	29.00	14.46	25.00	18.06
JOHNSON /"GB" "SA"	45.00	12.33	32.00	17.68	25.00	20.73
JOHNSON/ "AB" "SA"	56.00	8.17	22.00	18.96	9.00	28.11
LEVELLAND/N CEN UN "SA"	42.00	14.51	31.00	22.53	23.00	40.60
MABEE/JE MABEE 'A' "SA"	45.00	9.48	22.00	19.66	21.00	22.07
MEANS "SA"	48.00	14.70	36.00	32.00	19.00	37.79
OWNBY "SA"	60.00	14.60	50.00	27.32	41.00	30.10
OWNBY/BL GILSTRAP "SA"	40.00	12.44	32.00	35.43	20.00	42.41
SABLE "SA"	36.00	19.81	21.00	36.76	19.00	43.07
SEMINOLE/"SA"	48.00	18.82	30.00	42.57	26.00	51.04
SHAFTER "SA"	43.00	13.98	34.00	20.62	30.00	21.75
SLAUGHTER/IGOE SMITH "SA"	51.00	14.83	26.00	40.01	22.00	42.99
TRIPLE-N "GB"	89.00	10.14	51.00	22.08	28.00	25.53
WASSON/BENNET "SA"	33.00	8.23	24.00	21.02	15.00	25.44
WASSON/CORNELL "SA"	27.00	12.06	21.00	33.44	15.00	36.27
WASSON/DENVER "SA"	66.00	12.40	43.00	35.40	18.00	42.40
WASSON/REBORTS "SA"	70.00	13.46	36.00	29.08	32.00	31.51
WASSON/WILLARD "SA"	60.00	7.30	44.00	18.41	29.00	23.30
WEST SEMINOLE "SA"	56.00	7.39	39.00	18.61	24.00	23.54

Table 4
Clearfork Data

Name of Field/Unit	WSP acre/well	PR % OOIP	WSW acre/well	WR % OOIP	WSI acre/well	IR % OOIP
DIAMOND M/JACK	64.00	8.65	36.00	16.00	19.00	25.10
DIAMOND M/McLA AC 1	65.00	7.88	40.00	9.54	22.00	13.09
DOLLARHIDE/'AB'	34.00	11.34	33.00	22.68	15.00	32.64
FLANAGAN/CLEARFORK CONS	52.00	15.28	46.00	32.12	44.00	34.43
FULLERTON	40.00	13.56	36.00	21.33	26.00	37.04
GLDSMTH 5600/CA GLDSMTH	33.00	10.23	23.00	17.50	19.00	18.71
GOLDSMTH/LANDRETH (2)	41.00	24.38	40.00	35.08	30.00	42.47
LEE HARRISON/WEST	77.00	10.37	48.00	13.24	35.00	16.20
MONAHANS	75.00	6.30	38.00	14.60	20.00	25.10
NORTH RILEY "CF"	53.00	7.06	50.00	8.63	30.00	12.67
OWNBY/UCFU	51.00	9.33	50.00	17.08	31.00	25.53
PRENTICE 6700/6700 CLFK	43.00	12.57	42.00	15.50	33.00	23.72
PRENTICE/NE	53.00	17.25	49.00	24.79	25.00	44.08
PRENTICE/SW	40.00	16.14	29.00	36.58	16.00	57.38
ROBERTSON/NORTH	45.00	7.91	38.00	9.76	13.00	15.80
RUSSEL/7000 CFU	46.00	19.17	43.00	24.81	28.00	27.76
SMYER/EAST	85.00	8.39	44.00	19.69	33.00	24.79
SMYER/ELLWOOD "A"	40.00	10.44	32.00	24.22	28.00	29.52
WASSON 72/GAINES	42.00	12.30	41.00	14.69	32.00	15.88
WASSON 72/GIBSON	44.00	9.12	39.00	10.90	32.00	14.25
WASSON 72/SOUTH	41.00	16.76	29.00	22.61	27.00	25.13
WASSON 72/YOAKUM	81.00	17.67	57.00	18.74	51.00	20.23
WASSON NE CF/NORTH	53.00	14.53	45.00	18.54	37.00	20.89

Table 5
The Forecast Models for Infill Drilling Recovery Index
(San Andres Units)

For Central Basin Platform Region #1:

$$IDRI = 1.7828 - 0.0000387AREA - 0.4788HNG - 1.6432DP - 0.001759SW$$

R - square	=	0.9999
F value	=	3916.0
Prob > F	=	0.0003

For Central Basin Platform Region #2:

$$IDRI = 1.4248 + 0.07528TRAN$$

R - square	=	0.9941
F value	=	167.90
Prob > F	=	0.0490

For Northern Shelf Region #3:

$$IDRI = 1.5174*10^{14}*DP^{21.0241}*KH^{-1.7073}*SW^{-0.3599}*FVF^{-3.7094}$$

R - square	=	0.9991
F value	=	816.97
Prob > F	=	0.0001

For Northern Shelf Region #4:

$$IDRI = -0.8738 + 2.3657GPN$$

R - square	=	1.0000
F value	=	695946
Prob > F	=	0.0020

Table 6
The Forecast Models for Infill Drilling Recovery Index
(Clearfork Units)

For Central Basin Platform Region #1:

$$IDRI = -5.1485 + 0.01039GROSS + 0.06326API - 0.01746PERM$$

R - square	=	0.9998
F value	=	1622.8
Prob > F	=	0.0182

For Central Basin Platform Region #2:

$$IDRI = 54.4865*PR^{-1.9635}$$

R - square	=	0.9998
F value	=	6658.2
Prob > F	=	0.0078

For Northern Shelf Region #3:

$$IDRI = -19.122 + 0.001152DEPTH - 0.7245PERM + 0.02131SOP + 3.7301VIS$$

R - square	=	0.9968
F value	=	155.89
Prob > F	=	0.0064

For Northern Shelf Region #4:

$$IDRI = -27.8668 + 1.0463API$$

R - square	=	0.9343
F value	=	14.232
Prob > F	=	0.1650

For Northeast of Northern Shelf and Eastern Shelf Region #6:

$$IDRI = 1.9948 - 0.03837SW + 0.002678KH$$

R - square	=	0.9955
F value	=	222.54
Prob > F	=	0.0045

Table 7
Test Results

Name of Unit	Well Spacing (acre)	Actual Recovery (%OOIP)	Forecasted Recovery (%OOIP)	Relative Error (%)
Johnson JL AB	40(initial)	13.30	13.30	
	22.00	16.30	16.30	
	10.00	19.40	19.80	2.06
Dollarhide	37(initial)	24.29	24.29	
	31.00	25.75	27.28	5.94
	26.00	27.90	29.31	5.04
	21.00	33.25	32.07	-3.55
Monahans	75(initial)	8.50	8.50	
	36.00	15.00	14.99	
	19.00	23.30	21.61	-7.25
Average Absolute Relative Error				4.77

* Using the average value resulted from two methods .

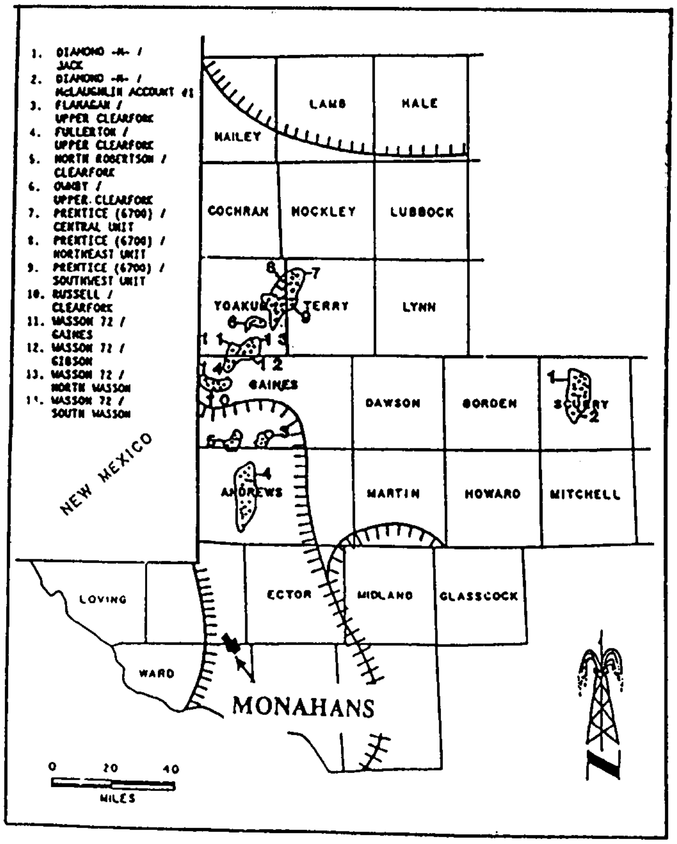

Figure 1 - Monahans Clearfork Field location map

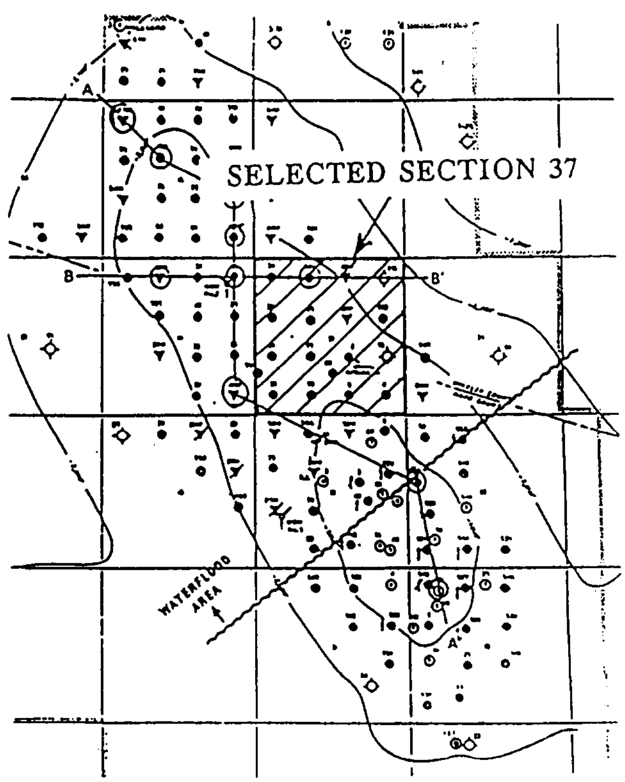

Figure 2 - Monahans Clearfork Unit map
(from reference 14)

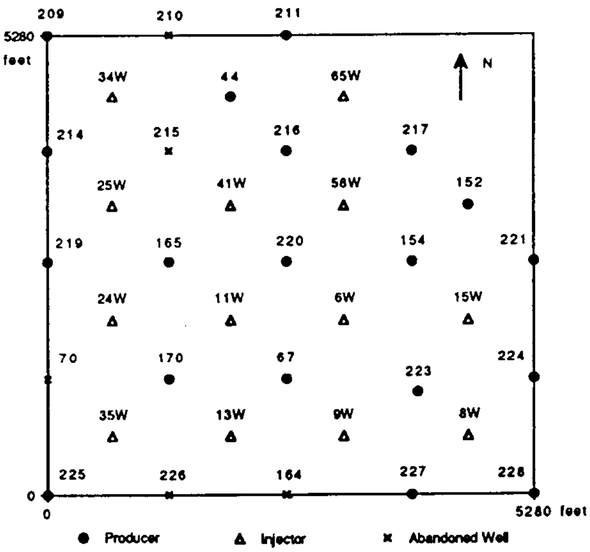

Figure 3 - Detailed well location map
Section 37 of Monahans
Clearfork Unit

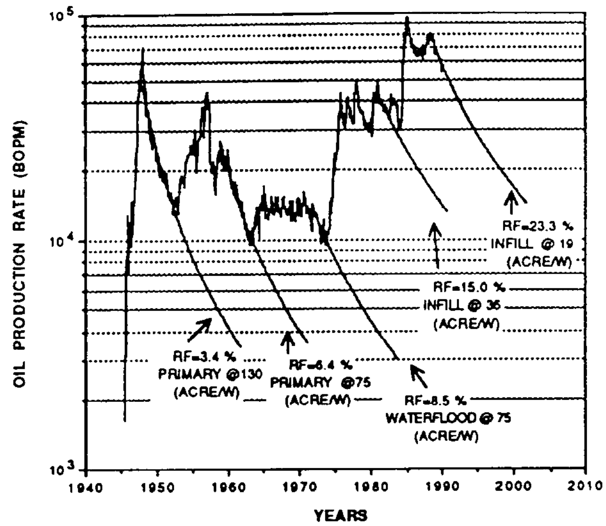

Figure 4 - Oil production decline analysis
Monahans Clearfork Unit

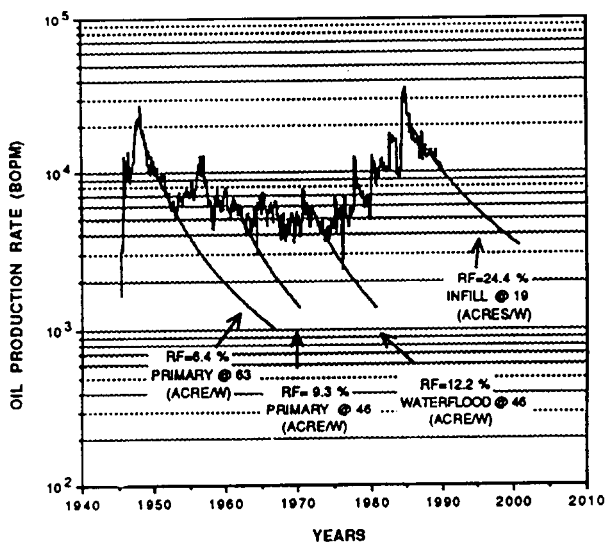

Figure 5 - Oil production decline analysis
Section 37 of Monahans
Clearfork Unit

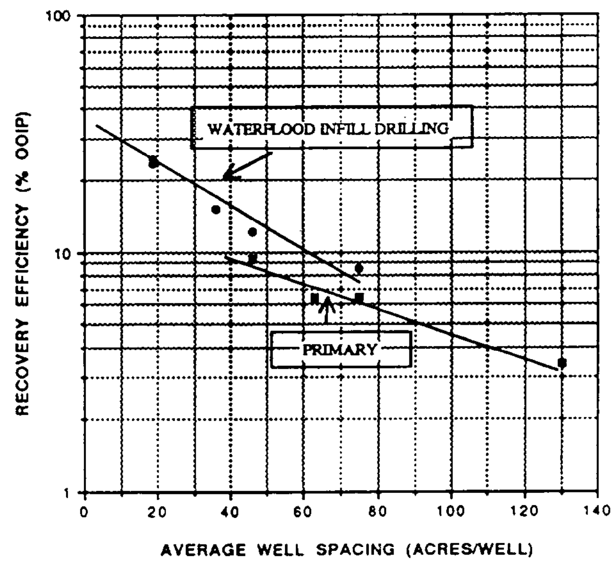

Figure 6 - Impact of well spacing reduction
on oil recovery efficiency
Monahans Clearfork Unit

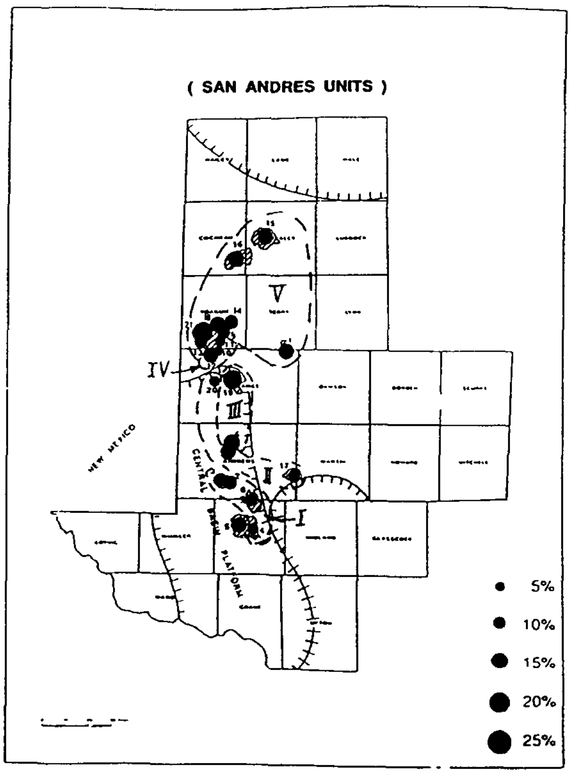

Figure 7 - Distribution of primary recovery efficiency (%OOIP) (San Andres Units)

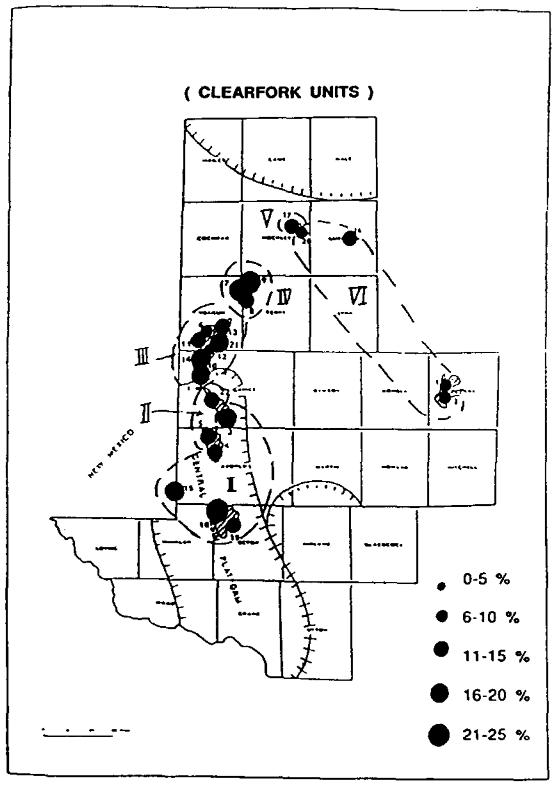

Figure 8 - Distribution of primary recovery efficiency (%OOIP) (Clearfork Units)

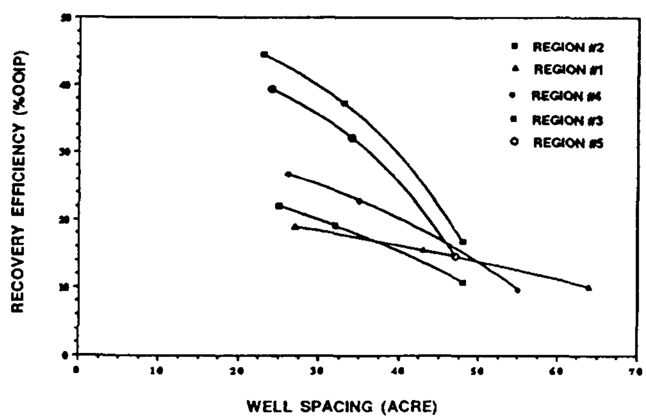

Figure 9 - The correlation of recovery efficiency vs. well spacing of San Andres Units

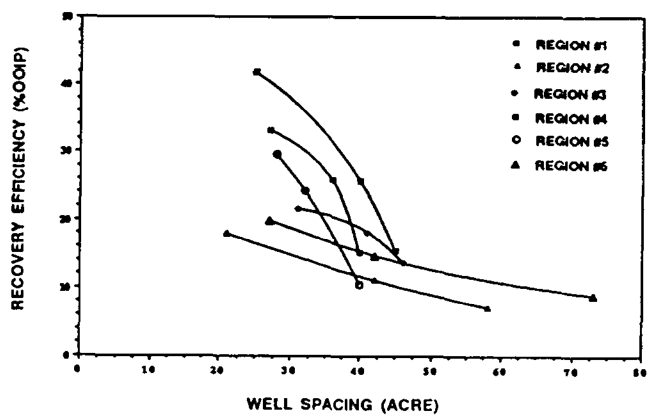

Figure 10 - The correlation of recovery efficiency vs. well spacing of Clearfork Units

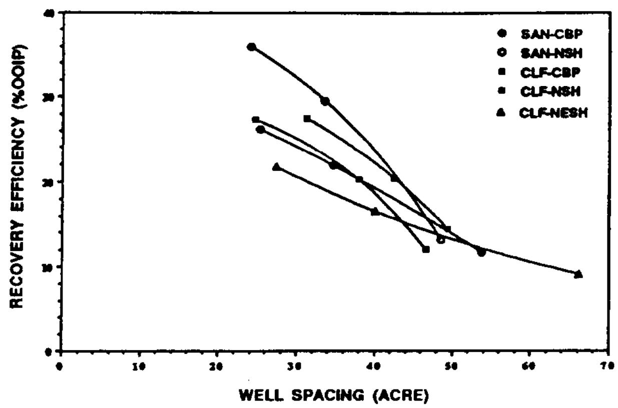

Figure 11 - The correlation of recovery efficiency vs. well spacing

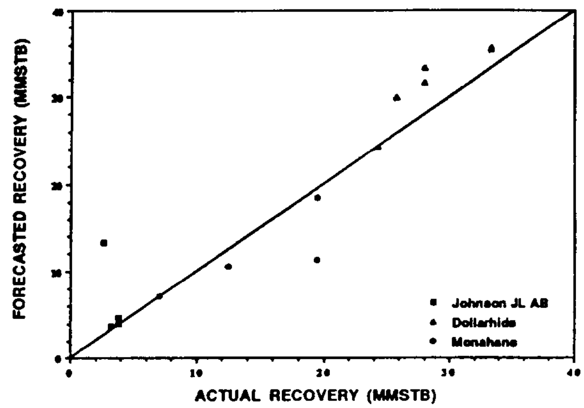

Figure 12 - Forecasted and actual recovery efficiency (using forecast model for IDUR)

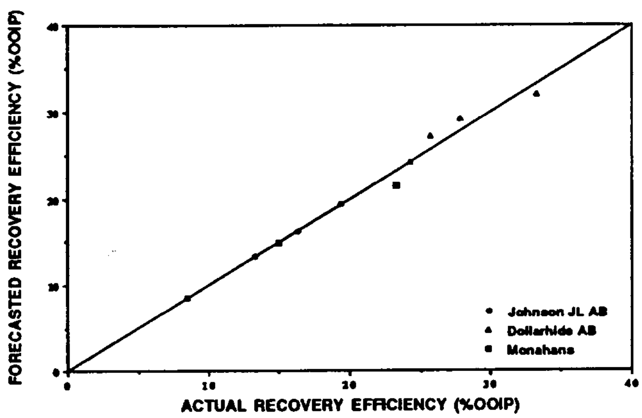

Figure 13 - Forecasted and actual recovery efficiency (using forecast model for IDRI)

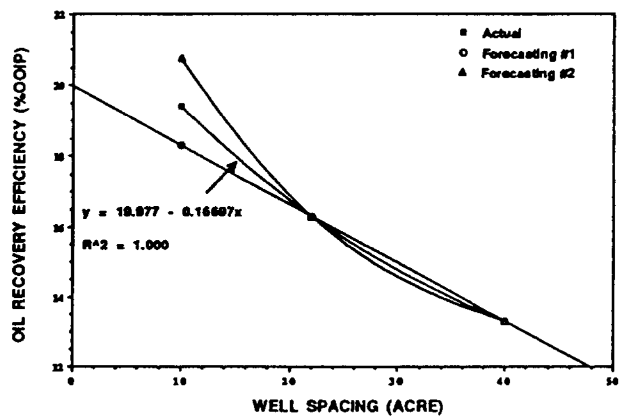

Figure 14 - Forecasted and actual recovery efficiency (Johnson JL "AB" Unit)

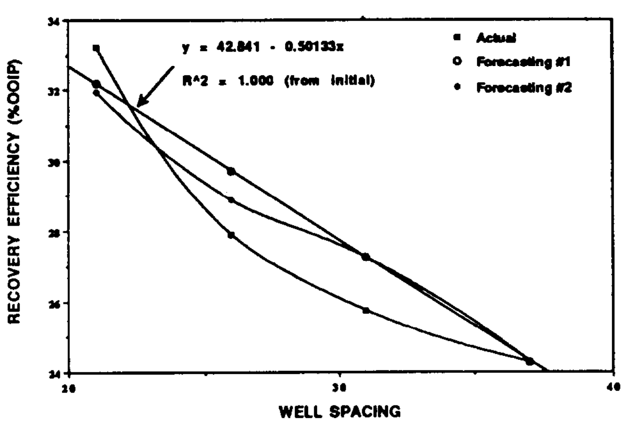

Figure 15 - Forecasted and actual recovery efficiency (Dollarhide Clearfork AB)

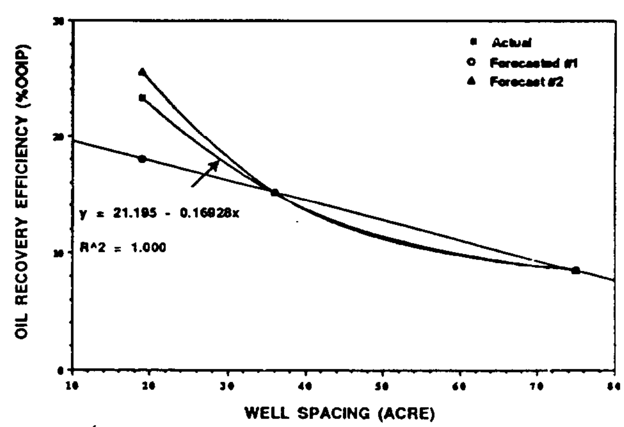

Figure 16 - Forecasted and actual recovery efficiency (Monahans Unit)