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The Redevelopment of Depleted Queen Waterflood Projects in the Permian Basin

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Introduction

Significant future reserve additions in the Permian Basin of West Texas and Southeastern New Mexico will come about through improved oil recovery techniques (IOR) applied to existing reservoirs. The major companies have an impressive list of improved or enhanced recovery projects on their strategic lists. On the other side of the street, independents are competing to acquire the major's non-strategical properties that are judged to have IOR potential. The Permian Basin is certainly one of the world's most mature producing provinces, but it is also a frontier for advanced IOR technology.

Primary development of the world class Permian Age producing horizons in the Permian Basin occurred from the mid-1930's through the 1950's. The 1960's was the era of secondary recovery with the establishment of many of the Basin's water injection projects. A majority of these waterflood projects were probably based on the "Tank Model" concept of a reservoir, involving little or no geologic input. The fallout from the initial failure of some of these projects started industry on the road to developing a joint geological/engineering approach. One of the earlier papers to appear in engineering literature discussing the geological aspects was Dowling's 1970 paper titled "Application of Carbonate Environmental Concepts to Secondary Recovery Projects"(1). A recent contribution in this area is a 1991 SPE Paper by Holtz, Ruppel and Hocott with the Bureau of Economic Geology at the University of Texas(2). Reading these two papers together shows the advances in carbonate geology and it's application to reservoir exploitation.

On the engineering side, much of the emphasis has been infill drilling. A 1974 paper by Driscoll listed nine factors that influence additional recovery through infill drilling(3). In 1976, Stiles authored a paper on optimizing waterflood recovery in the Clearfork(4). This was the first of several papers by Stiles and his colleagues at Exxon that has served as the foundation for the technology that has evolved into reservoir characterization. A good summary of what has been accomplished through infill drilling and reservoir characterization in West Texas carbonates is contained in a 1991 article by Wu et.al.(5)

Nearly all the current IOR efforts, and hence the literature, in the Permian Basin have been directed towards the San Andres and Clearfork carbonates. To paraphrase Willy Sutton, the infamous bank robber, in justifying his profession, "that's where the money is." The bulk of the remaining oil-in-place (ROIP) exists in these two horizons where the facies stacking nature of the marine depositional cycles creates complex, heterogeneous reservoirs often over a thousand feet in gross thickness. Following primary depletion, the remaining mobile oil volumes within these thick sections were the targets for secondary recovery through water injection. Now both the remaining mobile oil and residual oil are targets

References at end of paper

for IOR technology. Major companies that choose to remain active in the basin are consolidating their holdings in properties that contain this large potential.

However, the large Clearfork and San Andres reservoirs are not the only IOR candidates in the Basin. Independent companies are hoping to build a reserve base by applying IOR technology to properties acquired from the majors. The attributes that the independents look for in a IOR candidate are:

1. Can be purchased for existing production without paying a premium for potential.
2. Located in an area that can be developed and operated at low cost.
3. Can be adequately evaluated at a reasonable cost.
4. Contains a high remaining mobile oil saturation.

The Queen sand producing trend along both the northeastern and northwestern margin of the Central Basin Platform meets these criteria (Figure 1). The Queen is shallow, (3600-4700'), the oil is not very sour, the gravity is greater than 30° API and the formation is very susceptible to waterflooding as proven by many success projects. Most of the area in these two Queen trends had been unitized and waterflooded by 1965 and are currently near depletion. Many of the projects contain high mobile oil saturation due to low ultimate recovery. All of the projects were developed on 40-acre density. The reserve potential in these areas is normally not significant enough to be of interest to the majors and ownership has already past to smaller companies in many instances.

The authors have evaluated over a dozen of these depleted Queen waterfloods for IOR potential in recent years. The term "redevelopment" has been applied to the process of exploiting the potential of these depleted floods since both infill drilling and the reestablishment of full-scale water injection is involved. These studies have required innovations to overcome a lack of quantitative data, limited budgets for analyzing the potential, and a shortage of investment funds that dictates a "bootstrap" approach to development.

This paper describes the approaches and analogs used in quantifying the potential and developing an exploitation plan on six separate projects. Although over sixty 20-acre infill wells have been drilled on three of the projects, none have been completely redeveloped with full scale injection. Fifteen different projects are referenced in this article, some with similar names. To facilitate the discussion, the projects have all been assigned a unique abbreviation as shown on Table 1.

Geology

The Queen formation is a complex sequence of sandstone, carbonates and evaporites of Permian (Guadalupian) age that extend across the North Central Platform and the Northwest Shelf of the Permian Basin. The Queen is part of the Artesian group, a back-reef facies of the Capitan-Goat Seep Reef complex which surrounded the Delaware Basin during Guadalupian time (Figure 2)[7]. The Queen sandstones formed stratigraphic or structural-stratigraphic traps across the Permian Basin. The redevelopment projects are located along the northeastern and northwestern margin of the Central Basin Platform.

Holley and Mazzullo describe the lithology, depositional environment and reservoir properties of Queen sandstones in the northeastern area located in Andrews County, Texas[8]. Production in this area is from the A and B sand members of the upper Queen which are described as wavy sheet sandstones with an average thickness of 17 and 22 feet, respectively. Figure 3 is a type log for the area. The deposition of each sand was preceded by a major sea level fall exposing older high-stand sediments to erosion. A slow rise in sea level buried the eroded surface by a succession of sandy braided streams, alluval plains and tidal flat sandstones and sillstones which form the Queen A and B sands. Continual rise of the sea level returned the area to the normal carbonate/evaporite-dominated shelf environment.

The productive sands are described as fine grained, well sorted, arkosic, and silty. Petrographic studies show that the porosity which is reduced, secondary and intergranular in texture, was created by partial dissolution of anhydrites and dolomite cements. The sands have a high gamma ray response due to the presence of feldspar.

The sand members are readily correlatable across the trend. The fields are found in connection with elongated anticlines, which suggests that the reservoirs were formed by the structural entrapment on blanket sands. The fields were developed on uniform 40-acre spacing in accordance with accepted concepts that ignored depositional or diagenetic complexities. Detailed studies have subsequently revealed that the fields are a series of stratigraphic traps.

The Queen productive intervals are somewhat more complex along the northwestern trend in Lea County, New Mexico where production is primarily from the lower half of the Queen section. This section is locally referred to as the Penrose, although on occasion this designation has been applied to the total Queen and depositional setting is based on study in the Keystone (Colby) field in Winkler County, Texas. This field produces from the lower half of the Queen formation which is the equivalent of the Penrose formation in New Mexico[7]. In contrast to the depositional environment described by Holly and Mazzullo for the northeastern margin area, Vanderhill attributes the numerous separate rock units to minor shifts in the local depositional environment and not large sea level fluctuations. The sands were deposited in a shallow marine setting but in somewhat deeper water than the shallow tidal or strandline dolomites. Although both papers agree that the majority of the porosity is secondary in nature, Vanderhill attributes it to the dissolution of feldspar. A total of 32 sand units six inches or greater in thickness have been identified in the Colby section. Figure 4 is a type log from the Myers Langlie Mattix Unit which identifies ten correlatable sand units within the gross productive interval.

Concepts

At first glance the old adage, poor primary recovery gives poor secondary recovery, would appear to hold true within the Queen formation. Projects with good primary performance exhibited good secondary recovery. Conversely projects with poor secondary recovery invariably had low primary recovery. That mindset combined with the concept that the pay intervals are continuous sands across structural traps may help explain why many projects were essentially abandoned after poor initial secondary response.

High remaining mobile oil saturation in a depleted waterflood is due to a lack of vertical and areal injection coverage. Poor vertical coverage can result from: 1) pay intervals not fully identified, 2) inefficient completion techniques, 3) out of zone injection, 4) pay intervals not completely penetrated, 5) water quality. The lack of areal injection coverage can be due to: 1) lateral discontinuity, 2) insufficient well density, 3) inadequate injection to withdrawal ratio, 4) improper pattern alignment, 5) directional permeability, 6) inadequate withdrawals.

Overall the lack of injection coverage results from the relationship between natural, i.e. reservoir and fluid parameters, and controlled, i.e. reservoir management, factors. Within the thick Permian carbonate sequences, the IOR potential is predominately a function of reservoir heterogeneity. In the Queen, where the lithologies are not nearly so complex, the potential results more from low reservoir energy, completion in efficiencies and operational difficulties. The primary and secondary development techniques utilized in the Queen reflected prevailing concepts which have since been rendered obsolete by engineering and geological advances.

TANFL (there ain't no free lunches), applies also to depleted Queen waterfloods. Contrary to popular belief, blanket infill drilling is not necessarily the solution. An integrated geological /engineering analysis is required to focus redevelopment on the most highly productive areas. Emphasis is not on maximizing recovery, but optimizing economics. This requires sound reservoir management techniques at every stage from the analysis and design through the implementation and surveillance. Companies that acquire depleted waterfloods without doing their homework may achieve less than anticipated results.

Approach

This section was initially titled methodology, which suggested a routine approach to a problem. The peculiar nature of each project, the availability of data and the financial situation of the operator requires flexibility and innovations in the analysis and exploitation. However, the goals of each study were similar: 1) identify the potential, 2) quantify the potential, 3) map the distribution of the potential, 4) design an optimum exploitation plan, 5) project performance, 6) forecast economics, 7) set up a surveillance and data gathering program.

1. Identifying the potential requires determination or understanding of why primary and/or secondary recovery was low. The starting point is to characterize the reservoir which fortunately does not require the complex facies identification process necessary with carbonate reservoirs. Defining the net pay sequence from logs, cores, and tests is usually sufficient. A key step is determining the well completion efficiency from cross-sections connotated with completion and test information. This involves tedious and time-consuming work, but is indispensable for identifying zones that have not been drained due to being behind pipe, inefficiently completed or not penetrated. Knowledge is also gained about zonation and continuity. This characterization effort combined with information about original reservoir conditions, usually explains the primary recovery.

Understanding the reasons for low secondary response is critical to judging the potential. This requires a secondary performance review to analyze injection/withdrawal ratio, injection efficiency, oil response, pattern alignment, directional permeability and operational problems.

2. Quantifying the potential involves volumetric determination of original oil-in-place (OOIP). Again this is simpler for the Queen than for the Permian carbonates even with the normal lack of data. The various sand units are correlatable over a wide area. The porosity-permeability relationship is fairly constant allowing use of a single porosity cut-off value within a unit for determining net pay. Also, an average water saturation can usually be estimated with reasonable accuracy.

It was possible to determine a usable OOIP volume on five of the six waterfloods being discussed. Adjusting the OOIP volume for cumulative production and residual oil gives the remaining mobile oil-in-place volume which represents the target for an IOR project.

3. The distribution of the remaining mobile oil volume is essential to focusing the redevelopment effort in the most productive areas. Direct calculation of current saturations is impossible due to the influence of past production/injection operations. Detail analysis of individual well and pattern performance reveals trends in secondary response. To some degree, this replaces the facies distribution studies in carbonate reservoirs. Secondary response has varied greatly within the individual Queen waterfloods studied. The areas of good response usually relate to favorable rock properties, completion efficiency and adequate injection support. Conversely, areas of poor secondary response exhibit under-injection, lack of injection coverage, unfavorable reservoir properties and operational problems.

4. The optimum design of a redevelopment project is based on remaining mobile oil quantification and distribution studies. Independent operators normally obtain outside funding to undertake development projects. This requires a low risk project with a reasonable economic forecast that provides the investor with an acceptable rate of return. To achieve this situation the redevelopment is staged, starting with the highest potential and lowest risk area first, then utilizing the information gained in the first stage to lower the risk and improve the forecast on the second stage.

5. Projecting the performance of a redevelopment stage involves analogy and limited infill drilling results within the areas of interest. Simplistic modeling was done to aid in the performance projections on some projects.

6. In this age of dwindling profit margins, it is extremely important that realistic development and operating costs be used in forecasting the economics. The operator should be involved in both designing and costing the implementation plan. Obviously the oil price forecast is critical to the economics. Pricing is normally dictated by the operator or investor.

7. Additional data gathering and performance surveillance are critical to the success of these staged Queen redevelopment projects and are an integral part of the implementation plan. The amount of infill drilling involved provides a lot of quantitative information from modern logs, cores and tests. This information along with performance surveillance improves the design and lowers the risk of the next phase. The ability to bootstrap one phase from another is crucial both to the technical success and the ability of the operator to obtain financial backing.

Analogy

The Queen formation has proven to be a good waterflood candidate. Table 2 is a summary of recoveries for successful waterflood projects in the two areas. The locations of these waterfloods in relation to the six redevelopment projects are shown by Figure 5. The performance of the Exxon Means Queen Unit has been excellent as a result of both good reservoir properties and advanced reservoir management practices in the design and implementation of the flood[8]. The other projects are more typical of successful Queen waterfloods with low primary recovery but a secondary/primary ratio greater than one.

Substantiating the low Queen reservoir energy is difficult since primary development occurred over 30 years ago. Pressure and PVT data have been unobtainable so far. The Means Queen Field was reported to have initial gas-in-solution of 360 cu ft/bbl at an original reservoir pressure of 1570 psig[8]. Initial potentials in the WDQSU reported GORs in the 150-350 cu ft range. Initial GORs in the SUC1U and SUC2U area were in the 300-500 cu ft/bbl range.

Ultimate recoveries have been higher in the Andrews County waterfloods than in the Lea County projects. Stratigraphically, the Queen is more complex along the northwestern shelf margin. The SRQU and SESRQU are completed in both the Seven Rivers and Queen/Penrose intervals. The Seven Rivers and part of the Upper Queen are gas-bearing, although this may have had little impact on the waterflood performance in view of the horizontal stratification involved. The presence of high mobile oil saturation in underperforming Queen waterfloods was confirmed by infill drilling. Table 3 summarizes infill drilling results in the study areas that were available to the authors. Except for the S-PAU, infill drilling occurred on projects in an advanced stage of depletion where injection had been reduced to the return of produced water. Although some of the infill wells achieved economic recoveries without active water injection support, they are the exceptions. Effective water injection into closed patterns is required to provide the reservoir energy and sweep necessary for the economic recovery of remaining mobile oil through infill drilling.

The Bridge operated MFQAU is a direct south offset to the Sirgo SUC2U (Figure 5A). A total of 17 wells were drilled in the eastern two-thirds of the Unit during 1988-89 either as 20-acre infill or replacement wells (Figure 7). A semi-symmetrical injection pattern was established creating several situations that approximate 20-acre infill drilling with full injection support. Some wells have maintained high producing rates for several years in contrast to the rapid decline experienced by most Queen infill wells. Well No. 4532, which is offset by 3 injection wells, potentialed for 110 BOPD on 8/89 and was tested for 70 BOPD on 3/91 and 108 BOPD on 7/91. The performance of this unit with infill drilling is shown by Figure 6. The incremental average infill recovery is estimated at 52 MB per well.

Bridge has done similar redevelopment on the ULB4QU. Individual well information was not available, but the recent unit performance suggests that the production increases realized from the drilling of infill and replacement wells are being sustained by water injection (Figure 8).

All of the projects in the study areas have been subjected to millions of barrels of water injection. Water saturations and consequently permeability to water, while erratic, are high throughout much of the reservoir. The redeveloped projects will produce at high water cuts from the start, requiring the handling of large volumes of water. Economic recovery under these circumstances dictates that the redevelopment focus on the most prospective areas and be designed to produce the most oil in the least time.

Project Analysis

Table 4 summarizes basic data on the six redevelopment projects. The development and performance history of the individual units are summarized on Figures 9-14. Table 5 presents primary and secondary performance parameters for the projects. Each project is scheduled to be redeveloped on forty-acre five-spot injection patterns (20-acre well density) in phases starting with the lowest risk phase first. Implementation of each phase depends on results from the preceding phase. Redevelopment plans and the basis for recovery projections are summarized on Table 6. A final residual oil saturation of 30% was assumed for all cases. The conformance factors were based on estimates of vertical coverage and areal sweep for each project as modified by the detailed performance analyses.

Infill drilling has been completed on just one of the six redevelopment projects. Full scale pattern injection has not yet been implemented in any project. The presence of high mobile oil saturation has been established on all the projects either by infill drilling within the project or on a direct offset.

The pace of development is dependent upon the ability of small independents to raise capital in today's market. Not only are the redevelopment stages ranked according to risk and potential, but also the projects. The lower priority projects are deferred until the investment climate improves or the project is upgraded by additional information or offset performance.

1. West Dollarhide Queen Unit

The Sirgo-operated WDQU produces from what is termed the Penrose but is equivalent to the total Queen Section at 3600 feet. The development and performance history is shown on Figure 9. The project was acquired essentially as a salvage operation with plans to work over wells in an attempt to increase production. The original feasibility study suggested that the unit had good infill potential due to numerous possible productive zones either behind pipe or not penetrated. A preliminarily study in 1986 used limited data to make a volumetric estimation of OOIP and remaining mobile oil (Table 4). The unit was divided into five phases based on potential and risk as determined by individual well performance analysis (Figure 16). Phases 1 and 2 were located in the area of good secondary response (Figure 17). Based on the 1986 study, thirty infill wells were drilled and the study revised in 1988 utilizing the information gained. As each well was drilled, the logs were analyzed to improve the data base for volumetric calculations and reserve estimations. The OOIP volume was revised from 34 MMB to 44 MMB, so the original volumetrics proved reasonable in spite of the lack of data. Figures 15A and 15B show the original and revised net pay isopach maps.

The unit production increased from 40 BOPD to 1500 BOPD upon completion of the first 30 infill wells which almost equals the peak primary response from 60 wells. A number of the infill wells had initial potential in excess of 200 BOPD, positive evidence of the high mobile oil saturation remaining within areas of the unit. Without water injection support, however, the wells declined rapidly. Figure 18 shows the average per well production by months for the infill wells.

A total of 52 wells were drilled to complete the infill development scheduled for phases 1-4. Phase 5 was considered high risk because of high water saturation. This analysis has been confirmed by limited infill drilling in the phase area.

2. Skelly - Penrose B Unit

The Sirgo-operated S-PBU produces from the same Queen/Penrose section as the WDQSU in Lea County, New Mexico (Figure B). The development and performance history is shown on Figure 10. Following rapid primary depletion, water injection was initiated in 1966 with oil response peaking at 500 BOPD in early 1971. The unit has experienced a high water cut throughout it's life. Injection has been reduced to the disposal of produced water. A majority of the wells were completed in the Penrose only. Prior to waterflooding, the upper Queen section exhibited high GORs. Primary recovery only averaged 28 MB per well with a secondary primary recovery ratio estimated at 1.0. In contrast, the off-setting S-PAU, averaged 66 MB per well under primary recovery with the secondary primary ratio estimated at 1.22 (Table 2). A detailed study of the S-PAU has not been made that might explain the recovery differences. This large of a difference on projects with the same original operator probably involves pay quality.

Due to a lack of data, no attempt was made to calculate unit-wide volumetrics. A simplified reservoir model was constructed to: 1) test the reasonableness of estimated reservoir parameters, 2) approximate primary and secondary performance for an average well, and 3) establish a basis for estimating redevelopment reserves.

A five-well twenty-acre infill program on the offsetting S-PAU in 1973-74 proved successful with the incremental average recovery estimated at 90 MB per well. These wells were located in the interior of the unit where active injection was occurring. Six infill wells were drilled by Sirgo on the S-PBU in 1988 with potentials ranging from 7 to 32 BOPD. Since the infill wells have no effective injection support, production has declined.

3. Myers Langley Mattix Unit

The Texaco-operated MLMU is also located in the Queen/Penrose trend of Lea County, New Mexico (Figure 5), but is several times larger than the WDSQU or S-PBU projects. Primary development began in 1936 in the unit area and continued through 1961. Water injection did not begin until 1975 and the project is still an active waterflood. The development and performance history is shown on Figure 11.

Primary recovery was estimated at 7.8% and the secondary primary recovery ratio at 0.76. A detailed performance analysis found a wide variation in secondary response. Fifteen wells had peak secondary oil response exceeding 100 BOPD. Fourteen wells are projected to produce over 100 MB of secondary oil each.

Five twenty-acre infill wells were drilled in 1986. In spite of inadequate injection support, several of these wells encountered significant reserves, including one well projected to recover over 200 MB. Redevelopment is projected to achieve an improved primary recovery ratio of 3.0 for an ultimate recovery of 23%.

4. Magutex Queen Unit

The Sirgo-operated MXQU is a depleted waterflood producing from the A and B sands of the Upper Queen section in Andrews County, Texas. Water injection was initiated in 1963 with only marginal oil response (Figure 14). Accurate water production and injection data were not available between 1980-90. Currently, only produced water is being injected.

Primary recovery was estimated at 7.2% and the secondary primary recovery ratio at 0.93 for a total recovery of only 15%. This is less than half of the recovery experienced by successful Queen waterfloods in the same producing trend (Table 2). However, an analysis of individual well performance indicated that two wells had produced over 240 MB of secondary oil each and another four wells produced around 100 MB of secondary oil per well. These six wells account for nearly 60% of the total secondary recovery. The overall poor secondary performance resulted from out-of-zone injection, channeling due to excessive injections pressure and downhole scaling problems. The proposed redevelopment is projected to increase the improved-to-primary recovery ratio to 2.2, giving a 22.7% ultimate recovery.

5-6, State University Consolidated #1 and #2 Units

The Sirgo-operated SUC1U and SUC2U are adjacent to one another in the Upper Queen producing trend. They share a common development and operating history with 40-acre primary development occurring in the late 1950's and water injection starting in 1961 (Figures 12 and 13). Both projects are depleted waterfloods, injecting only produced water. SUC2U was never fully developed as indicated by the average density of 57 acres per well. Primary recovery was less than 7% for both units and ultimate recovery is only in the 15% range. Similar to the other Queen projects studied, areas of good secondary response were found in both projects.

A low injection-withdrawal balance and operational problems contributed to poor secondary performance. Both units received pressured water from the Means System in lieu of having their own injection facilities. The Bridge-operated MFQAU project has achieved some significant results where infill wells are being supported by water injection (Table 3 and Figure 8). MFQAU offsets the SUC1U and SUC2U to the south (Figure 5). Redevelopment of the SUC1U is projected to give an improved/primary recovery ratio of 3.0 for a 23% ultimate recovery. Similarly, redevelopment of the SUC2U is projected to give an improved/primary ratio of 2.3 for a 23% ultimate recovery also.

Conclusions

1. Infill drilling has confirmed that some depleted Queen Sand Waterfloods still contain high mobile oil saturations.

2. This mobile oil saturation is not uniformly distributed and detailed analysis is required to define the more prospective areas.

3. The economic recovery of the remaining mobile oil requires redevelopment of the waterfloods by infill drilling and adequate water injection support.

4. Good reservoir management and financing requirements dictate that the most prospective areas be exploited first and the results used to upgrade the other stages.

Acknowledgements

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References

1. Dowling, Paul L.: "Application of Carbonate Environmental Concepts to Secondary Recovery Projects," paper presented at the 45th Annual Fall Meeting of the SPE, Houston, Oct. 4-7, 1970.

2. Holtz, Mark H., Ruppel, Stephen C., and Hocott, Claude: "Analysis of Reserve Growth Potential in Leonardian Restricted Platform Carbonate Reservoirs, Permian Basin: An Integrated Approach," paper SPE 22900 presented at the 66th ATC&E of the SPE, Dallas, Oct. 6-9, 1991.

3. Driscoll, Vance J.: "Recovery Optimization Through Infill Drilling Concepts, Analysis, and Field Results," paper SPE 4977 presented at the 49th Annual Fall Meeting of the SPE, Houston, Oct. 6-9, 1974.

4. Stiles, L. H.: "Optimizing Waterflood Recovery in a Mature Waterflood, The Fullerton Clearfork Unit," paper SPE 6198 presented at the 51st ATC&E of SPE, New Orleans, Oct. 3-6, 1976.

5. French, R. L., Brimhall, R. M. and Wu, C. H.: "A Statistical and Economic Analysis of Incremental Waterflood Infill Drilling Recoveries in West Texas Carbonate Reservoirs," paper SPE 22624 presented at the 66th ATC&E of SPE, Dallas, Oct. 6-9, 1991.

6. Holley, C. and Mozzullo, J.: "The Lithology, Depositional Environments, and Reservoir Properties of Sandstones in the Queen Formation, Magutex North, McFarland North, and McFarland Fields, Andrews County, Texas," Permian Basin Sec. SEPM Spec. Pub. 88-28, pp. 55-63.

7. Vanderhill, James B.: "Depositional Setting and Reservoir Characteristics of Lower Queen (Permian, Guadalupian) Sandstones, Keystone (Colby) Field, Winkler County, Texas," Permian Basin Sec.-SEPM Publication 91-12, p. 119-129.

8. Kunkel, G. C. and Bagley, J. W., Jr.: "Controlled Waterflooding, Means Queen Reservoir," *JPT* (Dec. 1965) 1385-1388.

OPERATOR	UNIT	ABBREVIATION	STATE
ARCO	Seven Rivers Queen Unit	SRQU	NM
Marathon	South Eunice Seven Rivers Queen Unit	SESRQU	NM
Sirgo	Myers Langlie Mattix Unit	MLMU	NM
Sirgo	Skelly - Penrose B Unit	S-PBU	NM
Sirgo	West Dollarhide Queen Sand Unit	WDQSU	NM
Texaco	Skelly - Penrose A Unit	S-PAU	NM
Bridge	McFarland Queen Unit	BMFQU	TX
Bridge	McFarland Queen A Unit	MFQAU	TX
Bridge	University Land Block 4 Queen Unit	ULB4QU	TX
Exxon	Means Queen Unit	MQU	TX
Mobil	McFarland Queen North Unit	MFQNU	TX
Sirgo	Magutex Queen Unit	MXQU	TX
Sirgo	State University Consolidated #1 Unit	SUC1U	TX
Sirgo	State University Consolidated #2 Unit	SUC2U	TX
SW Royalty	McFarland Queen Unit	SWMFQU	TX

Table 1 - Queen Waterflood Projects in Study Area

UNIT	AREA (ac)	WELL DENSITY (ac/WELL)	PRIMARY ULTIMATE (MB/WELL)	PRIMARY RECOVERY (%)	SECONDARY START INJECTION	SECONDARY/PRIMARY (VOL/VOL)	INJECTORS/PRODUCERS (RATIO)	INJECTION/RECOVERY (VOL/VOL)	TOTAL ULTIMATE (MB/WELL)	TOTAL RECOVERY (%)
				Lea County, New Mexico						
S-PAU	2427	38	66	5	1978	1.22	0.78	12*	146	18
SRQU	2262	31	52	10	1973	1.22	0.62	10*	115	22
SESRQU	1840	35	58	10	1973	1.16	0.73	12*	120	21
				Andrews County, Texas						
MQU	11500	57	58	15	1960	1.87	0.67	3**	173	44
BMFQU	1680	35	18	9	1961	2.64	0.65	5**	71	31
SWMFQU	1320	53	59	13	1964	1.37	1.40	7**	141	30
MFQNU	2600	42	50	13	1984	1.74	0.77	9**	138	35

* 1988 CUM VOLUMES
** 1986 CUM VOLUMES

Table 2 - Pre-Redevelopment Performance on Successful Queen Waterfloods

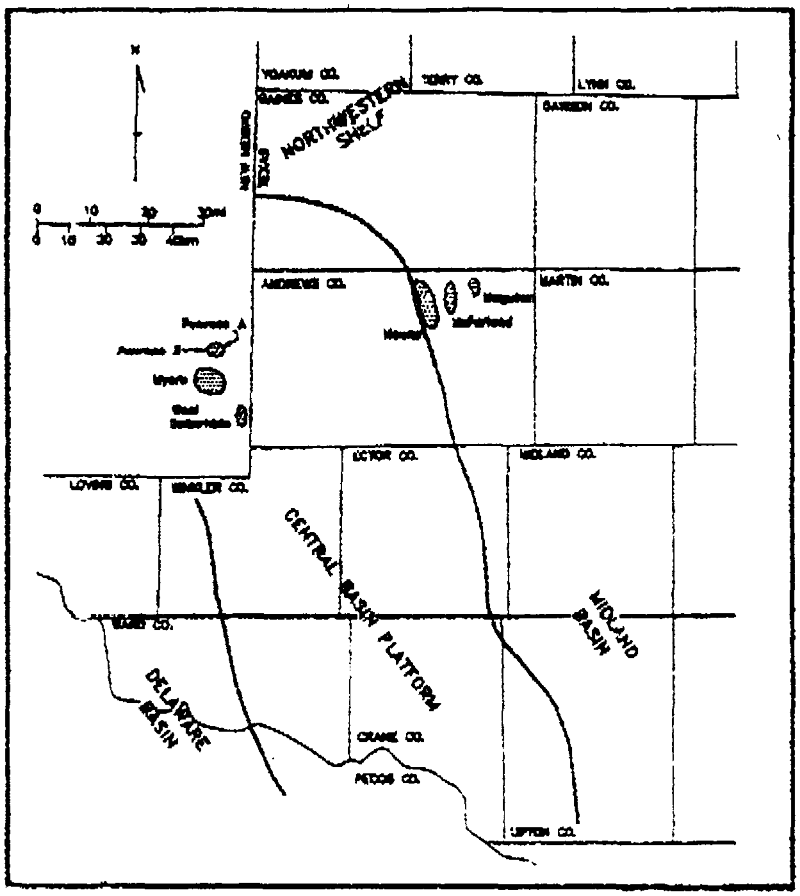

Figure 1 – Regional Map

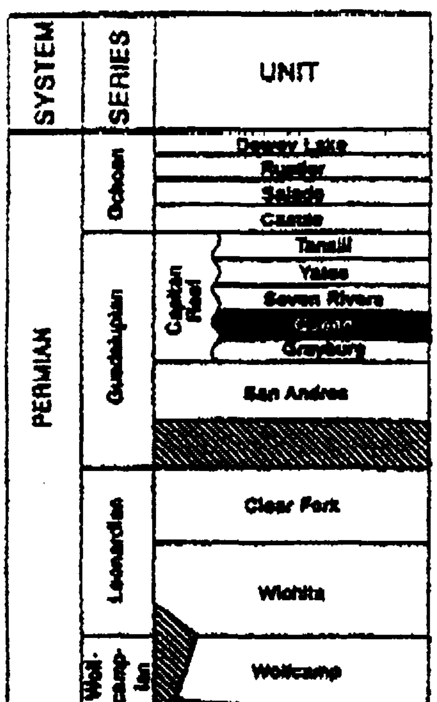

Figure 2 – Permian Stratigraphy

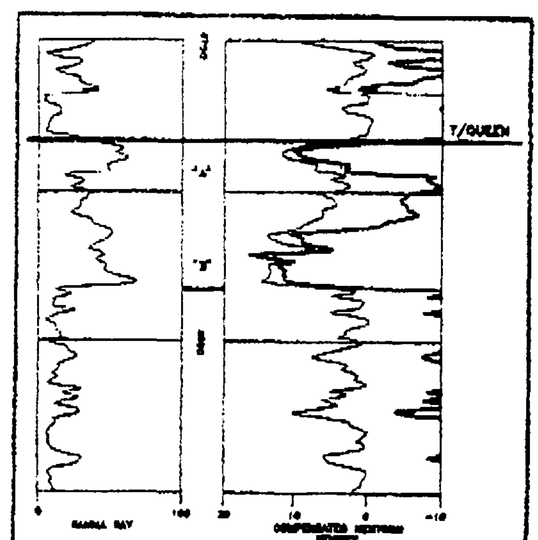

Figure 3 – Type Log -- State Univ. Queen Cons. 2 NO.3036
Andrews County, Texas

OPERATOR	UNIT	NO. WELLS	PERIOD	----AVERAGE----- INITIAL RATE (BOPD/WELL)	(BWPD/WELL)	EUR (MB/WELL)	COMMENTS
Texaco	S-PAU	5	1973-74	82	139	90	Full Injection support
		1	1985	85	145	24	Located near 3MMB injector
Sirgo	WDSQU	52	1987-88	55	115	43	Marginal support from injection of produced water only
Sirgo	S-PBU	6	1988	15	176	12	No injection support
Bridge	MFQAU	13	1988-89	62	39	52	Full injection support on some wells since mid 1988
Texaco	MLMU	5	1986	61	226	78	Partial injection support from existing line drive
Sirgo	SUC1U & SUC2U	5	1990	48	77	15	No injection support

Table 3 – Results of 20 ac. Infill Drilling in Queen Waterfloods

PROJECT	ZONE	DEPTH (ft)	AREA (ac)	WELL DENSITY (ac)	----AVERAGE PROPERTIES--- Ø (%)	NET PAY (ft)	Sw (%)	K (md)	FVFI (VOL/VOL)	POROSITY CUTOFF (%)	OOIP (MMB)
				Lea County, New Mexico							
WDQSU	QUEEN/ PENROSE	3700	2500	40	13.5	34	40	0.1-167	1.20	9.5	44
S-PBU	PENROSE	3600	2612	41	NA	NA	NA	NA	NA	NA	NA
MLMU	QUEEN/ PENROSE	3600	9560	42	13.0	23	40	0.1-100	1.18	9.0	115
				Andrews County, Texas							
MXQU	UPPER QUEEN	4800	2144	40	14.0	18	40	1.0-31	1.17	10.0	20
SUC1U	UPPER QUEEN	4800	2560	57	14.0	18	35	0.3-32	1.15	10.0	29
SUC2U	UPPER QUEEN	4800	2120	40	14.5	20	35	0.3-29	1.15	10.0	32

Table 4 – Basic Reserve Data for Redevelopment Projects

PROJECT	----PRIMARY---- ULTIMATE (MB/WELL)	RECOVERY (%)	-----SECONDARY----- START INJECTION	SECONDARY/ PRIMARY (VOL/VOL)	INJECTORS/ PRODUCERS (RATIO)	INJECTION/ RECOVERY (VOL/VOL)	----TOTAL---- ULTIMATE (MB/WELL)	RECOVERY (%)
				Lea County, New Mexico				
WDSQU	50	7.4	1964	0.45	0.73	24	72	10.6
S-PBU	28	NA	1966	0.88	0.70	25	52	NA
MLMU	40	7.8	1975	0.78	0.92	27	68	13.8
				Andrews County, Texas				
MXQU	28	7.2	1963	1.09	0.93	9	54	15.0
SUC1U	38	5.8	1961	1.51	1.04	11	95	14.6
SUC2U	42	6.8	1961	1.33	1.30	7	97	15.9

Table 5 – Primary & Secondary Performance for Redevelopment Projects

PROJECT	-INFILL LOCATIONS- PROPOSED	DRILLED	INJECTORS/ PRODUCERS (RATIO)	RMOIP/ OMOIP (VOL/VOL)	CONFORMANCE (DECIMAL)	--PROJECTED IMPROVED/ PRIMARY (VOL/VOL)	TOTAL-- RECOVERY (%)
			Lea County, New Mexico				
WDSQU	67	52	0.98	.53	.29	1.50	19.1
S-PBU	57	6	1.10	NA	NA	3.2	NA
MLMU	142	5	1.23	.54	.39	2.0	23.0
			Andrews County, Texas				
MXQU	21	0	1.17	.48	.33	2.2	22.7
SUC1U	47	0	1.12	.40	.50	3.0	23.0
SUC2U	21	0	1.85	.38	.41	2.3	23.0

Table 6 – Plans & Projections for Redevelopment Projects

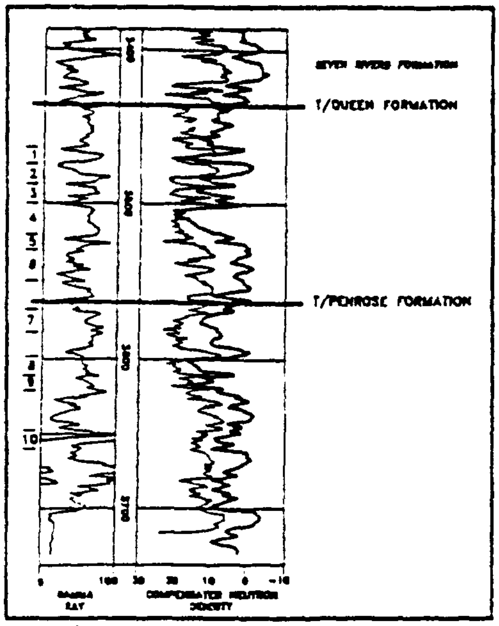

Figure 4 – Type Log – Myers Langlie Mattix Unit NO. 11:
Lea County, New Mexico

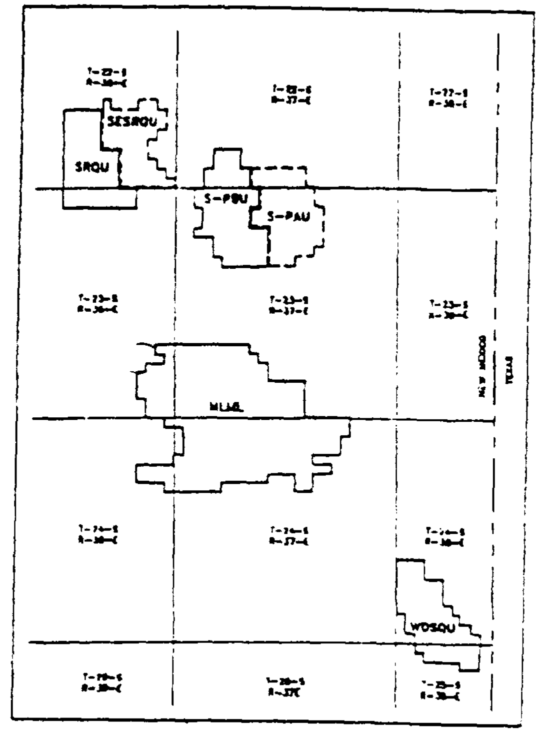

Figure 5A – Location of Projects
Lea County, New Mexico

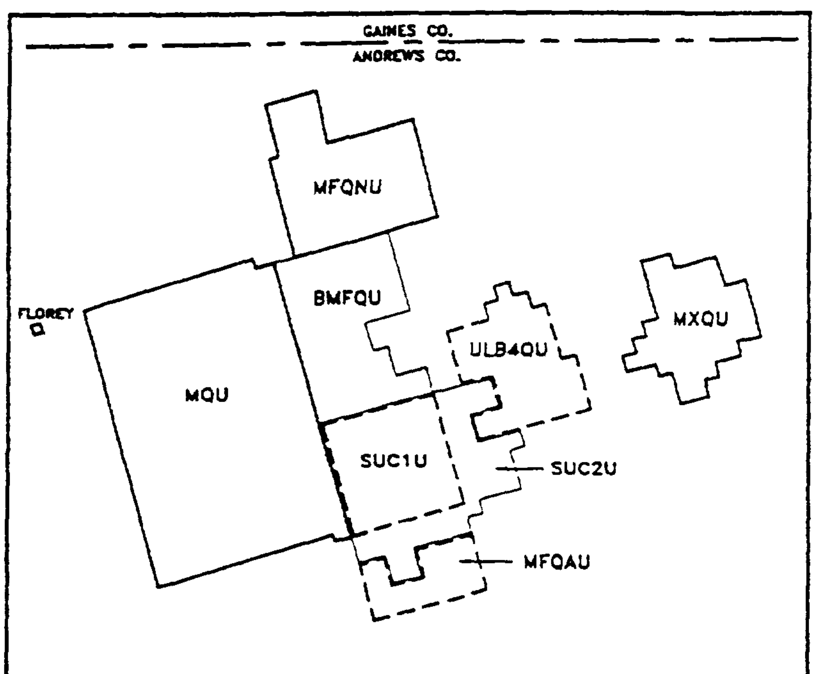

Figure 5B – Location of Projects
Andrews County, Texas

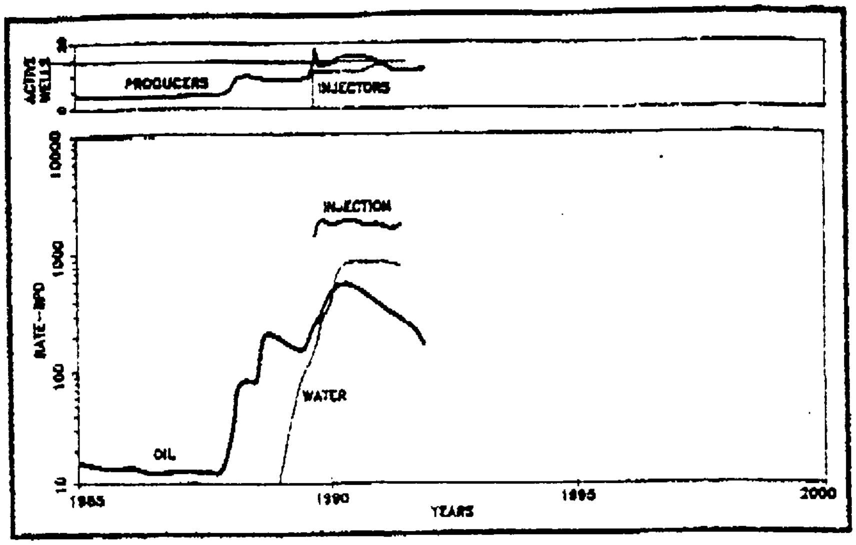

Figure 6 – Performance Graph
Bridge-McFarland Queen A Unit
Andrews County, Texas

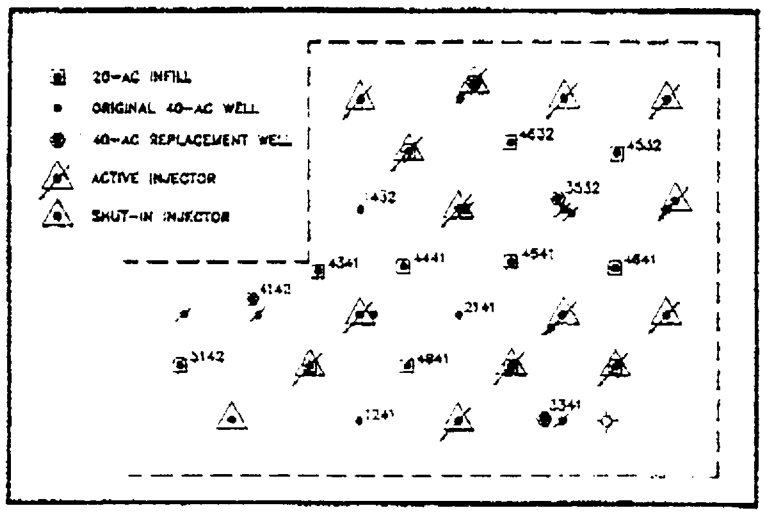

Figure 7 – Redevelopment Area
Bridge-McFarland Queen A Unit
Andrews County, Texas

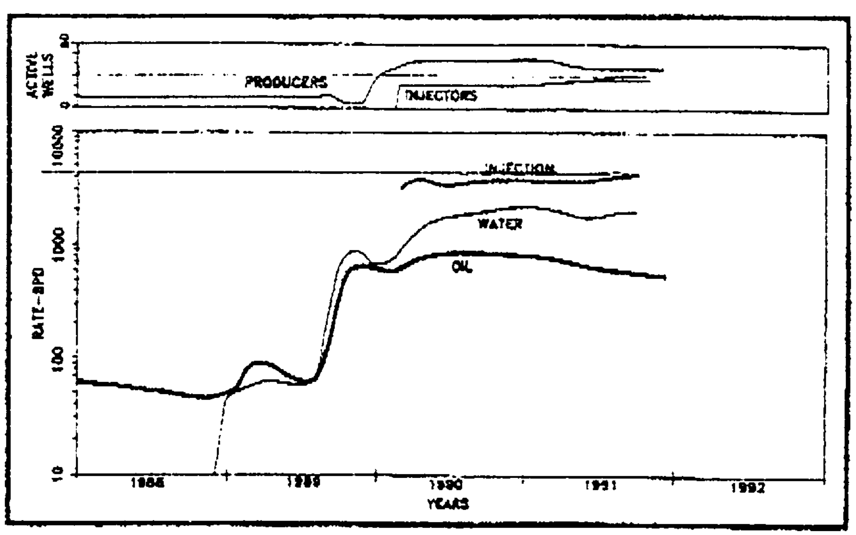

Figure 8 – Performance Graph
Bridge-University Lands Blk. 4 Queen Unit
Andrews County, Texas

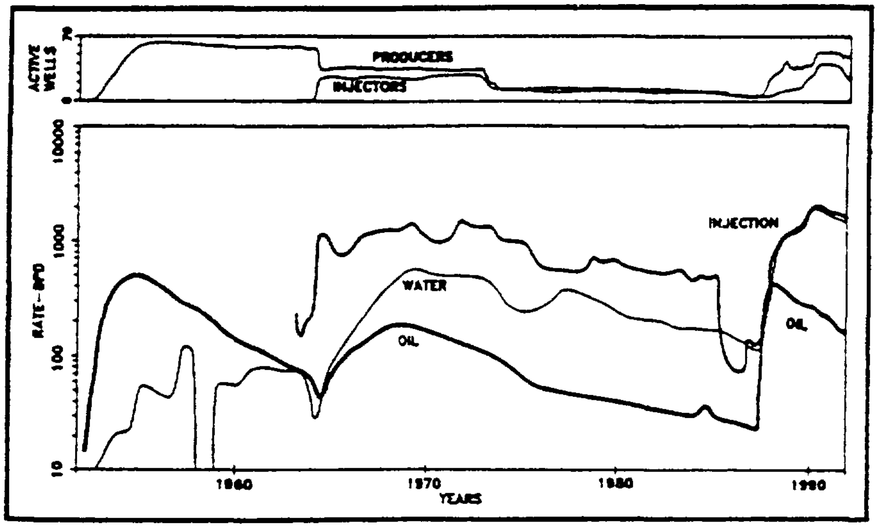

Figure 9 – Performance Graph
Sirgo–West Dollarhide Queen Sand Unit
Lea County, New Mexico

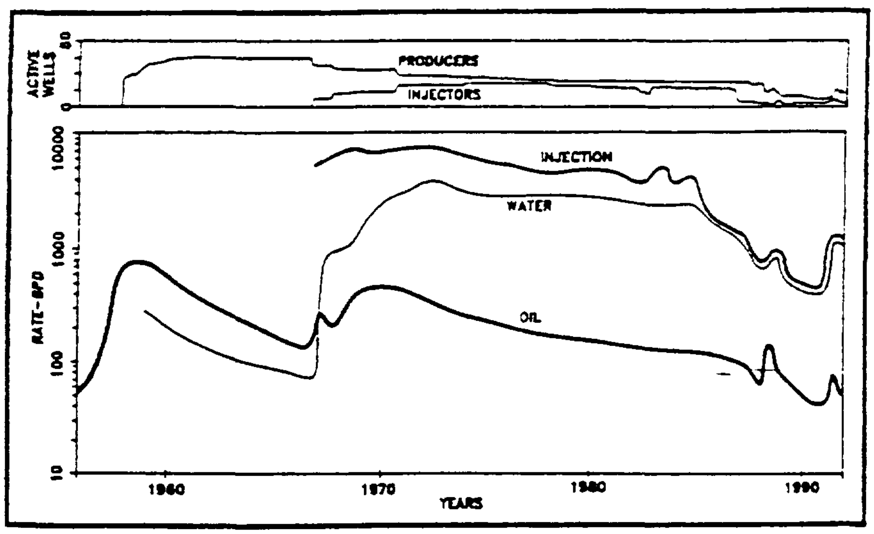

Figure 10 – Performance Graph
Sirgo–Skelly–Penrose B Unit
Lea County, New Mexico

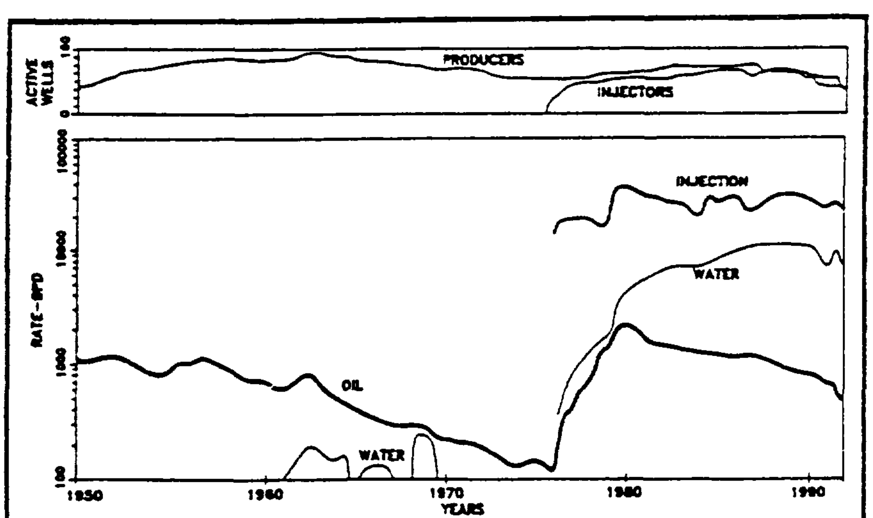

Figure 11 – Performance Graph
Sirgo–Myers Langlie Mattix Unit
Lea County, New Mexico

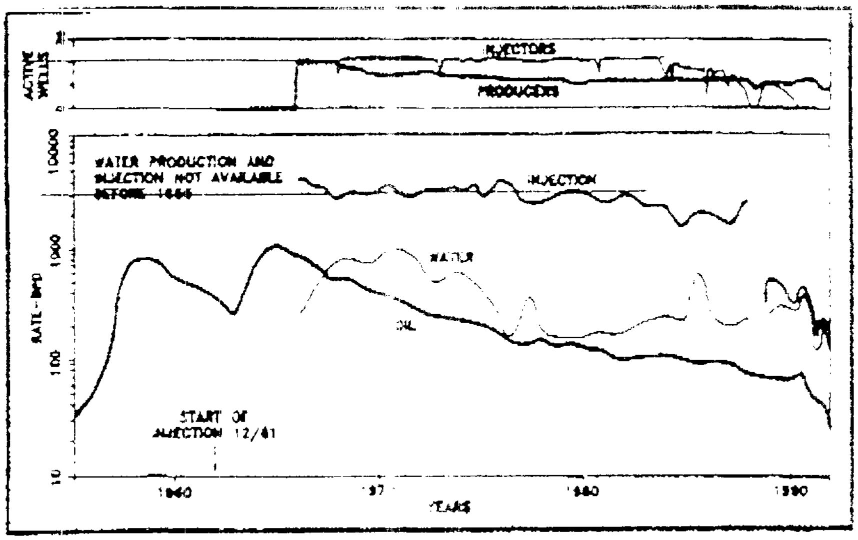

Figure 12 - Performance Graph
Sirgo-State University Consolidated #1 Unit
Andrews County, Texas

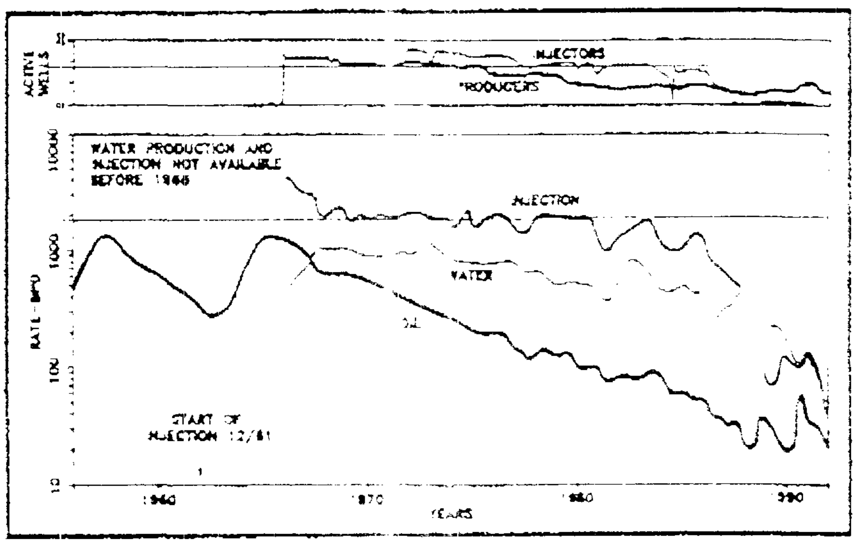

Figure 13 - Performance Graph
Sirgo-State University Consolidated #2 Unit
Andrews County, Texas

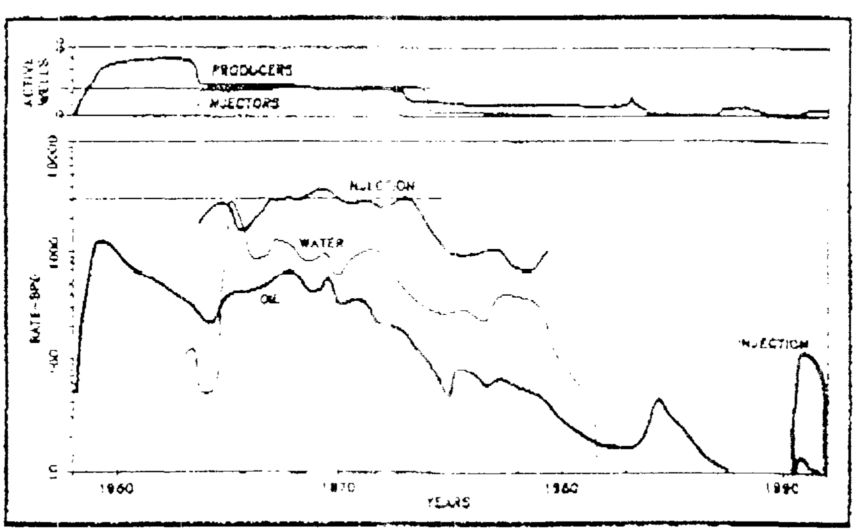

Figure 14 - Performance Graph
Sirgo-Magutex Queen Unit
Andrews County, Texas

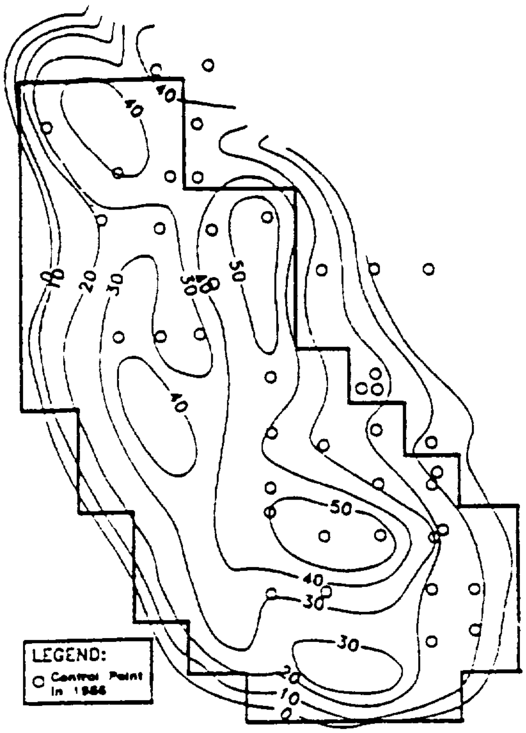

Figure 15A – Net Pay Isopach, 1986
Sirgo–West Dollarhide Queen Sand Unit

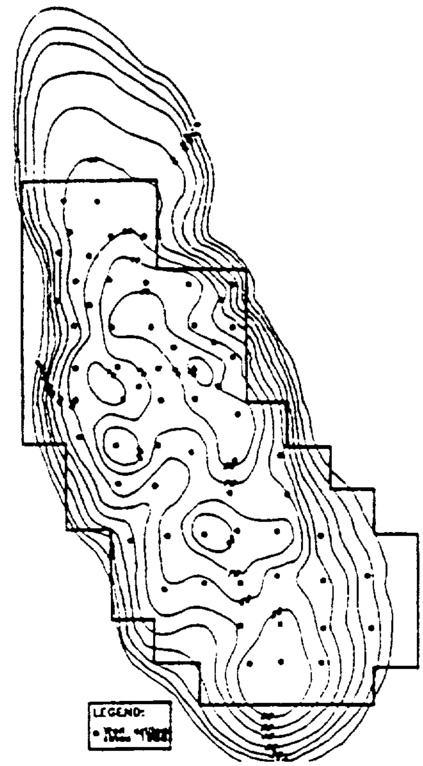

Figure 15B – Net Pay Isopach, 1988
Sirgo–West Dollarhide Queen Sand Unit

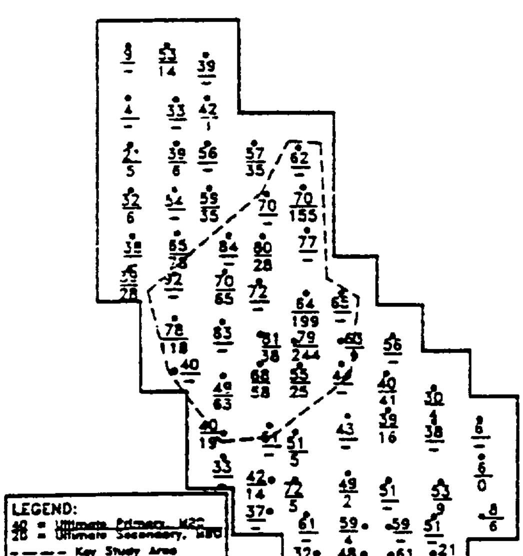

Figure 16 – Initial Estimated Recoveries as of 5–1–87
Sirgo–West Dollarhide Queen Sand Unit

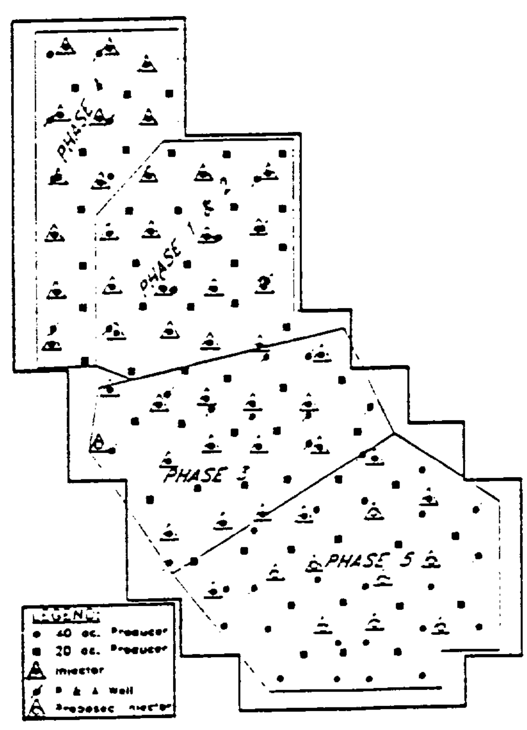

Figure 17 – Redevelopment Phase Areas
Sirgo–West Dollarhide Queen Sand Unit

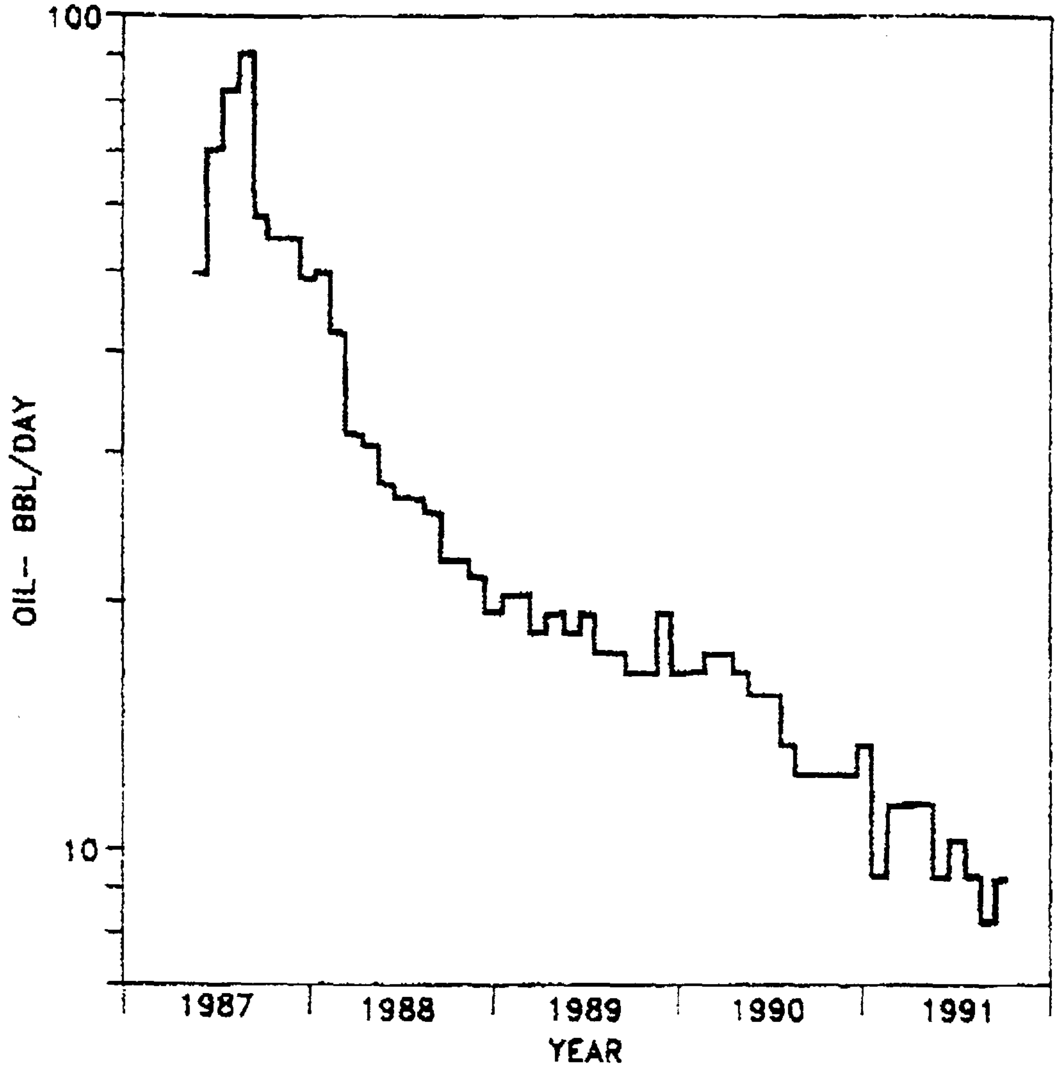

Figure 18 – Average Per Well Production During Redevelopment
Sirgo–West Dollarhide Queen Sand Unit