The Development of a Marginal Clearfork Waterflood Prospect

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ABSTRACT

The effect of depressed oil and gas prices on investors' confidence has been reflected by the low activity levels in the Permian Basin as elsewhere. Yet, even during the 1986-87 period viable projects were available to the industrious and imaginative. One example is the Wentz (Clearfork) Field where a small independent operator recognized potential in what appeared to be a very marginal waterflood prospect. Through data gathering and engineering, the potential was documented to the point that investor funding became available. A cooperative waterflood plan was agreed to with the field's other operator. The project was installed with an emphasis on practicality, cost savings and attention to details. After a year of injection, production response is exceeding expectations.

INTRODUCTION

Most of the major carbonate oil reservoirs on the Central Basin Platform of the Permian Basin were discovered and developed during the 1940's and 1950's before modern logging tools at a time when reservoirs were usually visualized as "tanks". This lack of reservoir characterization led to inefficient well spacing and completion practices that became evident only after failure of some of the earlier waterflood projects. The problems of slow response, low recovery, early water breakthrough and injection out of zone led to the realization that a gross pay section consisted of many separate reservoirs in the form of stringers that had little or no communication except through wellbores. A successful waterflood requires that the main pay stringers contain sufficient input and output points spaced to efficiently sweep the productive area. As this concept gained acceptance, nearly all major secondary projects in the Permian Basin's carbonate trends were infill drilled from 40-acre to 20-acre spacing and to 10-acre on many EOR projects.

Reservoir characterization requires the identification of net pay by facies type and the determination of each facies' spatial distribution within the reservoir. The evolution of reservoir characterization in the Permian Basin is well documented in the major fields.[1-5] There are hundreds of smaller carbonate reservoirs also created by the complex cyclic depositional and diagenetic processes that form highly stratified, heterogeneous producing intervals. Often each field

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has numerous independent operators, and consequently, has not received the indepth study that the majors are able to apply to the larger fields. One such field is the Wentz (Clearfork) Field in northeastern Pecos County, Texas, which produces from the Glorieta and Clearfork formations of the Lower Permian between 2200' and 2550'. The field was discovered in 1953 and developed with 85 wells over 2000 acres (Figure 1). Nominal well density varies from 20 to 40 acres per well. Total production has been 2.7 MMBBL, which is only 31 MBBL per well recovery.

A majority of the leases at Wentz were put up for sale in 1986. The reservoir had never been waterflooded although large volumes of produced water had been disposed of into the pay zone with no significant effect. Many years of stripper operations had depleted the reservoir energy and maximized voidage. Net pay is scattered over 350' of a lithologically complex section. There were limited core data and no modern logs for quantitative analysis. Irregular well spacing and highly fragmented royalty ownership would make unitization difficult. Overall, it appeared to be a very marginal waterflood prospect, particularly in view of 1986 oil prices.

Wilton became interested in the field due to a geologic study that indicated considerable behind pipe pay potential. A waterflood feasibility study was commissioned, which found that the low primary recovery resulted from inefficient completions. The zonal continuity was good and minimal drilling would be required for waterflood development since the subject acreage was effectively on 20-acre spacing already. All analogous Clearfork waterfloods investigated with 20-acre spacing or less were successful. This fact was given heavy weight in the study, which concluded that the reservoir could be economically flooded. A significant investment would be required up front to define net pay by gathering and interpreting data from coring, logging and testing. Watercut would be high throughout the life, but large water volumes could be lifted economically from this depth.

Based on the study's recommendations, Wilton purchased the available leases with the intent of acquiring the remaining properties in the field and forming a waterflood unit. Before this plan could be implemented, another company acquired the remaining leases for waterflood purposes. As is often the case, both companies wanted to operate. However, rather than to waste time in endless negotiations, both parties readily agreed to a cooperative data gathering and waterflood effort involving six lease line injectors. The entire Glorieta-Clearfork section would be cored in the initial lease line well prior to finalizing the completion intervals and injection pattern. Wilton also discovered that there were over 500 royalty owners in their properties, which made unitization impractical. The feasibility study was revised accordingly and still showed favorable economics for a non-unitized, cooperative waterflood. The economics were aided by sharing the costs of the water source and new injectors.

Three existing wells were logged with modern cased hole logs and selected intervals were straddle tested. The results were combined with the full diameter core analysis and log interpretation from the initial lease line well to define the net pay intervals both in existing and new wells. This intensive data gathering effort confirmed that there was considerable pay behind pipe, but it was pressure depleted due to wellbore communication and good zonal continuity.

GEOLOGY

The Wentz (Glorieta-Clearfork) reservoir is located along the southeastern edge of the Central Basin Platform (Figure 2) and is similar to various other carbonate reservoirs on the platform margin. The formation was deposited as limestone by repetitive cycles in a shallow marine shelf environment. Diagenesis involved dolomitization of the limestone and destruction of primary porosity by the deposit of evaporates. The actual trap was formed by the restoration of porosity through the dissolution of evaporates by circulating of meteoric water. A high degree of horizontal stratification is normal.

The result is a very heterogeneous reservoir with several types of porosity, creating complex relationships between porosity, permeability and fluid saturations. The reservoir is characterized by numerous porous dolomite stringers. Although structural closure exists, the hydrocarbon trapping is primarily stratigraphically controlled by lateral and vertical limits of porosity and permeability. A depositional environment study with detailed facies description and distribution analysis would have developed a more quantitative characterization of the reservoir, but was not justified for this particular project.

NET PAY DETERMINATION

For comparison purposes various modern cased-hole logs (Compensated Neutron-Gamma Ray, Natural Gamma Ray Spectrometry, Gamma Spectrometry and several different computer interpretations) were run in three existing wells. After logging, selected intervals in the wells were isolated, treated and swab tested. Interpretation of the lithological, porosity and test data revealed that the pay consisted of both radioactive and non-radioactive porous dolomitic stringers interbedded with anhydrite, shale and dense dolomite layers. Log porosities ranged from 8-15% and agreed with the core data in one of the test wells. Computed water saturations from 25-45% were reasonable.

Radioactivity makes some pay zones appear as shale intervals on standard gamma ray-neutron logs, which explained the past difficulties in identifying productive intervals. Consequently, there were considerable amounts of net pay behind pipe as the geologic study suggested. However, the zonal testing indicated that the unperforated pay intervals are pressure depleted and will add little to primary recovery. These intervals do contain good oil saturation and will contribute significantly to secondary recovery.

Three hundred feet of full diameter core were cut on the first lease line injector drilled (Shenandoah-Hollingsworth A-6) and modern open hole logs were run (Compensated Density-Neutron and Dual Laterolog-Micro-Laterolog). Net pay determination based on porosity cutoff is not sufficient in complex carbonate reservoirs where several porosity systems exist. Complete pay description requires an indication of permeability and oil saturation. From the Hollingsworth A-6 core analysis a net pay criteria was established with a minimum residual oil saturation of 5% and minimum permeability of 0.3 md. This generally corresponded to a porosity cutoff of 8%. Table 1 shows the average rock properties from core for the net pay zones in the Hollingsworth A-6. The correlation between core porosity and neutron-density cross-plot porosity is given on Figure 3. The match between core and log net pay intervals is displayed graphically by Figure 4. The magnitude of the radioactive pay effect is shown by the difference between the raw and uranium corrected gamma-ray curves from the Hollingsworth B-3.

In lieu of core data, some indicator of permeability is needed. In new wells with modern logs, movable oil which is an indication of permeability can be calculated or implied from Sw/Sxo calculations. A Sw/Sxo ratio of 0.7 or less was found to give a reasonable estimate of net pay when combined with a porosity cutoff of 8%.

To aid in determining net pay within existing wells, Spectrologs were run in all wells scheduled for conversion to injection. The Spectrolog was chosen based on the special logging and testing in the three wells discussed. It allows the radioactive dolomite to be identified and when combined with the neutron porosity cutoff of 8% delineates potential pay zones. Although no indication of permeability or saturation are available from the Spectrolog, careful correlation with nearby wells having modern open hole logs or core analyses further refines the net pay determination.

PRIMARY PERFORMANCE

Net pay isopach maps were prepared for the Glorieta, Clearfork-1 and Clearfork-2 zones. The composite Glorieta-Clearfork net pay isopach is given by Figure 5. The reservoir volume was measured and OOIP calculated to be 29.4 MMBBL using 10% porosity and 40% water saturation. Primary performance is shown on Figure 6. The effect of additional drilling in the mid-1970's is clearly seen. Ultimate primary production was projected to be 2.82 MMBBL for a primary recovery of 9.6%. Only one of the analogous Clearfork reservoir studied had recovery this low. The lack of reservoir pressure data precluded any attempt at material balance calculations.

The gas production history could not be documented, but appeared to be similar to other Clearfork reservoirs in the area. Current gas production is low and there are no gas sales. The water production history is also unknown, but was averaging only a few barrels per day per well prior to waterflood development.

SECONDARY RECOVERY

Zonal continuity was investigated during the course of the waterflood feasibility study using procedures proposed by Stiles (Figure 7).[1] The percentage of pay continuity as a function of distance between wells for an east-west cross section covering seven wells over 1.6 miles is given by Figure 8. At Wilton's average density of 20 acres per well, continuity is 90% plus. This is offset to some degree by the irregular spacing.

Waterflood recovery was estimated by Buckley-Leverett frontal advance calculations using a nine layer model. The available core permeabilities were statistically ordered with the resulting distribution suggesting three separate permeability systems. Relative permeability relationships were derived from production performance of analogous Clearfork waterflood projects. The single pattern results were factored up to the assumed total floodable area, resulting in a secondary to primary ratio of 0.88.

The objective in designing the injection pattern was to get maximum injection coverage with minimal drilling. The constraints of irregular spacing, net pay distribution, minimal drilling and compensating injectors across lease lines have produced a dense pattern with 51 producers and 39 injectors. While exhibiting some aspects of both a staggered line drive and five spot, it is probably best described as "opportunistic" (Figure 9).

Fillup calculations were based on 325 BWPD per injector. The project performance projection for Wilton was derived by analytical calculations (Craig-Griffin-Morse) as modified by analogy (Figure 10). A peak oil rate of 20 BPD per well was assumed.

WATERFLOOD DEVELOPMENT

The installation of a pilot was considered and rejected. To a degree, the field already had a pilot. An estimated 925 MBBL has been injected into the McDonald A-1 disposal well since 1968 with no appreciable effect on offset production. Actually, the McDonald A-11 had watered out, but this was not known until after the project started. It was reasoned that the extremely low reservoir pressure and lack of injection backup prevented the creation of pressure sinks around offset wells necessary to capture any banked oil that moved by. An actual pilot could be expected to have similar results. Based on performance of analogous waterflood projects there was little doubt that oil could be banked by water injection at Wentz. The only benefit from a pilot would be information about injectivity and directional permeability. This did not justify the cost and delay of a pilot, particularly for a small project where directional permeability was not a major concern due to the dense injection pattern.

Although some existing wells has been perforated below the Clearfork-2 in the Clearfork-3 and Clearfork-4, these were marginal pay zones that could be flooded only at considerable costs. Wilton decided to exclude these minor zones from the project and inject water only in the main pay intervals.

Full scale development of the cooperative waterflood required Wilton to: (1) convert 25 producers to injectors, (2) drill 4 injectors, (3) drill 3 producers and (4) rework the remaining 37 producers. The objective of the well work was to open all net pay within the Glorieta-Clearfork-2 section in both injectors and producer. Originally, the non-pay and deeper (below Clearfork-2) perforated intervals were to be isolated. However, injection profile analyses run to date indicate no significant injection loss into these intervals, which eliminated at least temporarily, the need for expensive remedial work. Selection of perforated intervals in the lease line injectors was done jointly by the two operators. As of December 1989, Wilton lacked only the drilling of three producers and one edge injector plus the workover of some producers.

Even through this project was being installed in a depressed domestic energy industry, low oil prices were offset to some degree by the utilization of used equipment and by bidding out service work in large batches. Used equipment was carefully selected, tested and reconditioned before being placed in service. Prior to the selection of equipment, the field supervisors of similar waterflood projects were contacted for their recommendations. Among the conclusions reached was that cement is still the most cost efficient lining for water lines. Costs were reduced significantly by not burying the injection lines in the rocky soil. Drains were installed in low areas in case of shut down during cold weather. The injection plant was sized for 8,000 BWPD at 1350 psi with room for expansion. The actual design and fabrication of the plant was contracted out to an experienced third party.

Non-unitized operations required that tank batteries be maintained on each lease. All batteries were rebuilt with the gun barrels being replaced by heater treaters. Three phase metering test separators were installed on most leases. By using a portable test meter and lease water meters, an individual well test frequency of at least three tests per month is possible.

Several potential water sources were available including fresh water from the Trinity formation at 400'. The decision was made to use brackish water from the Pecos River alluvium at a depth of 100' located three miles away. There is no indication of water incompatibility between the brackish (5000 BPM total dissolved solids) make-up water and produced water. Nevertheless, the water handling facilities were designed to keep produced water and make-up water separated to preclude potential problems, since the produced water contains hydrogen sulfide.

PROJECT PERFORMANCE

Water injection was initiated in October 1988. Through November 1989, a total of 1736 MBBL of water has been injected into the 26 Wilton operated injection wells. The current average injection rate of 154 BPD per well is less than anticipated. Surface injection pressures are maintained around 1500 psi to stay below the formation parting pressure established by initial step rate tests. More recent step rate testing indicates parting pressure is increasing with fillup.

Injection response is being carefully monitored by Wilton with well tests and fluid level checks. Production has increased more rapidly than originally projected as seen on Figure 10 and detailed by well on Table 2. The total increase in oil and water production for each well during the first year of injection is shown on Figure 11. Initial oil response occurred around the McDonald A-1 disposal well. The disposal volume not only filled up the reservoir voidage, but banked oil that had already swept by the McDonald A-11 before waterflood start up. Once injection started in the area, the oil bank was concentrated around the McDonald A-4 which went from 6 BOPD to 48 BOPD in 11 months. The south and west offsets to McDonald A-1 have also shown production increases. Selectively shutting in the three injectors surrounding McDonald A-11 proved that McDonald A-1 was not channeling directly to McDonald A-11. This is cited as evidence that disposal into McDonald A-1 had formed a bank of oil that moved by McDonald A-11 undetected because of the low reservoir pressure and lack of injection backup.

Major response has also occurred on the Wilton-Hollingsworth B Lease. This had always been the field's most productive area and now exhibits the best injectivity. The Hollingsworth B-5 has gone from 0 BOPD and 40 BWPD to 50 BOPD and 146 BWPD. Other producers on the lease are experiencing lesser increases. This early response is credited to the high injectivity and dense spacing. The higher permeability zones are being pressurized by differential injection, creating a "psuedo" fillup situation. The only direct water-break through in the project occurs on this lease between B-3 (injector) and B-4 (producer).

Besides the two areas discussed, some response is occurring over most of the Wilton acreage. This is due not only to "pseudo" fillup, but also the small amount of repressuring to date. The reservoir's production is sensitive to small pressure changes due to the extremely low reservoir pressure. For example, the small amount of backpressure that was required when the gun barrels were replaced by treaters has adversely affected production.

The composite performance of the Wilton leases in comparison to the projection can be seen on Figure 10. The watercut is high at 80%, but this was anticipated. There is no evidence of directional permeability and only one instance of direct water breakthrough. The irregular spacing and low injectivity will make it impossible to balance the patterns. There will be a wide variation in "floodout" times both within and between patterns. Maximizing areal sweep will require additional injector conversions and well abandonments in the future. Monitoring the performance constantly on an individual well basis is the key to successfully operating the waterflood.

CONCLUSIONS

This project has only been under injection for a little over a year so obviously the ultimate results are unknown. However, the early results exceed expectations and are encouraging. The apparent success of this project can be attributed to:

1. Recognition of the waterflood potential in smaller complex carbonate reservoirs.

2. Identification by a feasibility study of:

   a. problems with net pay definition that cause inefficient completions.

   b. good zonal continuity.

   c. existing well density equivalent to the spacing in successful Clearfork waterfloods.

3. Willingness of both field operators to agree to a cooperative flood effort.

4. Gathering and interpretation of sufficient data initially to define net pay.

5. Omitting a pilot and devising a practical waterflood plan that concentrates on the high potential areas and minimizes drilling.

6. Developing the project with proven techniques, taking advantage of used equipment and volume discounts.

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Table 1
Core Summary–Shenandoah-Hollingsworth A-6
Wentz (Clearfork) Field, Pecos County, Texas

Zone	Net Pay (ft)	Porosity (%)	Porosity Thickness (dec-ft)	Permeability (md)	Permeability Thickness (md-ft)
Glorieta	31	12.12	3.758	3.55	110.200
Clearfork-1 (Upper)	2	8.25	0.165	0.54	1.070
Clearfork-2	56	12.64	7.079	5.48	306.900
Total	89	12.36	11.002	4.70	418.170

Table 2
Production Tests on Wilton-operated Wells
Wentz (Clearfork) Field, Pecos County, Texas

		Initial Well Test			Recent Well Test		
Lease	Well No.	Date	Oil (BPD)	Water (BPD)	Date	Oil (BPD)	Water (BPD)
C. C. Hart	1	9/12/88	2.5	40.0	11/07/89	12.9	5.4
	2	6/22/88	2.3	4.0	12/06/89	4.3	3.8
	6	6/22/88	0.8	17.5	12/07/89	13.4	15.6
Hollingsworth "B"	1	1/26/89	0.0	0.0	12/05/89	1.8	1.5
	2	1/19/89	1.0	0.0	11/18/89	13.4	15.6
	4	1/20/89	0.0	82.0	9/23/89	3.0	116.0
	5	1/21/89	0.0	40.0	12/77/89	50.0	146.0
	8	1/23/89	1.0	0.0	12/01/89	3.6	3.4
	9	1/22/89	3.0	9.0	12/04/89	9.0	27.5
Hollingsworth "C"	3	1/18/89	3.0	1.0	12/02/89	3.5	13.3
	5	1/16/89	5.0	3.0	12/05/89	2.6	16.3
	6	1/27/89	0.0	30.0	12/07/89	9.0	67.7
	8	2/15/89	0.3	1.8	12/03/89	2.5	4.2
Howard-Hollingsworth	2	3/03/89	4.9	22.8	11/28/89	0.1	0.1
	3	1/13/89	0.0	0.0	11/27/89	8.1	18.0
Kokomo-Hollingsworth	1	2/15/89	0.7	1.9	10/29/89	1.2	4.0
McAlester-Hart	1	2/16/89	1.2	4.5	11/23/89	2.3	2.0
McDonald "A"	2	2/22/89	2.5	0.5	12/05/89	12.5	3.7
	4	1/14/89	6.0	1.0	12/06/89	48.2	4.2
	5	2/20/89	0.6	0.4	12/07/89	17.5	110.0
	7	2/17/89	2.3	10.7	10/29/89	2.0	5.0
	8	2/24/89	14.3	8.7	10/25/89	33.0	12.0
	11	1/12/89	0.0	17.0	8/89	9.0	219.0
	13	2/18/89	1.3	1.7	12/01/89	1.2	5.1
	15	2/16/89	2.5	12.5	12/02/89	3.5	81.5
	16	2/24/89	1.1	2.1	12/03/89	3.2	3.5
	17	2/21/89	1.4	3.6	12/04/89	16.2	5.2
McDonald "B"	2	- - - - -	- - - -	- - - -	TA - - - -	- - - -	- - - -
	3	1/24/89	2.0	2.0	12/05/89	2.5	2.5
	4	1/25/89	0.5	4.5	12/05/89	1.0	5.0
Greef-McDonald	1	2/16/89	0.3	2.7	11/26/89	1.5	2.0
Pollard-Hart	1	2/16/89	3.0	0.3	12/06/89	10.4	2.0
Pollard-Hollingsworth	3	6/25/88	1.8	8.3			
	4	2/16/89	1.3	3.5	12/07/89	17.0	
	5	2/16/89	1.7	3.4			
Vick "A"	1	4/20/89	0.0	10.6			
	2	4/30/89	0.5	22.6	12/06/89	3.5	
	4	4/21/89	0.3	14.3			

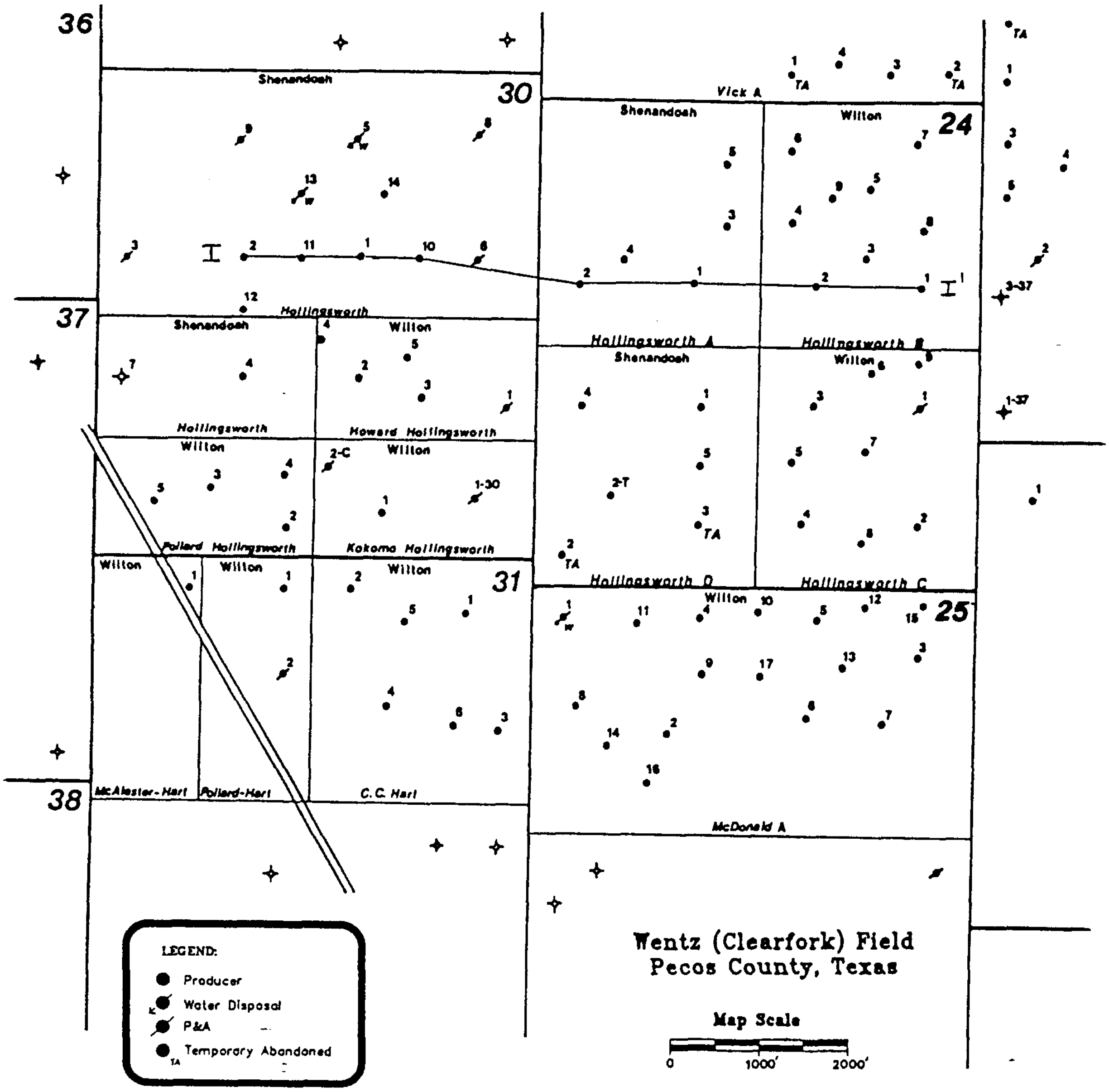

Figure 1 - Pre-waterflood field map

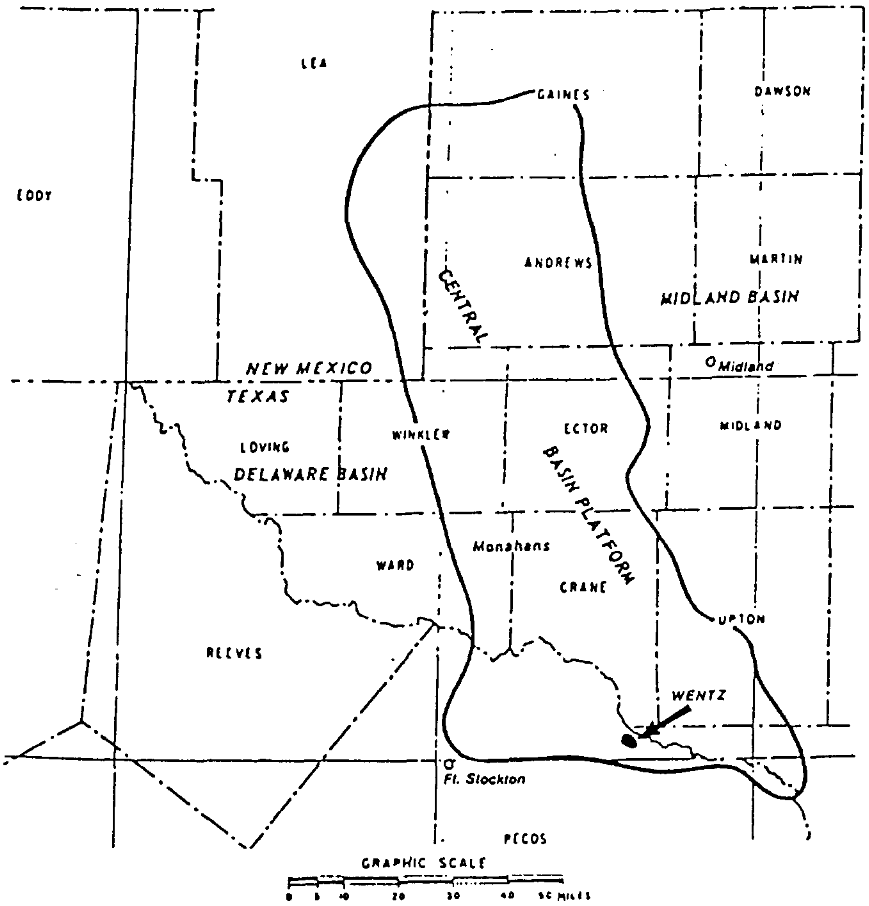

Figure 2 - Regional map

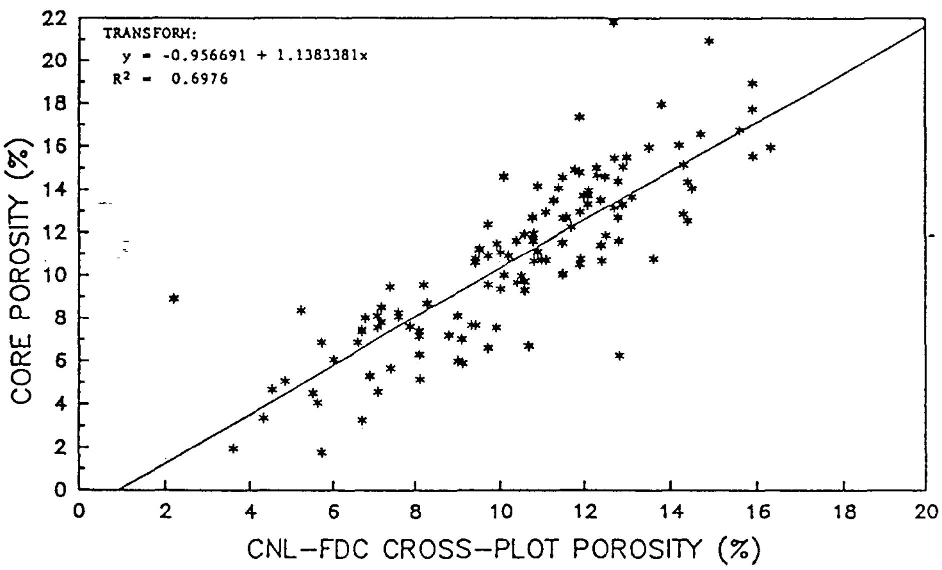

Figure 3 - Core vs. log porosity
Wentz (Clearfork) Field

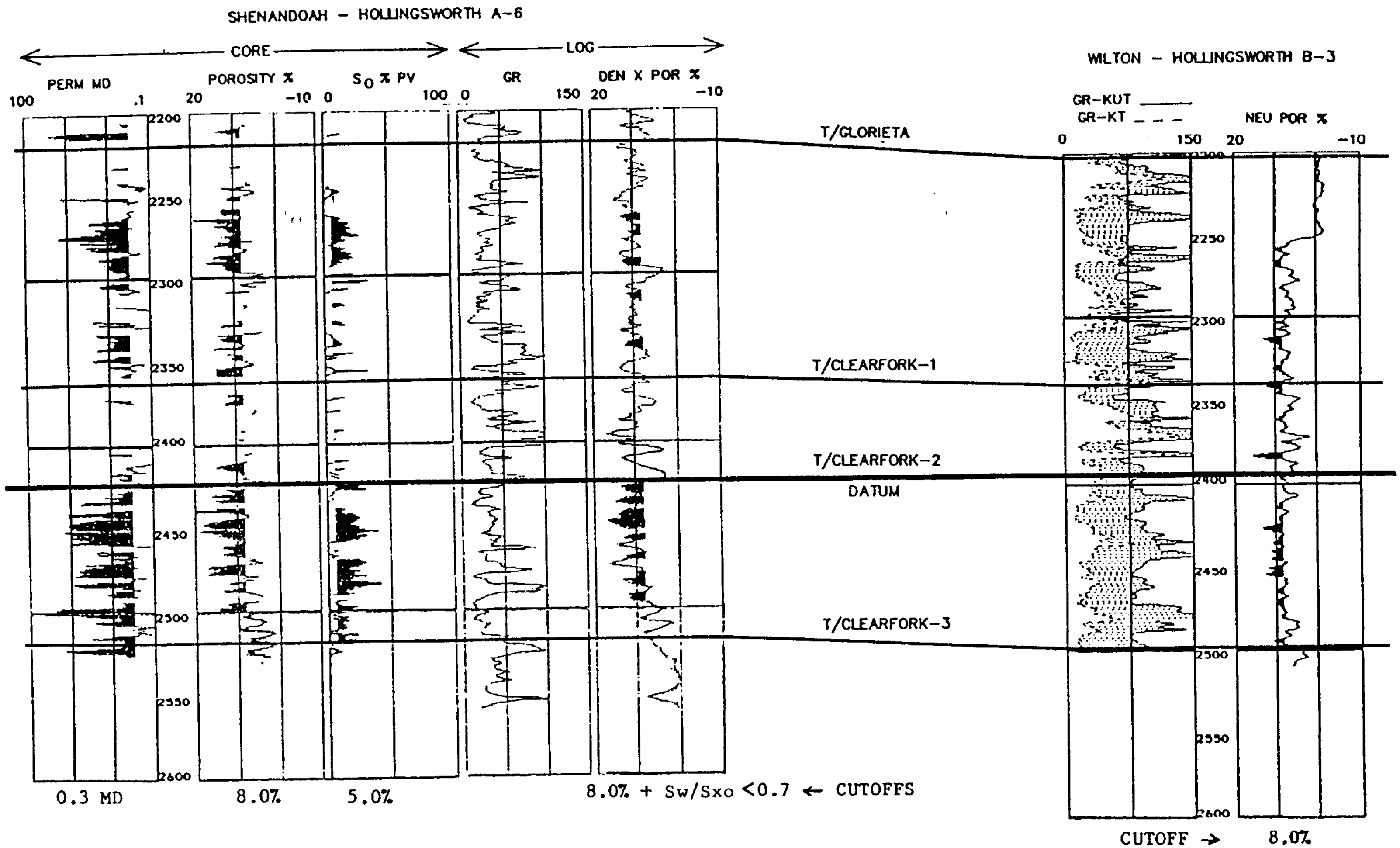

Figure 4 - Net pay correlations, Wentz (Clearfork) Field, Pecos County, Texas

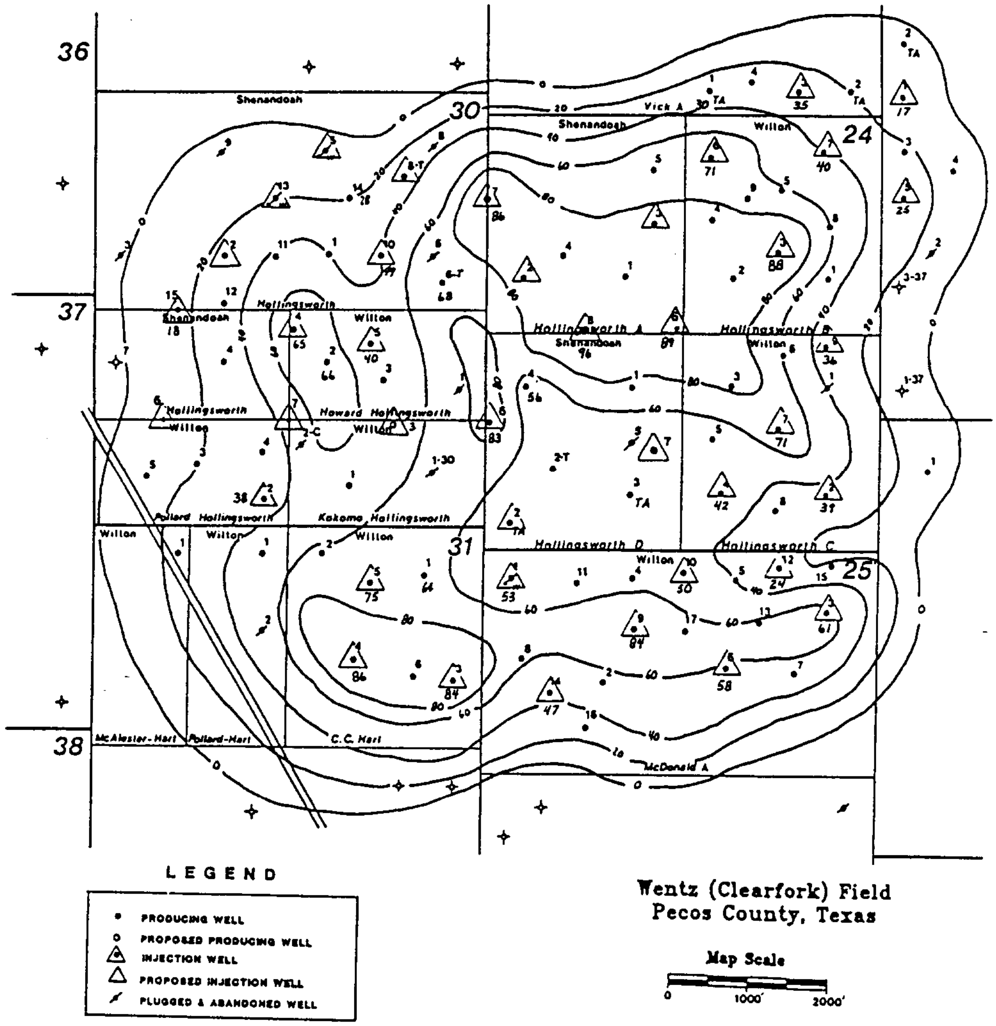

Figure 5 - Composite net pay isopach

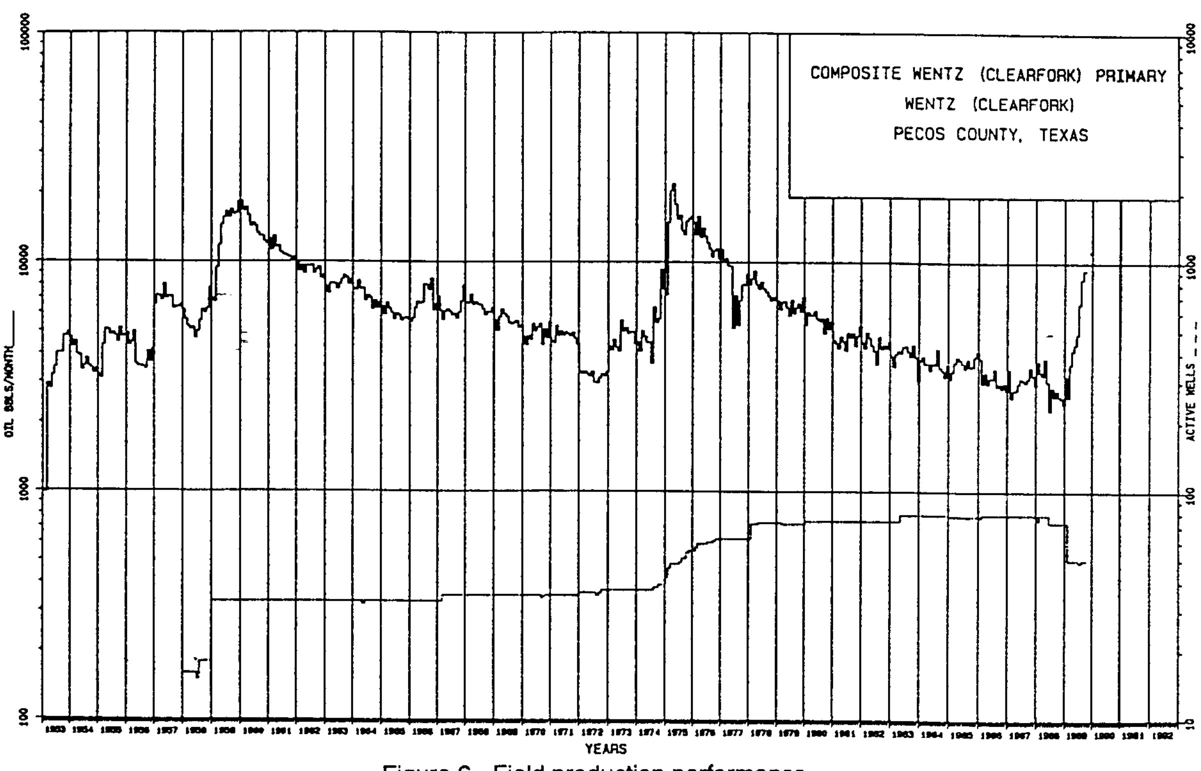

Figure 6 - Field production performance

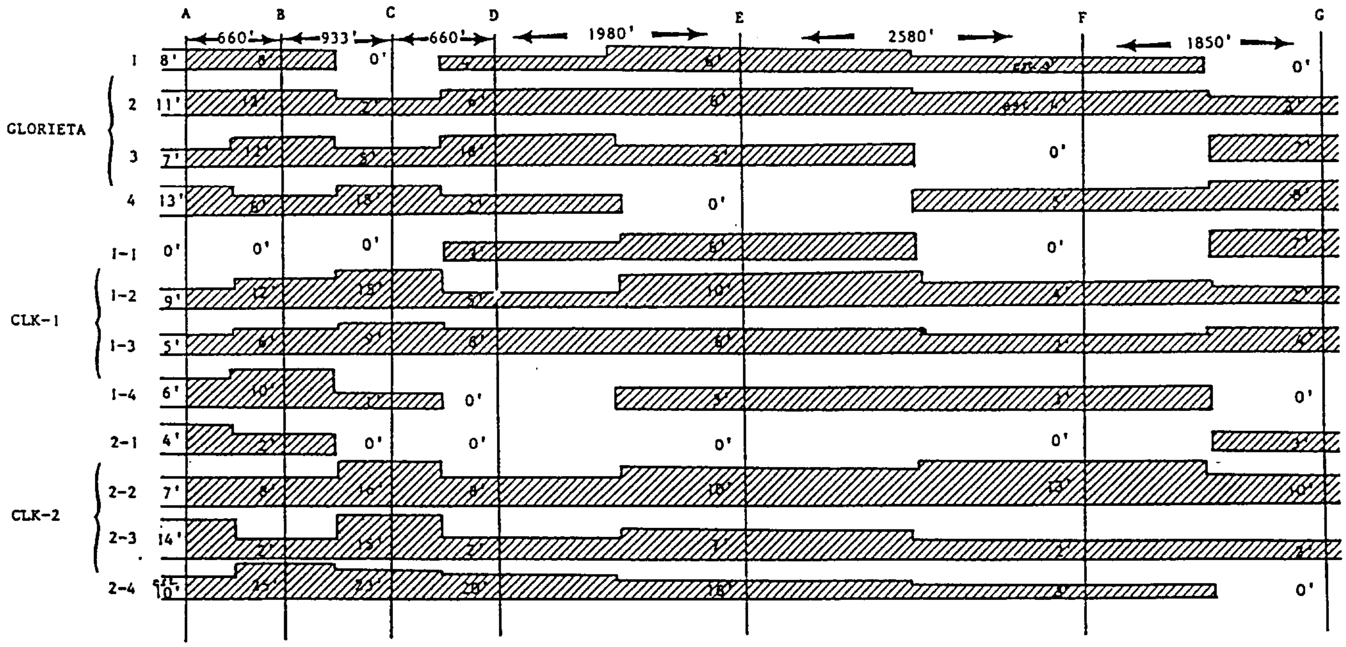

Figure 7 - Diagramatic continuity cross-section I-I'
Wentz (Clearfork) Field

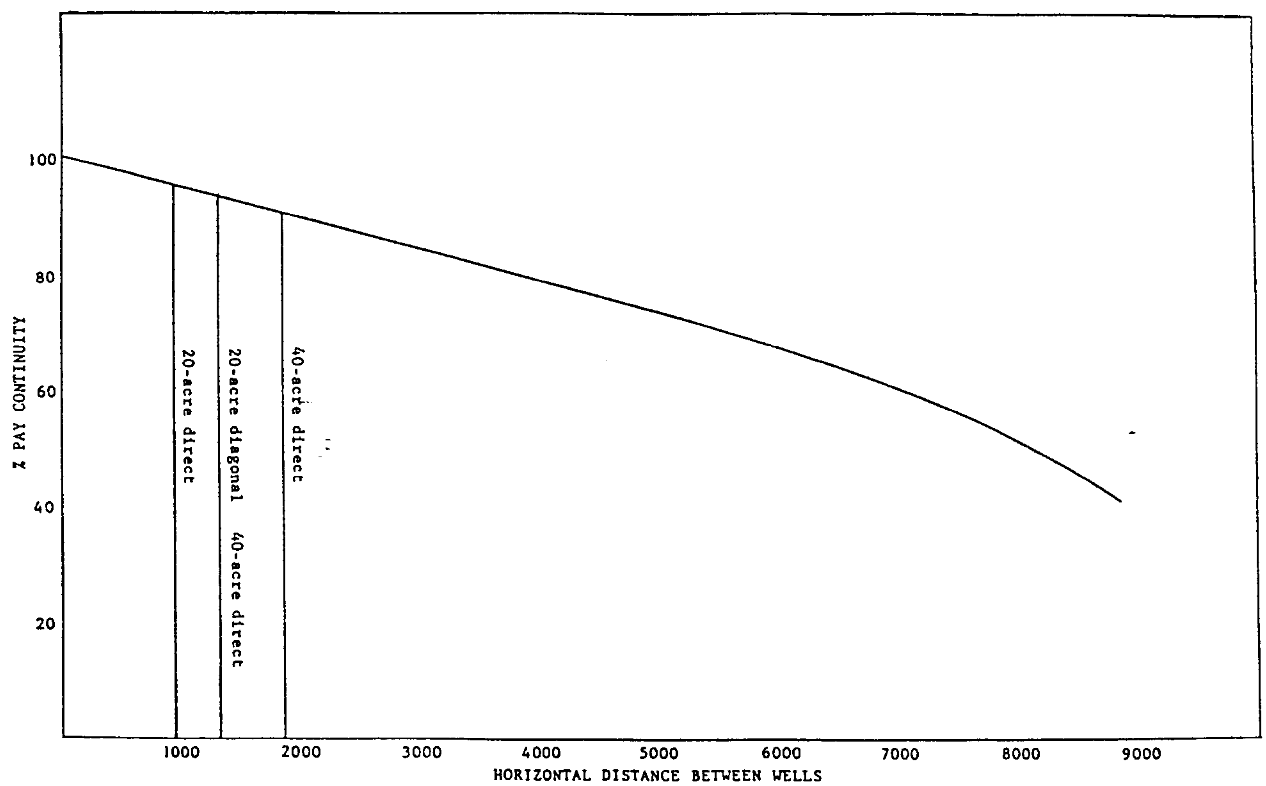

Figure 8 - Pay continuity vs. distance east-west cross-section I-I'
Wentz (Clearfork) Field

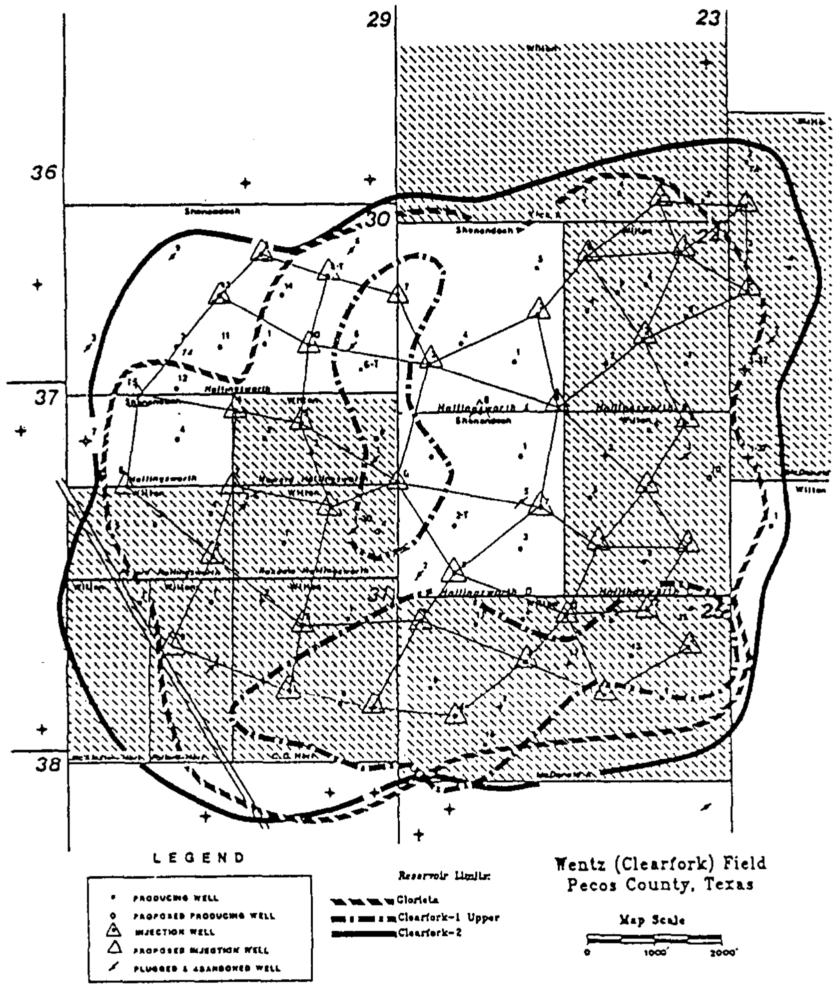

Figure 9 - Injection pattern plat

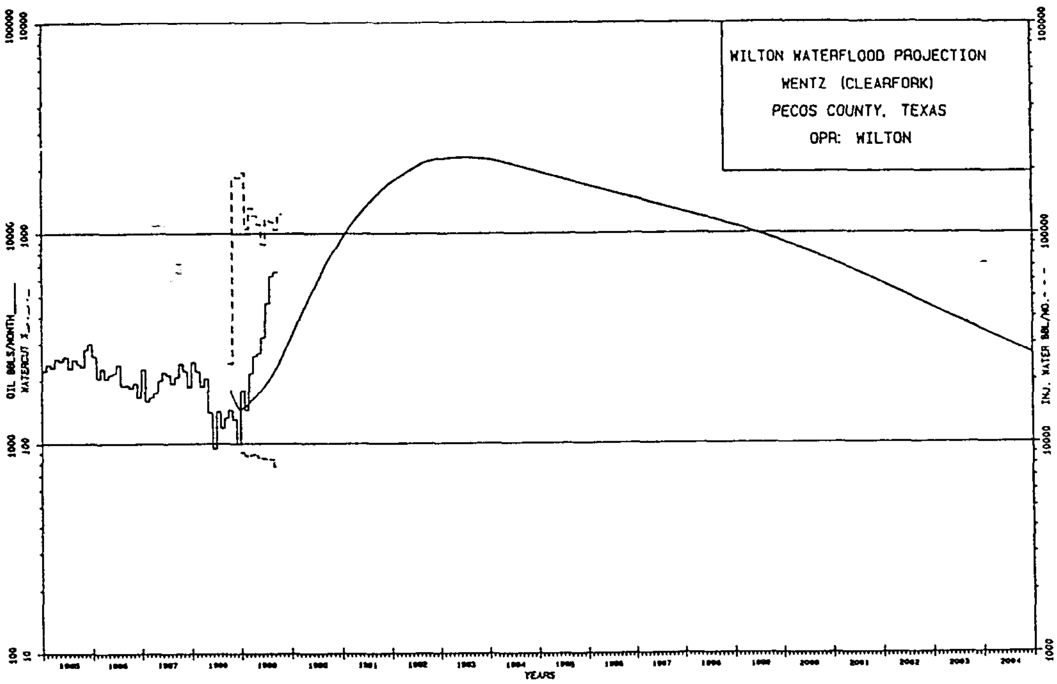

Figure 10 - Project performance–historical vs. projection

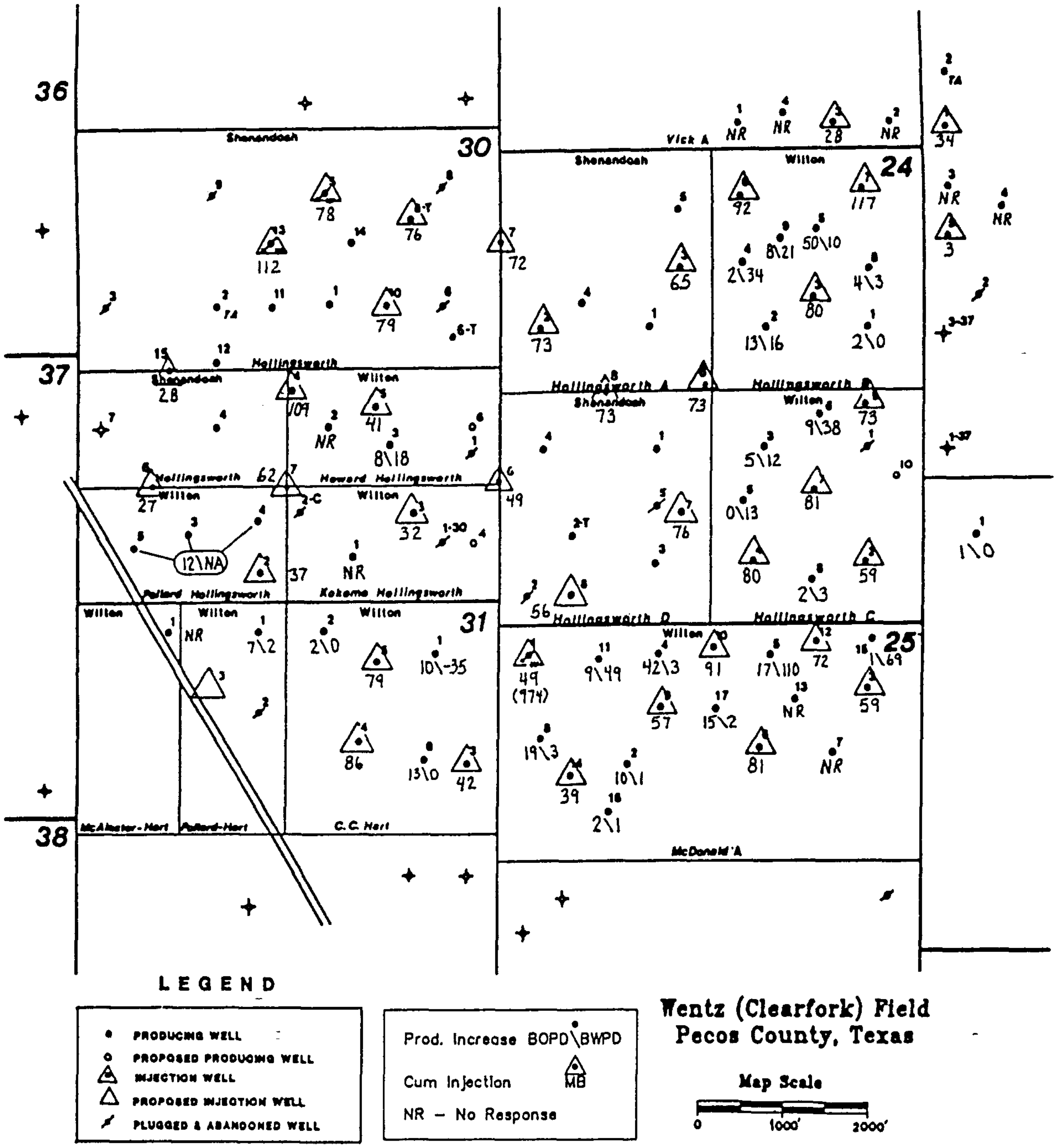

Figure 11 - Waterflood response