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EVALUATION OF AREA OF REVIEW VARIANCE OPPORTUNITIES FOR THE EAST TEXAS FIELD

Final Report

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The methodology used herein was developed under sponsorship of the American Petroleum Institute in coordination with the Ground Water Protection Council. Funding for this project was provided by the U.S. Department of Energy's Office of Fossil Energy through its Metarie Site Office in New Orleans, Louisiana.

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ABSTRACT

The East Texas oil field, discovered in 1930 and located principally in Gregg and Rusk Counties, is the largest oil field in the conterminous United States. Nearly 33,000 wells are known to have been drilled in the field.

The field has been undergoing water injection for pressure maintenance since 1938. As of today, 104 Class II salt-water disposal wells, operated by the East Texas Salt Water Disposal Company, are returning all produced water to the Woodbine producing reservoir. About 69 of the presently existing wells have not been subjected to U.S. Environmental Protection Agency Area-of-Review (AOR) requirements.

A study has been carried out of opportunities for variance from AORs for these existing wells and for new wells that will be constructed in the future. The study has been based upon a variance methodology developed at the University of Missouri-Rolla under sponsorship of the American Petroleum Institute and in coordination with the Ground Water Protection Council.

The principal technical objective of the study was to determine if reservoir pressure in the Woodbine producing reservoir is sufficiently low so that flow of salt-water from the Woodbine into the Carrizo-Wilcox ground water aquifer is precluded. The study has shown that the Woodbine reservoir is currently underpressured relative to the Carrizo-Wilcox and will remain so over the next 20 years. This information provides a logical basis for a variance for the field from performing AORs.

INTRODUCTION

The East Texas oil field is located in the extreme eastern part of Texas and comprises approximately 131,000 acres. The field is located principally in Gregg and Rusk Counties and in very limited portions of Cherokee, Smith and Upshur Counties (Figure 1). The field was discovered in 1930 and is the largest oil field in the conterminous United States in the number of wells and volume of oil produced (McWilliams, 1972). An evaluation of the Texas Railroad Commission (TRRC) well location database for the five East Texas field counties shows a total of nearly 33,000 wells for the field (Table 1).

Because of pressure declines in the reservoir, as will be discussed later, the field has been undergoing water injection for pressure maintenance since 1938 (East Texas Salt Water Disposal Company, 1958). As of today, a total of 104 Class II salt-water disposal wells, operated by the East Texas Salt Water Disposal Company (SWDC), are returning all produced salt water to the Woodbine sand producing reservoir.

Since 1982, all new Class II injection wells constructed in Texas have had to have Underground Injection Control (UIC) permits from the TRRC. A condition of the permits for new wells is the performance of an Area of Review (AOR) analysis as required by U.S. Environmental Protection Agency (EPA) regulations. An AOR analysis for a Class II injection well begins with the identification and location of all wells of all types within a one-quarter mile radius of the injection well or within the radius-of-endangering-influence of the injection well, whichever radius is lesser. The construction and abandonment of each deep well must then be documented. This includes the details of each casing string or liner and all cement emplaced during construction and any modifications to these during operation and abandonment. Abandonment details also include all flow barriers such as cement and cast iron bridge plugs and weighted mud emplaced during abandonment. The purpose of the AOR is to demonstrate that all boreholes intersecting both the injection reservoir(s) and a USDW contain flow barriers adequate to prevent flow of fluids, principally salt water, from the reservoir(s) to a USDW. In the case of the East Texas field, because of its historically pressure-depleted status, such AORs have not been required until recently (personal communication, Mr. Jerry Mullican, TRRC and Mr. Jerry Adams, SWDC).

At present, AORs are being required for the East Texas field because the TRRC believes that sufficient pressure increases may have occurred from salt water injection and natural reservoir repressuring to allow migration of water from the Woodbine injection reservoir to the Carrizo-Wilcox underground source of drinking water (USDW), should a pathway for such migration exist. Furthermore, the U.S. EPA has been expected to possibly revise its regulations to require such AORs for Class II injection wells constructed prior to 1982, which have been exempt from that requirement to date. This would affect about 69 disposal wells in the East Texas field. In a preliminary study of the impact of such revised regulations on the East Texas field, it was estimated (Calhoun, 1993) that the cost of compliance by the SWDC and private operators would be $86.2 million for the first five years after the promulgation of new regulations requiring AORs on previously exempted wells.

Beginning in 1990, the University of Missouri-Rolla (UMR) conducted research to develop a methodology for variance from AOR requirements (Warner et al., 1993). The methodology developed at UMR was subsequently revised and adopted by the Underground Injection Practices Research Foundation of the Ground Water Protection Council (GWPC, 1994).

The variance methodology developed at UMR has been applied to the San Juan Basin of New Mexico (Warner et al., 1993a) and application to the Texas Permian basin counties is nearly completed. At the suggestion of various East Texas field operators, and with the agreement and encouragment of the SWDC and the TRRC, UMR proposed to the U.S. Department of Energy (DOE) a study of AOR variance opportunities for the East Texas field in order to determine if a basis could be found for relief from this regulatory requirement.

To initiate the study, a Steering Committee was formed to provide guidance and advice. The membership of the Steering Committee is listed in Appendix 1. At the initial meeting of the Steering Committee, which was held May 13, 1994, it was recommended that UMR study the variance method based upon the lack of sufficient petroleum reservoir pressure to cause flow into the lowermost USDW. This report documents the results of UMR's investigation of this variance option. The study supports DOE Domestic Natural Gas and Oil Initiative objectives of streamlining and improving regulations and supporting risk-based regulatory decisions by the State of Texas and the EPA (U.S. Department of Energy, 1993 and 1995).

GEOLOGY AND HYDROGEOLOGY OF THE EAST TEXAS FIELD

The East Texas oil field lies within the broad belt of Cretaceous and Tertiary age rocks which border the Gulf of Mexico and unconformably overlap pre-Cretaceous rocks. The East Texas field produces from the Cretaceous age Woodbine sand found at an average depth of 3,600 feet. Figure 2 is a generalized west-to-east cross section of the field showing that it is formed by westward dipping Woodbine sands that are unconformably truncated and overlain by the Austin Chalk. The maximum Woodbine sand thickness is 70 to 120 feet on the west side of the fields. It thins toward the east and terminates against the base of the Austin Chalk, forming the trap that contains the oil.

Figure 3 shows a generalized columnar section for the East Texas field. As previously mentioned, the Woodbine sand is the producing reservoir. Of special interest, in addition to the Woodbine sand, are shales of the Eagel Ford, Ozan-Brownstown, Navarro and Midway Formations. These shales could possibly act as squeezing and/or caving units that would close an open borehole or close an uncemented annular space behind casing.

Groundwater resources in the area of the East Texas field have been the subject of various studies and reports that date back many years. Preston and Moore (1991) authored the most recent such report and a bibliography of publications dated earlier than 1991 is contained in their report.

The principal ground water aquifer and lowermost USDW over the area of the East Texas field is the Carrizo-Wilcox aquifer, which is comprised of the Wilcox Group and the overlying Carrizo Formation. Preston and Moore (1991) show the Carrizo-Wilcox aquifer to be 800 - 1200 feet thick over the East Texas field. In the very southern end of the field, the Carrizo-Wilcox is about 1200 feet thick and it is exposed at the surface. The aquifer thins to 800 feet in thickness at the north end of the field and, there, it is overlain by several hundred feet of younger formations, including the Reklaw and Queen City Formations which are minor aquifers that may yield moderate to small amounts of usable-quality water.

Preston and Moore (1991) report that, in general, the Carrizo-Wilcox and Queen City-Reklaw aquifers contain relatively good quality water throughout most of the study area, but within each of the aquifers, water quality deteriorates with depth. In the Carrizo-Wilcox, the lowermost USDW, the base of usable quality water is generally just above the base of the Wilcox (personal communication, R.K. Earley, 1994). Thus, using the base of the Wilcox as the base of the lowermost USDW, as has been done in this study, is a conservative approach to protecting usable ground water.

ANALYSIS OF THE PRESSURE POTENTIAL FOR VERTICAL MIGRATION OF WOODBINE RESERVOIR WATER INTO THE CARRIZO-WILCOX USDW

General Study Approach

The theory underlying this study and procedure for practical application of the theory to a study similar to this one are described, respectively, by Warner et al. (1993) and Laudon et al. (1994; Appendix 2).

The general process for this study was:

1. Obtain reliable petroleum reservoir pressure data, ground water head elevations for the lowermost USDW and elevation data for the base of the lowermost USDW.

2. Convert reservoir pressure data from 1. to fresh-water head elevations using the base of the lowermost USDW as a datum.

3. Subtract USDW heads from 1. from petroleum reservoir fresh-water heads from 2.

The difference between the petroleum reservoir heads and the USDW heads is referred to as a residual head. If the residual head is negative, the USDW head is greater than the petroleum reservoir fresh-water head, as referenced to the base of the USDW, and no upward flow of water from the petroleum reservoir to the USDW can occur. If such residuals are positive, then the potential for such flow exists but, in order for flow to occur, a pathway must exist. That is, there would have to be, for example, an abandoned borehole that had an unobstructed pathway between the petroleum reseroir and the USDW.

The procedure of using the data from step 1, above, in steps 2 and 3 can be carried out manually for a single point or several points but the manual procedure is not very practical over an area such as the East Texas field. In practice, data are computer plotted using latitude and longitude coordinates. The data are then converted from the random locations at which they occur to a regular grid by an interpolation algorithm. The gridded data are then contoured or compared by computer as is appropriate. A more detailed description of the management of each data set will be given. An example of a manual calculation is given in Appendix 4 and the manual calculation is compared with the computer generated results to allow the reader to better understand the basis for the computer generated results.

Petroleum Reservoir Pressures

It is fortunate that operators in the East Texas field conduct annual measurements of shut-in bottom-hole Woodbine reservoir pressure in selected wells throughout the field. These data are collected by the East Texas Engineering Association, Kilgore, Texas (ETEA). The pressure is measured at an appropriate depth in each well but, then, all data are adjusted to -3,300 feet mean-sea-level (MSL) elevation using the specific gravity of Woodbine water in each particular wellbore. Referencing of pressure data to a common datum is necessary so that the pressures for all wells can be compared or displayed as in Map 1. The reason for selection of -3300 ft MSL as a common datum is not known. It can be speculated that it was selected because it is a datum just below the original oil/water contact (Figure 2).

Woodbine reservoir pressure data for 1991, 1992 and 1993 were obtained from the ETEA. The data for 1993 are given in Column D of Table 2 for 107 wells. The data from the ETEA included 111 wells. Four wells were dropped from the ETEA data set because the pressure values were so anomalously low or high that it is clear that they are not representative.

In Table 2, American Petroleum Institute (API) numbers were supplied by ETEA to the SWDC and, in turn, to UMR. The API numbers were matched against ones in a data set from the TRCC to obtain latitudes and longitudes which are essential for locating the wells on a basis common to other data. The Woodbine reservoir data of Column D, Table 2, are plotted on Map 1 along with computer contours of those data.

Elevation of the Base of the Carrizo-Wilcox USDW

Data in Table 3 for the base of the Wilcox Group, a geologic unit, were obtained from the Texas Water Development Board (TWDB). These data were generated by the TWDB from subsurface data from wells drilled in and near the East Texas field. The data given in Table 3 and shown on Map 2 are a small part of a much larger data set that covers a much larger geographic area than that shown in Map 2.

Inspection of Map 2 shows that the data set covering the area of this study are rather sparse. This is probably because of a lack of good quality geophysical borehole logs from which to pick the base of the Wilcox. Although the data are sparse, they are considered sufficient for the purpose of generating the contours of Map 2 which are used in the analysis process.

As was explained, earlier, the base of the Wilcox Group is probably somewhat below the base of usable quality water in the Carrizo-Wilcox USDW. However, UMR has used the elevation of the base of the Wilcox Group as the base of the Carrizo-Wilcox USDW, a slightly conservative procedure that underestimates pressure needed to raise water from the Woodbine into the Carrizo-Wilcox. Each 100 feet by which the elevation of the base of the USDW is underestimated leads to an underestimation of the pressure by 1.9 psi. That is, if the base of usable water in the Carrizo-Wilcox is, for example, 200 feet above the stratigraphic base used in this study then the calculation in Appendix 4 would change by about 4 psi to 255 psi as compared with 251 psi.

After the data posted on Map 2 have been contoured, Map 2 is overlain on Map 1 and the elevation of the base of Carrizo-Wilcox is determined, manually, for each well shown on Map 1. Those manually interpolated elevation values are listed in Column F of Table 2.

Petroleum Reservoir Salt-Water and Fresh-Water Heads

In order to compare the potential for pressures in the Woodbine reservoir to force water from the Woodbine into the Carrizo-Wilcox USDW, the Woodbine pressures shown in Column D of Table 2 must be converted to heads. This is because potentiometric data for ground-water aquifers is obtained as water-level elevations which cannot be compared directly with pressures.

The procedure for conversion of pressure to heads is to first divide the pressures in Column D of Table 2 by the average saline water pressure gradient of 0.452 psi/ft. A gradient of 0.452 psi/ft is representative of an average Woodbine sand formation water of about 67,000 mg/l total dissolved solids. Those converted data are given in Column G of Table 2. The Column G data are salt-water heads with a datum of -3,300 ft MSL.

The next step in the conversion process is to subtract the elevation of the base of the Carrizo-Wilcox at each well, as given in Column F of Table 2, from the Column G salt-water heads. The resulting values are given in Column H of Table 2.

If the elevation of the salt-water head of Column G is less than the elevation of the base of the Carrizo-Wilcox in Column F (the Column G value is -) the Column G value is transported directly to Column J. For example, the third value from the top of Column G, for API well No. 18330067, is

-1,172 feet. Because this is less than the Column F value, the salt-water head in that well doesn't reach the base of the USDW and the salt-water head value is transferred directly to Column J.

In the case where the salt-water head is above the base of the USDW, as for the first well in Table 2, the Column H positive value is multiplied by the ratio of salt water to fresh water densities (1.044) and posted in Column I. As a final step, the Column F and I values are added to obtain the Column J fresh-water equivalent heads for comparison with directly measured USDW heads. The values shown in Table 2, Column J are posted and contoured on Map 3.

Carrizo-Wilcox USDW Head Elevations

A computer file was obtained from the TWDB of the Carrizo-Wilcox aquifer head elevations obtained by the agency in conjunction with the State ground-water monitor well network. The file for the East Texas field area contained head elevations measured during 1932-1993. Some values were the only ones for a particular well while other wells had many years of record.

The measurements used for this study are listed in Table 4 and are plotted and contoured on Map 4. The data in Table 4 are the most recent publishable head elevations and are listed by latitude from north to south. Inspection of the Table 4 listing shows that measurements ranging in date from 1934-1993 were used. Some of the values represent the only measurement for a particular well while others are the most recent of many annual measurements. The TWDB data were sorted in many different ways, plotted and contoured. As far as could be determined it made little difference to the end result how the data were sorted. For instance, when a map of the oldest publishable data was compared with Map 4, which displays the most recent publishable data, no important differences between the maps were apparent.

It would have been desirable to use a set of data from the most recent year of measurement only (1993). Unfortunately, only 17 usable values were available for 1993. That seems to be representative of the number of wells that are usually included in the TWDB monitor-well network for the area of study. To obtain a sufficient density of measurements for contouring all of the data in Table 4 were used. These data include measurements for some years, for example 1936 and 1966, when many more than the usual number of measurments were made. These one-time measurements provided a much greater density of data than was otherwise available. Since no temporal trends in the data were apparent, use of all of the data in Table 4 was judged to provide the most satisfactory result.

Residual Analysis

The end result of the pressure potential analysis is, as described earlier, a set of residual head data. This data set is obtained by subtracting the Map 4 results from the Map 3 results. This can be done manually by overlaying the maps and subtracting the USDW heads from the petroleum reservoir heads at each point where the map contours intersect. In this study, the analysis was done by computer by a somewhat different process. The end result of the computer analysis is Map 5, in which the residual data are contoured. No actual residual data are plotted because these are computed on a regular grid and don't coincide with any well locations. As a check on the validity of the computer generated residual head contours, Map 4 can be overlaid on Map 3 and residual heads can be manually calculated for selected pairs of reservoir and USDW heads. This was done along the western border of the field and it was found that the manually calculated values compared very closely with the contour values shown on Figure 5.

The interpretation of Map 5 is that all residual numbers are negative, which means the shut-in Woodbine reservoir heads are less that the USDW heads everywhere in the East Texas field. As would be expected, the difference is the least along the west side of the field, where the disposal wells are located. In that area, the minimum residual adjacent to an injection well can be seen to be about -400 feet. This minimum residual head value tranlates into a reservoir pressure that is 173 psi less than the amount that would be needed to equal the head in the Carrizo-Wilcox USDW. A pressure of over 173 psi would be needed to allow upward flow from the Woodbine reservoir into the USDW.

Pressure Buildup from Injection

As evaluated in the previous section, an injection pressure buildup of a minimum of over 173 psi would be required to initiate flow from the Woodbine reservoir into the Carrizo-Wilcox USDW.

This section evaluates the amount of pressure buildup that is expected to occur as a result of injection and compares that value with the present minimum 173 psi underpressure.

Injectivity Test Results

To obtain reliable reservoir data for pressure buildup calculation and to provide a field observation of pressure buildup in the AOR, a 24.5 hour injectivity test was performed on the new SWDC Everett-Lake No. 5 disposal well during January 3-4, 1995. At the same time, bottom hole pressures were measured in the Everett-Lake No. 6 located 561 feet away from the injection well.

Appendix 3 contains data from the test for the Everett-Lake No. 5 along with interpretation by FESCO, Inc. of the test. According to FESCO's interpretation, the Woodbine reservoir permeability to water is 2425 md with a skin factor of 134. UMR analysis of the same data determined that 2425 md is within the range of reasonable values for permeability of the reservoir. UMR also obtained a very high skin factor, although less than FESCO's value. The SWDC (1958) reports the average Woodbine sand permeability as 2200 md, very close to the value obtained for the Everett-Lake No. 5.

Data for the Everett-Lake No. 6 observation well are not included in the report, but are available at the SWDC. The maximum pressure buildup observed at the Everett-Lake No. 6, during the 24.5 hours of injection into the Everett-Lake No. 5 was 9.15 psi. This value will be used to confirm the validity of pressure buildup calculations that will be shown later.

Determination of Pressure Buildup

Warner, et al. (1979) provide extensive discussion and evaluation of analytical methods for evaluating the radius of pressure influence of injection wells.

As presented by Warner, et al. (1979) the equation for pressure buildup resulting from a constant rate of injection through a single well that fully penetrates the injection reservoir (Figure 4) can be written as:

$$P_r = P_i + 70.6\,\frac{q\mu\beta}{kh}\left[E_1\left(\frac{39.5\ \varphi\mu c r^2}{kt}\right)\right]$$

where, E_I is the exponential integral.

In calculating the pressure buildup for injection through the Everett-Lake No. 5 well, the following values were used:

P_i = initial reservoir pressure = 1382.77 psia
q = injection rate = 16,992 STB/day
μ = formation water; viscosity at reservoir; temperature of 105°F = 0.75 cp
β = formation volume factor = 1
h = reservoir thickness = 102 ft
k = reservoir permeability = 2425 md
t = injection time = 7300 days
ϕ = reservoir porosity = 0.2
c = reservoir compressibility = 6×10^{-6} psi^{-1}
r_1 = 0.276 ft, at sand face of the borehole
r_2 = 561 ft at Everett-Lake No. 6
t_1 = 1 day at end of injection test
t_2 = 7300 days at end of life of well

The resulting calculated pressures and pressure buildups are:

	Pressure (psi) @		**ΔPressure (psi) @**	
	r(ft) = 0.276	r(ft) = 561	r(ft) = 0.276	r(ft) = 561
@ t (days) = 1	1455.6	1400.25	72.8	17.5
@ t (days) = 7300	1488.0	1432.60	105.2	49.2

As shown above, the maximum calculated pressure buildup at the wellbore radius of 0.276 ft is 105.2 psia after 20 years of injection at 16,992 B/D. The validity of this calculation is supported by the fact that the pressure buildup observed at Everett-Lake No. 6 was, actually, 9.15 psi after one day of injection as compared with the caclulated value of 17.5 psi. The lower than expected pressure buildup indicates a reservoir permeability even higher than 2425 md.

The conclusion that can be derived from this pressure-buildup analysis is that there is no radius-of-endangering-influence, as defined by the U.S. EPA. With no radius-of-endangering-influence, there is no need for an AOR evaluation and this should be the basis for consideration of a variance from AORs for the East Texas field. It is believed that this analysis for the Everett-Lake No. 5 well can, reasonably, be applied to all of the SWDC injection wells. The reasons for this are:

1. All of the SWDC injection wells are located along the western edge of the field where the Woodbine sand thickness is 70-120 feet. This thickness along with an average permeability of 2200 md provides reservoir conditions comparable to those analyzed for at the Everett-Lake No. 5.

2. All SWDC injection wells inject about 15,000 STB/day. None inject significantly more than that.

SUMMARY AND CONCLUSIONS

An evaluation has been conducted by the University of Missouri-Rolla of the possibility of the basis for a variance from AORs for disposal wells in the East Texas field. The field has been studied to determine if the Woodbine reservoir is sufficiently underpressured relative to the Carrizo-Wilcox USDW to justify consideration of a variance.

Very good quality data have been obtained for reservoir pressure, USDW heads, elevation of the base of the USDW and reservoir engineering properties. Using these data, maps have been prepared and contoured that display the information necessary to compare fresh-water equivalent heads of the Woodbine reservoir with Carrizo-Wilcox USDW heads. The comparison process shows that Woodbine reservoir pressure would have to be increased by a minimum of 173 psi to balance the USDW heads and a pressure increase greater than 173 psi is needed to initiate upward flow of reservoir water into the USDW.

Analysis of an injectivity test of the Everett-Lake No. 5, a new SWDC disposal well, provided Woodbine reservoir properties and allowed monitoring of injection pressure buildup in the Woodbine reservoir in a nearby shut-in disposal well, the Everett-Lake No. 6.

Engineering calculations have been made that predict that injection pressure at the Everett-Lake No. 5 will buildup only 105.2 psi over the lifetime of the well, much less than the over 173 psi that would be required to initiate flow to the USDW. The validity of this analysis is confirmed by the very small observed pressure buildup in the Everett-Lake No. 6, 561 feet from the disposal well, during a 24.5 hour injectivity test. It is believed that this result can, reasonably, be applied to all SWDC disposal wells.

The above analysis shows that the Woodbine reservoir is currently underpressured relative to the Carrizo-Wilcox USDW and will remain so over the next 20 years. This information provides a logical basis for a variance for the field from performing AORs. Relief from the need to perform AORs would significantly benefit all field operators, but particularly smaller ones to whom incremental costs are most important.

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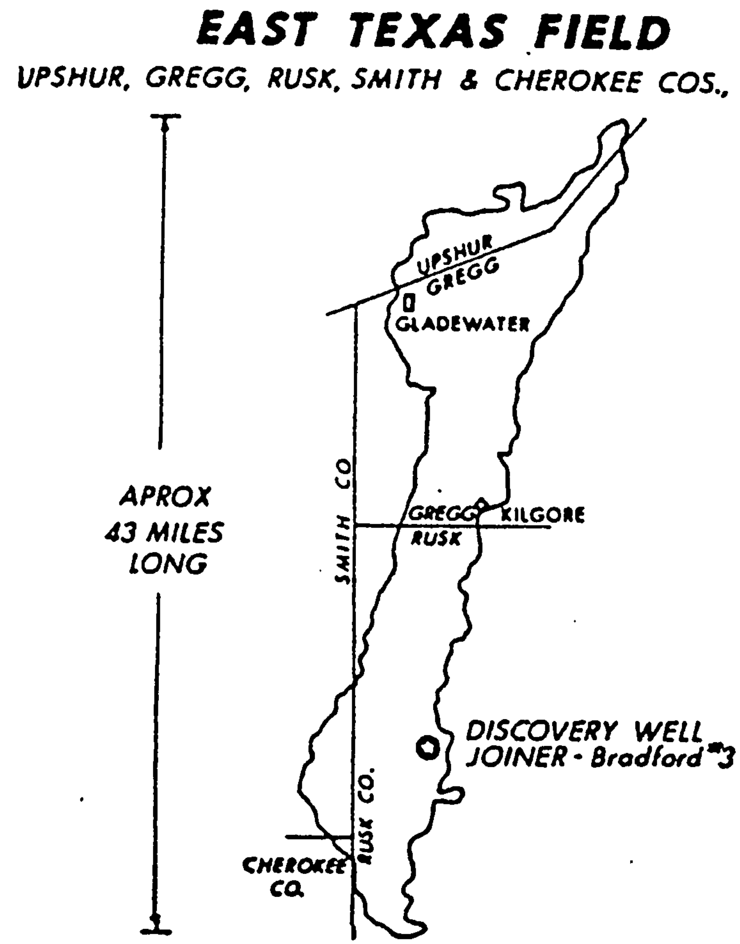


DISCOVERED	SEPT., 1930
PRODUCTIVE AREA	204 SQ. MILES
PEAK PRODUCING WELLS - 1939	26,000
EST. PRODUCING CAPACITY	15,771,000 BBLS/HR.
EST. ORIG. OIL IN PLACE	6,700,000,000 BBLS.

Figure 1: Location map and pertinent data for East Texas field (McWilliams, 1972).

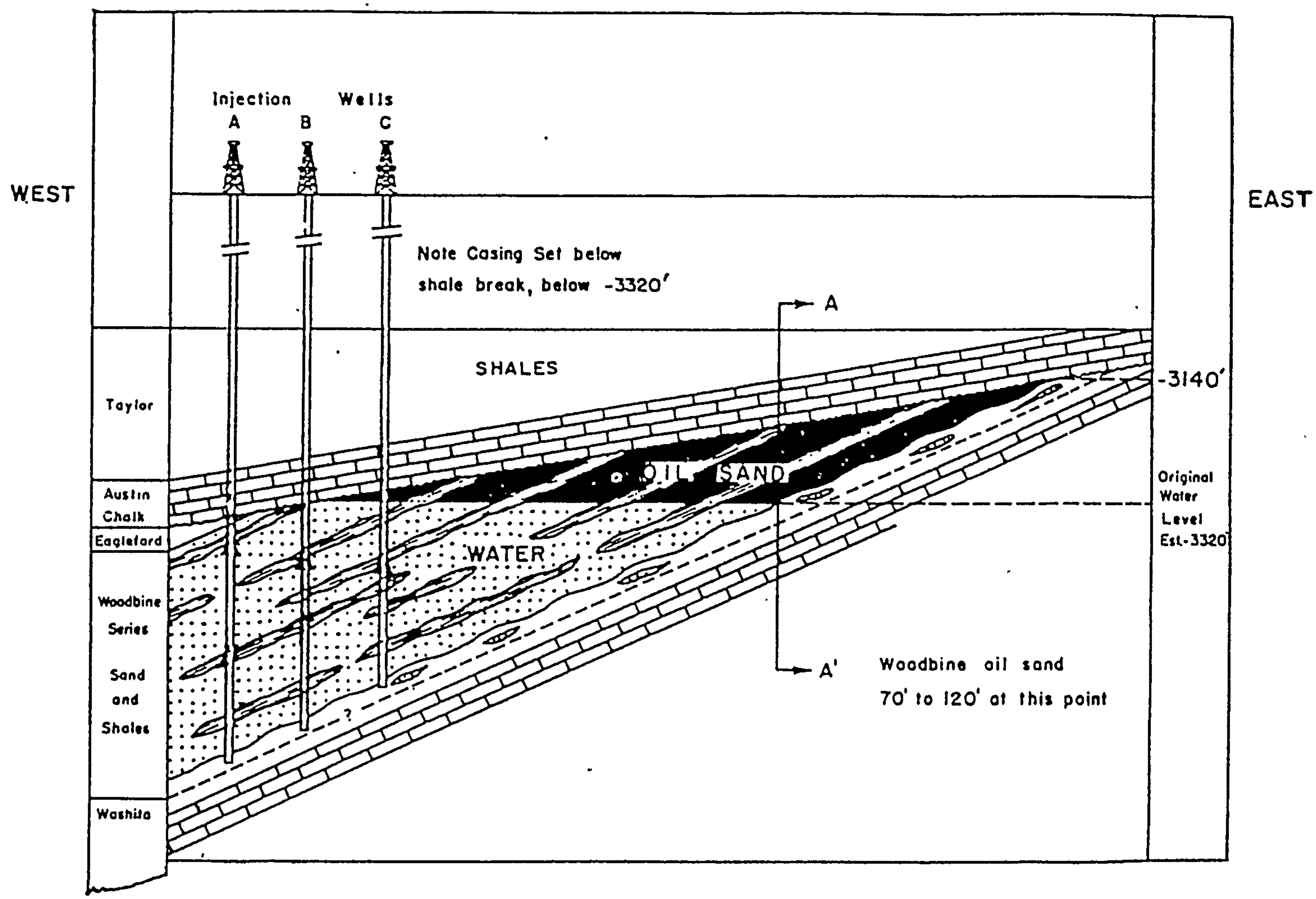


Figure 2: Generalized East-West cross section for the East Texas field (McWilliams, 1972).

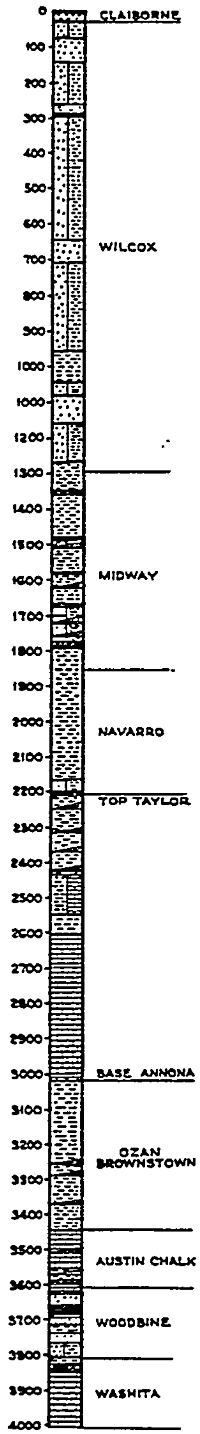


Figure 3: Generalized columnar section for the East Texas field (Minor and Hanna, 1941).

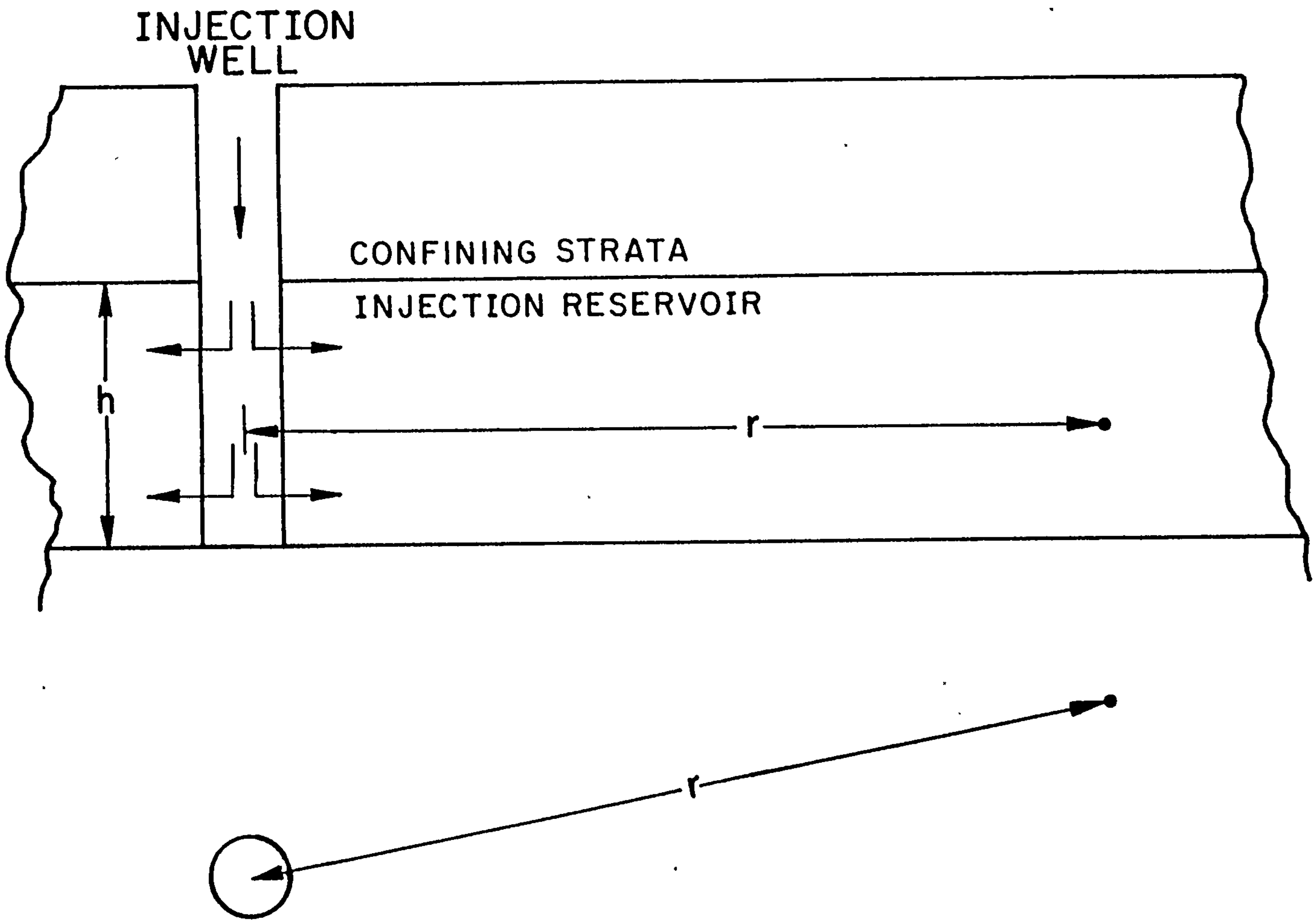
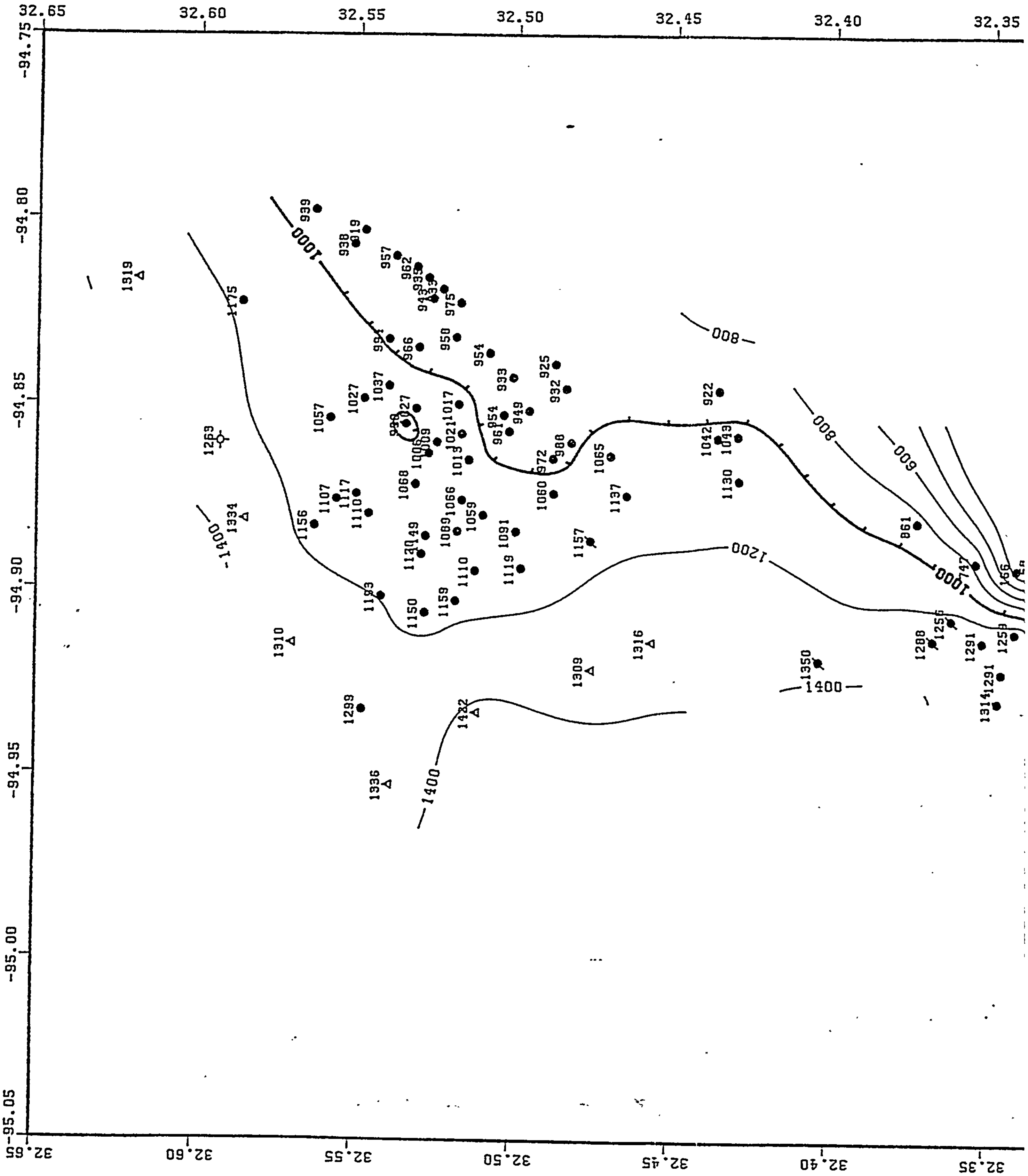
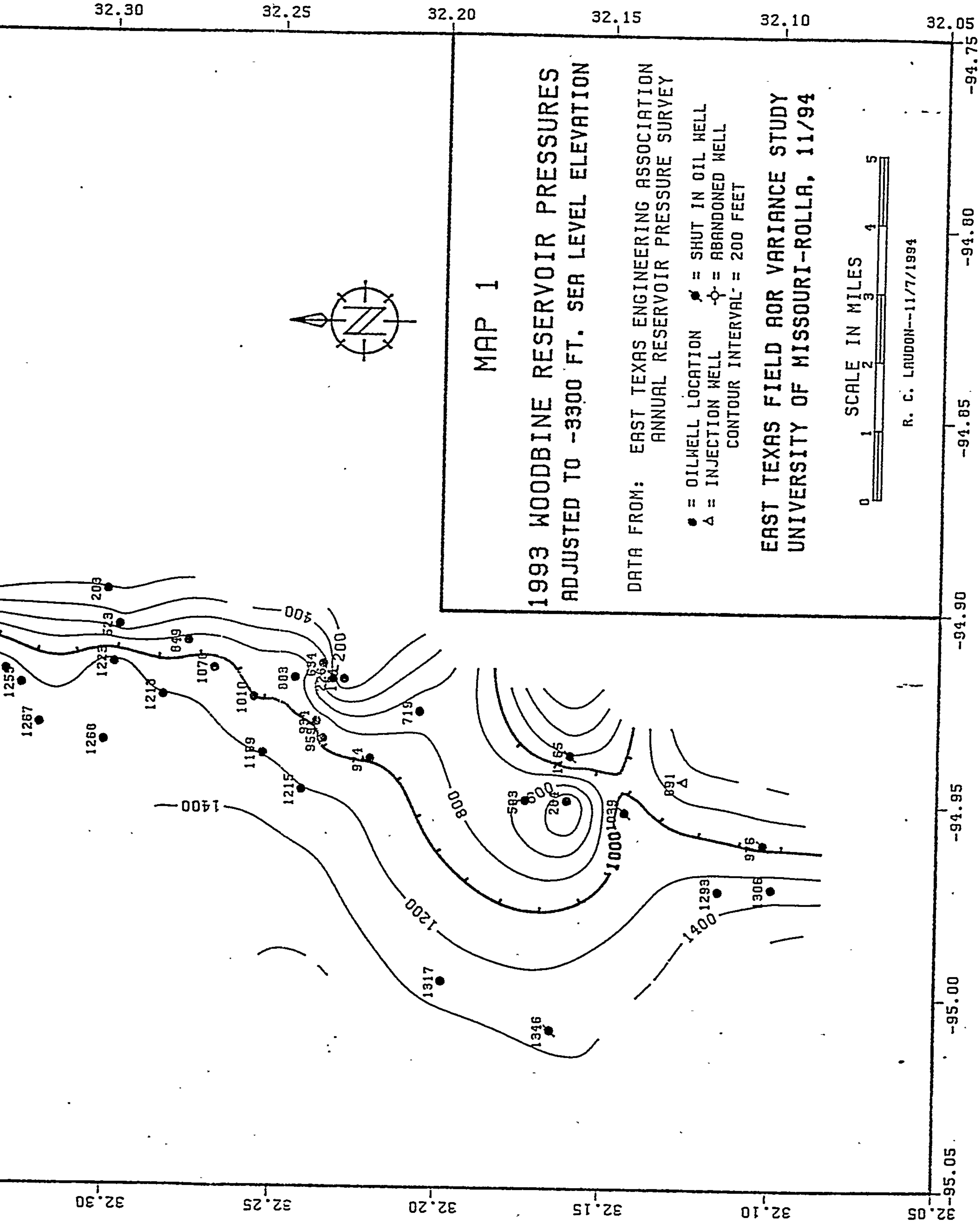
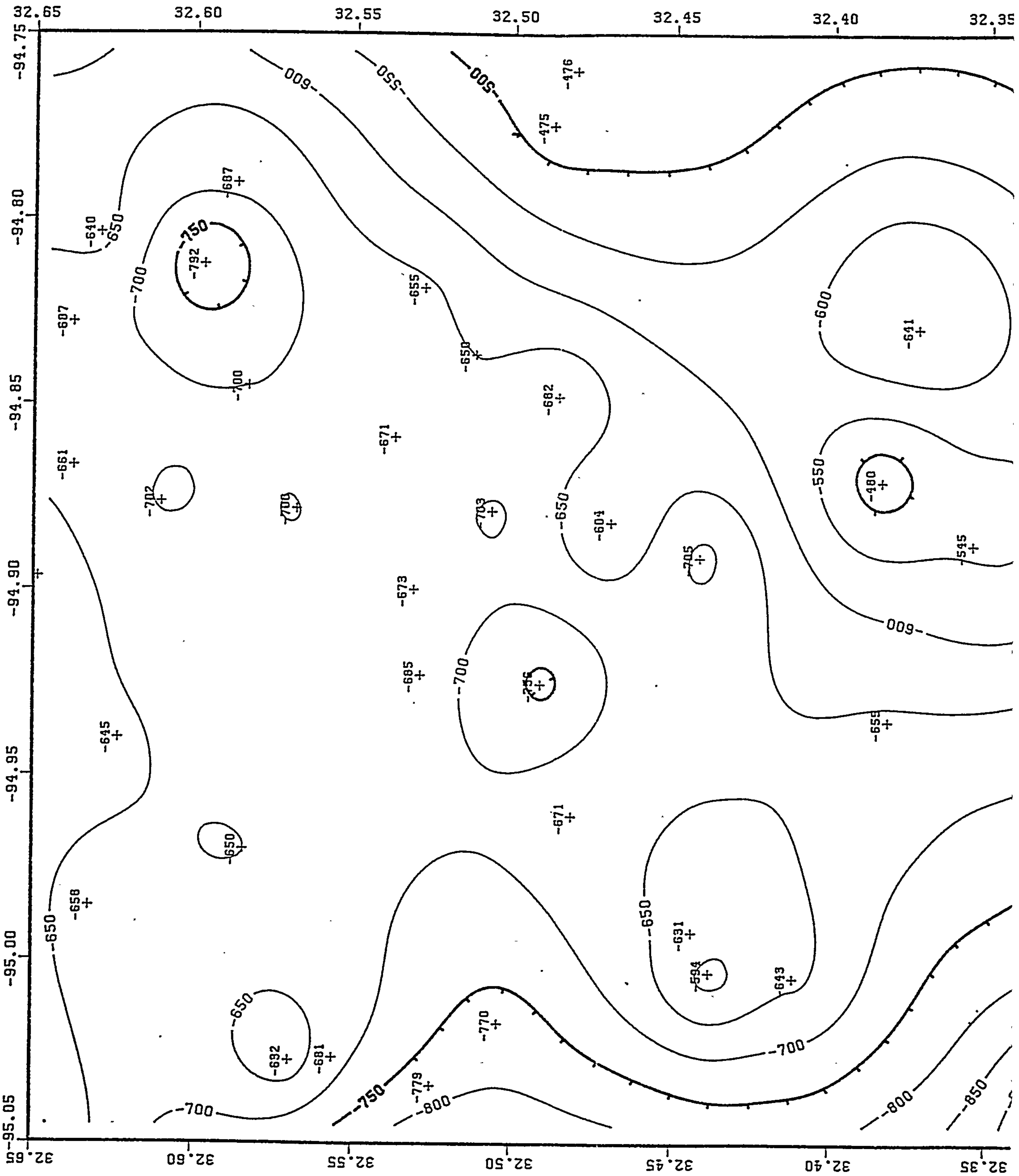


Figure 4: Profile and plan views of a completely penetrating well injecting into a confined reservoir. Pressure is to be calculated at a point r distance from the well.

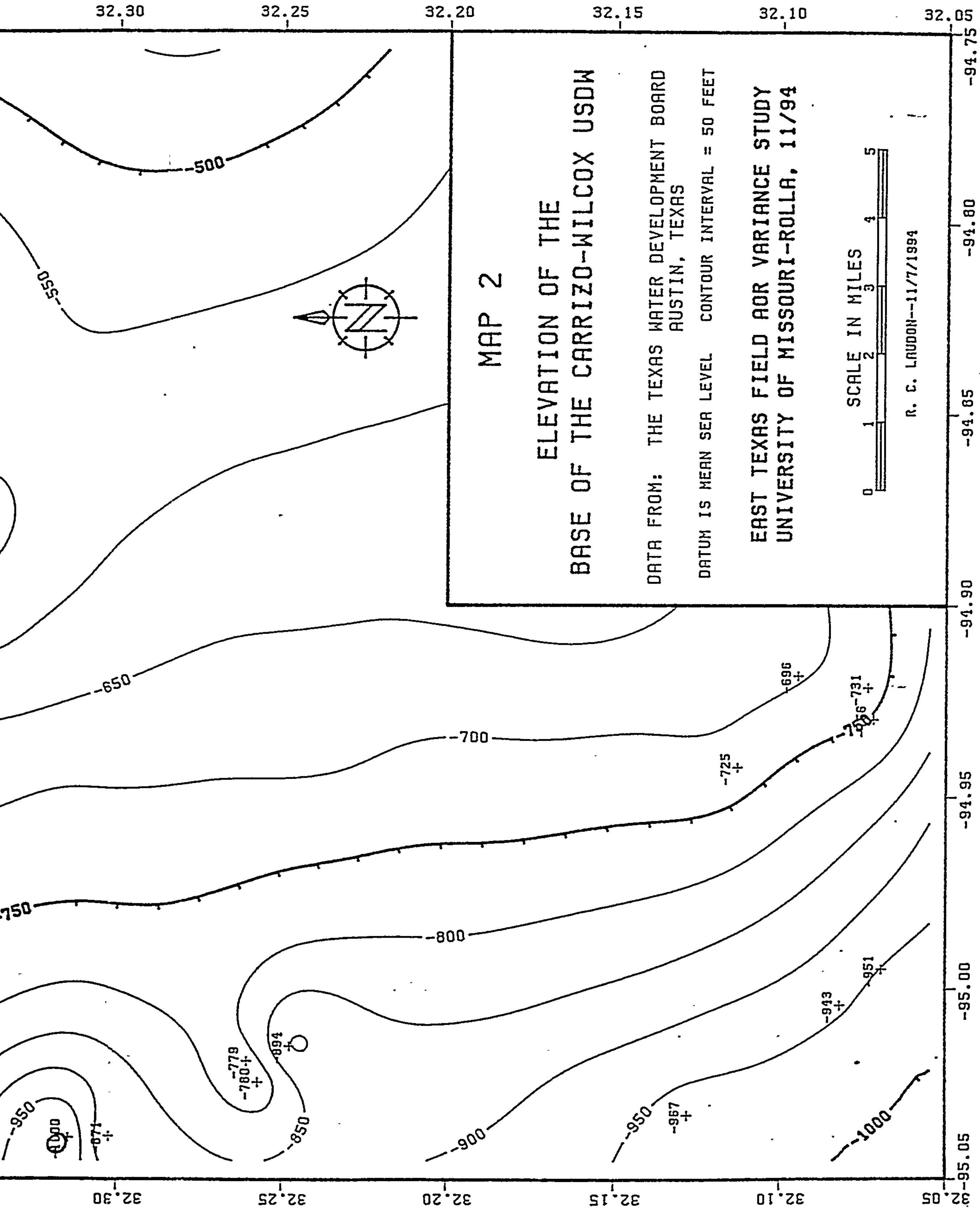


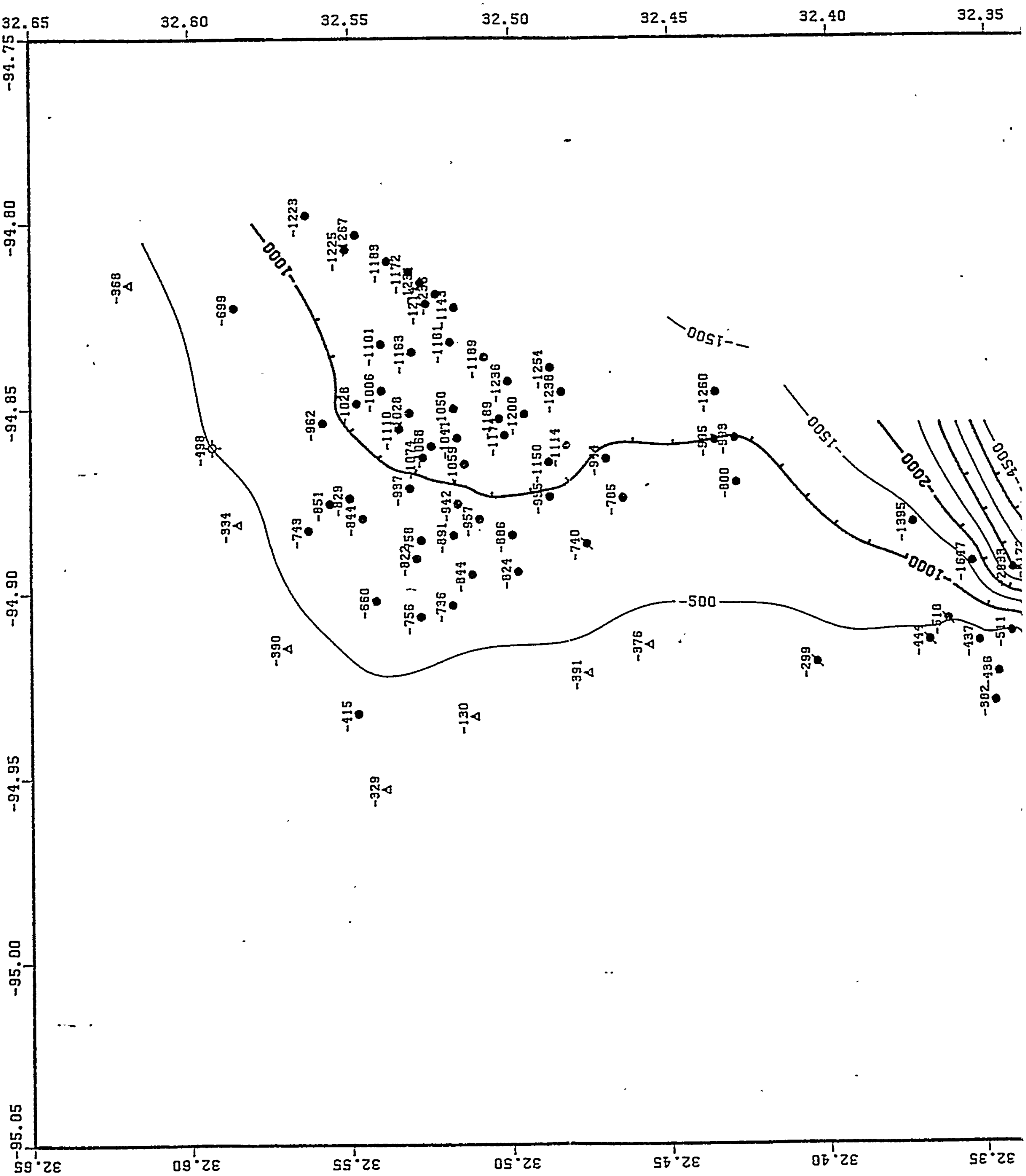
32.65
32.60
32.55
32.50
32.45
32.40
32.35
-94.75
-94.80
-94.85
-94.90
-94.95
-95.00
-95.05
800
600
1000
1200
1400


MAP 1
1993 WOODBINE RESERVOIR PRESSURES
ADJUSTED TO -3300 FT. SEA LEVEL ELEVATION
DATA FROM: EAST TEXAS ENGINEERING ASSOCIATION
ANNUAL RESERVOIR PRESSURE SURVEY
= OILWELL LOCATION
= SHUT IN OIL WELL
Δ = INJECTION WELL
= ABANDONED WELL
CONTOUR INTERVAL = 200 FEET
EAST TEXAS FIELD AOR VARIANCE STUDY
UNIVERSITY OF MISSOURI-ROLLA, 11/94
SCALE IN MILES
0 1 2 3 4 5
R. C. LAUDON--11/7/1994
32.30
32.25
32.20
32.15
32.10
32.05
-94.75
-94.80
-94.85
-94.90
-94.95
-95.00
-95.05
400
200
800
1000
1200
1400

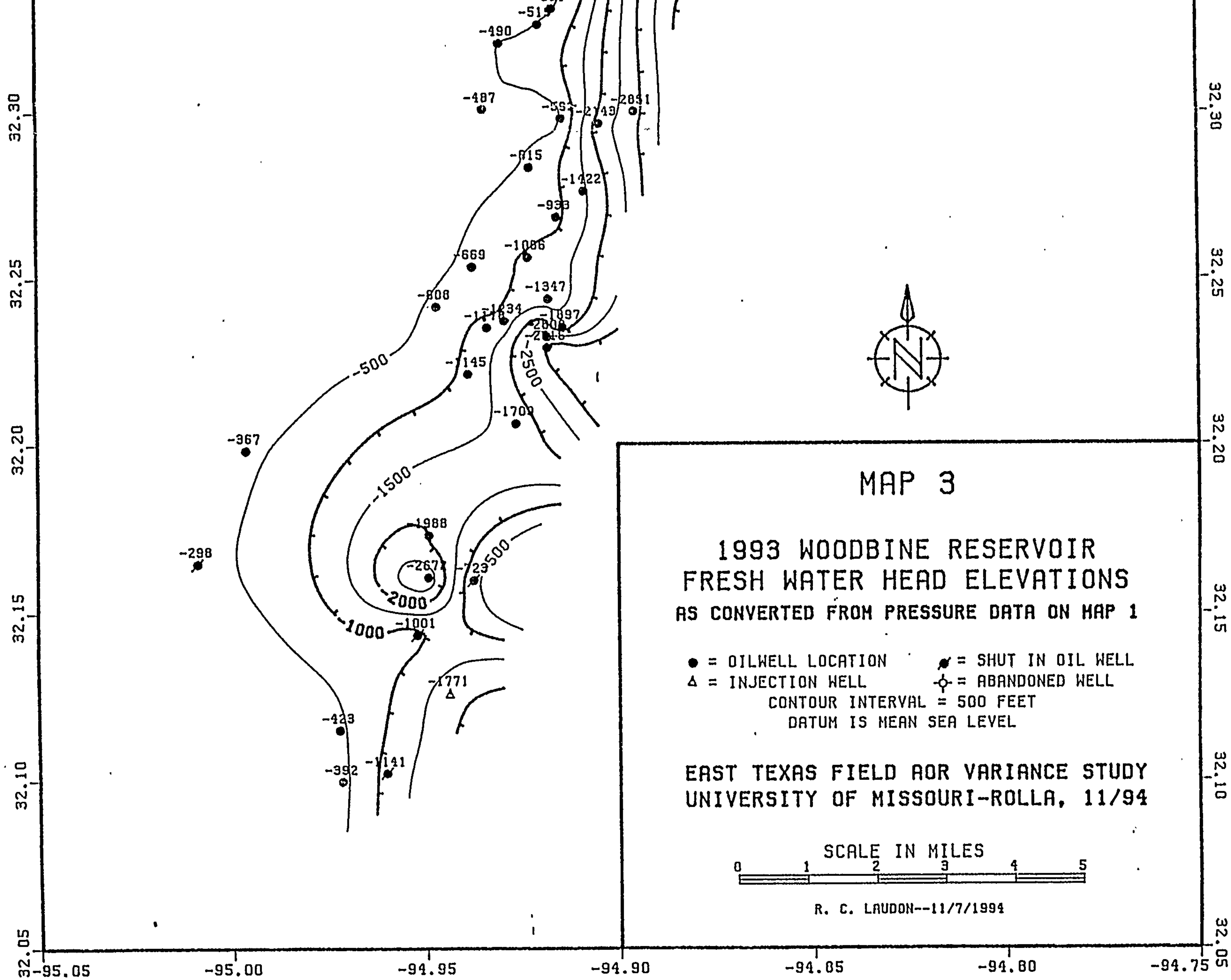


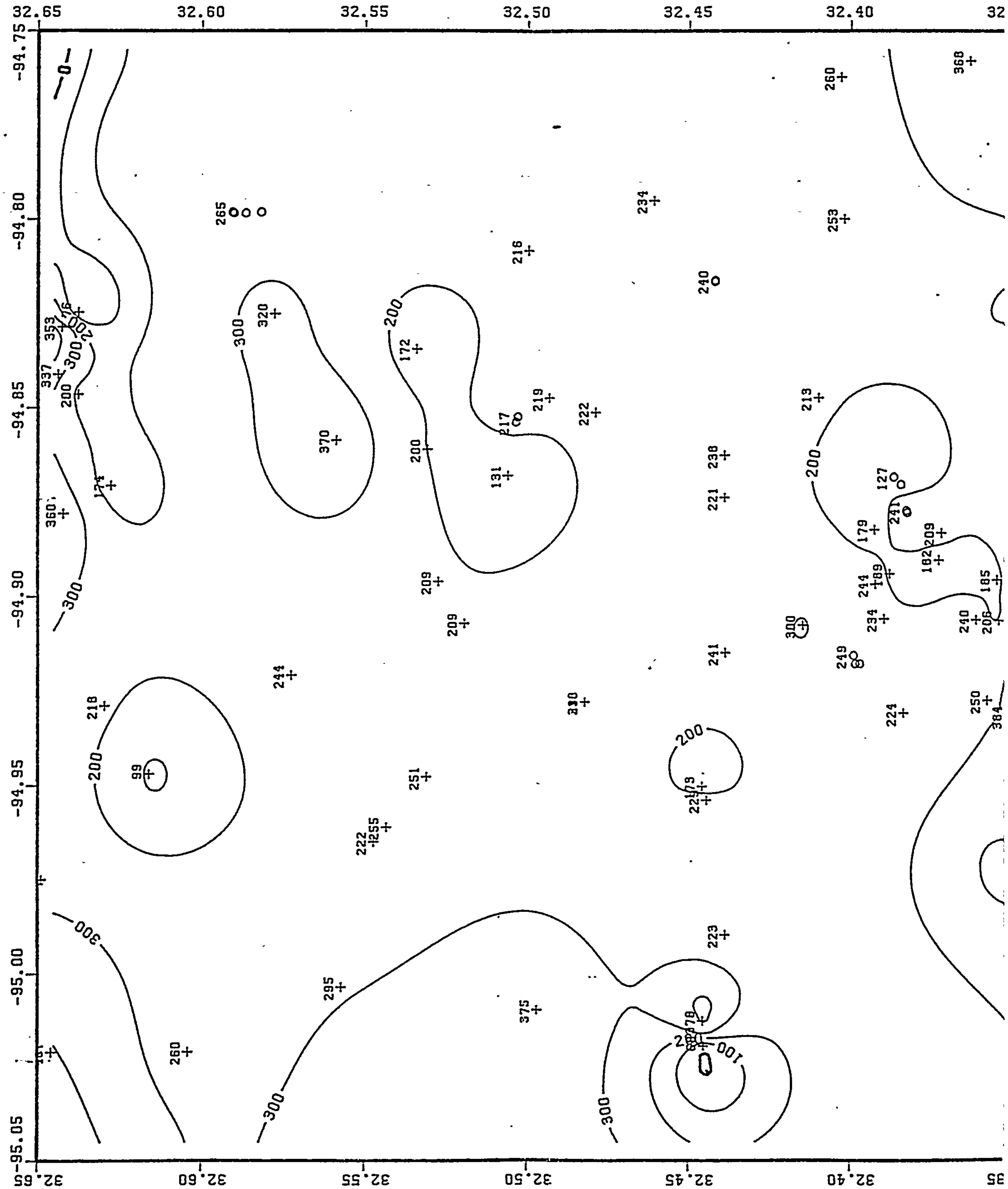
32.65
32.60
32.55
32.50
32.45
32.40
32.35
-94.75
-94.80
-94.85
-94.90
-94.95
-95.00
-95.05


MAP 2
ELEVATION OF THE
BASE OF THE CARRIZO-WILCOX USDW
DATA FROM: THE TEXAS WATER DEVELOPMENT BOARD
AUSTIN, TEXAS
DATUM IS MEAN SEA LEVEL CONTOUR INTERVAL = 50 FEET
EAST TEXAS FIELD AOR VARIANCE STUDY
UNIVERSITY OF MISSOURI-ROLLA, 11/94
SCALE IN MILES
0 1 2 3 4 5
R. C. LAUDON--11/7/1994
32.30
32.25
32.20
32.15
32.10
32.05
-94.75
-94.80
-94.85
-94.90
-94.95
-95.00
-95.05
-500
-550
-650
-700
-750
-800
-850
-900
-950
-1000
-696
-731
-725
-943
-951
-957
-779
-780
-894
-971

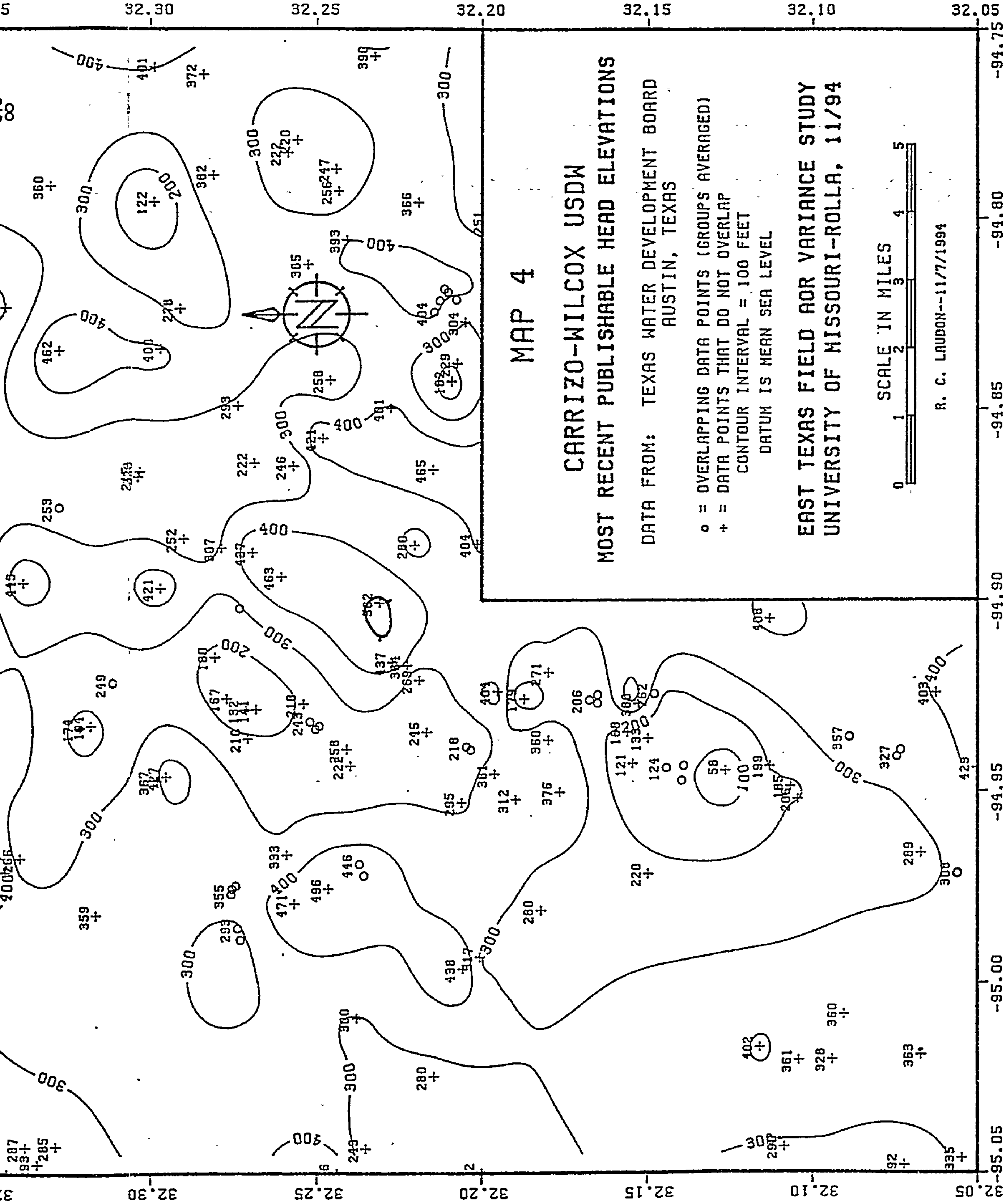


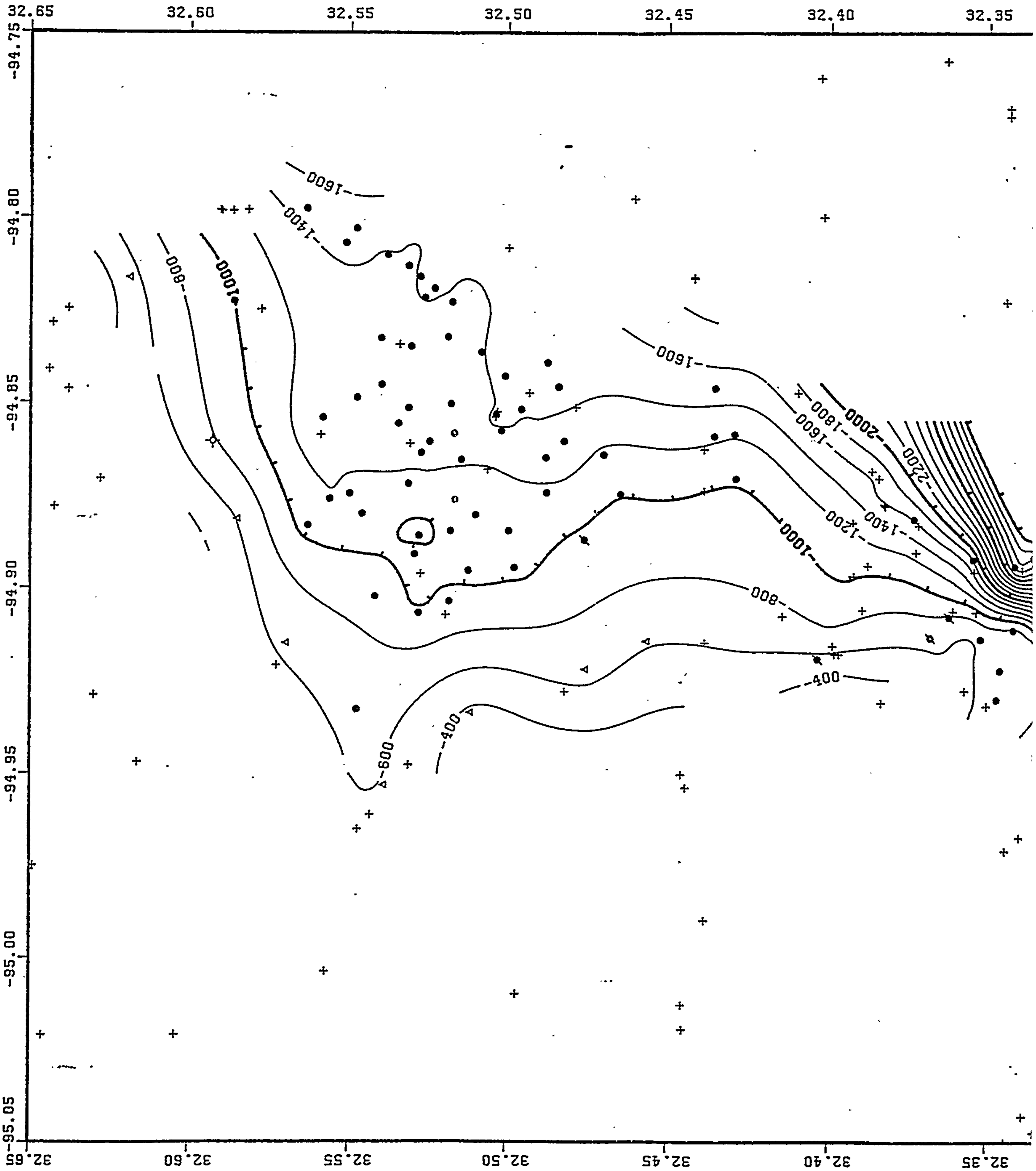
32.65
32.60
32.55
32.50
32.45
32.40
32.35
-94.75
-94.80
-94.85
-94.90
-94.95
-95.00
-95.05
-500
-1000
-1500
-2000


MAP 3
1993 WOODBINE RESERVOIR
FRESH WATER HEAD ELEVATIONS
AS CONVERTED FROM PRESSURE DATA ON MAP 1
● = OILWELL LOCATION
= SHUT IN OIL WELL
Δ = INJECTION WELL
= ABANDONED WELL
CONTOUR INTERVAL = 500 FEET
DATUM IS MEAN SEA LEVEL
EAST TEXAS FIELD AOR VARIANCE STUDY
UNIVERSITY OF MISSOURI-ROLLA, 11/94
SCALE IN MILES
0 1 2 3 4 5
R. C. LAUDON--11/7/1994
-95.05
-95.00
-94.95
-94.90
-94.85
-94.80
-94.75
32.05
32.10
32.15
32.20
32.25
32.30
-500
-1000
-1500
-2000
-2500



32.65
32.60
32.55
32.50
32.45
32.40
-94.75
-94.80
-94.85
-94.90
-94.95
-95.00
-95.05


MAP 4
CARRIZO-WILCOX USDW
MOST RECENT PUBLISHABLE HEAD ELEVATIONS
DATA FROM: TEXAS WATER DEVELOPMENT BOARD
AUSTIN, TEXAS
o = OVERLAPPING DATA POINTS (GROUPS AVERAGED)
+ = DATA POINTS THAT DO NOT OVERLAP
CONTOUR INTERVAL = 100 FEET
DATUM IS MEAN SEA LEVEL
EAST TEXAS FIELD AOR VARIANCE STUDY
UNIVERSITY OF MISSOURI-ROLLA, 11/94
SCALE IN MILES
R. C. LAUDON--11/7/1994



32.65
32.60
32.55
32.50
32.45
32.40
32.35
-94.75
-94.80
-94.85
-94.90
-94.95
-95.00
-95.05
-1600
-1400
-800
-1000
-1200
-1800
-2000
-2200
-600
-400

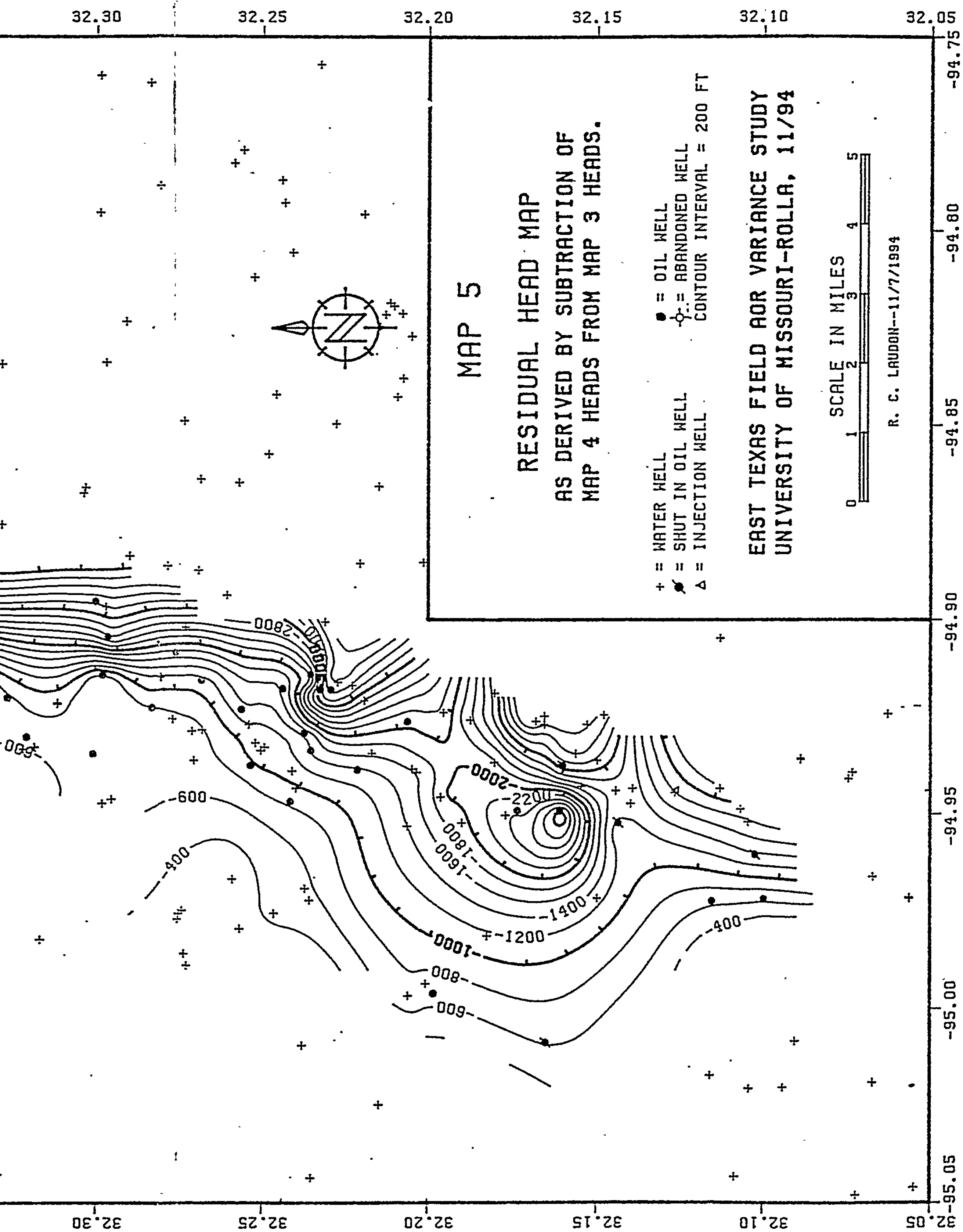

MAP 5
RESIDUAL HEAD MAP
AS DERIVED BY SUBTRACTION OF
MAP 4 HEADS FROM MAP 3 HEADS.
+ = WATER WELL
= SHUT IN OIL WELL
Δ = INJECTION WELL
● = OIL WELL
= ABANDONED WELL
CONTOUR INTERVAL = 200 FT
EAST TEXAS FIELD AOR VARIANCE STUDY
UNIVERSITY OF MISSOURI-ROLLA, 11/94
SCALE IN MILES
R. C. LAUDON--11/7/1994

Table 1

SUMMARY OF WELL COUNTS FROM THE EAST TEXAS FIELD
DATA FROM RAILROAD COMMISSION MIMS DATA

First line shows well counts for wells WITH FULL API NUMBERS.
Second line shows well counts for wells with API BY COUNTY ONLY.
Third line is the sum of the first two.

	CHEROKEE	GREGG	RUSK	SMITH	UPSHUR	TOTAL
WELL LOCATIONS	0	7	11	0	2	20
RR CODE = 2	0	0	3	0	1	4
	0	7	14	0	3	24
DRY HOLES	0	44	33	8	9	94
RR CODE = 3	14	296	265	62	127	764
	14	340	298	70	136	858
OIL WELLS	0	5,853	3,726	2	156	9,737
RR CODE = 4	0	140	185	8	9	342
	0	5,993	3,911	10	165	10,079
GAS WELLS	0	0	0	0	0	0
RR CODE = 5	0	0	4	0	0	4
	0	0	4	0	0	4
OIL/GAS WELLS	0	0	1	0	0	1
RR CODE = 6	0	0	1	0	0	1
	0	0	2	0	0	2
PLUGGED OIL WELLS	0	3,471	2,349	3	376	6,199
RR CODE = 7	49	5,132	6,836	1,546	1,860	15,423
	49	8,603	9,185	1,549	2,236	21,622
PLUGGED GAS WELLS	0	0	0	0	0	0
RR CODE = 8	0	0	3	0	0	3
	0	0	3	0	0	3
CANCELLED/ABANDONED	0	5	22	0	3	30
LOCATIONS	0	0	0	0	0	0
RR CODE = 9	0	5	22	0	3	30
PLUGGED OIL/GAS WELLS	0	0	0	0	0	0
RR CODE = 10	0	0	12	0	0	12
	0	0	12	0	0	12
INJECTION WELLS	0	42	92	6	27	167
RR CODE = 11	0	1	3	0	0	4
	0	43	95	6	27	171
SHUT IN OIL WELLS	0	0	4	0	0	4
RR CODE = 19	0	0	0	0	0	0
	0	0	4	0	0	4
OIL TO INJECTION WELLS	0	2	107	0	0	109
RR CODE = 21	0	0	1	0	0	1
	0	2	108	0	0	110
WATER SUPPLY WELLS	0	1	1	0	0	2
RR CODE= 74,75,76,77	0	0	0	0	0	0
	0	1	1	0	0	2
TOTAL WITH FULL API	0	9,425	6,346	19	573	16,363
TOTAL W/O FULL API	63	5,569	7,313	1,616	1,997	16,558
GRAND TOTAL ALL WELLS	63	14,994	13,659	1,635	2,570	32,921

TABLE 2

SPREAD SHEET FOR EAST TEXAS RESERVOIR PRESSURE
AND FRESH WATER HEAD DATA.
REVISED 11/94

Note: See bottom of table for further explanation of columns.

A API #	B NORTH LATITUDE	C WEST LONGITUDE	D PRES ADJ -3300	E CPS WELL CODE	F BASE WLCX 11/94	G SALT WATER HEAD ELEV. -3300+ (COL D /.452)	H DIFF (SWH-BASE WLCX) COL G -COL F	I HEAD BASE WLCX SEE BELOW	J TOTAL HEAD ADJ FOR FRESH WATER COL F +COL I
18330009	32.45657	-94.91454	1316	3	-670	-388	282	294	-376
18330038	32.51157	-94.93371	1422	3	-705	-154	551	575	-130
18330067	32.53147	-94.81319	962	16	-650	-1172	-522	-1172	-1172
18330504	32.47567	-94.92212	1309	3	-710	-404	306	319	-391
18380074	32.53133	-94.87182	1068	16	-675	-937	-262	-937	-937
18380116	32.54181	-94.90228	1193	16	-675	-661	14	15	-660
18380124	32.50813	-94.83646	954	16	-648	-1189	-541	-1189	-1189
18380164	32.54994	-94.87444	1117	16	-680	-829	-149	-829	-829
18380177	32.54003	-94.83276	994	16	-665	-1101	-436	-1101	-1101
18380183	32.51830	-94.90356	1159	16	-690	-736	-46	-736	-736
18380193	32.52782	-94.81613	935	16	-650	-1231	-581	-1231	-1231
18380195	32.52799	-94.88591	1149	16	-685	-758	-73	-758	-758
18380333	32.48224	-94.86059	988	16	-655	-1114	-459	-1114	-1114
18380462	32.42904	-94.87067	1130	16	-630	-800	-170	-800	-800
18380496	32.55608	-94.87587	1107	16	-685	-851	-166	-851	-851
18380532	32.49940	-94.88470	1091	16	-695	-886	-191	-886	-886
18380547	32.51783	-94.85029	1017	16	-665	-1050	-385	-1050	-1050
18380624	32.51887	-94.83228	958	16	-652	-1181	-529	-1181	-1181
18380698	32.48764	-94.87438	1060	16	-655	-955	-300	-955	-955
18381021	32.49767	-94.89464	1119	16	-680	-824	-144	-824	-824
18381122	32.58608	-94.82273	1175	16	-745	-700	45	47	-698
18381168	32.54597	-94.87989	1110	16	-680	-844	-164	-844	-844
18381513	32.51446	-94.86531	1013	16	-680	-1059	-379	-1059	-1059
18381562	32.52319	-94.81919	933	16	-650	-1236	-586	-1236	-1236
18381773	32.43581	-94.85923	1042	16	-620	-995	-375	-995	-995
18381980	32.55127	-94.80699	938	16	-660	-1225	-565	-1225	-1225
18382068	32.52626	-94.82176	943	16	-655	-1214	-559	-1214	-1214
18382686	32.55822	-94.85404	1057	16	-680	-962	-282	-962	-962
18383007	32.49553	-94.85194	949	16	-660	-1200	-540	-1200	-1200
18383404	32.47593	-94.88712	1157	18	-645	-740	-95	-740	-740
18383489	32.53060	-94.83498	966	16	-660	-1163	-503	-1163	-1163
18383758	32.48743	-94.83938	925	16	-655	-1254	-599	-1254	-1254
18384145	32.37307	-94.88167	861	16	-520	-1395	-875	-1395	-1395
18385541	32.53986	-94.84525	1037	16	-670	-1006	-336	-1006	-1006
18385801	32.54798	-94.80313	919	16	-648	-1267	-619	-1267	-1267
18385841	32.53132	-94.85146	1027	16	-670	-1028	-358	-1028	-1028
18385888	32.53805	-94.81024	957	16	-650	-1183	-533	-1183	-1183

18386640	32.51675	-94.85827	1021	16	-675	-1041	-366	-1041	-1041
18387267	32.51655	-94.87617	1066	16	-690	-942	-252	-942	-942
18387448	32.46457	-94.87483	1137	16	-640	-785	-145	-785	-785
18387508	32.46981	-94.86416	1065	16	-645	-944	-299	-944	-944
18387654	32.42951	-94.85869	1043	16	-605	-992	-387	-992	-992
18387681	32.52467	-94.86049	1009	16	-675	-1068	-393	-1068	-1068
18387870	32.48788	-94.86494	972	16	-660	-1150	-490	-1150	-1150
18388288	32.53447	-94.85558	990	16	-670	-1110	-440	-1110	-1110
18388318	32.50172	-94.85758	961	16	-670	-1174	-504	-1174	-1174
18388375	32.48394	-94.84595	932	16	-655	-1238	-583	-1238	-1238
18388482	32.52928	-94.89091	1120	16	-675	-822	-147	-822	-822
18388537	32.51214	-94.89533	1110	16	-690	-844	-154	-844	-844
18388676	32.52805	-94.90673	1150	16	-680	-756	-76	-756	-756
18388702	32.40359	-94.91934	1350	18	-630	-313	317	331	-299
18388728	32.43552	-94.84628	922	16	-595	-1260	-665	-1260	-1260
18388815	32.52733	-94.86349	1006	16	-675	-1074	-399	-1074	-1074
18388832	32.56281	-94.88313	1156	16	-690	-742	-52	-742	-742
18388849	32.54765	-94.84868	1027	16	-680	-1028	-348	-1028	-1028
18389121	32.50977	-94.88030	1059	16	-700	-957	-257	-957	-957
18389279	32.56341	-94.79775	939	16	-670	-1223	-553	-1223	-1223
18389359	32.51792	-94.88464	1089	16	-690	-891	-201	-891	-891
18389568	32.50067	-94.84300	933	16	-665	-1236	-571	-1236	-1236
18389576	32.50345	-94.85316	954	16	-670	-1189	-519	-1189	-1189
18389608	32.54756	-94.93281	1299	16	-680	-426	254	265	-415
18389622	32.51755	-94.82290	975	16	-645	-1143	-498	-1143	-1143
18389867	32.53908	-94.95322	1336	3	-690	-344	346	361	-329
40130009	32.23526	-94.91409	634	16	-670	-1897	-1227	-1897	-1897
40130653	32.12659	-94.94383	691	3	-725	-1771	-1046	-1771	-1771
40180235	32.33095	-94.91644	1263	16	-615	-506	109	114	-501
40181404	32.30006	-94.89532	203	16	-610	-2851	-2241	-2851	-2851
40181570	32.36787	-94.91359	1288	18	-605	-450	155	161	-444
40181587	32.22092	-94.93859	974	16	-698	-1145	-447	-1145	-1145
40181607	32.36204	-94.90799	1256	18	-590	-521	69	72	-518
40181948	32.34180	-94.91146	1259	16	-595	-515	80	84	-511
40181975	32.34594	-94.92239	1291	16	-625	-444	181	189	-436
40181999	32.34701	-94.93029	1314	16	-645	-393	252	263	-382
40182088	32.25338	-94.93742	1189	16	-690	-669	21	21	-669
40182111	32.24374	-94.91779	883	16	-665	-1346	-681	-1346	-1346
40182261	32.35214	-94.91396	1291	16	-600	-444	156	163	-437
40182416	32.28331	-94.92259	1213	16	-660	-616	44	46	-614
40182432	32.27611	-94.90845	849	16	-645	-1422	-777	-1422	-1422
40182649	32.29789	-94.91420	1223	16	-640	-594	46	48	-592
40182672	32.29634	-94.90448	523	16	-630	-2143	-1513	-2143	-2143
40182702	32.30076	-94.93451	1268	16	-675	-495	180	188	-487
40183029	32.26825	-94.91554	1070	16	-660	-933	-273	-933	-933
40183627	32.11558	-94.97239	1293	16	-810	-439	371	387	-423
40183628	32.09972	-94.97179	1306	16	-830	-411	419	438	-392
40183729	32.16079	-94.94919	284	16	-730	-2672	-1942	-2672	-2672
40183732	32.17319	-94.94909	593	16	-732	-1988	-1256	-1988	-1988
40184448	32.24144	-94.94676	1215	16	-705	-612	93	97	-608
40184697	32.32627	-94.92001	1255	16	-630	-523	107	111	-519
40184792	32.34137	-94.89428	166	16	-555	-2933	-2378	-2933	-2933
40184794	32.20609	-94.92630	719	16	-685	-1709	-1024	-1709	-1709
40185108	32.15991	-94.93749	1165	18	-705	-723	-18	-723	-723
40185162	32.33530	-94.89208	58	16	-555	-3172	-2617	-3172	-3172

A API #	B NORTH LATITUDE	C WEST LONGITUDE	D PRES ADJ -3300	E CPS WELL CODE	F BASE WLCX 11/94	G SALT WATER HEAD ELEV. -3300+ (COL D /.452)	H DIFF (SHW-BASE WLCX) COL G -COL F	I HEAD BASE WLCX SEE BELOW	J TOTAL HEAD ADJ FOR FRESH WATER COL F +COL I
40185315	32.14347	-94.95216	1039	18	-740	-1001	-261	-1001	-1001
40185422	32.10230	-94.96036	976	18	-795	-1141	-346	-1141	-1141
40185488	32.25615	-94.92302	1010	16	-670	-1065	-395	-1065	-1065
40185544	32.35450	-94.89244	747	16	-550	-1647	-1097	-1647	-1647
40185635	32.32067	-94.93021	1267	16	-655	-497	158	165	-490
40185680	32.23510	-94.93359	959	16	-690	-1178	-488	-1178	-1178
40185725	32.23715	-94.92912	934	16	-680	-1234	-554	-1234	-1234
40185754	32.22894	-94.91805	174	16	-665	-2915	-2250	-2915	-2915
40185924	32.23226	-94.91800	226	16	-670	-2800	-2130	-2800	-2800
42380196	32.16488	-95.00874	1346	18	-865	-322	543	567	-298
42380197	32.19824	-94.99609	1317	16	-825	-386	439	458	-367
45930520	32.56966	-94.91489	1310	3	-680	-402	278	290	-390
45930593	32.59283	-94.86042	1263	12	-690	-506	184	192	-498
45980564	32.61896	-94.81639	1319	3	-695	-382	313	327	-368
45980566	32.58509	-94.88138	1334	3	-690	-349	341	356	-334

This table shows:

1. Pressure Monitoring Well Data--Columns A-D.
2. Column D is 1993 Woodbine reservoir pressure data, as obtained from the East Texas Engineering Association, adjusted to -3300 feet subsea elevation datum.
3. Column E is Radian Corporation's CPS well plotting symbol code.
4. Column F is the elevation of the Base of the Carrizo-Wilcox USDW as determined by manual inspection of overlays of Maps 1 and 2.
5. Column G calculates the salt water head equivalent of the reservoir pressure.
6. Column H calculates the salt water head equivalent elevation relative to the base of the Wilcox.
7. Column I does one of two things:
   - If Column H is negative, then there is no adjustment for fresh water, and Column G is used.
   - If Column H is positive, then a fresh water adjustment must be made for that portion of the head above the base of the Wilcox.
     The adjustment is given by (1.044 * Column H) where:
     1.044 = (0.452 psi/ft divided by 0.433 psi/ft) where:
     0.452 psi/ft = salt water gradient and
     0.433 psi/ft = fresh water gradient.
8. Column J is the total head, based on MSL elevation, adjusted for fresh water above the base of the Wilcox.

TABLE 3

BASE OF THE CARRIZO-WILCOX
ELEVATION DATA
EAST TEXAS FIELD AREA

Data from: Texas Water Development Board, June 1994

	API #	LATITUDE	LONGITUDE	ELEVATION
1	34328	32.52389	-95.08278	-1060
2	35437	32.27278	-94.73361	-422
3	35583	32.11916	-94.76417	-658
4	35586	32.06667	-94.75806	-550
5	37024	31.95056	-94.87167	-1247
6	37024	31.93528	-94.84001	-1153
7	37049	31.90167	-94.51918	-917
8	37101	31.85000	-94.83111	-1232
9	3408701	32.90000	-95.08639	-473
10	3415601	32.80861	-95.13056	-498
11	3416101	32.86500	-95.10250	-483
12	3416301	32.87139	-95.01222	-513
13	3416503	32.81667	-95.05972	-521
14	3416803	32.78084	-95.06306	-474
15	3423901	32.64528	-95.13499	-1143
16	3424203	32.71445	-95.04806	-511
17	3424701	32.64861	-95.11388	-902
18	3424702	32.63056	-95.11667	-1000
19	3424802	32.65445	-95.06612	-543
20	3428405	32.55083	-95.59056	-316
21	3428503	32.56445	-95.56583	-669
22	3429801	32.51445	-95.43500	-1019
23	3430503	32.57250	-95.30000	-903
24	3430802	32.52833	-95.31667	-791
25	3430902	32.52417	-95.25417	-1012
26	3430903	32.51667	-95.28139	-989
27	3430906	32.53333	-95.26417	-1011
28	3431703	32.53556	-95.24499	-1121
29	3432101	32.59055	-95.08861	-877
30	3432401	32.57750	-95.10333	-861
31	3432601	32.57000	-95.02723	-632
32	3432602	32.55611	-95.02639	-681
33	3432801	32.52500	-95.03416	-779
34	3432901	32.50389	-95.01722	-770
35	3436304	32.48111	-95.50722	-1088
36	3436602	32.45334	-95.53806	-970
37	3436603	32.44028	-95.50667	-962
38	3437302	32.48472	-95.39806	-1113
39	3437403	32.44389	-95.49528	-987
40	3437404	32.45667	-95.47889	-1054
41	3438304	32.49500	-95.26028	-980
42	3438305	32.49056	-95.28528	-1012
43	3438306	32.49222	-95.26972	-998
44	3438307	32.48417	-95.25389	-1046

45	3438308	32.47833	-95.26750	-1026
46	3438309	32.45945	-95.27639	-1036
47	3438310	32.46278	-95.26918	-1052
48	3438503	32.44000	-95.32556	-1205
49	3438504	32.44250	-95.31639	-1137
50	3438507	32.43167	-95.29861	-1138
51	3438509	32.41750	-95.30251	-1232
52	3438603	32.45223	-95.28833	-1082
53	3438604	32.43862	-95.26444	-1103
54	3438605	32.43695	-95.28333	-1102
55	3438702	32.37972	-95.34834	-1196
56	3439202	32.48222	-95.18417	-1259
57	3439701	32.38167	-95.21139	-1210
58	3440602	32.43806	-95.00361	-594
59	3440704	32.41361	-95.10250	-861
60	3440705	32.41028	-95.11166	-902
61	3440707	32.40139	-95.09278	-948
62	3440708	32.37583	-95.11305	-985
63	3440901	32.41167	-95.00500	-643
64	3445201	32.37083	-95.43944	-570
65	3445202	32.37083	-95.43584	-984
66	3445503	32.33111	-95.42416	-1171
67	3445505	32.31056	-95.42083	-1300
68	3445604	32.33167	-95.39528	-1268
69	3445802	32.25500	-95.41917	-1703
70	3446509	32.29306	-95.32250	-1304
71	3446704	32.26584	-95.33750	-1415
72	3446806	32.26361	-95.32166	-1428
73	3446807	32.25306	-95.32639	-1439
74	3447503	32.29250	-95.20361	-1208
75	3447802	32.27083	-95.18333	-1166
76	3448101	32.37195	-95.09111	-989
77	3448102	32.34194	-95.11639	-909
78	3448402	32.31000	-95.12195	-851
79	3448403	32.30028	-95.11028	-851
80	3448504	32.31917	-95.08139	-853
81	3448601	32.31445	-95.03917	-1000
82	3448603	32.30222	-95.03861	-871
83	3448902	32.25722	-95.02444	-780
84	3448903	32.26056	-95.01889	-779
85	3453101	32.22028	-95.47833	-1095
86	3453501	32.19222	-95.45056	-955
87	3453603	32.16639	-95.37833	-1456
88	3453802	32.14195	-95.42499	-1629
89	3454102	32.20778	-95.35806	-1404
90	3454103	32.21778	-95.33472	-1490
91	3454203	32.22195	-95.29389	-1201
92	3454205	32.21250	-95.31334	-1576
93	3454304	32.24500	-95.27389	-992
94	3454403	32.18472	-95.34195	-1389
95	3454702	32.12778	-95.37028	-1572
96	3454903	32.13945	-95.27862	-1361
97	3455102	32.21445	-95.21166	-1193
98	3455202	32.21111	-95.19111	-1184
99	3455405	32.18167	-95.23084	-1383

100	3455602	32.18834	-95.14139	-1015
101	3455701	32.13083	-95.22972	-1208
102	3455803	32.15111	-95.18500	-1126
103	3455805	32.13945	-95.17611	-1131
104	3455806	32.13583	-95.17416	-1145
105	3455807	32.13056	-95.16832	-1106
106	3455904	32.16167	-95.13778	-1062
107	3455908	32.14306	-95.15056	-1130
108	3455911	32.13389	-95.14778	-1072
109	3456204	32.21889	-95.06001	-920
110	3456206	32.20973	-95.07305	-914
111	3456303	32.24750	-95.01500	-894
112	3456404	32.19389	-95.09528	-994
113	3456405	32.19167	-95.12417	-983
114	3456406	32.18334	-95.12222	-1037
115	3456801	32.13000	-95.07000	-957
116	3456901	32.12833	-95.03306	-967
117	3461602	32.06333	-95.38444	-1522
118	3461803	32.04194	-95.42250	-1781
119	3461901	32.00861	-95.41361	-1645
120	3461901	32.00889	-95.40778	-1645
121	3462101	32.12417	-95.34500	-1614
122	3462102	32.10139	-95.34806	-1606
123	3462301	32.09222	-95.25944	-1339
124	3462302	32.10222	-95.27278	-1400
125	3462401	32.07667	-95.35083	-1522
126	3462601	32.05667	-95.27251	-1347
127	3462701	32.01278	-95.34306	-1485
128	3462801	32.02889	-95.29778	-1380
129	3462802	32.01806	-95.30556	-1505
130	3462803	32.00889	-95.31833	-1442
131	3462902	32.03084	-95.26278	-1355
132	3462903	32.00334	-95.26139	-1428
133	3463102	32.10806	-95.22251	-1181
134	3463201	32.10444	-95.17833	-1224
135	3463202	32.08778	-95.20305	-1229
136	3463203	32.12250	-95.19806	-1194
137	3463401	32.04667	-95.21778	-1328
138	3463402	32.05111	-95.24416	-1289
139	3463404	32.08083	-95.22361	-1216
140	3463601	32.05250	-95.13444	-1260
141	3463701	32.02611	-95.23416	-1401
142	3463801	32.03278	-95.17250	-1298
143	3463901	32.01278	-95.14166	-1414
144	3464101	32.08472	-95.11806	-1114
145	3464201	32.09194	-95.06972	-1070
146	3464401	32.05389	-95.10778	-1208
147	3464501	32.06028	-95.07333	-1117
148	3464601	32.08167	-95.00417	-943
149	3464602	32.04306	-95.03306	-1102
150	3464701	32.03389	-95.09889	-1217
151	3464702	32.04111	-95.11583	-1188
152	3464703	32.01306	-95.11056	-1262
153	3464801	32.03333	-95.07639	-1163
154	3464802	32.02250	-95.05806	-1128

155	3464901	32.01028	-95.03555	-1133
156	3502801	32.88111	-94.81833	-655
157	3503703	32.88834	-94.72305	-759
158	3509301	32.86528	-94.90750	-753
159	3509402	32.82472	-94.98055	-566
160	3509502	32.82694	-94.94278	-760
161	3509701	32.78195	-94.99472	-613
162	3509803	32.75667	-94.94472	-543
163	3509804	32.78695	-94.92750	-542
164	3510301	32.84528	-94.75361	-608
165	3510601	32.80139	-94.75417	-579
166	3510801	32.77250	-94.79500	-604
167	3511406	32.83083	-94.72611	-616
168	3511701	32.76972	-94.72056	-553
169	3517207	32.71806	-94.92972	-633
170	3517604	32.70223	-94.90778	-583
171	3517605	32.69222	-94.88250	-611
172	3517702	32.63222	-94.98528	-658
173	3517902	32.64861	-94.89667	-625
174	3518101	32.72833	-94.85528	-635
175	3518302	32.71056	-94.78028	-672
176	3518402	32.67222	-94.85694	-678
177	3518501	32.70500	-94.81917	-678
178	3518601	32.67028	-94.79249	-629
179	3518703	32.63750	-94.86667	-661
180	3518802	32.66000	-94.80778	-637
181	3518803	32.63778	-94.82806	-687
182	3518804	32.62945	-94.80389	-640
183	3519101	32.72584	-94.72667	-731
184	3519401	32.69084	-94.72361	-654
185	3519701	32.64528	-94.74916	-578
186	3525102	32.58444	-94.97000	-650
187	3525201	32.62333	-94.94000	-645
188	3525301	32.61028	-94.87639	-702
189	3525601	32.56833	-94.87833	-700
190	3525803	32.52889	-94.92333	-685
191	3525903	32.53111	-94.90028	-673
192	3525904	32.50639	-94.87917	-703
193	3526101	32.58333	-94.84500	-700
194	3526205	32.59722	-94.81222	-792
195	3526301	32.58722	-94.79028	-687
196	3526710	32.53722	-94.85916	-671
197	3526711	32.51167	-94.83694	-650
198	3526802	32.52806	-94.81889	-655
199	3533101	32.48111	-94.96139	-671
200	3533203	32.49111	-94.92582	-756
201	3533301	32.46917	-94.88222	-604
202	3533401	32.44361	-94.99278	-631
203	3533602	32.44167	-94.89166	-705
204	3533804	32.38167	-94.93556	-655
205	3534103	32.48556	-94.84834	-682
206	3534301	32.48778	-94.77500	-475
207	3534302	32.48056	-94.76000	-476
208	3534701	32.38389	-94.87112	-480
209	3541305	32.35472	-94.88806	-545

210	3542201	32.37250	-94.82972	-641
211	3544201	32.35139	-94.56250	-355
212	3544301	32.34445	-94.50806	-396
213	3544502	32.31417	-94.57139	-363
214	3544801	32.26250	-94.58083	-382
215	3549901	32.14222	-94.89111	-626
216	3551201	32.22167	-94.68667	-420
217	3557201	32.11305	-94.94222	-725
218	3557204	32.09445	-94.91832	-696
219	3557401	32.04889	-94.98638	-967
220	3557402	32.06917	-94.99472	-951
221	3557501	32.07333	-94.92139	-731
222	3557502	32.07167	-94.92972	-756
223	3557801	32.00361	-94.95166	-1111
224	3557902	32.00472	-94.89389	-985
225	3559202	32.10250	-94.67083	-478
226	3559301	32.09472	-94.62611	-437
227	3559602	32.06778	-94.66334	-532
228	3559901	32.00806	-94.65028	-623
229	3701101	31.97917	-94.97972	-1233
230	3701102	31.98584	-94.98084	-1185
231	3701403	31.93833	-94.98666	-1865
232	3701502	31.93778	-94.91722	-1263
233	3701701	31.90722	-94.99083	-1322
234	3701801	31.88306	-94.94195	-1362
235	3701802	31.87639	-94.91611	-1255
236	3702302	31.98972	-94.77084	-800
237	3703601	31.92944	-94.64416	-1073
238	3703801	31.91139	-94.69056	-1251
239	3704101	31.97722	-94.60333	-818
240	3704103	31.98861	-94.61249	-759
241	3704501	31.91750	-94.56195	-983
242	3709401	31.79833	-94.99638	-1682
243	3717701	31.65222	-94.97417	-2428
244	3725501	31.56778	-94.93472	-2845
245	3725901	31.50806	-94.89528	-3232
246	3733203	31.49695	-94.93333	-3296
247	3805301	31.98750	-95.39028	-1485
248	3805601	31.95667	-95.41167	-1455
249	3805602	31.92056	-95.40222	-1473
250	3805802	31.91000	-95.42694	-1534
251	3805901	31.89389	-95.38416	-1632
252	3806101	31.98889	-95.35444	-1425
253	3806102	31.98806	-95.33918	-1443
254	3806202	31.98278	-95.33028	-1464
255	3806203	31.97361	-95.29833	-1526
256	3806204	31.96445	-95.33055	-1518
257	3806301	31.99556	-95.28001	-1533
258	3806302	31.97889	-95.28361	-1530
259	3806401	31.94833	-95.34668	-1597
260	3806403	31.92111	-95.36417	-1659
261	3806404	31.95750	-95.37139	-1580
262	3806502	31.92972	-95.32556	-1857
263	3806601	31.92889	-95.25806	-1657
264	3806602	31.92167	-95.27417	-1750

265	3806701	31.88889	-95.34834	-1757
266	3806801	31.89833	-95.31472	-1752
267	3806901	31.90306	-95.28499	-1698
268	3807101	31.99833	-95.21806	-1435
269	3807103	31.96389	-95.21667	-1790
270	3807201	31.98750	-95.18417	-1822
271	3807202	31.96611	-95.16666	-1638
272	3807301	31.98111	-95.13361	-1564
273	3807401	31.92611	-95.23416	-1648
274	3807402	31.92944	-95.21028	-1716
275	3807502	31.92028	-95.17499	-1442
276	3807601	31.92583	-95.13306	-1265
277	3807602	31.93278	-95.16556	-1608
278	3807701	31.89278	-95.23139	-1513
279	3807801	31.89417	-95.17889	-1471
280	3807901	31.87889	-95.14166	-1717
281	3808101	31.98833	-95.10638	-1290
282	3808102	31.97250	-95.09056	-1564
283	3808201	31.97945	-95.07611	-1566
284	3808202	31.97445	-95.04444	-1507
285	3808203	31.98445	-95.05667	-1471
286	3808301	31.97834	-95.00389	-1451
287	3808401	31.94361	-95.09084	-1644
288	3808501	31.95056	-95.04528	-1722
289	3808601	31.92750	-95.02472	-1600
290	3808602	31.94528	-95.00166	-1839
291	3808604	31.93611	-95.02945	-1795
292	3808801	31.91528	-95.06389	-1527
293	3808801	31.91528	-95.06389	-1527
294	3813201	31.85528	-95.42305	-1724
295	3813301	31.86667	-95.40472	-1644
296	3813602	31.81972	-95.38638	-1927
297	3814101	31.86472	-95.36028	-1749
298	3814102	31.84945	-95.33500	-1634
299	3814103	31.84139	-95.36667	-1850
300	3814301	31.85334	-95.26195	-1719
301	3814303	31.87278	-95.28416	-1755
302	3814401	31.82611	-95.36722	-1607
303	3814402	31.82278	-95.34834	-1697
304	3814601	31.81972	-95.27139	-1744
305	3814601	31.81972	-95.27139	-1744
306	3814701	31.78028	-95.34639	-1785
307	3814801	31.77861	-95.30445	-1843
308	3814902	31.78778	-95.27972	-1885
309	3814903	31.76528	-95.26528	-1905
310	3815101	31.85667	-95.22417	-1743
311	3815201	31.85833	-95.18972	-1770
312	3815401	31.81834	-95.21582	-1846
313	3815605	31.83139	-95.15139	-1776
314	3815701	31.78083	-95.22083	-1884
315	3815801	31.76111	-95.17778	-1964
316	3816101	31.84972	-95.11417	-1663
317	3816201	31.83889	-95.05639	-1586
318	3816301	31.86722	-95.01028	-1469
319	3816401	31.82306	-95.11305	-1782

320	3816402	31.81500	-95.09278	-1693
321	3816701	31.78333	-95.09222	-1797
322	3816801	31.75695	-95.06694	-1838
323	3816902	31.75389	-95.00361	-1752
324	3816903	31.76722	-95.02556	-1774
325	3822202	31.72111	-95.29361	-1986
326	3822601	31.67306	-95.26389	-2150
327	3822902	31.62972	-95.26000	-2353
328	3823102	31.72945	-95.24389	-2016
329	3823301	31.72639	-95.15861	-2064
330	3823502	31.68445	-95.18389	-2142
331	3823601	31.67417	-95.14416	-2209
332	3823702	31.63945	-95.22556	-2321
333	3823802	31.64806	-95.18305	-2309
334	3824302	31.71306	-95.02001	-2058
335	3824401	31.66583	-95.09306	-2343
336	3824702	31.64472	-95.09834	-2424
337	3824803	31.66583	-95.07139	-2384
338	3831102	31.62111	-95.22833	-2374
339	3831301	31.60222	-95.15000	-2640
340	3831502	31.57917	-95.19778	-2008
341	3832602	31.54639	-95.03639	-3004
342	3832902	31.53778	-95.00194	-3080

TABLE 4

MOST RECENT PUBLISHABLE HEAD ELEVATIONS
FOR THE
CARRIZO-WILCOX USDW.

Data from: Texas Water Development Board, Austin, Texas.

Note: See bottom of table for comments.

STATE WELL NUMBER	NORTH LATITUDE	WEST LONGITUDE	HEAD ELEV	DATE	*** CPS WELL CODE
3517704	32.64972	-94.97611	197.8	1989	1
3517701	32.64889	-94.97500	391.7	1993	1
3424902	32.64584	-95.02084	407.0	1966	1
3518701	32.64389	-94.84111	337.2	1993	1
3518805	32.64278	-94.82861	353.0	1987	1
3517901	32.64222	-94.87806	360.0	1966	1
3518806	32.63778	-94.82472	75.8	1989	1
3518704	32.63778	-94.84639	200.0	1977	1
3517801	32.62972	-94.92889	218.0	1966	1
3518702	32.62778	-94.87056	173.5	1967	1
3525202	32.61611	-94.94694	99.0	1985	1
3432301	32.60417	-95.02084	260.0	1967	1
3526201	32.59055	-94.79806	264.9	1966	6
3526202	32.59000	-94.79833	264.9	1966	6
3526204	32.58639	-94.79833	264.9	1966	6
3526501	32.58167	-94.79806	264.9	1966	6
3526502	32.57750	-94.82500	319.5	1966	1
3525501	32.57250	-94.92083	244.0	1970	1
3526401	32.55889	-94.85861	370.4	1993	1
3432603	32.55722	-95.00361	295.0	1968	1
3525403	32.54722	-94.96499	222.3	1987	1
3525401	32.54333	-94.96111	254.5	1966	1
3526708	32.53417	-94.83445	171.8	1966	1
3525801	32.53111	-94.94778	251.2	1966	1
3526709	32.53084	-94.86111	199.5	1966	1
3525902	32.52750	-94.89611	209.2	1966	1
3525901	32.51944	-94.90722	209.0	1947	1
3526701	32.50611	-94.86806	131.0	1961	1
3526706	32.50361	-94.85389	217.3	1993	6
3526705	32.50306	-94.85250	217.3	1966	6
3534202	32.49972	-94.80832	215.7	1966	1
3440301	32.49695	-95.00972	375.4	1993	1
3534101	32.49306	-94.84751	219.3	1966	1
3533204	32.48195	-94.92806	313.0	1983	1
3533202	32.48195	-94.92806	229.5	1966	1
3534102	32.47861	-94.85139	221.6	1993	1
3440202	32.47695	-95.05556	320.0	1960	1
3534201	32.46056	-94.79500	234.4	1966	1
3533501	32.44584	-94.95056	172.9	1993	1

3440601	32.44556	-95.01278	378.3	1960	1
3440603	32.44528	-95.01945	68.0	1989	1
3533502	32.44445	-94.95416	229.3	1966	1
3534502	32.44195	-94.81639	240.0	1966	6
3534501	32.44195	-94.81668	240.0	1966	6
3534402	32.43889	-94.86278	238.0	1960	1
3534403	32.43889	-94.87389	221.1	1993	1
3533601	32.43862	-94.91500	241.2	1966	1
3533402	32.43862	-94.99000	223.0	1988	1
3533915	32.41445	-94.90778	299.6	1988	1
3534703	32.40973	-94.84751	213.0	1938	1
3534901	32.40306	-94.76222	260.0	1963	1
3534801	32.40195	-94.80000	253.4	1966	1
3533911	32.39889	-94.91583	249.1	1966	6
3533802	32.39834	-94.91805	249.1	1976	6
3533801	32.39695	-94.91805	249.1	1966	6
3533910	32.39250	-94.88250	178.9	1966	1
3533906	32.39222	-94.89694	243.8	1964	1
3533907	32.38945	-94.90611	233.9	1936	1
3533904	32.38778	-94.89416	189.0	1966	1
3534701	32.38639	-94.86861	127.0	1966	6
3534702	32.38417	-94.87056	127.0	1934	6
3533803	32.38334	-94.93111	224.0	1966	1
3533902	32.38250	-94.87750	241.2	1966	6
3533901	32.38222	-94.87806	241.2	1966	6
3541302	32.37250	-94.89056	182.0	1957	1
3541303	32.37167	-94.88333	209.0	1966	1
3542303	32.36305	-94.75778	368.1	1936	1
3541304	32.36083	-94.90639	240.0	1939	1
3541201	32.35722	-94.92778	249.7	1941	1
3541301	32.35417	-94.89583	185.0	1957	1
3541309	32.35361	-94.90667	206.0	1940	1
3541202	32.35028	-94.93194	384.0	1936	1
3541101	32.34417	-94.97111	417.5	1936	1
3542202	32.34417	-94.82305	208.1	1993	1
3448201	32.34389	-95.05000	282.0	1962	1
3542302	32.34333	-94.77056	379.0	1936	6
3542301	32.34333	-94.77278	379.0	1981	6
3541102	32.33972	-94.96750	266.4	1981	1
3541307	32.33889	-94.89528	442.5	1942	1
3448203	32.33833	-95.04305	287.1	1962	1
3448202	32.33472	-95.04750	293.0	1962	1
3542601	32.33083	-94.79111	360.4	1936	1
3448501	32.32917	-95.04278	285.0	1962	1
3541602	32.32806	-94.87556	253.0	1981	6
3541603	32.32806	-94.87556	253.0	1981	6
3542403	32.32806	-94.83445	462.4	1936	1
3541504	32.32167	-94.93332	174.0	1950	1
3541503	32.31833	-94.93278	194.0	1949	1
3448502	32.31778	-95.05417	311.0	1962	1
3541401	32.31667	-94.98222	359.0	1936	1
3541502	32.31139	-94.92166	249.2	1979	6
3541501	32.31139	-94.92139	249.2	1983	6
3542404	32.30361	-94.86750	215.0	1988	1
3542401	32.30306	-94.86611	222.6	1979	1

3542602	32.29889	-94.76000	401.3	1936	1
3542502	32.29889	-94.79528	122.0	1987	1
3541509	32.29805	-94.94722	366.9	1941	1
3541601	32.29694	-94.89667	420.6	1993	1
3542402	32.29694	-94.83389	399.9	1936	1
3541510	32.29528	-94.94611	427.1	1940	1
3542802	32.29111	-94.82333	278.0	1988	1
3541906	32.29000	-94.88361	252.0	1988	1
3448804	32.28611	-95.06001	285.0	1982	1
3542904	32.28417	-94.76195	371.5	1936	1
3542903	32.28111	-94.78833	382.3	1981	1
3541901	32.28056	-94.91472	180.4	1981	1
3541905	32.27861	-94.88611	307.0	1988	1
3541809	32.27694	-94.92555	167.0	1980	1
3541705	32.27556	-94.97694	355.4	1941	6
3541707	32.27528	-94.97556	355.4	1940	6
3541702	32.27417	-94.97472	355.4	1947	6
3542703	32.27361	-94.84889	292.8	1988	1
3541703	32.27361	-94.98583	292.9	1979	6
3541902	32.27306	-94.90195	292.9	1936	6
3541701	32.27278	-94.98888	292.9	1985	6
3541803	32.27111	-94.92861	132.3	1974	1
3541807	32.27055	-94.93611	210.0	1979	1
3541904	32.26917	-94.88722	437.0	1936	1
3542701	32.26861	-94.86388	222.0	1965	1
3541804	32.26806	-94.92833	141.0	1952	1
3541903	32.26056	-94.89361	463.3	1936	1
3541704	32.25889	-94.96667	333.0	1937	1
3542901	32.25861	-94.78250	222.3	1979	1
3542702	32.25694	-94.86472	246.0	1988	1
3541706	32.25667	-94.97944	471.0	1936	1
3542902	32.25583	-94.77917	219.8	1979	1
3541811	32.25389	-94.92694	217.6	1988	1
3542801	32.25250	-94.81195	385.0	1991	1
3541808	32.25195	-94.93166	242.8	1981	6
3541810	32.25028	-94.93361	242.8	1941	6
3549203	32.24917	-94.93278	242.8	1981	6
3550101	32.24806	-94.85750	421.0	1936	1
3549101	32.24639	-94.97556	495.5	1936	1
3550105	32.24584	-94.84222	258.0	1988	1
3550304	32.24417	-94.78694	247.3	1988	1
3456203	32.24389	-95.05000	506.0	1960	1
3550207	32.24333	-94.79278	256.0	1988	1
3549201	32.24083	-94.93889	258.0	1942	1
3550203	32.24083	-94.80556	393.4	1936	1
3549202	32.23972	-94.94334	222.0	1947	1
3456301	32.23778	-95.00944	300.0	1958	1
3549102	32.23695	-94.96917	445.5	1936	6
3549103	32.23556	-94.97222	445.5	1936	6
3456201	32.23500	-95.04361	243.0	1962	1
3550302	32.23250	-94.75722	390.0	1990	1
3549304	32.23084	-94.90056	502.0	1936	1
3550102	32.22750	-94.84972	400.6	1936	1
3549303	32.22695	-94.91611	437.4	1936	1
3549208	32.22250	-94.91694	364.1	1940	1

3549302	32.22028	-94.88555	280.0	1974	1
3550205	32.21917	-94.79583	366.4	1936	1
3549209	32.21889	-94.92083	269.4	1944	1
3549206	32.21667	-94.93445	245.0	1978	1
3550103	32.21472	-94.86583	464.6	1936	1
3456302	32.21445	-95.02472	280.0	1956	1
3550201	32.21445	-94.82472	403.9	1962	6
3550202	32.21278	-94.82166	403.9	1981	6
3550204	32.21139	-94.81861	403.9	1962	6
3550206	32.21028	-94.81944	403.9	1964	6
3550106	32.20917	-94.84278	182.0	1988	1
3550501	32.20778	-94.82139	403.9	1993	6
3550401	32.20750	-94.83806	229.0	1979	1
3549504	32.20611	-94.95305	295.0	1941	1
3549405	32.20583	-94.99668	438.0	1940	1
3550506	32.20500	-94.82722	304.1	1988	1
3549503	32.20472	-94.93833	218.0	1940	6
3549501	32.20334	-94.93917	218.0	1947	6
3549606	32.20139	-94.88528	404.0	1988	1
3549404	32.20056	-94.99361	316.8	1940	1
3456502	32.20000	-95.05000	281.9	1972	1
3550502	32.19750	-94.80056	251.3	1981	1
3549510	32.19611	-94.94556	381.0	1931	1
3550505	32.19528	-94.81111	367.0	1988	1
3549509	32.19528	-94.92389	404.4	1936	1
3550604	32.19222	-94.76556	224.5	1988	1
3549502	32.18973	-94.95222	311.5	1993	1
3550403	32.18917	-94.86278	428.6	1936	1
3550402	32.18806	-94.84694	445.9	1936	1
3549511	32.18722	-94.92582	179.0	1988	1
3549401	32.18223	-94.98139	280.0	1944	1
3549507	32.18000	-94.91888	271.3	1940	1
3549506	32.18000	-94.93667	359.5	1940	1
3550603	32.17889	-94.77583	382.0	1986	1
3549603	32.17889	-94.89249	340.0	1938	1
3549505	32.17667	-94.95027	376.3	1941	1
3550404	32.17556	-94.83889	427.1	1936	1
3549601	32.17473	-94.87945	212.0	1981	1
3549602	32.17445	-94.87583	274.0	1975	1
3549604	32.17278	-94.87750	417.5	1937	1
3550601	32.16834	-94.78444	447.0	1936	1
3549512	32.16778	-94.92611	206.0	1988	6
3549808	32.16528	-94.92694	206.0	1981	6
3549811	32.16528	-94.92472	206.0	1981	6
3550704	32.16334	-94.85139	224.5	1988	1
3550913	32.15834	-94.75028	463.6	1940	1
3550912	32.15722	-94.75056	480.2	1939	1
3550702	32.15695	-94.85499	426.5	1940	1
3550906	32.15667	-94.75722	105.0	1979	1
3549805	32.15611	-94.93445	168.0	1979	1
3550907	32.15611	-94.75000	146.0	1981	1
3550902	32.15528	-94.78194	261.3	1940	1
3549813	32.15445	-94.94278	121.0	1982	1
3550911	32.15417	-94.77084	442.7	1936	1
3550802	32.15362	-94.79972	150.7	1981	1

3549807	32.15278	-94.92694	380.0	1936	1
3550910	32.15195	-94.78361	243.0	1940	1
3550703	32.15167	-94.84722	403.2	1940	1
3550801	32.15083	-94.79334	146.3	1993	1
3550903	32.15056	-94.78444	128.0	1981	1
3549812	32.14972	-94.93611	132.7	1981	1
3549702	32.14972	-94.97166	219.8	1979	1
3550905	32.14945	-94.77195	179.0	1955	1
3550904	32.14889	-94.78944	125.0	1981	1
3550701	32.14861	-94.87334	435.0	1936	1
3549902	32.14834	-94.88111	407.5	1936	1
3549810	32.14778	-94.92444	261.8	1971	6
3549809	32.14778	-94.92444	261.8	1981	6
3550901	32.14750	-94.78499	116.2	1981	1
3549804	32.14417	-94.94389	124.0	1968	6
3550909	32.14111	-94.75332	268.3	1981	1
3550908	32.14111	-94.75332	161.4	1981	1
3549803	32.13973	-94.94722	124.0	1965	6
3549814	32.13917	-94.94334	124.0	1988	6
3549815	32.12666	-94.94444	58.0	1983	1
3550914	32.12639	-94.76166	93.0	1988	1
3558202	32.11916	-94.83249	213.4	1979	1
3550805	32.11694	-94.81222	396.9	1936	1
3464305	32.11611	-95.01722	401.7	1936	1
3558303	32.11389	-94.76056	143.7	1988	1
3557201	32.11305	-94.94334	199.0	1974	1
3557301	32.11305	-94.90472	408.2	1936	1
3558103	32.11083	-94.84861	292.6	1981	1
3558301	32.11028	-94.77611	253.0	1965	1
3464202	32.10861	-95.04334	290.0	1954	1
3557202	32.10667	-94.94861	184.6	1979	1
3557203	32.10444	-94.95194	206.4	1979	1
3558102	32.10417	-94.85722	249.4	1979	1
3464302	32.10417	-95.02056	361.2	1993	1
3464304	32.09389	-95.02028	327.9	1936	1
3464303	32.09028	-95.00833	359.5	1936	1
3558302	32.08917	-94.75472	382.1	1936	1
3557206	32.08861	-94.93584	357.4	1981	6
3557205	32.08861	-94.93584	357.4	1981	6
3557207	32.08861	-94.93556	357.4	1981	6
3558101	32.08583	-94.86667	366.2	1993	1
3558201	32.08416	-94.80611	343.6	1975	1
3557506	32.07417	-94.94082	327.3	1981	6
3557505	32.07306	-94.93917	327.3	1981	6
3558502	32.07306	-94.80112	178.0	1965	1
3464502	32.07195	-95.04806	192.0	1988	1
3464505	32.07167	-95.05667	416.2	1936	1
3464605	32.06695	-95.01889	363.3	1936	1
3557407	32.06695	-94.96611	288.6	1981	1
3557503	32.06250	-94.92416	402.8	1981	1
3558401	32.05694	-94.85638	434.6	1993	1
3557405	32.05611	-94.97139	308.3	1981	6
3557403	32.05611	-94.97166	308.3	1981	6
3557404	32.05611	-94.97139	308.3	1981	6
3464503	32.05472	-95.04611	335.4	1936	1

3557601	32.05306	-94.89000	374.0	1936	1
3558402	32.05222	-94.85250	319.9	1981	1
3558403	32.05056	-94.85833	452.0	1981	1
3557504	32.05028	-94.94389	429.0	1936	1
3558601	32.05000	-94.77139	282.2	1976	1

Notes: Data are sorted by latitude, north to south.

"N" or "not publishable" data have been eliminated from the original data set.

*** Closely spaced and duplicate locations have been given a well code 6 (circles) on Map #4 and their elevations have been averaged in this table.

APPENDIX 1

**Membership of East Texas Field
AOR Variance Steering Committee**

STEERING COMMITTEE FOR THE STUDY OF
AOR VARIANCE OPPORTUNITIES FOR THE
EAST TEXAS FIELD

East Texas Salt Water Disposal Company, Chief Engineer	Jerry Adams Chief Engineer East Texas Salt Water Disposal Company 1209 Industrial Blvd. P.O. Box 2459 Kilgore, TX 75663 PHONE: 903-984-3063 FAX: 903-984-6952
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East Texas Salt Water Disposal Company, Environmental Manager	Ricky Clements Environmental Manager East Texas Salt Water Disposal Company 1209 Industrial Blvd. P.O. Box 2459 Kilgore, TX 75663 PHONE: 903-597-5507 903-984-3063

Steering Committee List
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Texas Railroad Commission Assistant Director, Oil and Gas Division	Jerry Mullican Assistant Director, Oil and Gas Division Texas Railroad Commission P.O. Drawer 12967 Capital Station Austin, TX 78711 PHONE: 512-463-6829 FAX: 512-463-7328
U.S. Department of Energy, Technical Project Officer	Brent Smith Project Manager for Environmental Research and University Programs U.S. Dept.of Energy, Metairie Site Office 900 Commerce Road, E. New Orleans, LA 70123 PHONE: 504-734-4970 FAX: 504-734-4909
University of Missouri-Rolla Project Principal Investigator and Committee Chairman	Don L. Warner Professor Emeritus of Geological Engineering 274 McNutt Hall University of Missouri-Rolla Rolla, MO 65401 PHONE: 314-341-4876 FAX: 314-341-4192

APPENDIX 2

Determination of Flow Potentials from Oil Reservoirs to Underground Sources of Drinking Water in the San Juan Basin of New Mexico

Environmental Geosciences, V. 1, No. 1 (June 1994), P. 21–31, 9 Figs., 1 Table

Determination of Flow Potential From Oil Reservoirs to Underground Sources of Drinking Water in the San Juan Basin, New Mexico[1]

Robert C. Laudon[2]
Don L. Warner[2]
Leonard F. Koederitz[2]
Shari Dunn-Norman[2]

ABSTRACT

When the Underground Injection Control Regulations were promulgated in 1980, existing Class II injection wells (saltwater disposal and secondary recovery injection wells) operating at the time were excluded from Area of Review (AOR) requirements. The U.S. EPA has expressed its intent to revise the regulations to include AOR requirements for such wells, but it is expected that oil- and gas-producing states will be allowed to adopt a variance strategy for these wells.

An AOR variance methodology has been developed by the authors under sponsorship of the American Petroleum Institute. The general concept of the variance methodology is a systematic evaluation of basic variance criteria that were agreed to by a Federal Advisory Committee. These criteria include absence of an underground source of drinking water (USDW), lack of positive flow potential from the petroleum reservoir to the overlying USDW, mitigating geological factors, and other compelling evidence.

To demonstrate lack of positive flow potential from the petroleum reservoir to the overlying USDW, the procedure that has been developed requires that reservoir pressures be converted to freshwater hydraulic head equivalents using the base of the USDW as the datum. These heads are then compared against USDW heads, and residuals are generated either graphically (using map overlays) or by subtracting grids on a computer and contouring. A negative residual implies that the hydraulic gradient between the oil reservoir and the USDW is such that there is no potential for flow of saline water from the oil reservoir to the USDW. Examples from the San Juan basin of New Mexico indicate that the procedure is simple in concept but complicated in practice.

INTRODUCTION

When the Underground Injection Control (UIC) Regulations were promulgated in 1980, operating Class II injection wells (saltwater disposal and secondary recovery injection wells) were excluded from Area of Review (AOR) requirements. The U.S. Environmental Protection Agency (EPA) has expressed its intent to revise the regulations to include AOR requirements for such wells.

In 1992 a Federal Advisory Committee (FAC) recommended that AORs for existing wells (not previously subject to that requirement) be performed within five years of promulgation of amended UIC regulations. The final document issued by the FAC (Warner et al., 1993) recognized that, under certain conditions, individual wells, whole fields, or whole basins could be exempted from the AOR procedure through a variance program. According to the FAC recommendations, a variance may be granted according to any of the following criteria.

1. The absence of USDWs.
2. The hydrocarbon reservoir is under-pressured relative to the USDW.
3. Local geologic conditions preclude upward fluid movement that could endanger USDWs.
4. Other compelling evidence.

A methodology for identification of areas that could be eligible for variance from AOR requirements based on all four FAC criteria has been developed by the authors (Warner et al., 1993). The principal subject of this paper is criterion #2. The following sections will comment briefly on criteria #1, #3 and #4, followed by a full explanation of criterion #2.

Criterion #1: Absence of USDWs

This criterion is self-explanatory. If no USDWs are present, then there is obviously no potential for contamination of a USDW. The absence of a USDW is included in a broader category denoted as "no intersection." No intersection also refers to the situation where a USDW and an injection horizon exist, but none of the wells in the immediate area are drilled deep enough to encounter the injection zone. Thus, there is no connection or fluid pathway between the injection zone and the USDW, and there can be no contamination of the USDW. The term "no intersection" is also expanded to include situations where the USDW in a particular area

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is also a petroleum reservoir. The Dakota, Gallup, and other Cretaceous age sandstones of the San Juan basin have areas where oil is produced from a reservoir that contains freshwater. One further possibility occurs when a USDW is present but that particular USDW has been exempted under provisions of the Safe Drinking Water Act so that it is no longer a protected aquifer.

Criterion #2: The Hydrocarbon Reservoir Is Under-Pressured Relative to the USDW

The procedure to identify under-pressured reservoirs relative to a USDW is the principal subject of this paper and will follow a discussion of Criteria #3 and #4.

Criterion #3: Local Geologic Conditions Preclude Upward Fluid Movement That Could Endanger USDWs

The FAC variance criteria include the presence of local geologic conditions that preclude upward fluid movement that could endanger USDWs. Such mitigating factors include sloughing, squeezing, and sink zones.

A sloughing formation refers to any geological horizon that is highly incompetent and tends to fall or cave into the well. With this type of formation, the rock material lost from sloughing could fall to the bottom of the well and form a solid barrier to flow. Examples of sloughing zones include unconsolidated formations, consolidated bentonitic shales, salt, and anhydrite.

A squeezing formation is one with strata that flow plastically under overburden stress to close an uncased borehole or to close the casing-formation annulus in a cased well. Examples of this type of formation also include unconsolidated shales, consolidated bentonitic shales, salt, and anhydrite.

A sink, or thief zone, refers to a geological horizon that has flow potential less than both the overlying USDW and the petroleum reservoir. Thief zones are intermediate formations (located between an injection horizon and a USDW) that act to divert fluids flowing up a well bore. By acting as a fluid sink, the thief zone prevents contaminating fluids from reaching the USDW. The Mesa Verde Group in parts of the San Juan basin is such a zone. A thief zone can also be a normally pressured formation that is so permeable and thick that it diverts virtually all upward-flowing fluid without experiencing significant pressure increase. The Wilcox Sand in the Lower Tuscaloosa producing trend of Mississippi and Louisiana was found by Warner and McConnell (1993) to be such a zone.

Squeezing, sloughing, and sink zones may or may not prevent USDW contamination. In order for a squeezing, sloughing, or sink zone to mitigate the contamination risk, it must be positioned and exposed to the well bore in a manner that will block fluid flow. The only means of assessing the presence and effectiveness of sloughing or squeezing zones may be qualitative evidence in the form of operator experience and observations by regulatory agency personnel.

Criterion #4: Variance Based on Other Compelling Evidence

Well construction and abandonment methods can also be considered as factors for an AOR variance. If all wells in an area are constructed and abandoned in a manner that precludes fluid migration from a reservoir to a USDW, then there is little potential for contamination through existing wells. The authors have developed a computer program that provides a quantitative assessment of the barriers to USDW contamination based on well construction and abandonment methods. The procedure requires statistical sampling of wells from an area and construction of well bore diagrams to identify potential barriers to fluid flow within those wells (Warner et al., 1993).

CRITERION #2: PROCEDURE TO DETERMINE POTENTIAL FOR FLOW OF SALTWATER UPWARD FROM A PETROLEUM RESERVOIR TO A USDW

Modern groundwater textbooks begin discussion of subsurface fluid flow by establishing that the total potential to cause flow is comprised of two components, elevation and pressure (Freeze and Cherry, 1979). Elevation is the distance above some datum, normally expressed in feet, and may be positive or negative with respect to the datum. Sea level is often used as a reference datum, but elevation can be measured with respect to any arbitrary level.

Pressure is the fluid gauge pressure as measured or calculated at the subsurface point of interest. In oil and gas wells pressures are normally measured at a particular depth in the borehole. The equation for total potential is as follows:

$$H_t = H_p + H_z \qquad (1)$$

where

H_t = total potential or head, ft
H_p = pressure head at point of pressure measurement, ft
H_z = elevation head, ft

In petroleum reservoir engineering, the pressures reported in a well bore are usually expressed in psi. Hence, to calculate total head using equation (1) it is first necessary to convert reservoir pressure in psi to feet of head. This is accomplished by dividing the pressure by the density of the fluid column as follows:

$$H_p = \frac{P}{\frac{\rho}{144}} = \frac{P}{\rho}(144) \qquad (2)$$

where

H_p = pressure head at point of pressure measurement, ft
P = reservoir or measured pressure, psi
ρ = fluid density, lb/ft^3

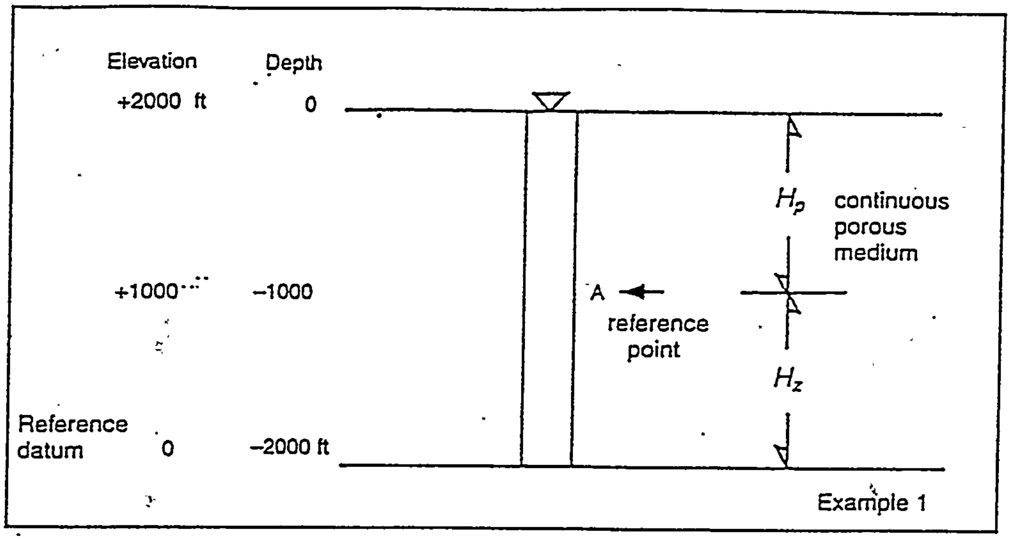

Figure 1. Pressure (H_p) and elevation (H_z) head at reference point A (example 1).

The constant in equation (2) is 144 in²/ft² and is used to convert the fluid density in lb/ft³ to a pressure gradient in psi/ft. For example, freshwater has a density of 62.4 lb/ft³. The pressure gradient in a column of freshwater would therefore be:

$$\text{grad} = \frac{62.4\frac{\text{lb}}{\text{ft}^3}}{144\frac{\text{in}^2}{\text{ft}^2}} = 0.433\ \frac{\text{psi}}{\text{ft}} \quad (3)$$

where
grad = fluid pressure gradient, psi/ft

In drilling mud weight terminology, gradients may be expressed in pounds per gallon (ppg) where one ppg is equivalent to .0519 psi/ft, and:

	Density	Gradient	Mud Weight
For freshwater	62.4 lb/ft³ =	.433 psi/ft =	8.3 ppg
For seawater	64.3 lb/ft³ =	.446 psi/ft =	8.6 ppg
For "average" gradient	64.8 lb/ft³ =	.45 psi/ft	= 8.67 ppg
For "average" brine	72.0 lb/ft³ =	.5 psi/ft	= 9.6 ppg

EXAMPLE 1: In groundwater practice, flow potentials are generally expressed as heads in units of feet. These values can be used directly in calculating total potential (equation 1). Figure 1 shows an example of these principles. In the figure there is a continuous porous medium, saturated with freshwater, which extends from surface to a depth of 2000 ft. A borehole has been drilled completely through the sediments as shown. The reference datum, which is assigned an elevation of 0, is the bottom of the hole.

The total potential at any point in the borehole can be determined by equation (1), since it is known that the fluid in the medium is freshwater. For example, if a pressure measurement was made at point A 1000 ft below the surface, there would be a hydrostatic pressure at point A of:

$$P = (\text{grad})\ (H_p) = (0.433\ \frac{\text{psi}}{\text{ft}})\ (1000\ \text{ft}) = 433\ \text{psi} \quad (4)$$

where
P = hydrostatic fluid pressure, psi
grad = fluid pressure gradient, psi/ft (freshwater = 0.433)
H_p = height of column of water generating the pressure

Converting this pressure to head (H_p), gives the following:

$$H_p = \frac{433}{62.4}(144) = 1000\ \text{ft} \quad (5)$$

The elevation potential (H_z) at point A is equal to:

$$H_z = (1000\ \text{ft}) - (0\ \text{ft}) = 1000\ \text{ft} \quad (6)$$

which represents the elevation of point A minus the elevation of the datum plane. Thus, at point A the total potential is equal to:

$$H_t = 1000\ \text{ft} + 1000\ \text{ft} = 2000\ \text{ft} \quad (7)$$

A similar calculation can be made at any other point in the borehole or for a different formation fluid density. For example, the pressure at a depth of 500 ft would be 217 psi (0.433 psi/ft × 500 ft = 217 psi), and the total potential at this point would be would be:

$$H_t = 500\ \text{ft} + 1500\ \text{ft} = 2000\ \text{ft} \quad (8)$$

Example 1 (Figure 1) assumes a single homogeneous aquifer containing water of a constant density. In this situation, the flow potentials are equal everywhere so that no flow can occur. Although this case demonstrates the concept of head and potential, the practical problem of interest is that of interaquifer flow, i.e.,

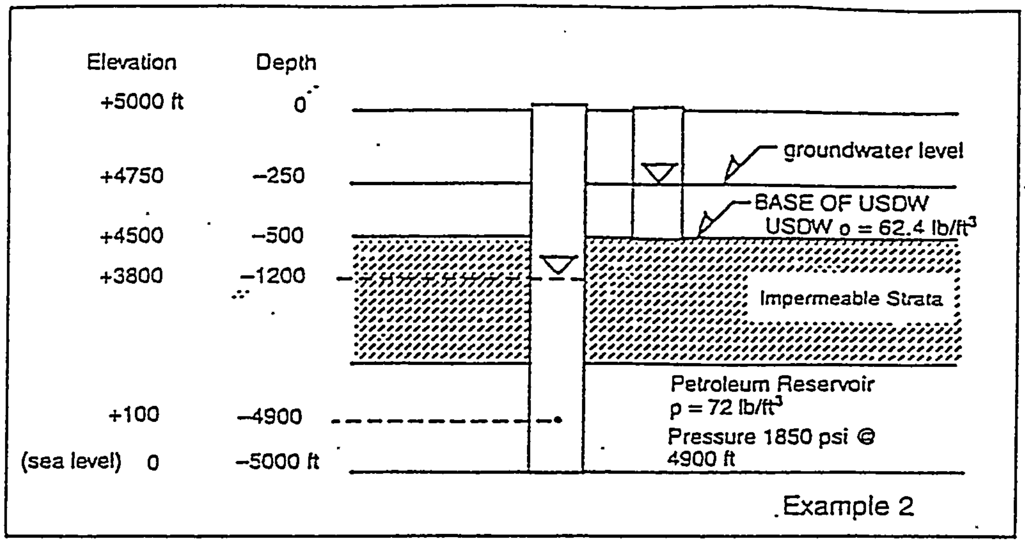

Figure 2. Flow potential conditions in a petroleum reservoir and overlying USDW (example 2).

where fluid from one aquifer or reservoir may flow into another aquifer.

EXAMPLE 2: Figure 2 depicts a USDW that overlies a petroleum reservoir. The USDW contains freshwater with a very low total solids content, and its density is approximately 62.4 lb/ft³ (pressure gradient = 0.433 psi/ft). The petroleum reservoir contains saltwater with a total dissolved solids content of 250,000 mg/L. The density of the saltwater is shown as 72 lb/ft³. The density contrast is exaggerated here to demonstrate the principles in the following examples. In this example and the others discussed herein it is assumed that the zones between the USDW and the petroleum reservoir are of such low permeability that flow through them does not occur.

The petroleum reservoir in Figure 2 has a reservoir pressure of 1850 psi at a depth of 4900 ft. Water from this reservoir can be calculated to have the potential to rise to an elevation of 3800 ft in an open borehole as follows:

$$H_t = \frac{1850 \text{ psi}}{72 \frac{\text{lb}}{\text{ft}^3}} (144 \frac{\text{in}^2}{\text{ft}^2}) + 100 \text{ ft} = 3800 \text{ ft} \qquad (9)$$

As this example shows, reservoir pressures are normally pressure measurements made at a specified depth. Groundwater aquifer potentiometric data are water levels measured in wells and reported with reference to sea level as a datum. To compare these data, reservoir heads must be calculated with reference to the same datum as the groundwater data. Hence, in equation 9, 100 ft is added to calculate the reservoir head relative to sea level.

The reservoir head data and USDW head data are then compared to determine if fluids from the reservoir have sufficient potential to flow into the USDW. The usual practice is to subtract the USDW head from the reservoir head. If the difference is positive, there is a potential for the reservoir fluid to flow into the USDW. However, in Figure 2 it can be seen that the height of the fluid column representing the saltwater potential is lower than the base of the USDW (deepest point where interaquifer flow can occur). This indicates that no flow can occur from the reservoir into the USDW.

EXAMPLE 3: If the reservoir head, that is, the height of the reservoir fluid column, is above the base of the USDW, there may or may not be potential for interaquifer flow. This depends on the amount of reservoir head relative to the base of the USDW, the density of the reservoir fluid, and the potential of the USDW. Figure 3 shows an example where there is not a sufficient potential for interaquifer flow, even though the reservoir potential is sufficient to cause a fluid column to rise above the base of the USDW.

In Figure 3, the reservoir pressure at a depth of 4900 ft is 2250 psi. The saltwater column in this case would rise to an elevation of 4600 feet as shown below:

$$H_t = \frac{2250 \text{ psi}}{72 \frac{\text{lb}}{\text{ft}^3}} (144 \frac{\text{in}^2}{\text{ft}^2}) + 100 \text{ ft} = 4600 \text{ ft} \qquad (10)$$

In order to determine if the reservoir head would actually be able to overcome the total head potential in the USDW and flow into it, the saltwater head above the base of the USDW must be converted into an equivalent freshwater head. In the case shown in Figure 3, the saltwater head is 100 ft greater than the base of the USDW. The equivalent freshwater head above the base of the USDW would therefore be:

$$(100 \text{ ft}) \left[\frac{72 \frac{\text{lb}}{\text{ft}^3}}{62.4 \frac{\text{lb}}{\text{ft}^3}} \right] = 115.4 \text{ ft} \qquad (11)$$

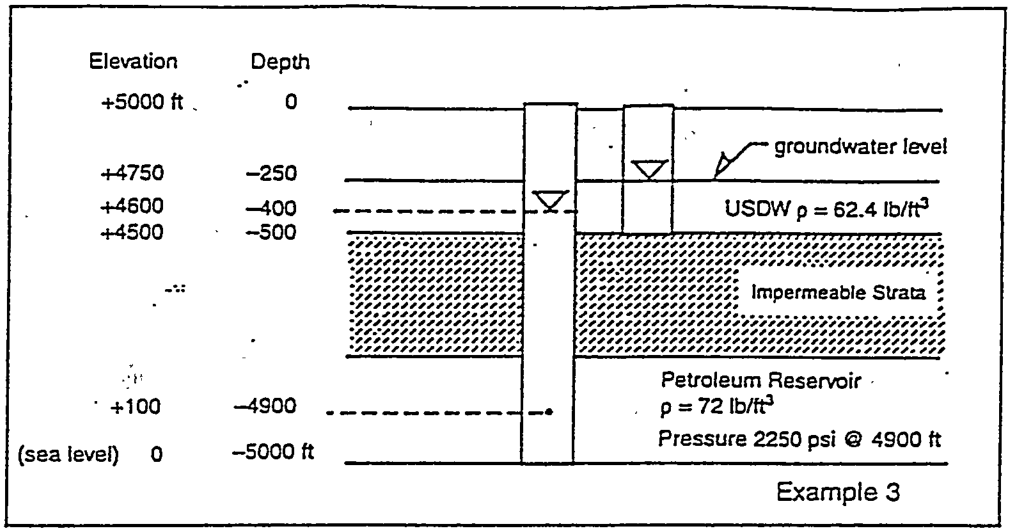

Figure 3. Flow potential conditions in a petroleum reservoir and overlying USDW (example 3).

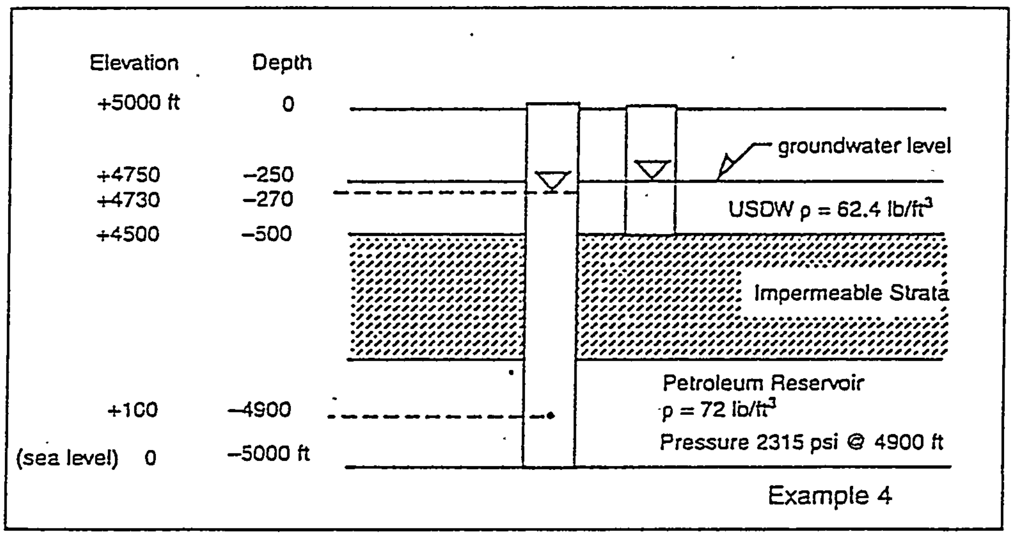

Figure 4. Flow potential conditions in a petroleum reservoir and overlying USDW (example 4).

Adding 115.4 ft to the elevation of the base of the USDW yields a total of 4615.4 ft (115.4 + 4500 ft). Since this is less than the USDW head of 4750 ft, the saltwater cannot flow into the USDW.

EXAMPLE 4: In the fourth example (Figure 4) there is sufficient potential for flow. In this case the reservoir pressure at a depth of 4900 ft is 2315 psi. The reservoir pressure of 2315 psi would cause the saltwater column to rise to an elevation of 4730 ft.

$$H_t = \frac{2315 \text{ psi}}{72 \frac{\text{lb}}{\text{ft}^3}} \left(144 \frac{\text{in}^2}{\text{ft}^2}\right) + 100 \text{ ft} = 4730 \text{ ft} \qquad (12)$$

The reservoir head (height of the fluid column) in this example is 230 ft above the base of the USDW. The equivalent freshwater head for this fluid column would be:

$$(230 \text{ ft}) \left[\frac{72 \frac{\text{lb}}{\text{ft}^3}}{62.4 \frac{\text{lb}}{\text{ft}^3}} \right] + 4500 \text{ ft} = 4765.4 \text{ ft} \qquad (13)$$

Since the total equivalent saltwater head of 4765.4 ft would exceed the 4750 ft freshwater head, the saltwater would have the potential to flow into the USDW (4765.4 − 4750 = +15.4 ft).

EXAMPLE 5: A fifth example is given to illustrate the case where reservoir head is greater than the head of the USDW, i.e., the height of the reservoir fluid column rises above the top of the USDW (Figure 5). In this case

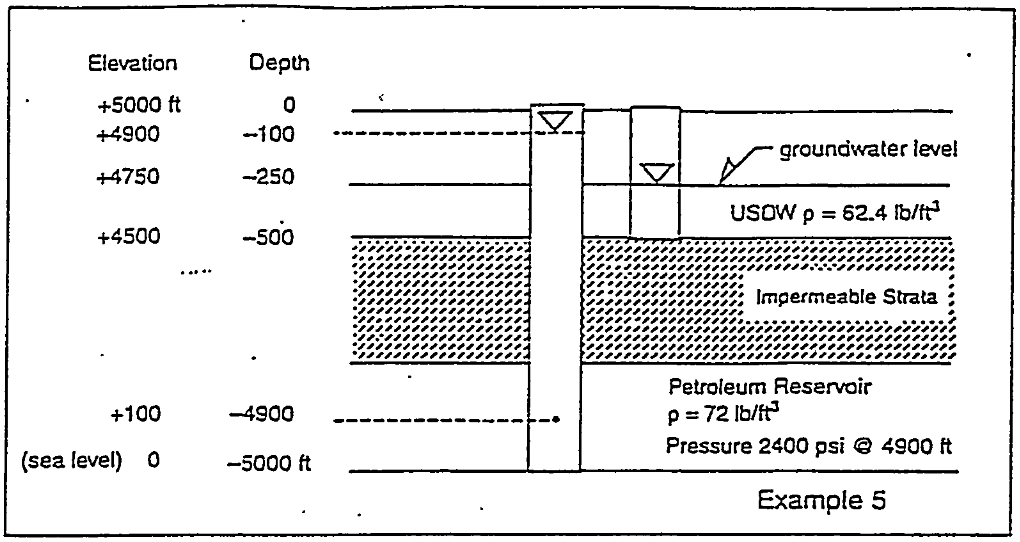

Figure 5. Flow potential conditions in a petroleum reservoir and overlying USDW (example 5).

the reservoir pressure at a depth of 4900 ft is 2400 psi, and the saltwater column would rise to an elevation of 4900 ft. The reservoir head is 400 ft above the bottom of the USDW. Converting this to an equivalent freshwater head, the total potential to cause flow would be:

$$(400 \text{ ft}) \left[\frac{72 \frac{\text{lb}}{\text{ft}^3}}{62.4 \frac{\text{lb}}{\text{ft}^3}} \right] + 4500 \text{ ft} = 4961.5 \text{ ft} \qquad (14)$$

Since the total equivalent saltwater head of 4961.5 ft exceeds the 4750 ft freshwater head, the saltwater would have the potential to flow into the USDW (4961.5 − 4750 = +211.5 ft). However, this determination is also obvious from visual inspection of Figure 5; that is, when the saltwater column rises above the freshwater level in the USDW, there is no question that the saltwater potential would be sufficient for flow into the USDW to occur.

Potential Calculations Where Elevation of the Base of USDW Is Unknown

In the four examples shown in Figures 2–5, a precise determination of the flow potential difference between the petroleum reservoir and the USDW can be calculated because the elevation of the base of the USDW was assumed to be known. In many cases, the USDW freshwater heads will be known, but the elevation of the base of the USDW will not. In those cases, the saltwater heads can be calculated as was previously shown, but a different procedure must be used to calculate the equivalent freshwater heads. The procedure that has been used in this study is to convert the entire saltwater head, above the elevation at which the pressure was measured, to an equivalent freshwater head. This procedure is conservative in that it overestimates the potential for upward flow. For the four examples, the freshwater heads calculated by the procedure are shown in Table 1.

Table 1 includes various reservoir heads calculated for the four examples shown in Figures 2–5. The head values summarized consist of the initial saltwater head (equations 9, 10, 12), the equivalent freshwater head relative to the base of the USDW (equations 11, 13), the total freshwater equivalent of the reservoir head (Table 1), and the USDW heads.

Conclusions that can be drawn from the above listing of head data are:

1. Only the petroleum reservoir equivalent freshwater heads calculated using the known elevation of the base of the USDW as a datum are accurate representations of the potential for flow of saltwater from a petroleum reservoir to a USDW.
2. If the calculated petroleum reservoir saltwater head is greater than the measured USDW head, there is potential for upward flow. The further calculation of the petroleum equivalent freshwater head will only serve to more accurately quantify the head differential, which will be larger than that between the calculated saltwater head and the measured USDW freshwater head.
3. If the petroleum reservoir equivalent freshwater head, calculated without knowledge of the elevation of the base of the USDW and using the elevation of the pressure measurement as the datum, is less than the measured USDW freshwater head, then there is no possibility of there being sufficient potential for upward flow of saltwater from the petroleum reservoir to the USDW.
4. When the elevation of the base of the USDW is unknown, then a practical procedure is to calculate the petroleum reservoir saltwater head and the equivalent freshwater head using the elevation of

Table 1. Calculated heads and residuals for examples 2–5.

	Reservoir Saltwater Head	Freshwater Head (Base USDW)	Freshwater Head Elevation	Measured USDW Head
Example 2	3800	*	4369	4750
Residuals	−950	—	−381	
Example 3	4600	4615	5292	4750
Residuals	−150	−135	542	
Example 4	4730	4765	5442	4750
Residuals	−20	15	692	
Example 5	4900	4961	5638	4750
Residuals	150	211	888	

* Cannot be calculated because saltwater does not rise to base of USDW.

the pressure measurement as the datum. These two results provide a range of heads that bracket the correct result.

CONCEPT OF HEAD RESIDUALS

In order to provide a readily understandable and easily visualized means of presenting information on the potential for flow of saltwater from a petroleum reservoir into a USDW, the concept of flow potential residuals has been adopted. A flow potential residual is defined as the arithmetic difference obtained by subtracting the measured USDW head from the calculated petroleum reservoir head. A negative residual indicates the absence of sufficient potential for upward flow from a petroleum reservoir to a USDW, while a positive residual indicates the presence of sufficient potential for such flow. A listing of the residuals from the four previous examples is shown in Table 1. From these calculations it is apparent that, in some cases, conflicting residual values can be obtained. The reasons for this are as follows:

In example 2, there in no potential for upward flow, since the two extreme residual values are both negative.

In example 3, the range of residuals is from −150 feet to 542 feet and, unless the elevation of the base of the USDW is known, the correct residual of −135 cannot be determined.

In example 4, the range of residuals is −20 feet to 692 feet. Again, unless the elevation of the base of the USDW is known, the correct residual of 15 feet cannot be determined.

In example 5, since the two extreme residuals are both positive there is potential for upward flow.

Mapping Procedures

In the examples given, both groundwater data and petroleum reservoir data have been provided from a single well or from two nearby wells. In actual geologic mapping, the groundwater data are primarily derived from water wells, and the hydrocarbon pressure data are derived from oil and gas wells. The two data sets must overlap in order to create residuals, but it is unlikely that many of the wells from the different data sets will coincide. Residuals may be created either manually, using overlays of the contour maps, or by computer. In the computer method areally identical grids are created for both sets of head data, and the grid points, not the data from individual wells, are subtracted to create the residuals.

In the manual method, both the USDW head map and the head map derived from reservoir pressure data must be hand contoured. When the maps are overlaid on a light table, the zero residual line can be found by locating the intersection of equal elevation lines from both maps (Figure 6). Positive and negative residual lines can be found by locating the intersection of head elevations from one map with those that are displaced by multiples of the contour interval on the other map (Figure 6). For example, the intersection of the 300-ft contour line in Figure 6A with the 250-ft contour line in Figure 6B locates a single positive 50-ft residual point. Additional points on the 50-ft residual line are located by identifying all points where the difference between the intersecting contour lines on the head maps is 50 feet.

SAN JUAN BASIN EXAMPLE

The San Juan basin is a nearly circular basin that covers approximately 15,000 square miles in the Four Corners Region of New Mexico (Figure 7). Most of the

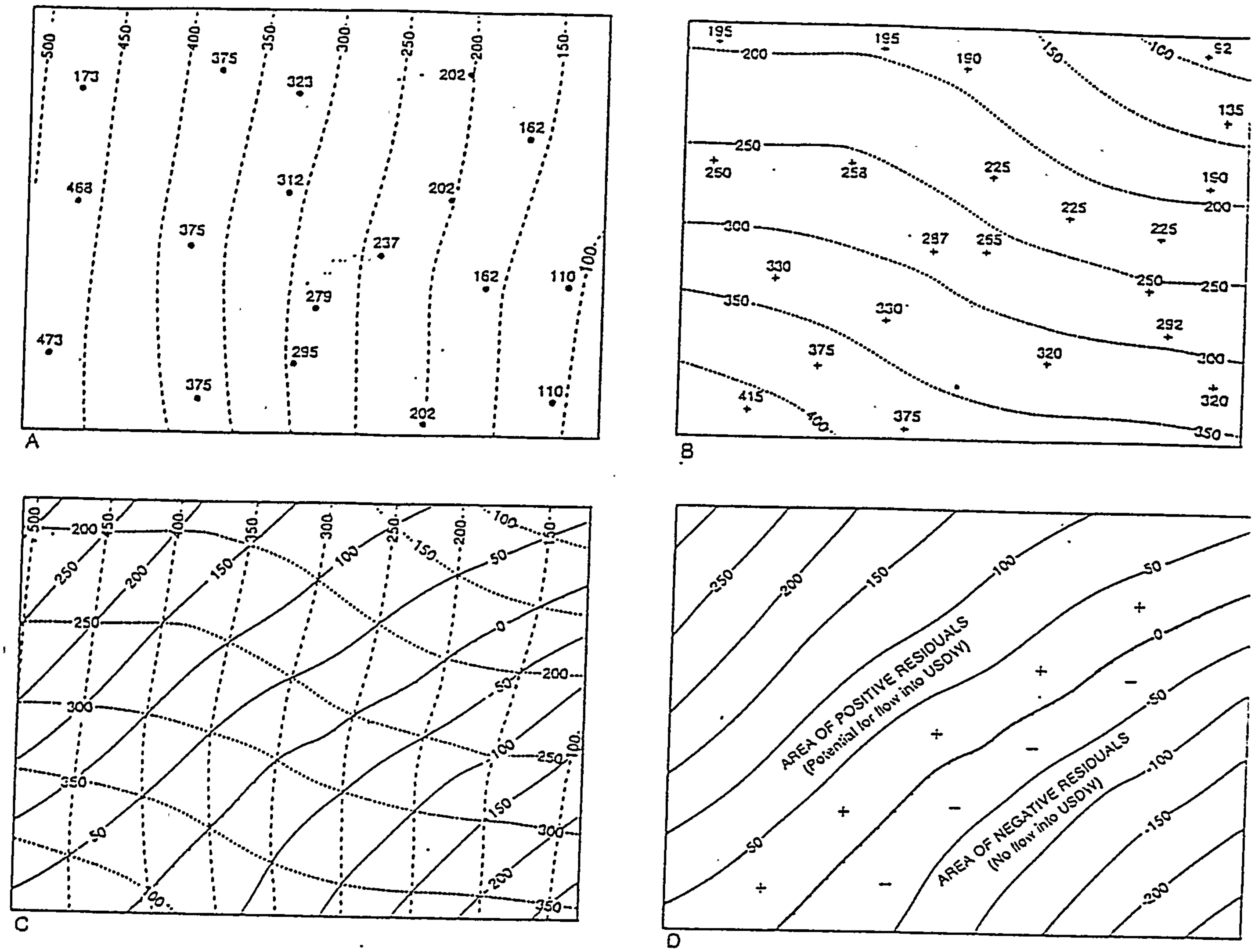

Figure 6. Sequence of hypothetical maps showing H_ts for a petroleum reservoir, H_t for a USDW, and the resulting residual found by connecting intersections. Contour interval = 50 ft. (A) Contour map of H_ts derived from reservoir pressures. (B) Contour map of USDW H_ts. (C) Contour map of residuals derived from intersections. (D) Contour map of residuals with H_ts removed.

basin is located in New Mexico, although outer margins are located in Colorado, Utah, and Arizona. The basin is an asymmetric depression (Figure 7) that formed principally during Laramide deformation (latest Cretaceous to early Tertiary time). Dips on the north flank average 8–10°, while dips on the south flank average less than 2°.

The basin contains six major USDW units. From oldest to youngest they are the Morrison Formation, Dakota Formation, Gallup Sandstone, Mesa Verde Group, Upper Cretaceous undifferentiated, and Tertiary rocks undifferentiated (Figure 7). Oil and gas production occurs from at least 11 different stratigraphic horizons, including all USDW units plus several deeper horizons. All formations dip toward the center of the basin, and all USDWs contain freshwater where they occur within approximately 2000 ft of the surface. All USDW waters become more saline toward the center of the basin, and with the exception of the Tertiary, all USDWs are comprised of an outer "doughnut-shaped" area of freshwater that grades into higher-salinity, nonpotable water toward the central part of the basin (Figure 7). The Tertiary USDW contains potable water throughout the central part of the basin.

Because of the geometry of the San Juan basin, residuals were prepared using differential comparisons between each producing horizon and all overlying USDW data. For example, the Mesa Verde residual map (Figure 8) is a comparison between Mesa Verde Group pressure heads measured against all overlying USDW head data combined (Upper Cretaceous and Tertiary).

Example of an Under-Pressured, Sink Zone

Figure 8 shows an example of a computer-generated residual map for the Mesa Verde Group of the San Juan

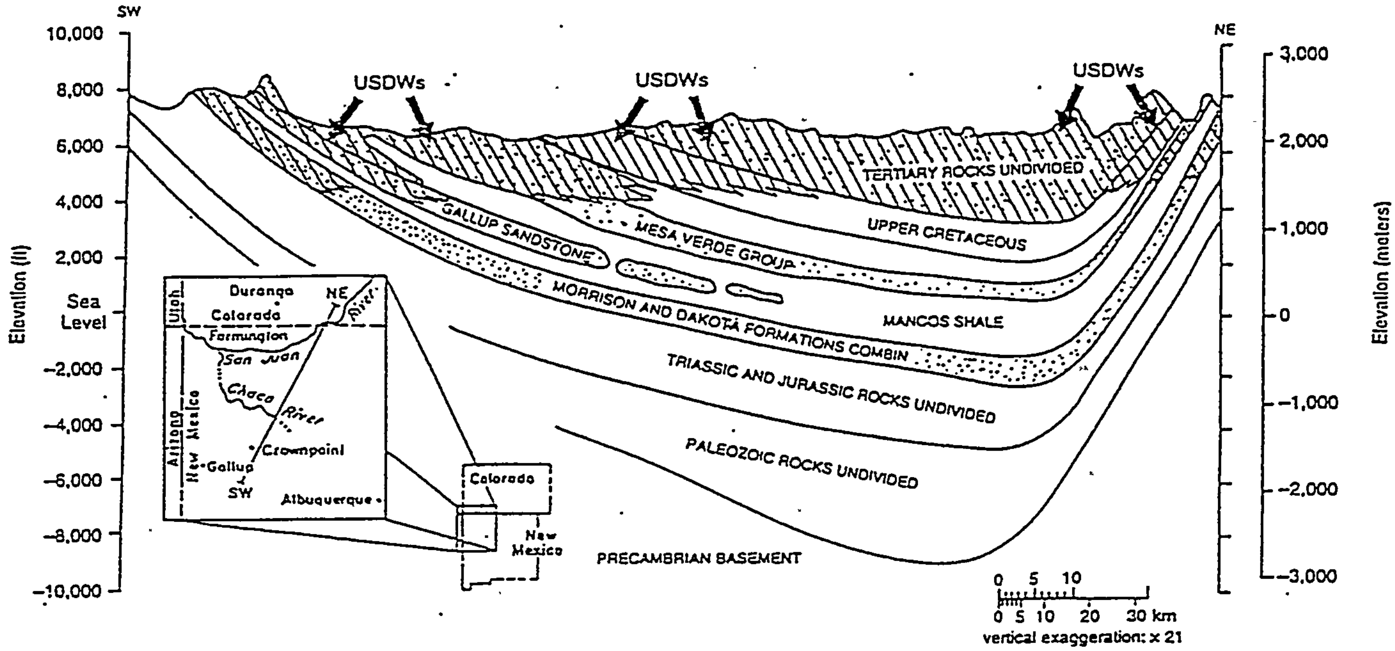

Figure 7. Generalized southwest–northeast cross section through the San Juan basin showing overall structure and near surface location of USDWs. Modified from Stone et al. (1983).

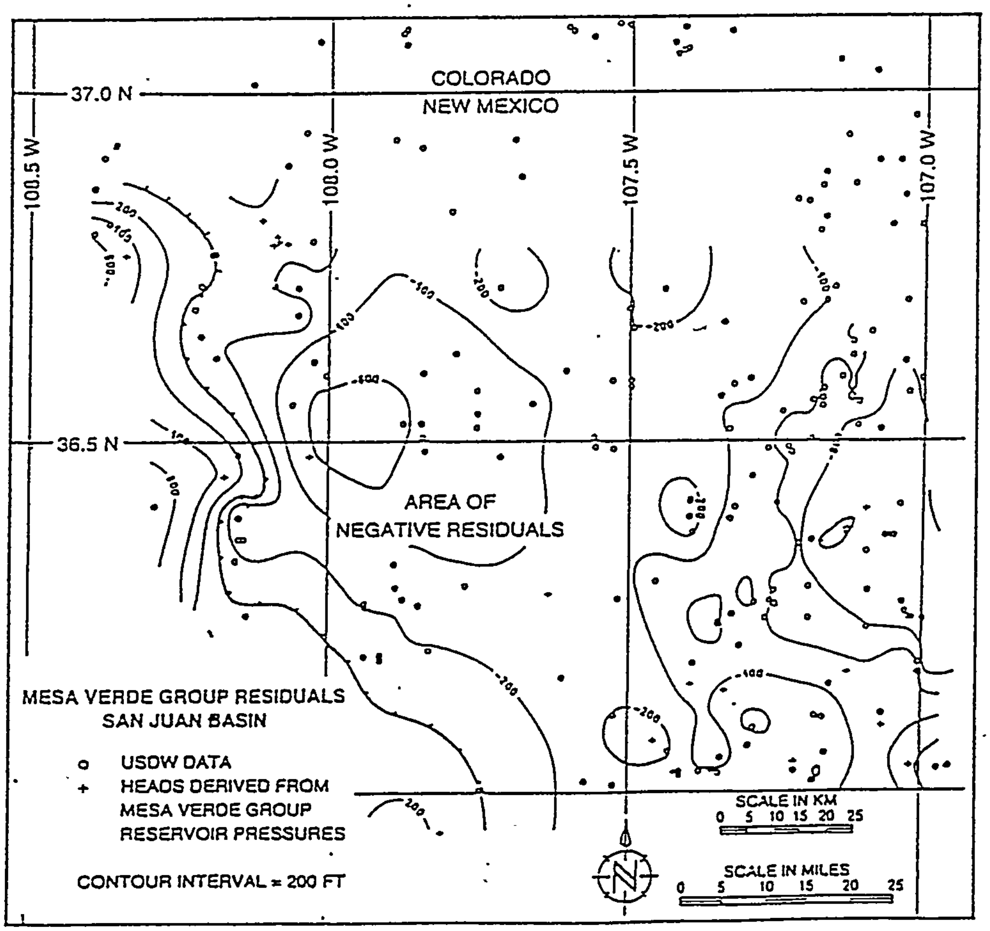

Figure 8. Contour map of residuals for the Mesa Verde Group. Note the large area of negative residuals to the east of zero line. Contour interval = 200 ft.

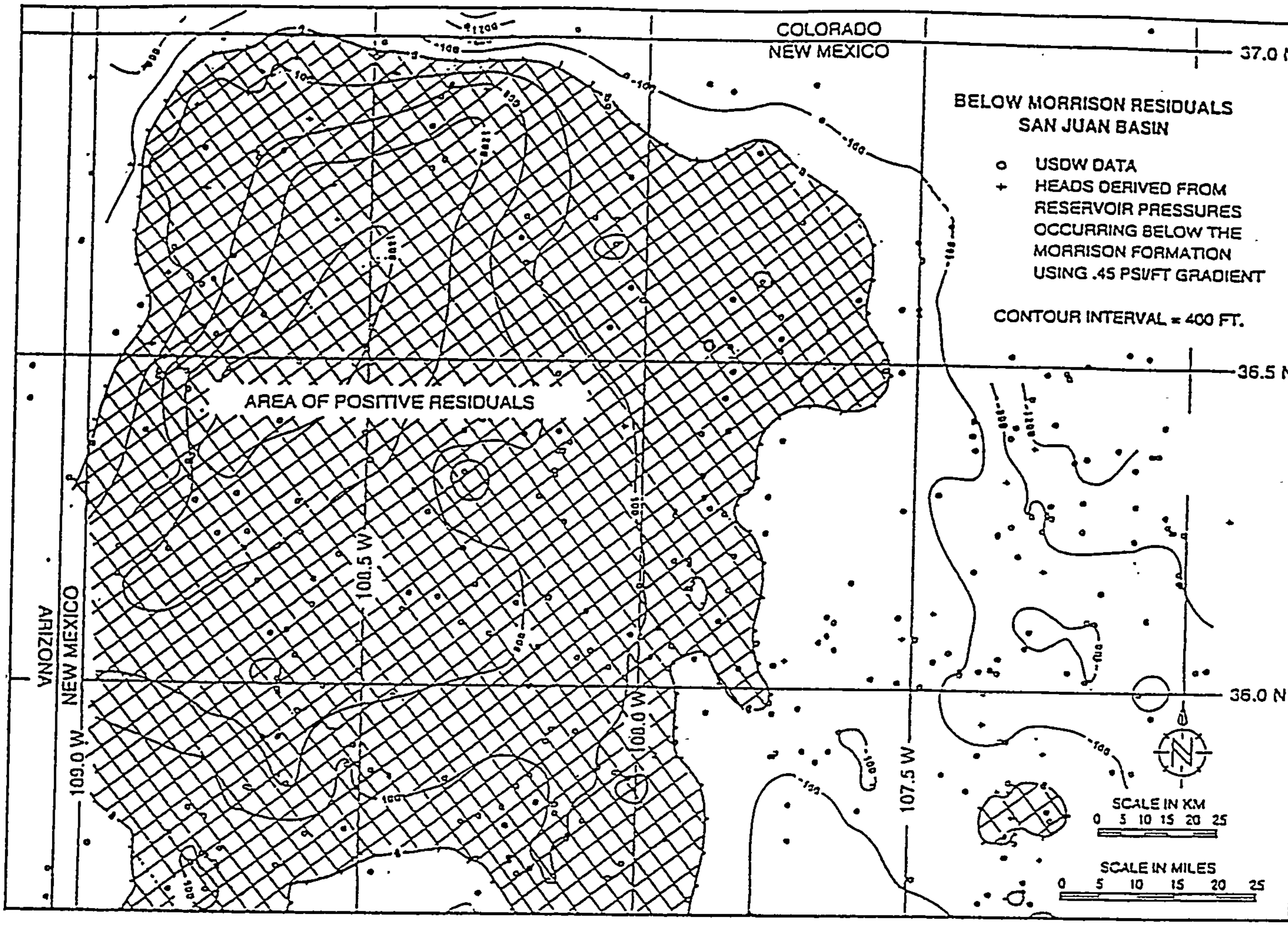

Figure 9. Contour map of residuals for all formations below the Morrison Formation. Note the large area of positive residuals (shaded area) on the west-central part of the map. Contour interval = 400 ft.

basin. This map shows a strong negative residual through the east-central part of the basin. The Mesa Verde Group has long been noted as an under-pressured geologic unit, and this residual map confirms that there is very little potential for contamination of overlying USDWs by wells that penetrate the Mesa Verde Group. Because it is under-pressured, it protects overlying USDWs from contamination by all underlying oil- and gas-producing horizons. For example, if an abandoned well were leaking an upward flowing reservoir brine from the underlying Gallup Formation, it is unlikely that the brine would ever reach the overlying USDW, because it would be diverted into the under-pressured Mesa Verde Group.

Example of an Over-Pressured Zone

Figure 9 shows the residual map for all producing horizons that occur below the Morrison Formation. These are mostly Paleozoic producers, and many of the formations are over-pressured. The USDW data are from all USDW horizons combined. The map shows a strong positive residual throughout the western part of the basin, and potential for contamination from upward fluid flow exists throughout this area. An additional part of the study was to analyze well construction and abandonment practices throughout the basin to determine the level of USDW protection provided by well casing, cement, and other flow barriers. It is interesting to note that the total potential for contamination (combination of fluid flow and mechanics) in this area is very low because of the USDW protection in the form of extra casing strings and cement present in all analyzed deep holes throughout this area.

Some Observations About Computer-Generated Residual Maps

Several important observations have been made in creating computer-generated residual maps in the San Juan basin.

1. Edge effects should be examined very carefully. Computers respond to mathematical algorithms that intentionally extrapolate into sparse or no data areas. These mathematical extrapolations can result

in unreasonable effects, particularly near the edges of maps where data are sparse. These perturbations can show up as false residuals.

2. Residual maps are very sensitive to heads derived from reservoir pressures. Small reservoir pressure errors can result in large head errors. Reservoir pressures derived from surface shut-in pressures were considered especially unreliable and were not used.
3. Reservoir pressures vary with time from first production. Depleted or partially depleted oil or gas reservoirs commonly appear to be under-pressured. Maximum reservoir pressures were used in an attempt to identify virgin reservoir pressures under the assumption that, on abandonment, all reservoirs will eventually return to initial or near-initial pressure conditions.
4. All data, and especially pressure data, must be edited very carefully. Areas that look like strong positive or negative residuals on contour maps commonly occur near bad data points or in areas where very closely spaced data create strong gradients. While strong positive or negative residuals may be caused by true anomalies and may be important, they should be analyzed critically to be certain that they make geologic sense.

CONCLUSIONS

1. A procedure has been developed for obtaining a variance to the area of review (AOR) procedure for certain Class II (saltwater disposal and secondary recovery) injection wells.
2. A variance could be obtained by using any one or a combination of four criteria. One method involves a procedure whereby oil and gas reservoirs can be shown to be under-pressured relative to underground sources of drinking water (USDWs).
3. The procedure involves creating head maps for both the USDW and the petroleum reservoir. The USDW head values are then subtracted from the petroleum reservoir heads either manually or by computer to create difference or residual maps. A positive residual implies potential for flow from the petroleum reservoir to the USDW. A negative residual implies no potential for flow from the petroleum reservoir to the USDW.
4. A negative residual, by itself, does not automatically qualify an area for an AOR variance. To qualify for a variance, bottom hole pressures during injection must be maintained such that positive residuals are not created.
5. The creation of residual maps may also identify thief or pressure sink zones that may protect USDWs from contamination by upward flowing water from petroleum reservoirs.
6. The creation of residual maps also identifies areas of potential contamination of USDWs from upward flow of water through abandoned petroleum wells.

ACKNOWLEDGMENTS

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APPENDIX 3

FESCO Pressure Transient Analysis for Everett-Lake No. 5

FESCO, Inc.
Petroleum Engineers

1408 EAST MAIN ST. • 512 664-3479 • ALICE, TEXAS 78332-3998

BEAUMONT..............409 842-3000
BRYAN.....................409 775-1825
CORPUS CHRISTI........512 882-4124
EL CAMPO................409 543-9451
HOUSTON SALES........713 995-0044
KILGORE...................903 984-4814
LAREDO....................210 724-7501
McALLEN...................210 686-7671
OZONA.....................915 392-3773
REFUGIO...................512 526-4644
VICTORIA..................512 575-7533

January 18, 1995

East Texas Salt Water Disposal
1209 Industrial
Kilgore, Texas 75662

Attention: Mr. Jerry Adams

Re: **Pressure Transient Analysis**
Everett-Lake No. 5

Gentlemen:

Enclosed are the results of the pressure transient analysis on the subject well located in the East Texas (Woodbine) field in Upshur County, Texas. FESCO, Inc. conducted a 24.5 hour injection test followed by a 45.7 hour falloff test 01/03 - 01/06/95. Bottomhole pressure data was obtained with an electronic strain gauge. The well is a water disposal well for produced water and is completed open hole with a 100 foot injection interval. The well had been shut-in for approximately six days prior to the injection test. The injection rate during the injection test was 16,990 B/D.

24.5 Hour Injection Test (01/03 - 01/04/95)

An initial log-log plot was generated in Figure No. 1 to identify flow regimes. A very short wellbore storage period (unit slope data) exists prior to the beginning of the radial flow middle-time region (MTR). The MTR is identified by a zero slope on the pressure derivative curve. The "noisy" derivative data is probably due to insufficient gauge pressure resolution.

A semilog analysis was conducted in Figure No. 2. A line was drawn through the data corresponding to the MTR as determined from Figure No. 1 A permeability to water of 2425 md and a skin factor of 53 were calculated from the slope of the MTR line. An injection efficiency of 16.14% was calculated from the skin factor. No conclusive boundaries were encountered within the injection test radius of investigation (+/- 6474 feet). It should be noted that very small changes in the MTR slope produce large changes in the calculated permeability to water.

A homogeneous reservoir type curve analysis was conducted in Figure No. 3. A fair match of the data on the family of wellbore storage with skin type curves indicated a permeability to water of 2425 md and a skin factor of 53. A specific type curve was generated in Figure No. 4.

45.7 Hour Falloff Test (01/04 - 01/06/95)

An initial log-log plot was generated in Figure No. 1 to identify flow regimes. The early time data is distorted by wellbore storage effects (unit slope data). A transition period follows prior to the beginning of the radial flow middle-time region (MTR). The late time slope increase on the derivative curve may be due to boundary effects or interference from another injection well.

A semilog analysis was conducted in Figure No. 2. A line was drawn through the MTR data as determined from Figure No. 1. A permeability to water of 2425 md and a skin factor of 134 were calculated based on an estimated injection rate of 3200 B/D. An unrealistic permeability to water was obtained using an injection rate of 16,900 B/D in the calculations. Apparently a gradual decrease in injection occurred due to the injection being shut-in at the pumps and not at the wellhead. The late time slope increase could be due to boundary effects or interference from another injection well.

A homogeneous reservoir type curve analysis was conducted in Figure No. 3. A fair match of the data on the family of wellbore storage with skin type curves indicated a permeability to water of 2425 md and a skin factor of 134. A specific type curve was generated in Figure No. 4.

In conclusion, the pressure transient analysis on the Everett-Lake No. 5 well indicates good permeability (2425 md) with possible extensive wellbore damage. The difference in skin factors between the injection (s = 53) and falloff (s = 134) tests could not be explained. The positive skin factor is due to wellbore damage and/or turbulence at the sandface. Two tests must be conducted at different injection rates to determine the skin factor due to wellbore damage. A plot of skin factor versus injection rate is extrapolated to zero injection rate to determine the actual skin due to damage. Permeability estimates could be better defined by using a pressure gauge with better resolution.

FESCO, Inc. appreciates the opportunity to work for East Texas Salt Water Disposal. Please call me at 1-800-375-4814 if you have any questions regarding this analysis.

Thank you.

Yours very truly,

FESCO, Inc.

Bobby P. Davis, rr

Bobby P. Davis
Petroleum Engineer
Kilgore, Texas

BPD/rr

FESCO, Inc.
Petroleum Engineers

PRESSURE TRANSIENT ANALYSIS

Company.................:	East Texas Salt Water Disposal
Well....................:	Everett-Lake No. 5
Field...................:	East Texas (Woodbine)
Test Date...............:	01/03-01/04/95
Test Type...............:	24.5 Hour Injection Test
Analyst Name............:	Bobby P. Davis
Formation...............:	Woodbine
Gauge Type..............:	McAllister
Gauge Serial Number.....:	080-0473
Gauge Depth - Measured..:	3635 ft
Reservoir Datum ....:	3703 ft.
Perforated Interval.....:	Open Hole (3652 - 3754 ft)

East Texas Salt Water Disposal
Everett-Lake No. 5
January 17, 1995
Page 1

TEST PARAMETERS

Test type - Constant rate injection test

Flow rate at surface (q)................	-16990.0000 STB/day
Reservoir initial pressure (Pi).........	1413.5100 psia
Total flowing time......................	24.5200 hr
Time when t=0...........................	0.0125 hr

RESERVOIR CONSTANTS

Formation thickness (h)..................:	102.0000 ft
Average formation porosity (0)..........:	0.2000
Well radius (rw)........................:	0.2813 ft
Water saturation (Sw)...................:	1.0000
Gas saturation (Sg).................... :	0.0000

PRODUCED FLUID PROPERTIES

Oil gravity.............................:	0.0000 API
Gas gravity.............................:	0.0000 sp grav
Produced gas-oil ratio..................:	0.0000 scf/STB
Produced WOR.......................... :	0.0000
Water salinity..........................:	90000.0000 ppm

FLUID PROPERTIES AT :

Average pressure........................:	1711.7900 psia
Temperature (T).........................:	93.0000 deg F

CORRELATIONS........: Bo,Pb,Rs : Not Used
Oil viscosity : Not Used

Solution gas-oil ratio..................:	0.0000 scf/STB
Bubble-point pressure (Pb)..............:	0.0000 psia
Oil density.............................:	0.0000 lb/ft3
Water density...........................:	66.1010 lb/ft3
Gas density.............................:	0.0000 lb/ft3

	FVF (V / V)	VISCOSITY		COMPRESSIBILITY
OIL...:	Bo.: 0.000 RB/STB	Uo.: 0.0000 cp		Co.:0.00E-00 psi-1
WATER.:	Bw.: 1.004 RB/STB	Uw.: 0.9633 cp		Cw.:2.54E-06 psi-1
GAS...:	Bg.:0.000000 ft3/scf	Ug.: 0.0000 cp		Cg.:0.00E-00 psi-1
			ROCK	Cf.:3.65E-06 psi-1
			TOTAL	Ct.:6.19E-06 psi-1

RESULTS FROM LOG-LOG ANALYSIS

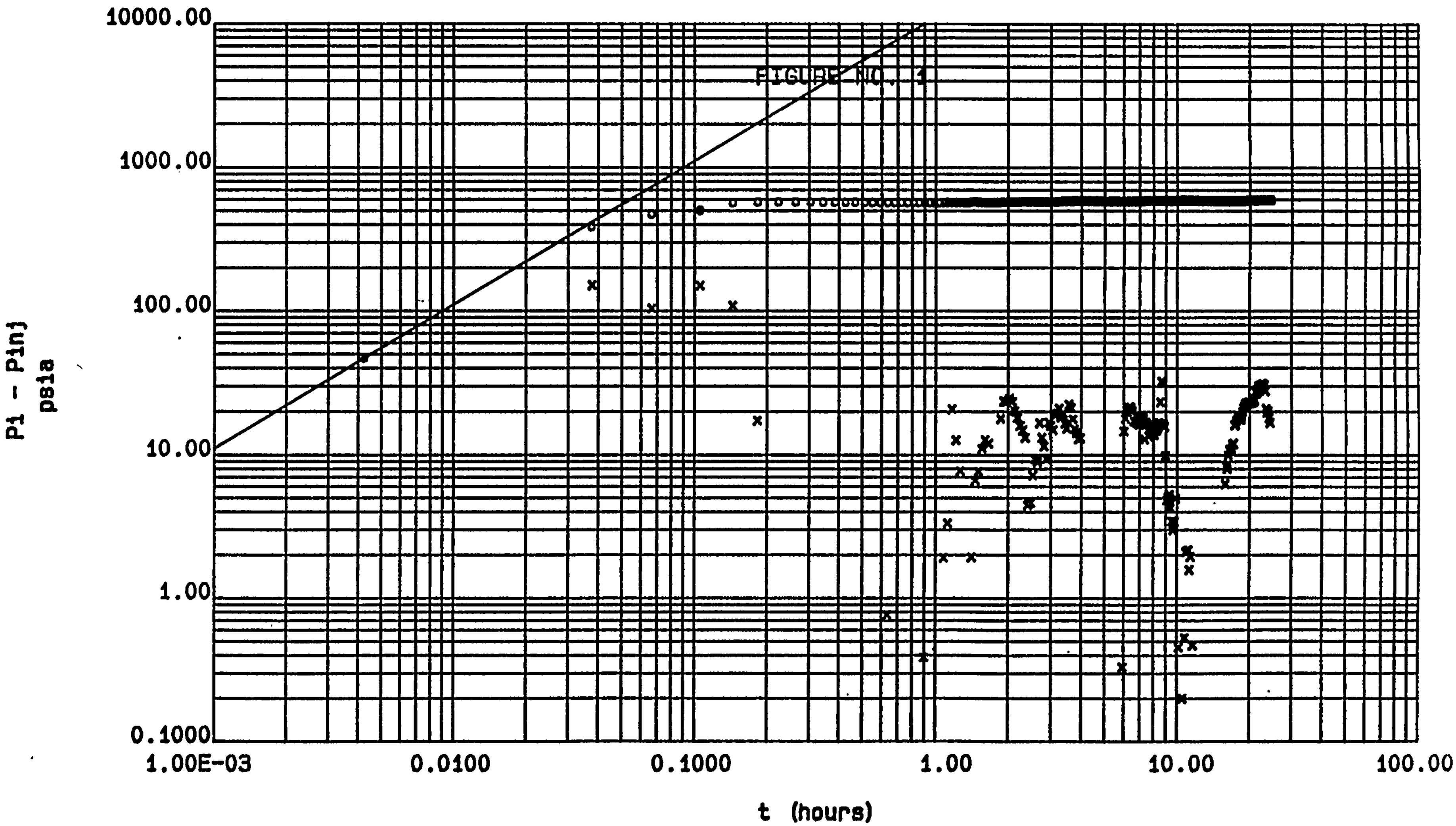
(FIGURE NO. 1)

Line :

Intercept...............................:	11099.0712
Slope...................................:	1.0000
Wellbore storage coefficient (C)........:	0.0640 bbl/psi
Dim. wellbore storage constant (Cd)....:	5729.3632

FESCO, INC. - LOG-LOG PLOT

File..................:	ET1.OIL	Test Date..............:	01/03-01/04/95	Slope........:	1.000
Company.................:	East Texas Salt Water Disposal	Test Type..............:	24 Hour Injection Test	Intercept....:	4.045
Well....................:	Everett-Lake No. 5	Analyst Name...........:	Bobby P. Davis	C(Storage)...:	0.0640
Field...................:	East Texas (Woodbine)	Formation..............:	Woodbine	CD(Storage)..:	5729.363



RESULTS FROM SEMILOG ANALYSIS

(FIGURE NO. 2)

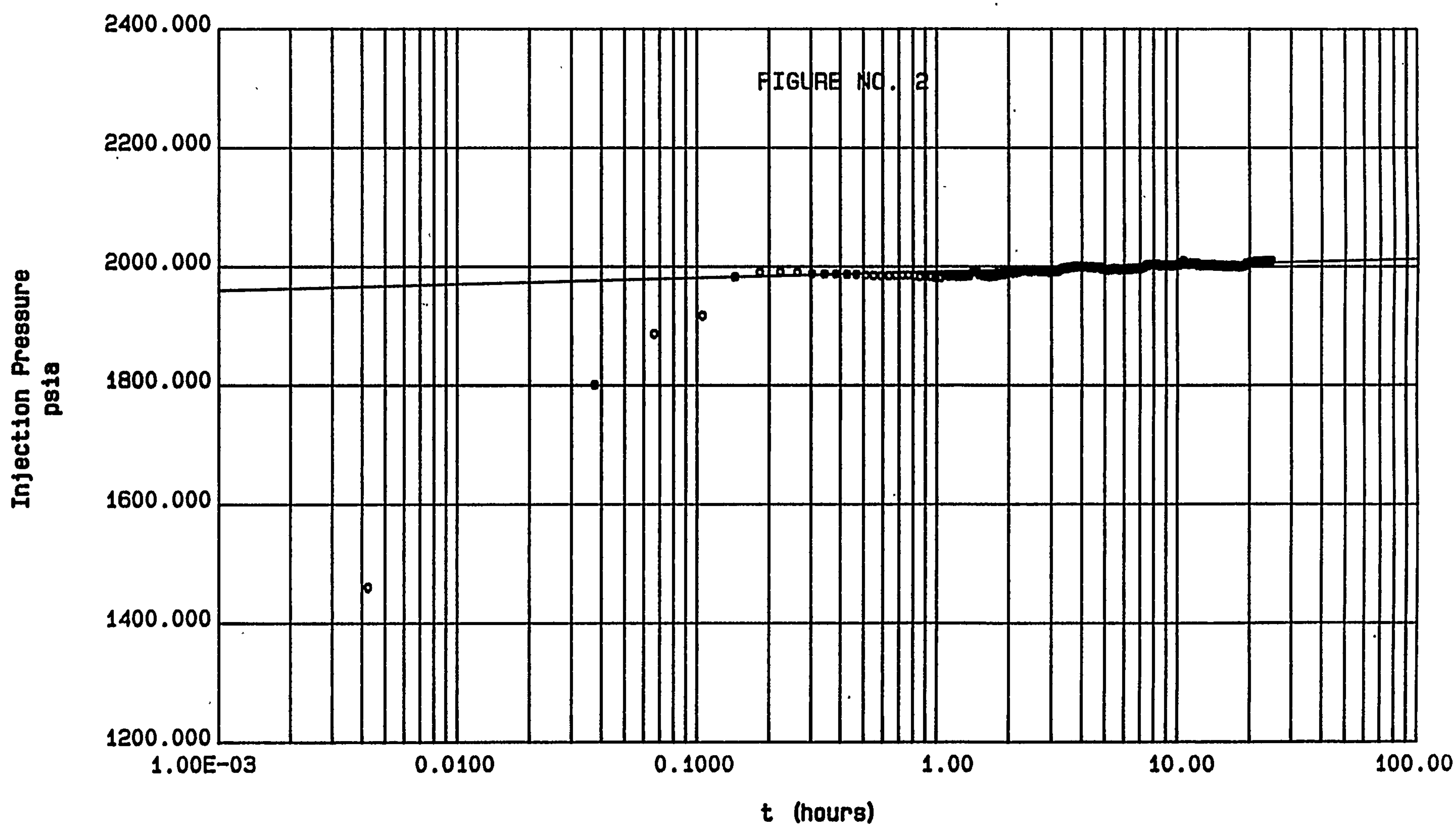
Line :

Intercept......................:	1991.335	
Slope..........................:	10.800	
Start of line..................:(	0.0000 ,	0.0000)
End of line....................:(	0.0000 ,	0.0000)
Coefficient of determination....:	0.0000	
Number of points................:	0	

Pressure at dt = 1 hour.................:	1991.3353	psia
Permeability-thickness (kh).............:	247379.3593	md.ft
Effective permeability to water (Kw)....:	2425.2878	md
Total skin factor (S)...................:	53.3389	
dP skin (constant rate).................:	-500.2696	psi
Radius of investigation.................:	6474.3735	ft
Flow efficiency.........................:	0.1614	

FESCO, INC. - SEMILOG PLOT

File....................:	ET1.OIL	Test Date...............:	01/03-01/04/95	Slope........:	10.800
Company.................:	East Texas Salt Water Disposal	Test Type...............:	24 Hour Injection Test	Intercept....:	1991.335
Well....................:	Everett-Lake No. 5	Analyst Name............:	Bobby P. Davis	Permeability.:	2425.288
Field...................:	East Texas (Woodbine)	Formation...............:	Woodbine	Skin.........:	53.339



RESULTS FROM A HOMOGENEOUS RESERVOIR TYPE-CURVE MATCH

(FIGURE NO. 3 - WELLBORE STORAGE ANALYSIS)

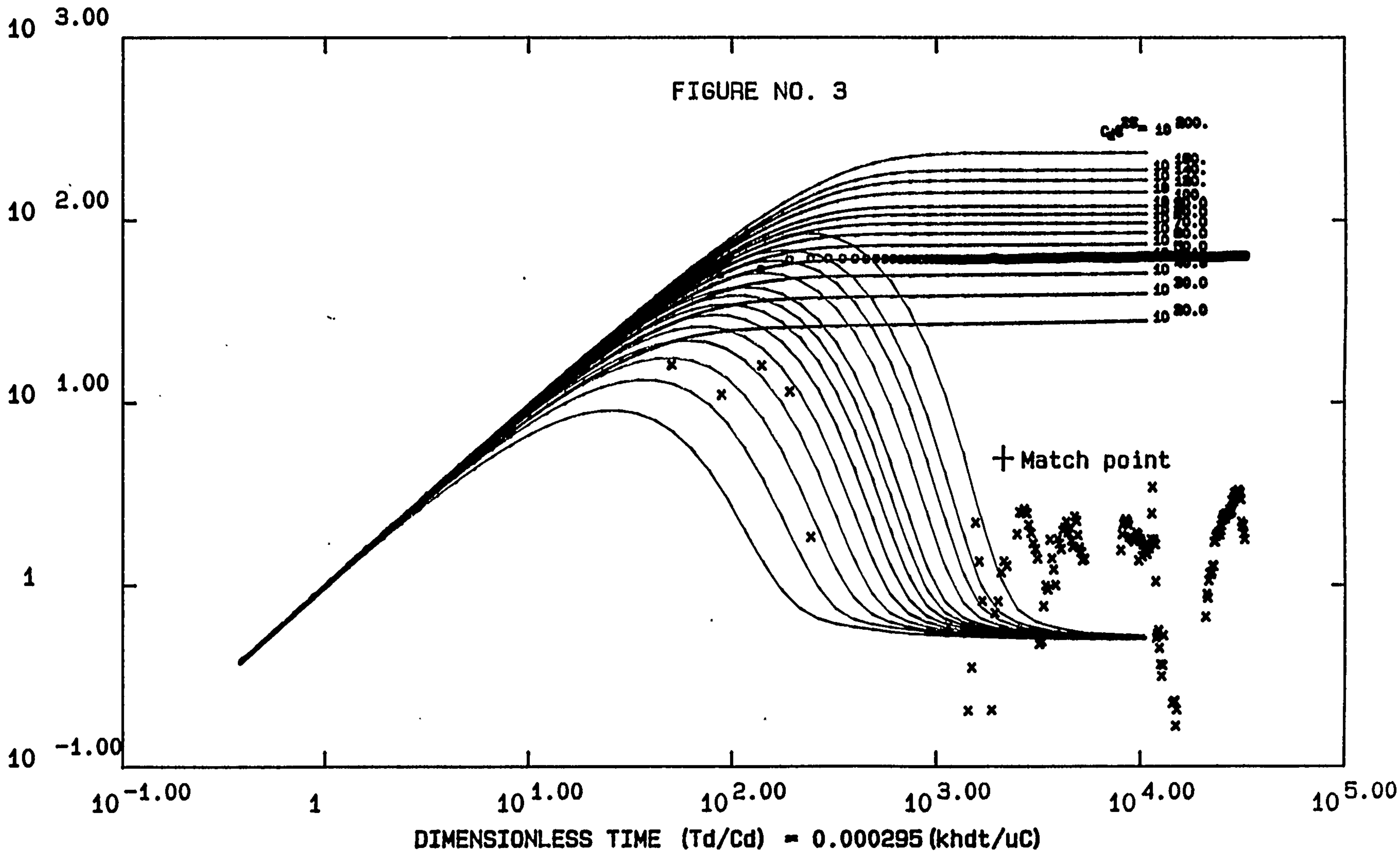
Data plotted using Real Elapsed Time

Dim. pressure match point Pd(match)....:	4.9482	
Dim. time match point Td/Cd(match).....:	2091.7644	
Matched curve Cde2S(match).............:	1.000E+50	
Pressure match point dP(match).........:	46.4159	
Time match point dt(match).............:	1.5849	
Permeability-thickness (kh).............:	247343.7812	md.ft
Permeability (k).......................:	2424.9389	md
Wellbore storage coefficient (C)........:	0.0574	bbl/psi
Dim. wellbore storage constant (Cd)....:	5132.5302	
Radius of investigation.................:	6473.9077	ft
dP skin (constant rate).................:	-499.9103	psi
Skin factor (S)........................:	53.2929	

FESCO, INC. - HOMOGENEOUS RESERVOIR TYPE CURVE PLOT

File	ET1.OIL	Test Date	01/03-01/04/95	Pd(match)	4.948	dp(match)	46.416
Company	East Texas Salt Water Disposal	Test Type	24 Hour Injection Test	Td(match)	2091.764	dt(match)	1.585
Well	Everett-Lake No. 5	Analyst Name	Bobby P. Davis	Permeability	2424.939	dp(skin)	-499.910
Field	East Texas (Woodbine)	Formation	Woodbine	Skin	53.293	C(Storage)	6473.908

Data plotted using Real Elapsed Time



RESULTS FROM A HOMOGENEOUS RESERVOIR TYPE-CURVE MATCH

(FIGURE NO. 4 - WELLBORE STORAGE ANALYSIS)

Data plotted using Real Elapsed Time

Dim. pressure match point Pd(match)....:	4.9482
Dim. time match point Td/Cd(match).....:	3025.8762
Matched curve Cde2S(match).............:	7.738E+48
Pressure match point dP(match).........:	46.4159
Time match point dt(match).............:	1.5849

Permeability-thickness (kh).............:	247343.7656 md.ft
Permeability (k)........................:	2424.9389 md
Wellbore storage coefficient (C)........:	0.0397 bbl/psi
Dim. wellbore storage constant (Cd)....:	3548.0778
Radius of investigation.................:	6473.9077 ft
dP skin (constant rate).................:	-489.6395 psi
Skin factor (S).........................:	52.1980

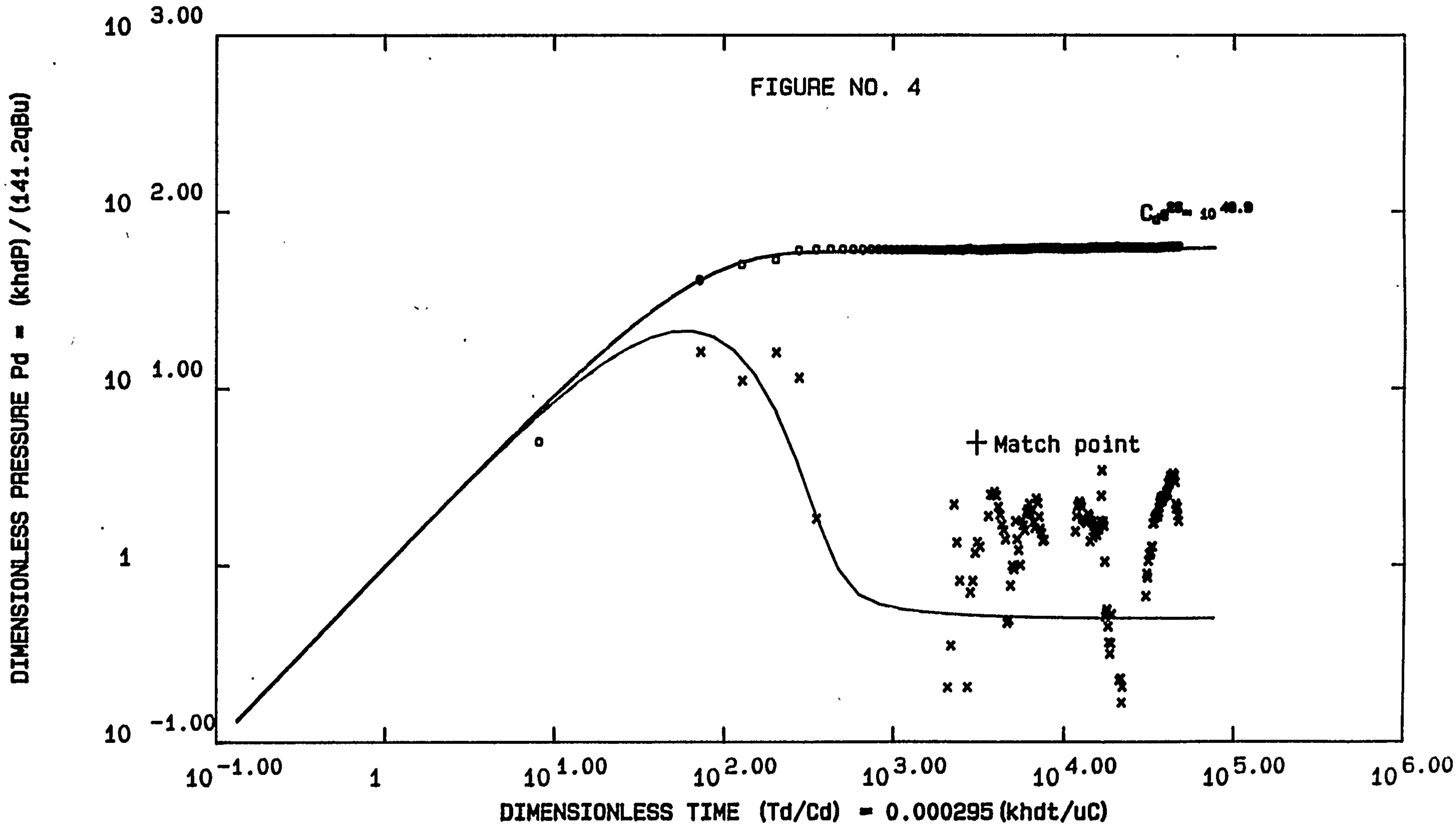
PARAMETER OPTIMISATION - STATISTICAL SUMMARY

Parameter	Optimised Estimate	95% confidence interval (+/-)	Percent (+/-)
K	2424.9389	624.0927 md	26.0975
Cd	3548.0778	68.7128	1.9375
Skin	52.1980	14.3109	27.4164

Goodness of match 5.6504 psi

FESCO, INC. - HOMOGENEOUS RESERVOIR TYPE CURVE PLOT

File..................:	ET1.OIL	Test Date..............:	01/03-01/04/95	Pd(match)....:	4.948	dp(match)..:	46.416
Company..................:	East Texas Salt Water Disposal	Test Type..............:	24 Hour Injection Test	Td(match)....:	3025.876	dt(match)..:	1.585
Well..................:	Everett-Lake No. 5	Analyst Name...........:	Bobby P. Davis	Permeability.:	2424.939	dp(skin)...:	-489.640
Field..................:	East Texas (Woodbine)	Formation..............:	Woodbine	Skin.........:	52.198	C(Storage).:	6473.908



TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
1.	0.0000	1413.5100
2.	0.0167	1460.7398
3.	0.0500	1800.7297
4.	0.0789	1886.6700
5.	0.1178	1917.1799
6.	0.1567	1982.4797
7.	0.1956	1990.3000
8.	0.2356	1991.1899
9.	0.2756	1990.1500
10.	0.3156	1988.4898
11.	0.3556	1987.8800
12.	0.3967	1988.0500
13.	0.4378	1987.4399
14.	0.4789	1987.5898
15.	0.5211	1985.8900
16.	0.5623	1985.0300
17.	0.6045	1984.6400
18.	0.6478	1984.4200
19.	0.6911	1985.0200
20.	0.7345	1985.3900
21.	0.7778	1985.7099
22.	0.8211	1983.9000
23.	0.8656	1983.0799
24.	0.9111	1983.1600
25.	0.9556	1983.2900
26.	1.0011	1981.1899
27.	1.0467	1981.2700
28.	1.0934	1984.8800
29.	1.1389	1983.7299
30.	1.1856	1984.1700
31.	1.2334	1983.2199
32.	1.2811	1983.1099
33.	1.3289	1983.6999
34.	1.3767	1984.5400
35.	1.4256	1990.6799
36.	1.4745	1993.5000
37.	1.5234	1986.5599
38.	1.5734	1984.4200
39.	1.6234	1983.2299
40.	1.6745	1982.6400
41.	1.7256	1984.4699
42.	1.7767	1984.8599
43.	1.8278	1985.5000
44.	1.8800	1986.4899
45.	1.9323	1987.6799
46.	1.9856	1988.8699
47.	2.0389	1989.3099
48.	2.0923	1989.3099
49.	2.1467	1989.3099
50.	2.2011	1990.3000

TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
51.	2.2567	1992.2800
52.	2.3111	1993.9100
53.	2.3678	1994.0999
54.	2.4234	1992.7199
55.	2.4800	1992.3199
56.	2.5378	1993.5100
57.	2.5945	1992.5200
58.	2.6534	1992.3199
59.	2.7111	1992.3199
60.	2.7700	1992.3599
61.	2.8300	1992.7600
62.	2.8900	1993.1500
63.	2.9500	1990.7299
64.	3.0100	1991.1700
65.	3.0723	1992.1600
66.	3.1334	1992.7600
67.	3.1956	1992.7600
68.	3.2578	1993.7500
69.	3.3211	1997.1199
70.	3.3845	1997.5100
71.	3.4489	1998.3499
72.	3.5134	1997.7099
73.	3.5789	1999.1400
74.	3.6445	1998.3499
75.	3.7100	2000.1300
76.	3.7767	2000.1300
77.	3.8445	2000.5300
78.	3.9111	2000.3299
79.	3.9800	2000.7299
80.	4.0489	1999.7399
81.	4.1178	2000.1300
82.	4.1889	1999.3399
83.	4.2578	1999.1400
84.	4.3289	1999.1400
85.	4.4000	1999.1400
86.	4.4734	1999.1400
87.	4.5445	1998.7900
88.	4.6178	1998.5899
89.	4.6911	1998.7900
90.	4.7645	1998.1500
91.	4.8400	1999.1400
92.	4.9156	1995.1799
93.	4.9911	1995.5699
94.	5.0689	1994.1400
95.	5.1445	1994.5400
96.	5.2223	1994.9799
97.	5.3000	1995.3800
98.	5.3800	1995.7700
99.	5.4600	1996.3699
100.	5.5400	1996.7600

TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
101.	5.6200	1995.1799
102.	5.7000	1995.3800
103.	5.7823	1995.3800
104.	5.8645	1994.9799
105.	5.9489	1994.7800
106.	6.0334	1996.3699
107.	6.1178	1995.1799
108.	6.2023	1995.5699
109.	6.2889	1996.7600
110.	6.3734	1995.5300
111.	6.4623	1996.1300
112.	6.5489	1996.9200
113.	6.6378	1996.9200
114.	6.7267	1997.1199
115.	6.8178	1997.1199
116.	6.9067	1996.9200
117.	6.9978	1996.5200
118.	7.0911	1996.9200
119.	7.1823	1998.2700
120.	7.2756	1999.0599
121.	7.3711	2001.0400
122.	7.4645	2002.6300
123.	7.5600	2002.1899
124.	7.6578	2002.8199
125.	7.7534	2003.3800
126.	7.8511	2003.5699
127.	7.9511	2003.5699
128.	8.0489	2003.1799
129.	8.1500	2003.5699
130.	8.2523	2003.9699
131.	8.3545	2001.9899
132.	8.4567	2001.9899
133.	8.5589	2001.9499
134.	8.6611	2002.1899
135.	8.7678	2002.3399
136.	8.8745	2001.9499
137.	8.9811	2001.5500
138.	9.0878	2001.9499
139.	9.1945	2002.0999
140.	9.3011	2002.1500
141.	9.4123	2001.7500
142.	9.5234	2001.5500
143.	9.6345	2001.5100
144.	9.7456	2002.3399
145.	9.8611	2002.7399
146.	9.9723	2003.1400
147.	10.0878	2003.3399
148.	10.2034	2003.4899
149.	10.3234	2003.7299
150.	10.4389	2005.8699

TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
151.	10.5589	2009.8299
152.	10.6745	2004.8800
153.	10.7945	2005.2800
154.	10.9189	2004.8800
155.	11.0389	2004.4799
156.	11.1634	2004.3299
157.	11.2878	2004.3299
158.	11.4123	2005.1199
159.	11.5367	2005.3199
160.	11.6656	2004.7199
161.	11.7945	2004.7199
162.	11.9234	2004.9200
163.	12.0523	2005.1600
164.	12.1878	2002.0599
165.	12.3211	2002.2199
166.	12.4545	2002.1799
167.	12.5878	2001.9799
168.	12.7211	2001.7800
169.	12.8545	2002.3800
170.	12.9878	2002.1799
171.	13.1378	2002.1400
172.	13.2711	2002.3800
173.	13.4045	2002.5699
174.	13.5545	2002.5699
175.	13.6878	2002.7700
176.	13.8378	2002.7700
177.	13.9878	2002.9699
178.	14.1378	2001.7800
179.	14.2711	2001.7800
180.	14.4211	2001.3399
181.	14.5711	2001.3399
182.	14.7211	2001.3399
183.	14.8711	2001.3399
184.	15.0211	2001.6999
185.	15.1878	2001.5400
186.	15.3378	2000.9100
187.	15.4878	2000.7099
188.	15.6545	2000.5100
189.	15.8045	2000.5100
190.	15.9711	2001.2600
191.	16.1211	2000.8199
192.	16.2878	2000.6199
193.	16.4545	2000.8199
194.	16.6211	2000.9799
195.	16.7878	2000.8199
196.	16.9545	2001.5699
197.	17.1211	2001.5699
198.	17.2878	2000.7800
199.	17.4545	2000.9799
200.	17.6378	2000.3399

TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
201.	17.8045	1999.9499
202.	17.9878	1999.9100
203.	18.1545	2000.1400
204.	18.3378	2000.0999
205.	18.5211	2000.1400
206.	18.7045	2000.7399
207.	18.8878	2000.5400
208.	19.0711	2001.6899
209.	19.2545	2004.6899
210.	19.4378	2005.4599
211.	19.6211	2005.1199
212.	19.8045	2006.0300
213.	20.0045	2006.5699
214.	20.1878	2006.8000
215.	20.3878	2006.9899
216.	20.5878	2007.3000
217.	20.7711	2007.6099
218.	20.9711	2007.8499
219.	21.1711	2008.4100
220.	21.3711	2008.4100
221.	21.5878	2008.3698
222.	21.7878	2008.6097
223.	21.9878	2008.6097
224.	22.2045	2008.8000
225.	22.4045	2008.8497
226.	22.6211	2009.0898
227.	22.8378	2008.9299
228.	23.0378	2009.1700
229.	23.2545	2009.2500
230.	23.4711	2009.5400
231.	23.6878	2009.8199
232.	23.9211	2009.6600
233.	24.1378	2009.7500
234.	24.3545	2009.7900
235.	24.5211	2010.0699

FESCO, Inc.
Petroleum Engineers

PRESSURE TRANSIENT ANALYSIS

Company.................:	East Texas Salt Water Disposal
Well....................:	Everett-Lake No. 5
Field...................:	East Texas (Woodbine)
Test Date...............:	01/04-01/06/95
Test Type...............:	45.65 Hour Falloff Test
Analyst Name............:	Bobby P. Davis
Formation...............:	Woodbine
Gauge Type..............:	McAllister Electronic
Gauge Serial Number.....:	080-0473
Gauge Depth - Measured..:	3635 ft.
Reservoir Datum ....:	3703 ft.
Perforated Interval.....:	Open Hole (3652 - 3754 ft)

TEST PARAMETERS

Test type - Constant rate falloff test

Flow rate at surface (q)................	-3200.0000 STB/day
Pressure prior to shut-in (p(dt=0)).....	1669.7600 psia
Time when dt=0.........................	0.0400 hr
Equivalent production time (Tp).........	25.4200 hr

RESERVOIR CONSTANTS

Formation thickness (h)..................:	102.000 ft
Average formation porosity (0)..........:	0.2000
Well radius (rw)........................:	0.2813 ft
Water saturation (Sw)...................:	1.000
Gas saturation (Sg).................... :	0.0000

PRODUCED FLUID PROPERTIES

Oil gravity.............................:	0.0000 API
Gas gravity.............................:	0.0000 sp grav
Produced gas-oil ratio..................:	0.0000 scf/STB
Produced WOR.......................... :	0.0000
Water salinity..........................:	90000.000 ppm

FLUID PROPERTIES AT :

Average pressure......................:	1543.710 psia
Temperature (T)..........................:	93.000 deg F

CORRELATIONS........: Bo,Pb,Rs :NOT USED
Oil viscosity :NOT USED

Solution gas-oil ratio..................:	0.0000 scf/STB
Bubble-point pressure (Pb)..............:	0.0000 psia
Oil density.............................:	0.0000 lb/ft3
Water density...........................:	66.090 lb/ft3
Gas density.............................:	0.0000 lb/ft3

	FVF (V / V)		VISCOSITY			COMPRESSIBILITY
OIL...:	Bo.:	0.000 RB/STB	Uo.:	0.0000 cp		Co.: 0.0000 psi-1
WATER.:	Bw.:	1.0040 RB/STB	Uw.:	0.9633 cp		Cw.:2.55E-06 psi-1
GAS...:	Bg.:	0.0000 ft3/scf	Ug.:	0.0000 cp		Cg.: 0.0000 psi-1
					ROCK	Cf.:3.65E-06 psi-1
					TOTAL	Ct.:6.20E-06 psi-1

RESULTS FROM LOG-LOG ANALYSIS

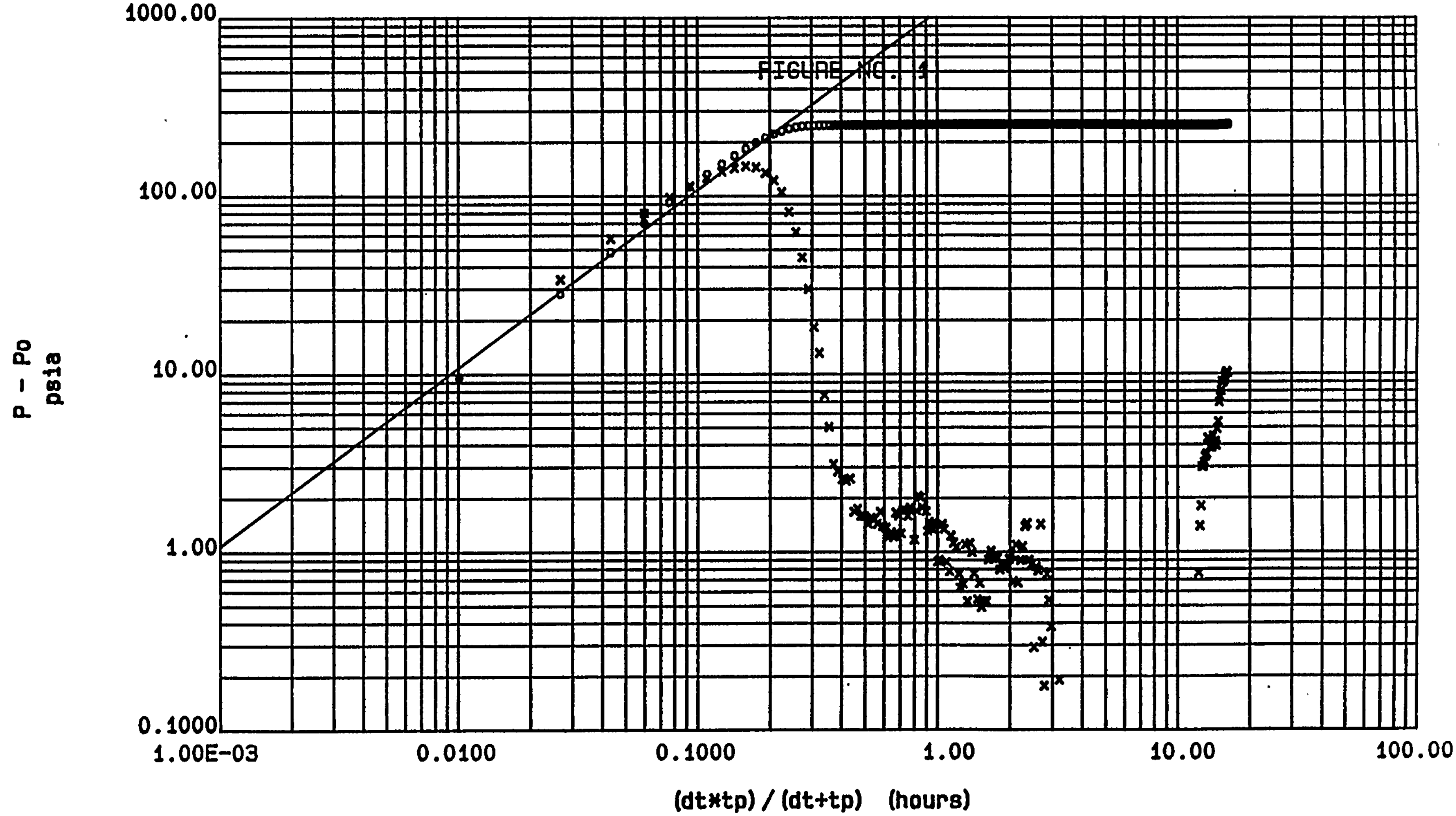
(FIGURE NO. 1)

Line :

Intercept..............................:	1083.602
Slope..................................:	1.000
Wellbore storage coefficient (C)........:	0.1235 bbl/psi
Dim. wellbore storage constant (Cd)....:	11035.161

FESCO, INC. - LOG-LOG PLOT

File...................:	ET2.OIL	Test Date..............:	01/04-01/06/95	Slope........:	1.000
Company.................:	East Texas Salt Water Disposal	Test Type..............:	45.65 Hour Falloff Test	Intercept....:	3.035
Well...................:	Everett-Lake No. 5	Analyst Name...........:	Bobby P. Davis	C(Storage)...:	0.1235
Field..................:	East Texas (Woodbine)	Formation..............:	Woodbine	CD(Storage)..:	11035.161



RESULTS FROM HORNER ANALYSIS

(FIGURE NO. 2)

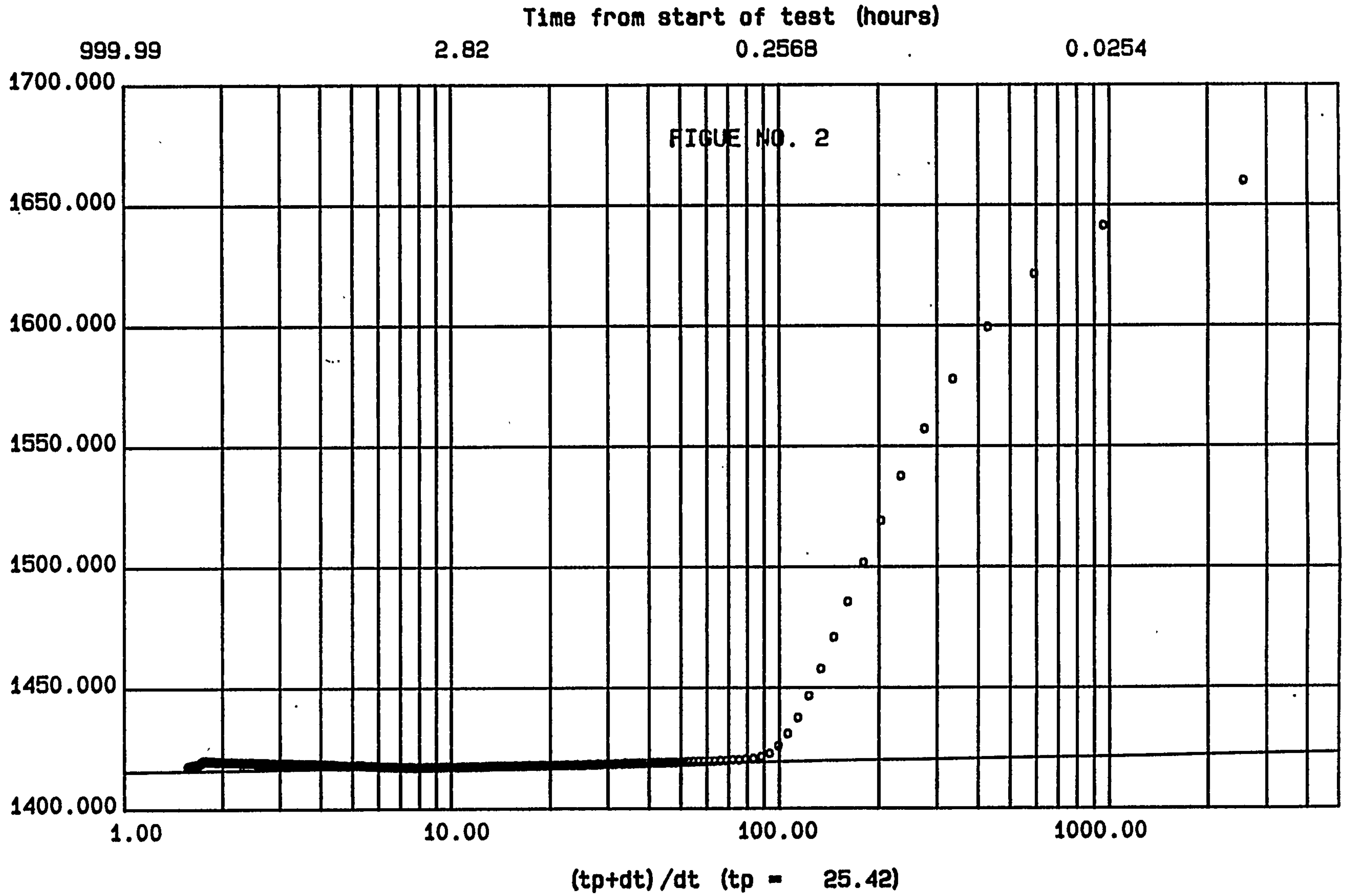
Line :

Intercept.......................:	1415.471	
Slope...........................:	2.034	
Start of line...................:(	0.0000 ,	0.0000)
End of line.....................:(	0.0000 ,	0.0000)
Coefficient of determination....:	0.0000	
Number of points................:	0	

Pressure at dt = 1 hour.................:	1418.362 psia
Extrapolated pressure...................:	1415.471 psia
Permeability-thickness (kh).............:	247396.140 md.ft
Effective permeability to water (Kw)....:	2425.452 md
Total skin factor (S)...................:	134.074
dP skin (constant rate).................:	-236.827 psi
Radius of investigation.................:	6588.560 ft
Flow efficiency.........................:	0.0687

FESCO, INC. - HORNER PLOT

File	ET2.OIL	Test Date	01/04-01/06/95	Slope	2.034
Company	East Texas Salt Water Disposal	Test Type	45.65 Hour Falloff Test	Intercept	1415.471
Well	Everett-Lake No. 5	Analyst Name	Bobby P. Davis	Permeability	2425.452
Field	East Texas (Woodbine)	Formation	Woodbine	Skin	134.074



RESULTS FROM A HOMOGENEOUS RESERVOIR TYPE-CURVE MATCH

(FIGURE NO. 3 - WELLBORE STORAGE ANALYSIS)

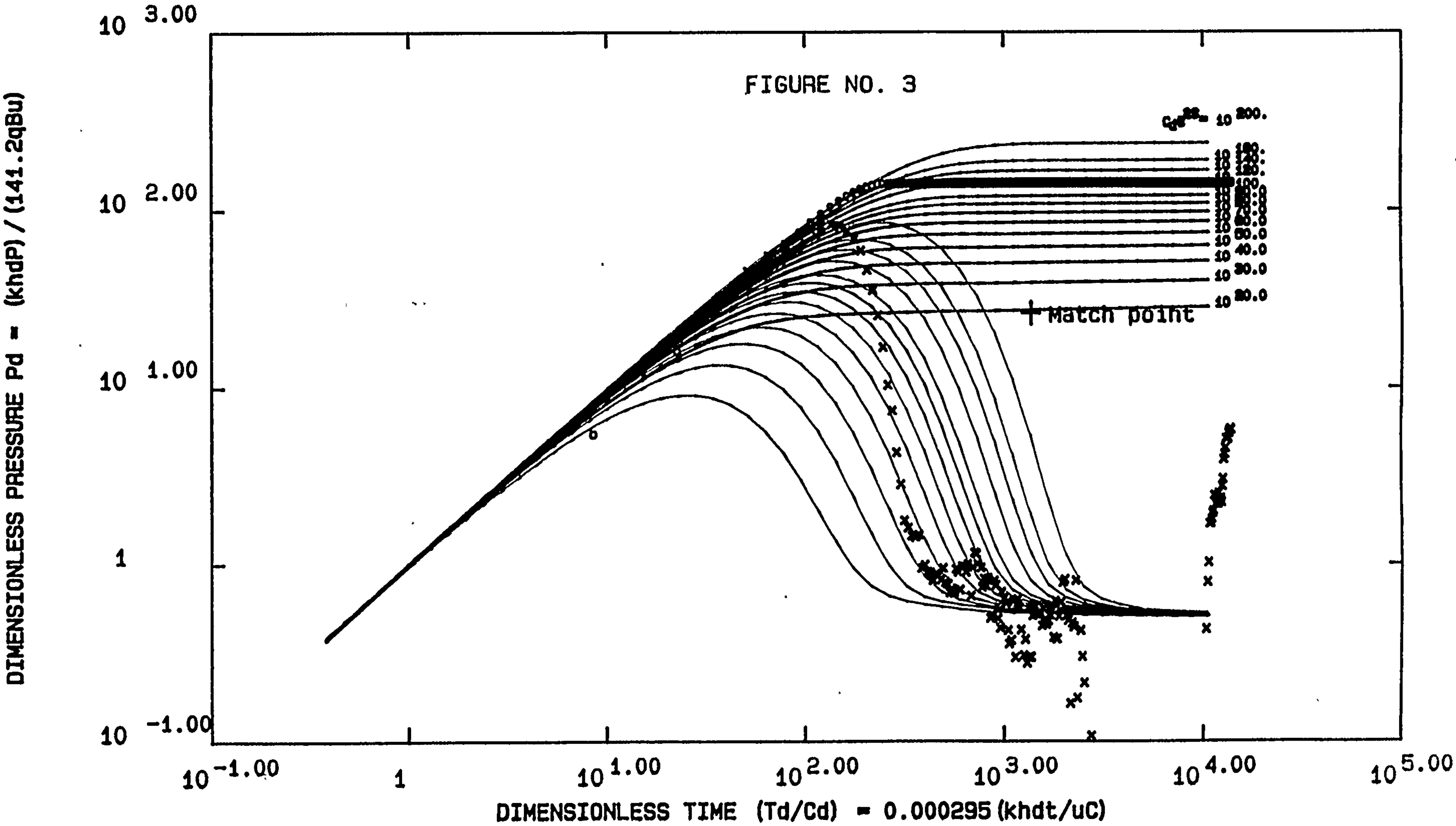
Data plotted using Agarwal Equivalent Time

Dim. pressure match point Pd(match)....:	26.102	
Dim. time match point Td/Cd(match).....:	1343.399	
Matched curve Cde2S(match).............:	1.000E+120	
Pressure match point dP(match).........:	46.416	
Time match point dt(match).............:	1.585	
Permeability-thickness (kh).............:	247396.140	md.ft
Permeability (k).......................:	2425.452	md
Wellbore storage coefficient (C)........:	0.0888	bbl/psi
Dim. wellbore storage constant (Cd)....:	7927.148	
Radius of investigation.................:	6566.500	ft
dP skin (constant rate).................:	-236.107	psi
Skin factor (S)........................:	133.666	

FESCO, INC. - HOMOGENEOUS RESERVOIR TYPE CURVE PLOT

File.................:	ET2.OIL	Test Date..............:	01/04-01/06/95	Pd(match)....:	26.102	dp(match)..:	46.416
Company..............:	East Texas Salt Water Disposal	Test Type..............:	45.65 Hour Falloff Test	Td(match)....:	1343.399	dt(match)..:	1.585
Well.................:	Everett-Lake No. 5	Analyst Name...........:	Bobby P. Davis	Permeability.:	2425.452	dp(skin)...:	-236.107
Field................:	East Texas (Woodbine)	Formation..............:	Woodbine	Skin.........:	133.666	C(Storage).:	6566.500

Data plotted using Agarwal Equivalent Time



RESULTS FROM A HOMOGENEOUS RESERVOIR TYPE-CURVE MATCH
(FIGURE NO. 4 - WELLBORE STORAGE ANALYSIS)

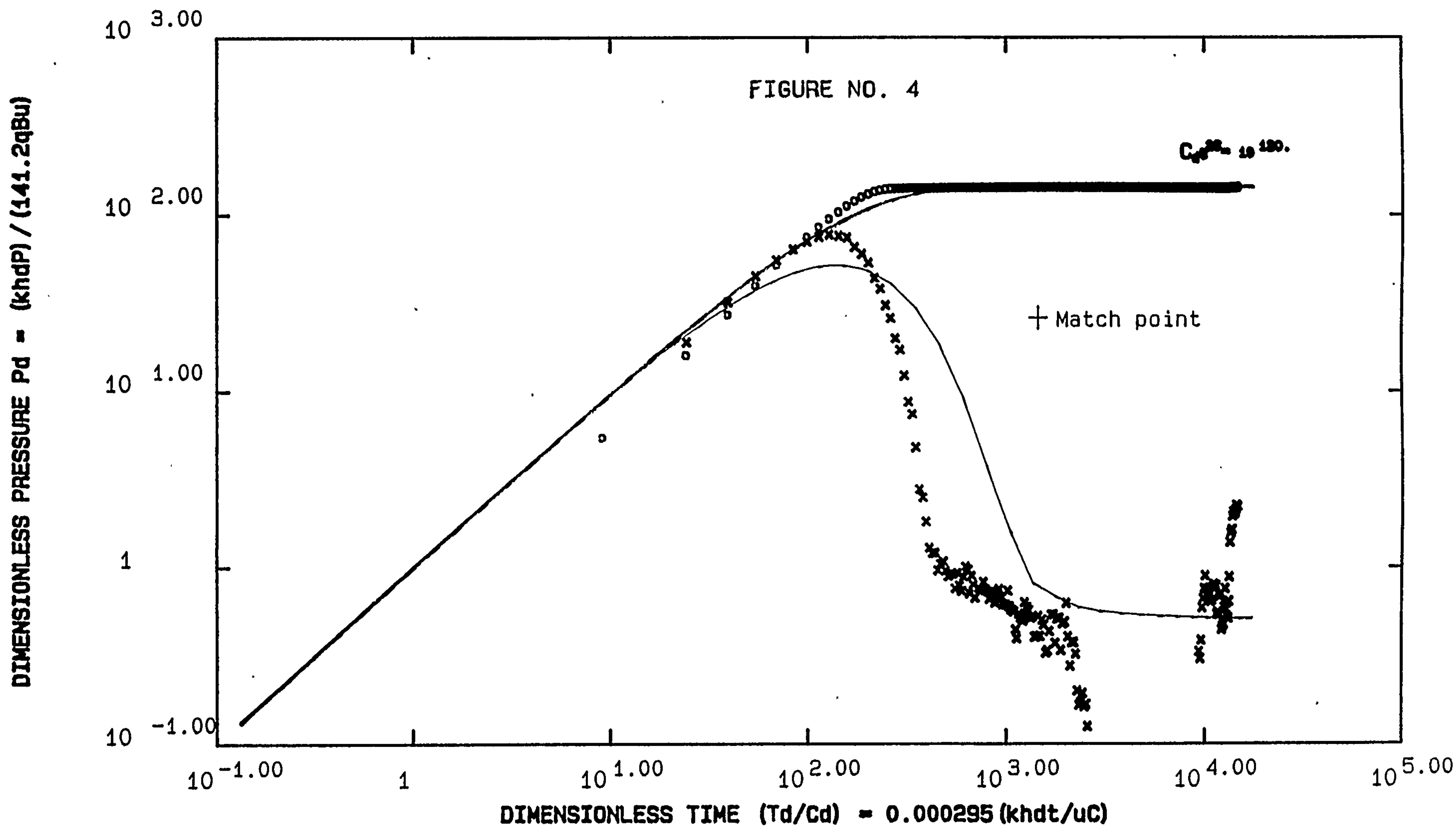
Data plotted using Agarwal Equivalent Time

Dim. pressure match point Pd(match)....:	26.102
Dim. time match point Td/Cd(match).....:	1425.103
Matched curve Cde2S(match).............:	1.001E+120
Pressure match point dP(match).........:	46.416
Time match point dt(match).............:	1.585
Permeability-thickness (kh).............:	245742.234 md.ft
Permeability (k)........................:	2409.238 md
Wellbore storage coefficient (C)........:	0.0837 bbl/psi
Dim. wellbore storage constant (Cd)....:	7472.670
Radius of investigation.................:	6566.500 ft
dP skin (constant rate).................:	-237.749 psi
Skin factor (S).........................:	133.696

FESCO, INC. - HOMOGENEOUS RESERVOIR TYPE CURVE PLOT

File.................:	ET2.OIL	Test Date.............:	01/04-01/06/95	Pd(match)....:	26.102	dp(match)..:	46.416
Company.................:	East Texas Salt Water Disposal	Test Type.............:	45.65 Hour Falloff Test	Td(match)....:	1425.103	dt(match)..:	1.585
Well.................:	Everett-Lake No. 5	Analyst Name...........:	Bobby P. Davis	Permeability.:	2409.238	dp(skin)...:	-237.749
Field.................:	East Texas (Woodbine)	Formation.............:	Woodbine	Skin.........:	133.696	C(Storage).:	6566.500

Data plotted using Agarwal Equivalent Time



TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
1.	0.0000	1669.7600
2.	0.0166	1670.7099
3.	0.0333	1669.7600
4.	0.0500	1660.0998
5.	0.0666	1641.4798
6.	0.0833	1621.4698
7.	0.1000	1599.3398
8.	0.1166	1577.7500
9.	0.1333	1557.1500
10.	0.1500	1537.5400
11.	0.1666	1519.1600
12.	0.1833	1501.7398
13.	0.2000	1485.5400
14.	0.2166	1470.8900
15.	0.2333	1457.8199
16.	0.2500	1446.7298
17.	0.2666	1437.6700
18.	0.2833	1430.9799
19.	0.3000	1426.0300
20.	0.3166	1422.9100
21.	0.3333	1421.5200
22.	0.3500	1420.7299
23.	0.3666	1420.5300
24.	0.3833	1420.1899
25.	0.4000	1420.2399
26.	0.4166	1419.8399
27.	0.4333	1419.8399
28.	0.4500	1419.6899
29.	0.4666	1419.6899
30.	0.4833	1419.4899
31.	0.5000	1419.5400
32.	0.5166	1419.4899
33.	0.5333	1419.3399
34.	0.5500	1419.3900
35.	0.5666	1419.1400
36.	0.5833	1419.1899
37.	0.6000	1419.1899
38.	0.6166	1419.1899
39.	0.6333	1419.0400
40.	0.6500	1419.0899
41.	0.6666	1419.0400
42.	0.6833	1419.0899
43.	0.7000	1418.8900
44.	0.7166	1418.8900
45.	0.7333	1418.9399
46.	0.7500	1418.9399
47.	0.7666	1418.7900
48.	0.7833	1418.7900
49.	0.8000	1418.7900
50.	0.8166	1418.8399

TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
51.	0.8333	1418.6400
52.	0.8666	1418.6899
53.	0.8833	1418.5000
54.	0.9000	1418.5000
55.	0.9166	1418.5400
56.	0.9333	1418.5400
57.	0.9666	1418.3900
58.	0.9833	1418.5899
59.	1.0000	1418.3900
60.	1.0333	1418.3900
61.	1.0500	1418.4399
62.	1.0833	1418.2900
63.	1.1000	1418.0999
64.	1.1333	1418.0999
65.	1.1500	1418.3399
66.	1.1833	1418.1400
67.	1.2166	1418.2399
68.	1.2333	1418.1899
69.	1.2666	1418.0899
70.	1.3000	1418.0899
71.	1.3333	1418.1400
72.	1.3500	1418.1400
73.	1.3833	1417.9899
74.	1.4166	1417.9899
75.	1.4500	1418.0400
76.	1.4833	1418.0899
77.	1.5166	1417.8900
78.	1.5500	1417.9399
79.	1.6000	1417.9899
80.	1.6333	1417.9899
81.	1.6666	1417.8399
82.	1.7000	1417.8399
83.	1.7500	1417.8900
84.	1.7833	1417.9300
85.	1.8333	1417.7900
86.	1.8666	1417.7900
87.	1.9166	1417.7900
88.	1.9500	1417.8800
89.	2.0000	1417.8800
90.	2.0500	1417.9300
91.	2.1000	1417.7800
92.	2.1500	1417.7800
93.	2.2000	1417.6800
94.	2.2500	1417.6800
95.	2.3000	1417.5300
96.	2.3500	1417.5799
97.	2.4000	1417.6300
98.	2.4666	1417.6800
99.	2.5166	1417.5300
100.	2.5833	1417.5300

TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
101.	2.6333	1417.5699
102.	2.7000	1417.5699
103.	2.7666	1417.4200
104.	2.8333	1417.5200
105.	2.9000	1417.3699
106.	2.9666	1417.6199
107.	3.0333	1417.4699
108.	3.1000	1417.5200
109.	3.1666	1417.3699
110.	3.2500	1417.2199
111.	3.3166	1417.4599
112.	3.4000	1417.3100
113.	3.4833	1417.3599
114.	3.5500	1417.4100
115.	3.6333	1417.2600
116.	3.7166	1417.3100
117.	3.8166	1417.1099
118.	3.9000	1417.4000
119.	3.9833	1417.4499
120.	4.0833	1417.3000
121.	4.1833	1417.3499
122.	4.2666	1417.4000
123.	4.3666	1417.4499
124.	4.4833	1417.5000
125.	4.5833	1417.5400
126.	4.6833	1417.5400
127.	4.8000	1417.5899
128.	4.9000	1417.6400
129.	5.0166	1417.6899
130.	5.1333	1417.5899
131.	5.2500	1417.8299
132.	5.3833	1417.8800
133.	5.5000	1417.9300
134.	5.6333	1417.7800
135.	5.7666	1418.0200
136.	5.9000	1418.1199
137.	6.0333	1418.1700
138.	6.1666	1418.2199
139.	6.3166	1418.0699
140.	6.4666	1418.1099
141.	6.6166	1417.9599
142.	6.7666	1418.0100
143.	6.9333	1418.1099
144.	7.0833	1418.1099
145.	7.2500	1418.0100
146.	7.4166	1418.2500
147.	7.6000	1418.4499
148.	7.7666	1418.5000
149.	7.9500	1418.4000
150.	8.1333	1418.4899

TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
151.	8.3333	1418.6899
152.	8.5166	1418.5899
153.	8.7166	1418.6400
154.	8.9166	1418.6800
155.	9.1333	1418.7800
156.	9.3333	1418.7800
157.	9.5500	1418.7199
158.	9.7833	1418.7700
159.	10.0000	1418.6700
160.	10.2333	1418.7199
161.	10.4833	1418.8100
162.	10.7166	1418.9100
163.	10.9666	1418.8100
164.	11.2333	1418.9000
165.	11.4833	1419.0000
166.	11.7500	1418.8900
167.	12.0333	1418.9899
168.	12.3166	1419.0400
169.	12.6000	1419.1300
170.	12.8833	1418.8800
171.	13.1833	1418.9699
172.	13.5000	1419.0200
173.	13.8166	1419.1600
174.	14.1333	1418.8599
175.	14.4666	1418.9599
176.	14.8000	1419.1999
177.	15.1500	1419.3000
178.	15.5000	1419.1899
179.	15.8500	1419.2900
180.	16.2333	1419.1400
181.	16.6000	1419.2800
182.	16.9833	1419.3299
183.	17.3833	1419.3800
184.	17.7833	1419.5200
185.	18.2000	1419.3699
186.	18.6333	1419.4100
187.	19.0666	1419.3100
188.	19.5000	1419.3599
189.	19.9666	1419.2600
190.	20.4333	1419.3499
191.	20.9000	1419.4000
192.	21.3833	1419.4899
193.	21.8833	1419.5400
194.	22.4000	1419.5899
195.	22.9166	1419.6300
196.	23.4500	1419.5300
197.	24.0000	1419.5300
198.	24.5500	1419.6700
199.	25.1333	1419.6700
200.	25.7166	1419.7600

TIME AND PRESSURE TABLE

Data Point	Time Hours	Pressure psia
201.	26.3166	1419.8100
202.	26.9166	1419.8599
203.	27.5500	1419.7099
204.	28.2000	1419.8000
205.	28.8500	1419.8499
206.	29.5166	1419.9000
207.	30.2000	1419.9399
208.	30.9166	1419.9899
209.	31.6333	1419.8399
210.	32.3666	1420.0799
211.	33.1166	1420.0799
212.	33.9000	1420.1800
213.	34.6833	1419.8299
214.	35.4833	1419.5300
215.	36.3166	1418.9399
216.	37.1666	1418.7398
217.	38.0333	1418.6400
218.	38.9166	1418.2398
219.	39.8166	1418.2398
220.	40.7500	1418.2900
221.	41.7000	1418.0898
222.	42.6666	1418.0400
223.	43.6666	1417.8398
224.	44.6833	1417.8000
225.	45.4666	1417.6500

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APPENDIX 4

Example Calculation of the Residual Head for the East Texas Salt Water Disposal Company Everett-Gladney No. 2 Disposal Well

The following is an example calculation of the residual head for the East Texas Salt Water Disposal Company Everett-Gladney No. 2 Disposal Well. Data for this example come from the 1993 STATIC BOTTOM HOLE PRESSURE SURVEY data sheet that is included at the end of this example calculation and from the maps and tables in the report that are cited, where appropriate.

Step 1 Example calculation of Woodbine reservoir salt-water head elevation from the reservoir pressure data.

DATA: Reservoir pressure at -3300 foot datum = 1336 psi from data sheet
Pressure gradient = .452 psi/ft for "average" Woodbine formation water

1. The reservoir water will rise above the -3300 foot datum by:

$$\frac{1336\ psi}{.452\ psi/ft} = 2956\ ft$$

to an elevation of:

$$\begin{array}{l} -\ 3300\text{ ft MSL} \\ \underline{+2956\text{ ft}} \\ -\ 344\text{ ft} \end{array}$$

2. The calculated elevation of -344 feet can be compared with the measured elevation from the data sheet as follows:

DATA (from data sheet): Measured surface elevation = 321 ft MSL
Measured depth to water = 665 ft

Measured elevation is:

$$\begin{array}{l} 321\text{ ft MSL} \\ \underline{-665\text{ ft}}\text{ depth to water} \\ -344\text{ ft} \end{array}$$

The above manual calculations demonstrate the validity of the salt-water head elevations in Column G of Table 2 as calculated by computer from the pressure data in Column D of Table 2.

The Everett-Gladney No. 2 has API No. 18389867 and appears on line 26 of p. 24, Table 2. It's pressure was 1336 psi (Column D) in 1993 and its computer calculated salt-water head elevation was -344 ft MSL (Column G) in 1993. This elevation will be used for all other calculations that follow and which are referenced to the Column or Columns in Table 2 for comparison.

3. *Base Wlcx (Column F) = -690 ft

4. SWH - Base Wlcx (Column H)

$$\begin{array}{r} -\ 344\text{ ft} \\ \underline{-(-)690}\text{ ft} \\ 346\text{ ft} \end{array}$$

***Obtained by manual overlay of Map 1 on Map 2 and visual interpolation between base of Wilcox contours to obtain -690 ft elevation at the Everett-Gladney No. 2 well location as shown on Map 1.**

5. SWH Adj. to FW (Column I) $346 \times 1.044 = 361$ ft

6. Total adj. head (Column J)

- 690	Base Wlcx
+361	Reservoir FW head
- 329 ft	MSL elev of reservoir FW head

7. Computer grid these values (Column J) and compare with computer gridded head elevations from Table 3.

As an example, a head elevation close to Everett-Gladney No. 2 is State Well No. 3525801 where the 1966 ground water elevation was +251 ft.

Map 3	- 329 ft
Map 4	-(+)251 ft
Residual Map 5	- 580 ft

-580 ft of residual head is equivalent to a reservoir underpressure of:

$580 \times .433 = 251$ psi

FESCO INC.

1408 East Main - Alice, Texas 78332

STATIC BOTTOM HOLE PRESSURE SURVEY

OR: East Texas Salt Water Disposal Co. TEST DATE: 03/31/93

ELL: Everett-Gladney No. 2 No. (43-E) FIELD: East Texas

TATUS: Shut in 48 Hrs RESERVOIR: ———

ELL DATA: Wellhead connection: 2.5" Reg
Zero at DF: 0.0 Ft above GL
Zero elevation: 321 Ft.
7" Csg set @ 3656 Ft
Open Hole
Datum: 3621 Ft (-3300)

TEST DATA

DEPTH, FT	PRESS, PSIG	GRAD, PSI/FT
Surface	0	Gauge
1121	206	.184
2121	657	.451
3121	1111	.454
3321	1200	.445
3521 (-3200)	1291	.455

REMARKS

1.25" 2000# BHP element SN:44305

Temp @ test depth: 120°F

Oil level: None
Water level: 665

Prev. BHP: 03/19/92 1337 Psig
Change: 1 Psi Loss

BHP EXTRAPOLATED TO DATUM

3621 (-3300)	1336	.455

Tester: L. Hughes, R. Byrd

Certified: FESCO INC - Kilgore, Texas

By: [signature]
District Manager - 903-984-4814

File: D090331
Job Number: J097274.001A Level: 8

EVALUATION OF AREA OF REVIEW VARIANCE OPPORTUNITIES FOR THE EAST TEXAS FIELD

Annual ~~Final~~ Report

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