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March 2, 1998

Mr. William B. Hathaway  
Director - Water Quality Protection Division  
Environmental Protection Agency  
1445 Ross Avenue  
Dallas, Texas 75202-2733

Re: Endangerment of Texas Ground Water  
from Texas Railroad Commission Approved  
Salt Water Disposal/Water Injection Well Projects

Dear Mr. Hathaway,

This letter and associated documents are being sent to you to express my opinion that the Texas Railroad Commission is not adhering to their EPA approved (April 23, 1982) program for Class II injection wells. Even if I'm wrong and the Commission is legally adhering to the EPA program, I still believe the fresh water sands of Texas are endangered by the current Commission program for Class II injection wells. The following pages of this letter contains the reasons why I believe the Texas Railroad Commission is endangering Texas fresh water sands.

The fresh water sands of Texas are endangered and are possibly being polluted by salt water disposal and water injection well operations. The potential for pollution results from fluid migration from an authorized injection zone to the fresh water sand through improperly plugged wells. Typically, an improperly plugged well for an injection project is a well that was plugged with mud laden fluid. It was legal to plug certain types of wells in Texas with mud laden fluid prior to January 1, 1967. Texas Railroad Commission literature indicates there are approximately 53,000 salt water disposal/water injection wells permitted by the Texas Railroad Commission (TRRC). The first injection permit was issued in 1938. Many of these injection projects are in reservoirs that have been penetrated by wells plugged with mud laden fluid.

The salt water disposal and water injection well application process at the TRRC Environmental Services Department has several problems and/or deficiencies. Most of the problems relate to the 1/4 mile Area of Review (AOR) study required by Texas Statewide Rules 9 and 46. The AOR study is used to identify improperly plugged wells. When improperly plugged wells are identified, pressure front calculations are commonly submitted to show no dangerous levels of pressure will result from the proposed injection operations. Some of the TRRC injection application and regulation problems are as follows.

- a. Improperly plugged wells (and/or wells plugged with mud) are not being identified by injection applicants and the TRRC within 1/4 mile Area of Review studies.
- b. Pressure front calculations are being submitted with applications and accepted by the TRRC which are scientifically incorrect.
- c. Pressure front calculations are being submitted with applications by individuals not qualified to perform such calculations. This act is the non-licensed practice of engineering and is a violation of the Texas Engineering Practice Act.
- d. Injection projects are being submitted by non-engineers and approved by the TRRC that would be in violation of the Texas Engineering Practice Act if submitted by a licensed engineer. These injection projects would be violations in that they endanger public health, safety and property.

- e. Improperly plugged wells, located outside the 1/4 mile Area of Review (AOR), may be potential conduits for fluid migration to fresh water sands. Evaluating improperly plugged wells that lie only in the 1/4 mile AOR circle will miss improperly plugged wells located within reservoir boundaries that are outside the 1/4 mile AOR circle.
- f. Salt water disposal and water injection projects are being approved and operated with injection rates and pressures that exceed formation parting pressures. Exceeding formation parting pressures creates uncontrolled fluid movement which also endangers fresh water sands.
- g. TRRC processing of injection applications do not accurately account for improperly plugged wells that may penetrate sloping reservoirs.
- h. A culture of dishonesty has developed among individuals applying for injection permits in that there is a tendency not to identify improperly plugged wells.

Details concerning only three problem areas are addressed by this letter. Not all of the aforementioned problems and issues are discussed in this document because a panel of experts, subsequent to this letter, would likely do a more thorough job. This letter is organized according to the following three problem areas.

- 1) Scientifically incorrect pressure front calculations,
- 2) Non-qualified individuals submitting pressure front calculations, and
- 3) Vague and ambiguous TRRC definition for an improperly plugged well.

The remaining pages will briefly describe the three problems areas.

### **1.0 Scientifically Incorrect Pressure Front Calculations**

To the best of the author's knowledge, the TRRC Environmental Services Department has been universally distributing and accepting pressure front calculations based on the infinite acting pressure transient equation for all reservoirs since 1991. The TRRC has not adopted or accepted the use of a more correct, pseudo steady state equation for pressure front calculations. Universal use of the infinite acting pressure transient equation for pressure front calculations is scientifically incorrect. Two reasons use of TRRC pressure front calculation program is incorrect are:

- 1) it is applied to the wrong type of reservoir, or
- 2) it is applied during the wrong flow period.

Some background information is necessary concerning pressure transient theory of reservoirs before describing why the TRRC Environmental Services Department use of the infinite acting pressure equation is wrong. Reservoir pressure transients have been characterized in petroleum engineering literature by the following three flow periods.<sup>1,2,3 & 4</sup>

- 1) Infinite Acting or Transient Period,
- 2) Late Transient Period, and
- 3) Semi Steady State or Pseudo Steady State Period and Steady State Period.

All reservoir pressure transients experience an infinite acting period. The type of boundaries within a reservoir determine whether or not late transient, pseudo steady state and steady state flow periods will develop. Reservoirs that are infinite never experience boundary effects so periods 2) and 3) do not develop. Reservoirs that have closed boundaries experience late transient and pseudo steady state flow periods. Reservoirs that have constant pressure boundaries experience late transient and steady state flow periods.

The infinite acting pressure transient equation (TRRC program) should be used to model pressure transients around a well that does not feel the effect of boundaries. The reservoir boundaries are infinite, hence an infinite reservoir volume. The average reservoir pressure of an infinite volume reservoir remains constant (or approximately constant). Reservoirs or scenarios that may approximate these conditions are: very large groundwater zones and very large artesian aquifers. The infinite acting pressure transient equation is also used to model the pressure transients around a well, in a bounded reservoir, that is in the infinite acting flow period. The infinite acting pressure transient equation used and distributed by the TRRC for pressure front calculations is as follows.

$$p(r,t) = p_i + \frac{162.60 q \mu B}{k h} \log \left( \frac{365 k t}{70.4 \phi \mu c_t r^2} \right) \quad (1)$$

Variables and units to equation (1) are as follows.

- B = fluid formation volume factor (rb/stb),
- c<sub>t</sub> = total reservoir system compressibility (psi<sup>-1</sup>),
- k = average reservoir permeability (millidarcy, md),
- h = average net pay thickness of reservoir (ft),
- ϕ = average reservoir porosity (fraction, dimensionless),
- p(r,t) = reservoir pressure at radius r and time t (psi),
- p<sub>i</sub> = average reservoir pressure before start of injection or production (psi),
- q = average flow rate: (+) for injection and (-) for production (stb/d),
- r<sub>w</sub> = wellbore radius, inside diameter used (ft),
- r = radial distance or point of interest for pressure calculations (ft),
- t = time of injection for pressure calculations (years),
- μ = reservoir fluid viscosity (centipoise, cp),
- psi = pressure units of pounds per square inch,
- stbpd = stock tank barrel per day, and
- rb/stb = reservoir barrel / stock tank barrel.

Reservoirs that do not satisfy the boundary criteria of an infinite reservoir are finite in volume. Most reservoirs associated with salt water disposal, water injection and oil and gas production are finite in volume. A reservoir that is finite in volume has no flow at the outer boundaries. No flow boundaries can be created by geologic processes that seal the boundary, such as those that create a permeability pinchout, shale or anhydrite caprock, or a sealing fault. No flow boundaries can also be created by drainage interference from offsetting wells. The suitable pressure transient equations for a finite volume reservoir are referred to as semi steady state or pseudo steady state equations. Boundary conditions associated with pseudo steady state equations are: finite reservoir boundaries and, the change in reservoir pressure with respect to change in time is a non-zero constant. A simpler way to describe the last boundary condition is that finite volume reservoirs tend to behave according to a material balance using the definition of compressibility. Finite volume reservoirs experience decreases in pressure when fluid is withdrawn (produced) and increases in pressure when fluid is added (injected).

It is the author's opinion that most of the pressure front calculations submitted to the TRRC should use pseudo steady state equations because they are for finite volume reservoirs. The pseudo steady state equation should be applied during the pseudo steady state flow period. The pseudo steady state equation for a cylindrical reservoir with closed boundaries is shown as equation (2). The oil field unit form of equation (2) is derived from equation C-2 of the Matthews, Brons and Hazebroek<sup>5</sup> paper.

$$p(r,t) = p_i + \frac{141.2 q \mu B}{k h} \left[ \frac{1}{2} \left( \frac{r}{r_e} \right)^2 + \frac{2 t_D r_w^2}{r_e^2} - \ln \left( \frac{r}{r_e} \right) - \frac{3}{4} \right] \quad (2)$$

where

$$t_D = \frac{0.0002637 k t}{\phi \mu c_t r_w^2} \quad (3)$$

Variables and units to equations (2) and (3) are as follows.

- B = fluid formation volume factor (rb/stb),
- c<sub>t</sub> = total reservoir system compressibility (psi<sup>-1</sup>),
- k = average reservoir permeability (millidarcy, md),
- h = average net pay thickness of reservoir (ft),
- φ = average reservoir porosity (fraction, dimensionless),
- p(r,t) = reservoir pressure at radius r and time t (psi),
- p<sub>i</sub> = average reservoir pressure before start of injection or production (psi),
- q = average flow rate: (+) for injection and (-) for production (stb/d),
- r<sub>e</sub> = effective drainage radius (ft),
- r<sub>w</sub> = wellbore radius, inside diameter used (ft),
- r = radial distance or point of interest for pressure calculations (ft),
- t<sub>D</sub> = dimensionless time (dimensionless),
- t = time of interest for pressure calculations (hours), and
- μ = reservoir fluid viscosity (centipoise, cp).

Steady state pressure transient equations are applied to finite volume reservoirs experiencing constant pressure boundaries<sup>4</sup>. Some reservoirs that may approximate constant pressure boundary conditions are: an injection pattern within a flood where withdrawals equal additions; a reservoir having a large gas cap drive mechanism; and, a reservoir with a large aquifer providing pressure support. The steady state equation should be applied during the steady state flow period.

The computer program used by the TRRC for pressure front calculations was developed using the BASIC programming language and is for use in MS-DOS/Windows type personal computers. The program is based on the infinite acting pressure transient equation. The pressure front calculations used by the TRRC are a “quick & dirty” approximation to determine if dangerous levels of reservoir pressures will develop in an improperly plugged borehole. This method assumes radial drainage geometry around an injection well and can be referred to as a cylindrical, tank model evaluation.

More complex methods should be used when complicated drainage geometries exist and a more accurate evaluation of reservoir pressures are required. Some of the more complex petroleum engineering methods are the use of the superposition principle, streamline reservoir simulation and finite difference, numerical reservoir simulation. The “quick & dirty” method of pressure front calculations has an advantage over more sophisticated methods in that it requires less time. The more sophisticated engineering methods may require 10 to 500 times more engineering time to set up than the “quick & dirty” method. The short time requirement of the “quick & dirty” method makes it ideal for TRRC examiner use in developing a “go” or “no-go” decision on granting an injection well permit.

## 2.0 Non-qualified Individuals Submitting Pressure Front Calculations

Individuals without the scientific training, education and experience are submitting pressure front calculations to the TRRC Environmental Services Department with salt water disposal/ water injection applications (Form W-14 and Form H-1). It is the author's opinion that the TRRC rarely reviews the pressure front calculations for the correct application of scientific principles and for correct calculations. The author has the opinion that the TRRC approves injection applications containing pressure front calculations whether they are correct or incorrect. As mentioned in the previous section, the TRRC's universal use of the infinite acting pressure transient equation is scientifically incorrect for most reservoirs being considered for salt water disposal and water injection operations.

The issue concerning qualifications of individuals submitting pressure front calculations involves the practice of engineering. Pressure front calculations are common to petroleum/reservoir engineering. The calculation methods may involve the specialties of pressure transient analysis, reservoir engineering and numerical reservoir simulation. These engineering methods are taught at several universities with accredited petroleum engineering departments. Petroleum engineering departments are located at: UT Austin, Texas A & M, Texas Tech, Texas A & M (Kingsville), University of Houston, Oklahoma University, University of Tulsa, Colorado School of Mines, Stanford, USC, Penn State, Louisiana State University, and the University of Missouri (Rolla). Other petroleum engineering programs exist which are not mentioned in this list. In Texas, the practice of engineering without a license, aiding and abetting in the non-licensed practice of engineering, and the incompetent practice of engineering are violations of the Texas Engineering Practice Act. Violations of the Texas Engineering Practice Act are a Class A misdemeanor. As of 1997, the possible penalties associated with a Class A misdemeanor in Texas are: imprisonment for one year; and/or, a fine of not more than \$4,000.

An example of how the TRRC Environmental Services Department assists non-engineers in the practice of engineering can be seen through their assistance in pressure front calculations for an injection application. The manner in which this act is done is illustrated by the following five steps.

- 1) Injection applicant informs and questions TRRC Environmental Services examiner concerning the need for pressure front calculations via telephone, fax or mail.
- 2) TRRC examiner requests input data from applicant for TRRC computer based pressure front calculations.
- 3) Injection applicant sends the input data to the TRRC examiner via mail, fax or telephone.
- 4) TRRC examiner runs the TRRC Pressure Front Program, then mails or faxes the output to the injection applicant.
- 5) Applicant mails a copy of the pressure front program output with other required documents for the injection well application to the TRRC Environmental Services Department.

Pages 6 and 7 of this letter are copies of documents where the TRRC assisted a geologist in submitting pressure front calculations with an injection well application. These documents were copied directly from the injection well permit file in the Central Records Department of the Texas Railroad Commission. The two pages were scanned and reduced to fit in this document. Page 6 is where Geologist ••••• faxes the input data to TRRC Geologist ••• Fuller. Page 7 is the TRRC Pressure Front Program Output sent from TRRC Geologist ••• Fuller to Geologist ••••• for filing with the application. Page 7 is also the pressure front calculations used to show that injection operations into the ••••• Well No. 6 will not develop adverse reservoir pressures in an improperly plugged well located 1200 feet away. The improperly plugged well is the ••••• Well No. 2 (SCS). The ••••• Well No. 6 injection project is located approximately 5 to 8 miles north-northwest of ••••• in the Cooke County Regular Field, Texas Railroad Commission District 9.





It is the author's opinion that both the TRRC and Geologist ••••• have committed violations described by Section 23 of the Texas Engineering Practice Act. A violation of the Act is a Class A misdemeanor. There are violations in that geologist Fuller assisted in helping geologist ••••• submit petroleum engineering calculations. Mr. Fuller's actions aided and abetted Mr. ••••• in the unlicensed practice of engineering. Mr. •••••'s actions are the actual unlicensed practice of engineering. And, to make matters worse, the wrong petroleum engineering equation was used. The result has been a permitted injection well, the ••••• Well No. 6 (TRRC Lease #•••••), that endangers the fresh water sands. Use of the pseudo steady state pressure transient equation, instead of the infinite acting equation, would have been more correct. The injection application indicates the well is in a 500 acre drainage area and is not an infinite reservoir. Pressure depletion data indicate the field is composed of several finite volume reservoirs.

A comparison of the predicted reservoir pressures from both the infinite acting and pseudo steady state pressure transient equations has been made. The TRRC pressure front program output, on page 7, indicates the lowest level of dangerous reservoir pressure occurs at 458 psi. A reservoir pressure of 458 psi can raise a column of oilfield brine from the injection zone to the base of the usable quality water. The TRRC pressure front program output indicates the reservoir will have a pressure of 247 psi at the ••••• Well No. 2 (SCS) location after 15 years of injection. Therefore, the infinite acting pressure equation shows no dangerous pressures after 15 years of injection.

When the same input data used for the infinite acting equation is used in the pseudo steady state pressure transient equation, the dangerous level of reservoir pressure of 458 psi is reached at the ••••• Well No. 2 location (1200 feet) after 0.45 years of injection. Table 1 lists the input data used in the tank model, pressure front calculations. The data is from the Form H-1 and the fax of input data from Geologist ••••• for the ••••• Well No. 6 injection application. Table 2 lists the pressures from both types of equations and the pressure difference for the time period from 0.10 to 0.45 years. Figure 1 is a plot comparing the pressure profiles of the infinite acting and pseudo steady state equations after 0.45 years of injection into the ••••• Well No. 6. Table 2 and Figure 1 indicate that the ground water (Antlers artesian aquifer) is in danger of coming into contact with injection zone fluid after 0.45 years of injection into the ••••• Well No. 6.

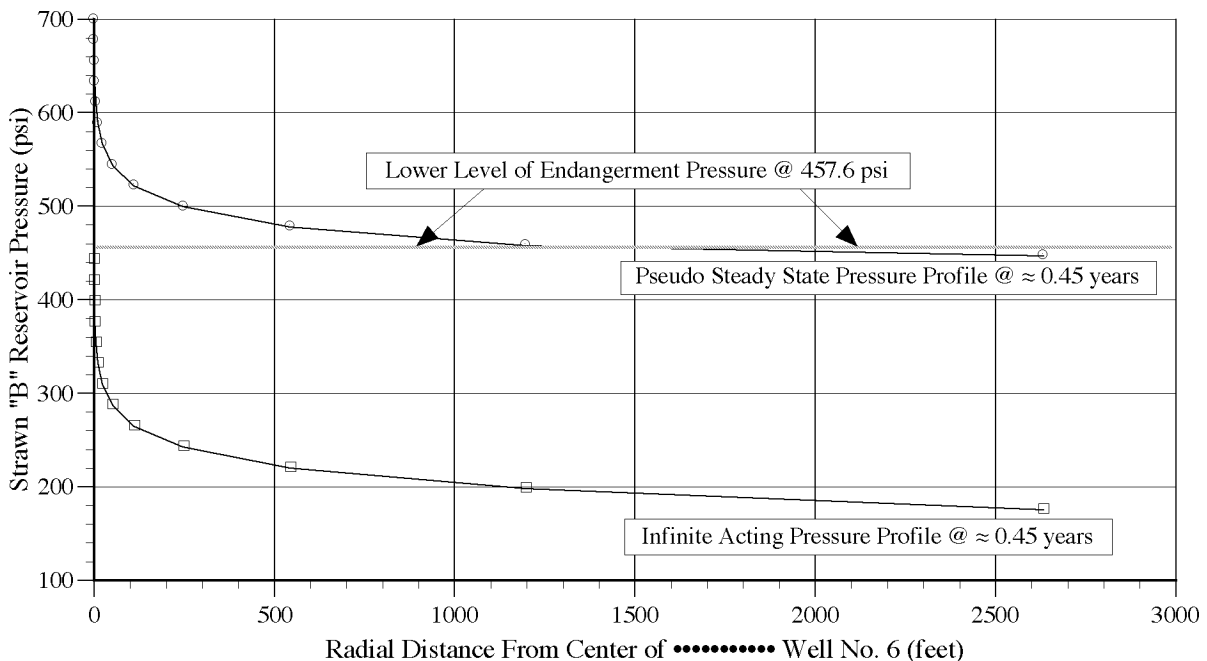
**Table 1:** Input Data for the ••••• Well No. 6 Pressure Front Calculations  
 (sources: H-1 application and pressure front calculation data)

Input Data Variable	Variable Description for Pressure Front Calculations	Units	Variable Value
$p_i$	average reservoir pressure before injection	psi	140
$q$	injection rate	stbw/d	200
$\mu$	injected fluid viscosity	cp	1.00
$B$	fluid formation volume factor	rb/stb	1.00
$k$	average reservoir permeability	md	100
$h$	average net pay height	feet	10
$\phi$	average reservoir porosity (fraction)	dimensionless	0.18
$c_t$	reservoir system compressibility	psi <sup>-1</sup>	1.50E-05
$r$	radial distance to improperly plugged well	feet	1200
$t$	injection time of interest	years	15.00
$\rho$	Brine Gradient	psi/ft	0.465
$\rho_{mud}$	mud weight in improperly plugged well	ppg	9.5
BUQW	Base of Usable Quality Water	feet	670
Top Inj. Zone	Top of Injection Zone Depth	feet	1654
Acres	Form H-1 estimated productive reservoir acres	acres	500

**Table 2:** Comparison of ..... Well No. 6 Pressure Front Values at 1,200 feet for the Infinite Acting and Pseudo Steady State Equations

..... Well No. 6 Time of Injection		Infinite Acting Reservoir Pressure at 1200 feet (psi)	Pseudo Steady State Reservoir Pressure at 1200 feet (psi)	Pressure Difference (psi)
Years	Hours			
0.10	876	176.6	213.6	37.1
0.15	1314	182.3	248.5	66.2
0.20	1752	186.4	283.3	97.0
0.25	2190	189.5	318.2	128.7
0.30	2628	192.1	353.0	160.9
0.35	3066	194.3	387.9	193.6
0.40	3504	196.2	422.8	226.6
0.45	3942	197.8	457.6*	259.8

\* Pressure front has reached the minimum pressure of the dangerous pressure range of 458 to 817 psi.



**Figure 1:** Pressure Profile Plots at 0.45 Years of Injection into the ..... Well No. 6

Adoption of the pseudo steady state equation into the TRRC method of pressure front calculation, for finite volume reservoirs, would show that dangerous levels of reservoir pressure will develop in improperly plugged wells, when the infinite acting equation does not. As mentioned earlier, the tank model evaluation used by the TRRC is a “quick & dirty” approximation of projected reservoir pressures due to injection operations. The TRRC method of pressure front calculations does not accurately account for the effects of a reservoir that has more than one well producing from and injecting in to the authorized injection zone. More complex engineering methods for pressure front calculations should be used when there are more than one well operating within a reservoir boundary. In the case of the ..... Well No. 6 pressure front calculations, more complex engineering methods probably should have been used since more than one well are probably operating in the authorized injection reservoir. A description of the more complex engineering methods is beyond the purpose of this document.

### 3.0 Vague and Ambiguous TRRC Definition for an Improperly Plugged Well

The TRRC does not have an “easy to use” or working definition of an “improperly plugged” well in regards to the 1/4 mile Area of Review (AOR) required for injection applications. Ambiguous and vague definitions of an improperly plugged well have been given by the Environmental Services Department personnel. One such general definition is as follows, “A well is improperly plugged if it was not plugged according to the regulations in effect at the time of plugging.” The author has been unable to get the TRRC Environmental Services Department to provide a clear and usable written definition of an improperly plugged well for AOR purposes.

Other research efforts were made to find a definition of an improperly plugged well. The *Underground Injection Control Reference Manual* (June 1995), published by the Texas Railroad Commission, indicates a properly plugged well prevents the movement of fluid into strata other than the authorized disposal/injection zone. Reversing this explanation defines an improperly plugged well to be one that allows movement of fluid into strata other than the authorized disposal/injection zone.

The *Texas Natural Resources Code*, Title 3, Subchapter C, Section 89.041, specifies how the TRRC is to determine whether or not a well has been properly plugged. The section, with changes made effective August 29, 1983, is presented below in its entirety.

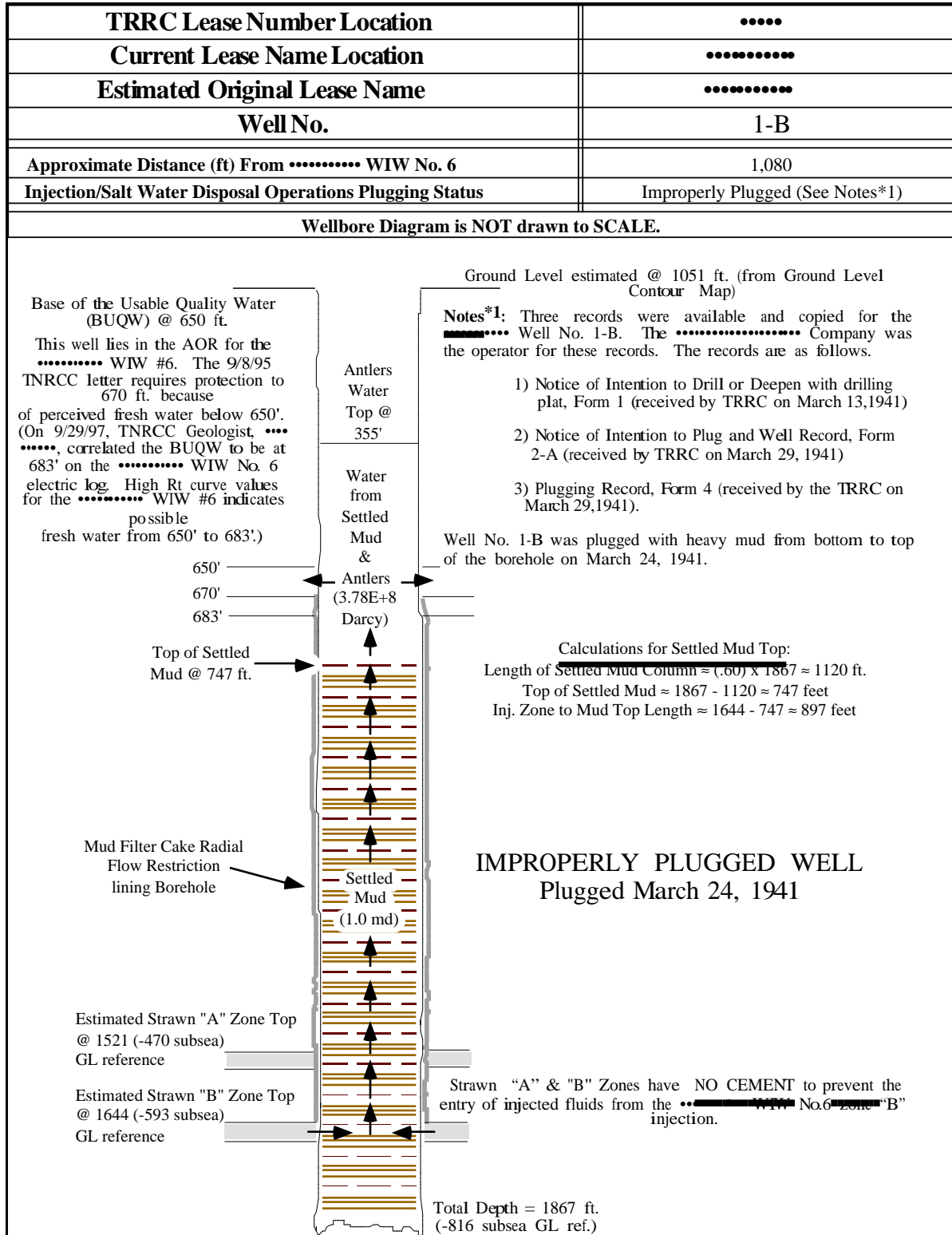
#### § 89.041. Determining Proper Plugging

If it comes to the attention of the commission that a well has been abandoned or is not being operated is causing or is likely to cause pollution of fresh water above or below the ground or if gas or oil is escaping from the well, the commission may determine at a hearing, after due notice, whether or not the well was properly plugged as provided in Section 89.011 or Section 89.012.

The above law indicates that a properly plugged well is not likely to cause pollution of fresh water whereas an improperly plugged well is likely to cause pollution of fresh water. In order to use the above law, an expert such as a reservoir engineer would be needed to show that reservoir pressures and plugged borehole conditions are such that fluid migration from the injection zone to the fresh water zone is likely to occur.

An explanation of why mud filled boreholes can become conduits for fluid migration involves a discussion of the physics inside a mud filled borehole. Wells plugged with mud laden fluid tend to segregate into a section of settled mud at the bottom of the hole and water from the settled mud on top. The settled mud has plastic characteristics because it has not had the time and overburden to fully undergo rock lithification processes. Because of its plastic characteristics, the horizontal stress exerted by the borehole materials is equal to the overburden stress of all the materials inside the borehole. When injection zone pressure is greater than the overburden stress of the materials inside the borehole, the borehole material is squeezed, elongated and compressed. Micro annulus and channel flow paths develop in the vacated space created by the compression and/or elongation of the borehole material. Micro annulus and channel flow paths tend to be highly permeable. This type of phenomenon is dependent on the configuration and characteristics of the borehole material. Sloughing beds and the bridging of beds may exist. Bridging beds may form efficient barriers to vertical flow; however, the reduced overburden stress under a bridging bed may increase the possibility of interaquifer flow below the bridging bed and cause problems elsewhere. Some wells plugged with mud may have bridging beds while others may not. It is the author’s opinion that there is no way to be certain about the configuration of borehole materials inside a well plugged with mud without re-entering the well.

Figure 2 is a wellbore diagram that illustrates how the settled mud might exist within the borehole of a well plugged with mud. The length of the settled mud is based on the work of an API committee described by Warner<sup>6</sup>. The settled mud height is estimated to be approximately 60 percent of the original fresh mud height and may have a porosity as high as 84 percent. This plugged well exists in the 1/4 mile AOR for the ●●●●●● Well No. 6. It was not identified as an improperly plugged well in the 1/4 mile AOR for the ●●●●●● Well No. 6 injection application.



**Figure 2:** Borehole Material Configuration of the •••••••••• Well No. 1-B

It is the author's opinion that all wells plugged with mud, located within the boundaries of a reservoir undergoing injection operations, are potential conduits for injection zone fluid to migrate into the fresh water zone. After reviewing several pre-1967 plugging records at the TRRC, the author has formed the opinion that pre-1967 wells plugged with mud laden fluid tend to have insufficient or no cement covering authorized injection zones and the base of the usable quality water. All wells plugged with mud should be viewed as potential conduits for fluid migration to the fresh water zone unless there is evidence of adequate cement covering both fresh water and authorized injection zones; or, there is substantial and verifiable evidence that bridging beds inside the borehole will prevent fluid migration to fresh water zones.

The question of what is adequate cement coverage for well plugging is probably best addressed by the latest plugging regulation, Statewide Rule 14; and the diagrams and plugging procedures of the TRRC publication, *Well Completion And Plugging Procedures Reference Manual* (March 1994). Any decisions to develop "improperly plugged," "properly plugged," and "adequate cement coverage" definitions that deviate from the Statewide Rule 14 plugging standard should probably be left to a committee of industry experts, or decided after further research and studies have been made.

The ambiguity concerning the definition of an improperly plugged well has contributed to the situation where Texas has several injection projects underway in reservoirs penetrated by wells plugged with mud. It is also likely that, at the time of this complaint, injection projects are being permitted by the TRRC into reservoirs penetrated by wells plugged with mud laden fluid. The primary reason for this permitting problem is that applicants and the TRRC tend to not identify wells plugged with mud laden fluid as being improperly plugged for injection projects.

An example of this problem can be seen in the 1/4 mile Area of Review (AOR) for the ..... Well No. 6. Figure 3 is a 1/4 mile AOR map for the permitted ..... Well No. 6 injection well. The author has identified 16 suspected or known improperly plugged wells located within or just outside the 1/4 mile AOR circle. The term "suspected" is being used to indicate a plugged well where specific details concerning the plugging are unknown. The improperly plugged well locations are indicated by red and blue arrows. In this injection application, only the ..... No. 2 (SCS), indicated by the blue arrow, was identified as an improperly plugged well. The ..... Well No. 6 and ..... No. 2 (SCS) were mentioned in problem 2.0 as the injection well application with the incorrect pressure front calculations.



However, this type of program would still require a more rigorous description of reservoir geometries and improperly plugged wells than what occurs in the current program. A case where this type of program would not work may occur in sloping reservoirs where down-dip improperly plugged wells may have injected fluid levels at or above the base of the usable quality water when the tested injector's static water level is not measurable.

In order to give you a better picture of the problems described by this letter, I have enclosed a larger map of the Cooke County Regular Field study area that contains nine 1/4 mile Areas of Review (AOR) for nine injectors. The AOR map contains arrows marking at least 29 suspected or known improperly plugged wells and the 1/4 mile Area of Review circles for the nine injectors. This map may not be perfectly accurate because of difficulty spotting wells and leases from questionable and old, state records. However, it is believed to be the most accurate map available as of the map date (January 20, 1997). Along with the AOR map (Map #9) are: a list of references to this letter; a regional contour map of the the base of Cretaceous Rock (Approximate Base of Usable Quality Water); a cross-section of regional aquifers; a table describing the nine injectors; and, a table describing the 29 suspected or known improperly plugged wells.

One of the reasons I made this study is because I am a consulting petroleum engineer where one of my business functions is to assist oil and gas operators in filing TRRC applications. My license as a professional engineer in Texas makes it illegal for me to file injection applications like the nine injectors shown on the large map (enclosed Map #9). It is my opinion that an engineer that files injection applications like the injectors on the enclosed map are in violation of the Texas Engineering Practice Act because the injectors endanger public health, safety, and property. It is also my opinion that the nine injectors are in violation of state laws requiring Texas fresh water sands to be protected from pollution. I believe current operating parameters set by TRRC injection permits for the study area's nine injectors endanger the drinking water supply for communities of Muenster, Gainesville, Whitesboro, Sherman and other down dip areas that receive drinking water from the Antlers and Twin Mountains formations. I know of no Texas law that allows the Texas Railroad Commission to approve injection projects that have the problems and defects discussed by this letter.

A letter format, instead of a report format, has been used to convey this information in an effort to maintain an informal dialogue concerning these problems. This work has been a non-funded effort. Any additional, non-funded time I spend related to these problems will be limited. Also, the problems discussed by this letter are very politically incorrect issues. They are politically incorrect because so many individuals have approved injection projects that are operating with these problems. I have had difficulty finding individuals willing to do the "right thing" concerning these issues.

Please let me know if you have questions concerning the information in this letter. I can be reached by telephone at (•••) •••-•••• or by mail at the address listed in the letterhead of page 1. A copy of my capabilities brochure has been enclosed to give you some idea of my professional credentials and business functions.

Sincerely,

**ORIGINAL SIGNED by David Voorhis**

David B. Voorhis, Ph.D., P.E.  
Owner

### **Additional Documents referenced by Letter:**

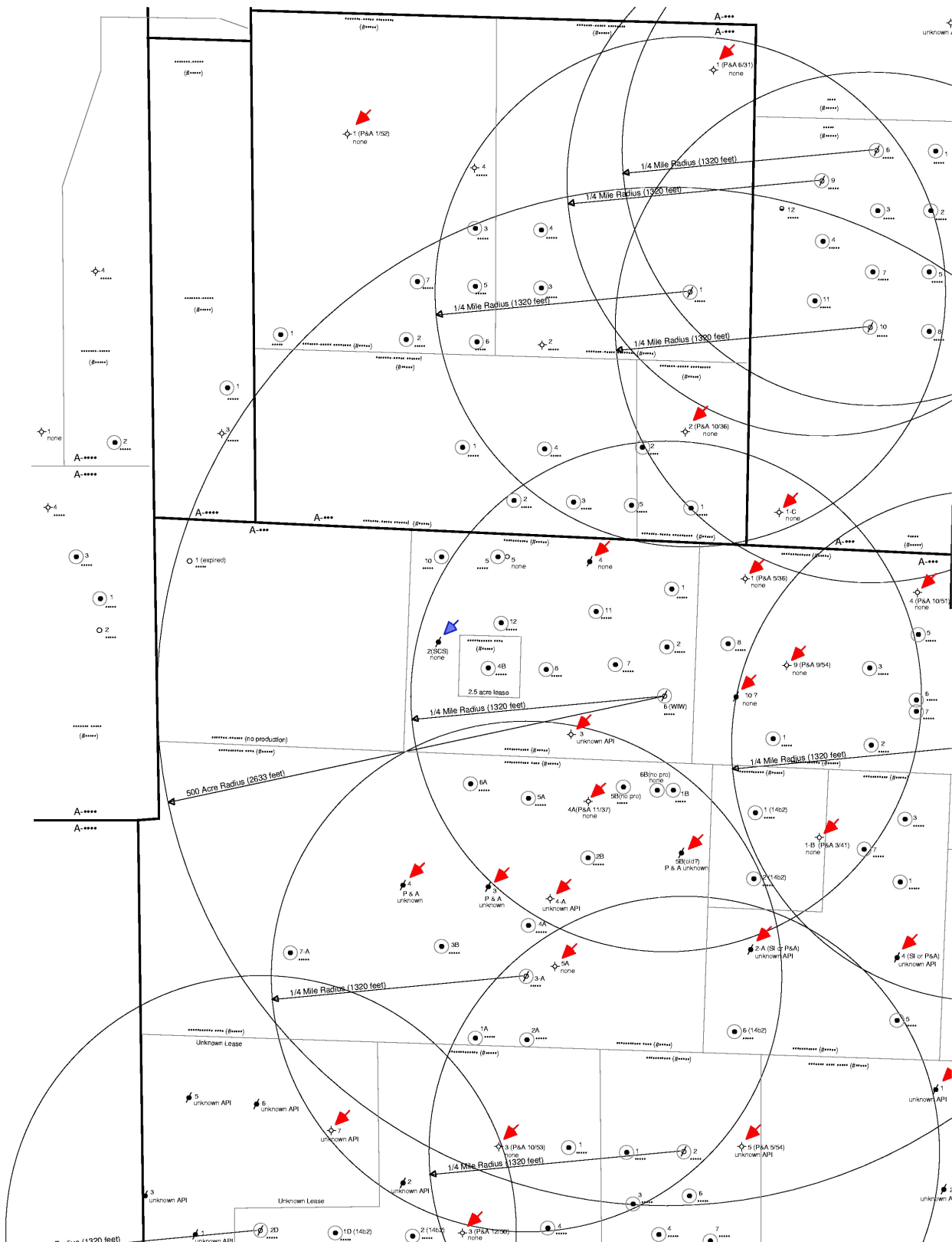
- 1) References to the superscripted numbers in the letter and attached geologic figures.
- 2) Map #9: 500+ Acre Study Area Map with 9 AOR Circles (located in the Cooke County Regular Field, Texas)
- 3) Figure 4: Base of Cretaceous Age Rock Contours for the Region (Approximate Base of Usable Quality Ground Water)
- 4) Figure 5: Cross-section of Ground Water Aquifers in the Region
- 5) Table C.2: Table of General Information on 9 Salt Water Disposal/Water Injection Wells in the Study Area
- 6) Table C.3: Table of 29 Suspected or Known Improperly Plugged Wells in the Study Area

### References to Letter and Attached Geologic Figures:

- 1) Matthews, C. S., and Russell, D. G.: *Pressure Buildup And Flow Tests in Wells* SPE Monograph Volume 1, SPE Dallas (1967), 4-17, 49-57.
- 2) Earlougher, R. C.: *Advances In Well Test Analysis* SPE Monograph Volume 5, SPE Dallas (1977), 6-15.
- 3) L. P. Dake: *Fundamentals of reservoir engineering*, Elsevier Scientific Publishing Company: Amsterdam (1981), 133-137.
- 4) Horne, R. N.: *Modern Well Test Analysis - A Computer-Aided Approach*, Petroway, Inc. Palo Alto (1990), 20-26.
- 5) Matthews, C. S., Brons, F. and Hazebroek, P.: "A Method for Determination of Average Pressure in a Bounded Reservoir," *Trans.*, AIME (1954) **201**, 182-191.
- 6) Warner, D. L. and McConnell, C. L.: "Abandoned Oil and Gas Industry Wells -- A Quantitative Assessment of their Environmental Implications," API Publication 4507 (1990).
- 7) Nordstrom, P. L.: "Occurrence, Availability, And Chemical Quality of Ground Water In The Cretaceous Aquifers Of North-Central Texas," Volumes 1 & 2, Report 269, Texas Department of Water Resources (April 1982).

# LEFT Side of Map 9

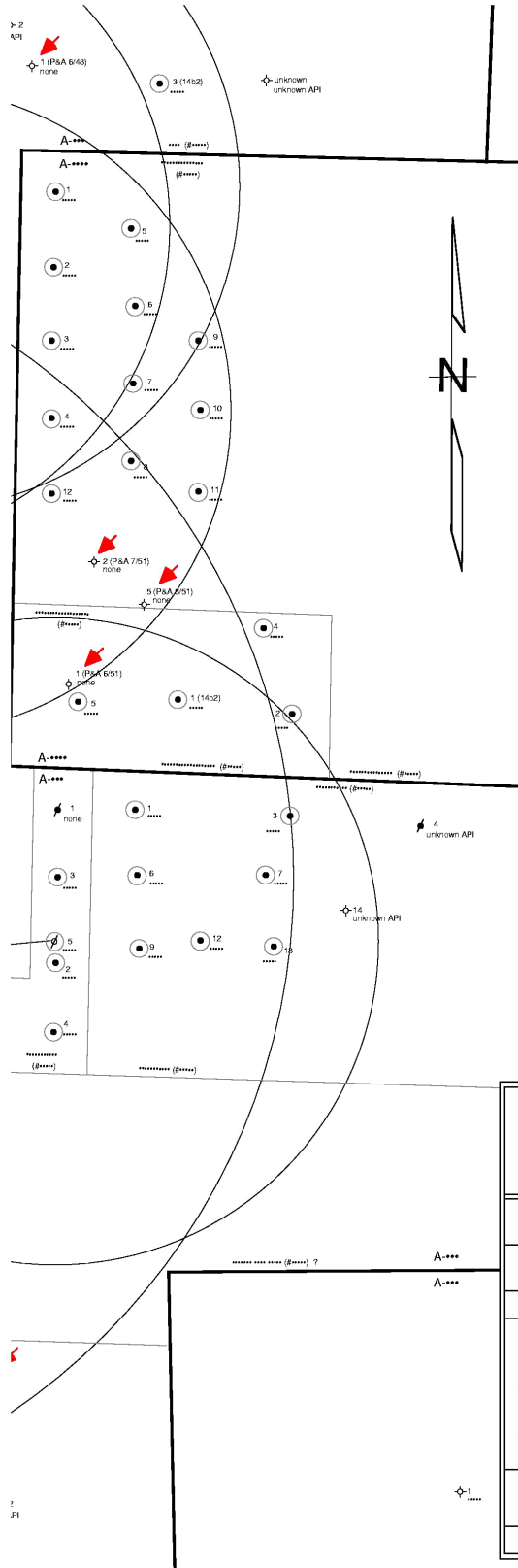
## Map 9: Split into TWO Pages (original size 11 x 17 inches)



# RIGHT Side of Map 9

Map 9: Split into TWO Pages (original size 11 x 17 inches)

Map #9



Completion Zone Color Legend	
○	Davenport Lime/Sand
○	Solomon Sand
○	Strawn "A" Sand
○	Strawn "B" Sand
○	Assumed Strawn "B" (unknown)
○	Childress Sand
○	Geurin Strawn/Basil Sand
○	Ellenburger

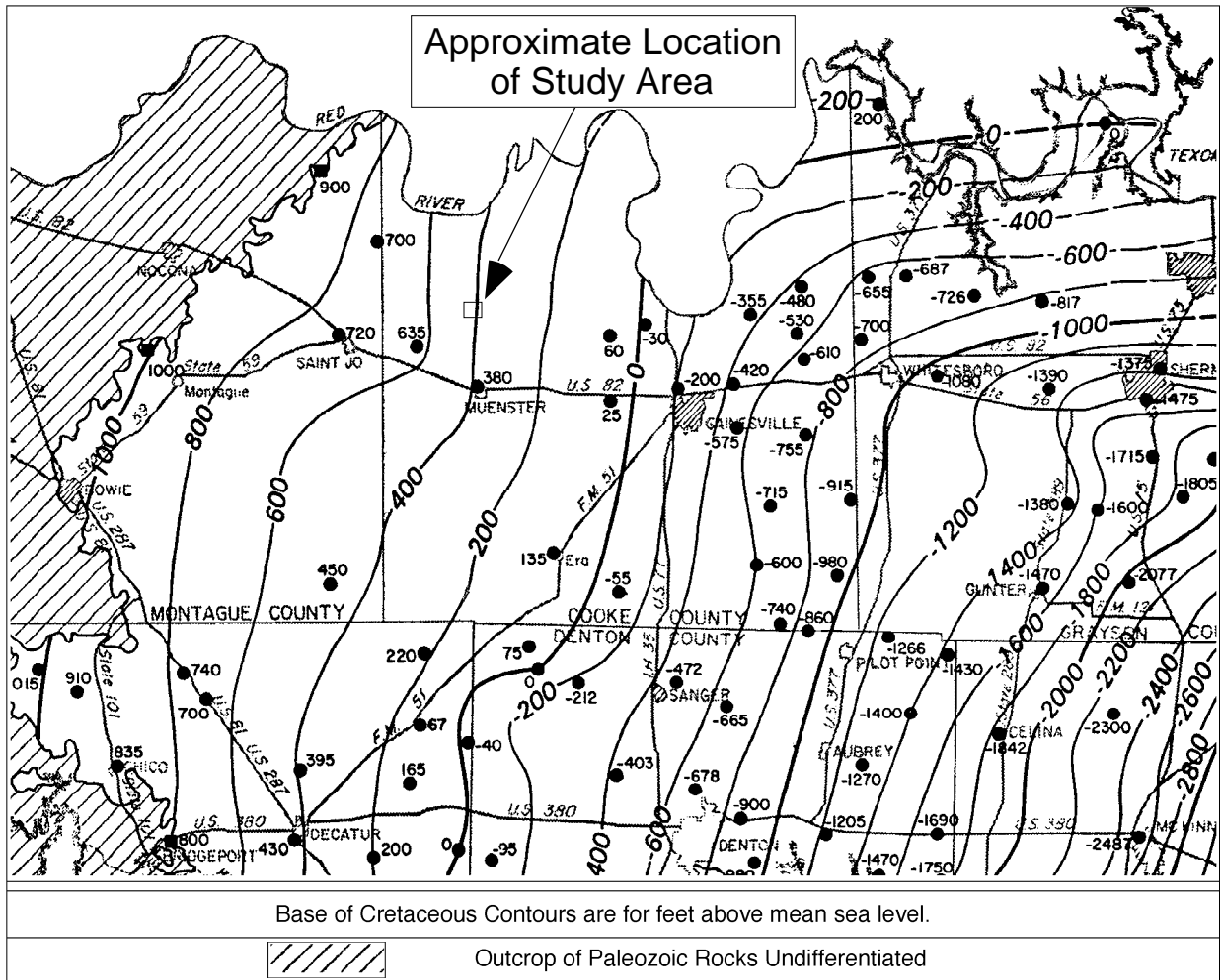
The completion zones are based upon geologic data and completion reports on file at the Texas Railroad Commission (TRRC) prior to the date of this map. There may be wells completed in zones that are different than what is indicated by this map. Some completion information may be inaccurate because some operators in this area have not been diligent about filing the required forms with the TRRC concerning their operations.

Symbol Legend	
○	Drilling Location
●	Cased Well - No Completion
●	Oil Well
⊕	Injection or SWD Well
⊖	Plugged Oil Well
⊕	Plugged Dry Hole
⚡	Marker for Suspected or Known Improperly Plugged Well

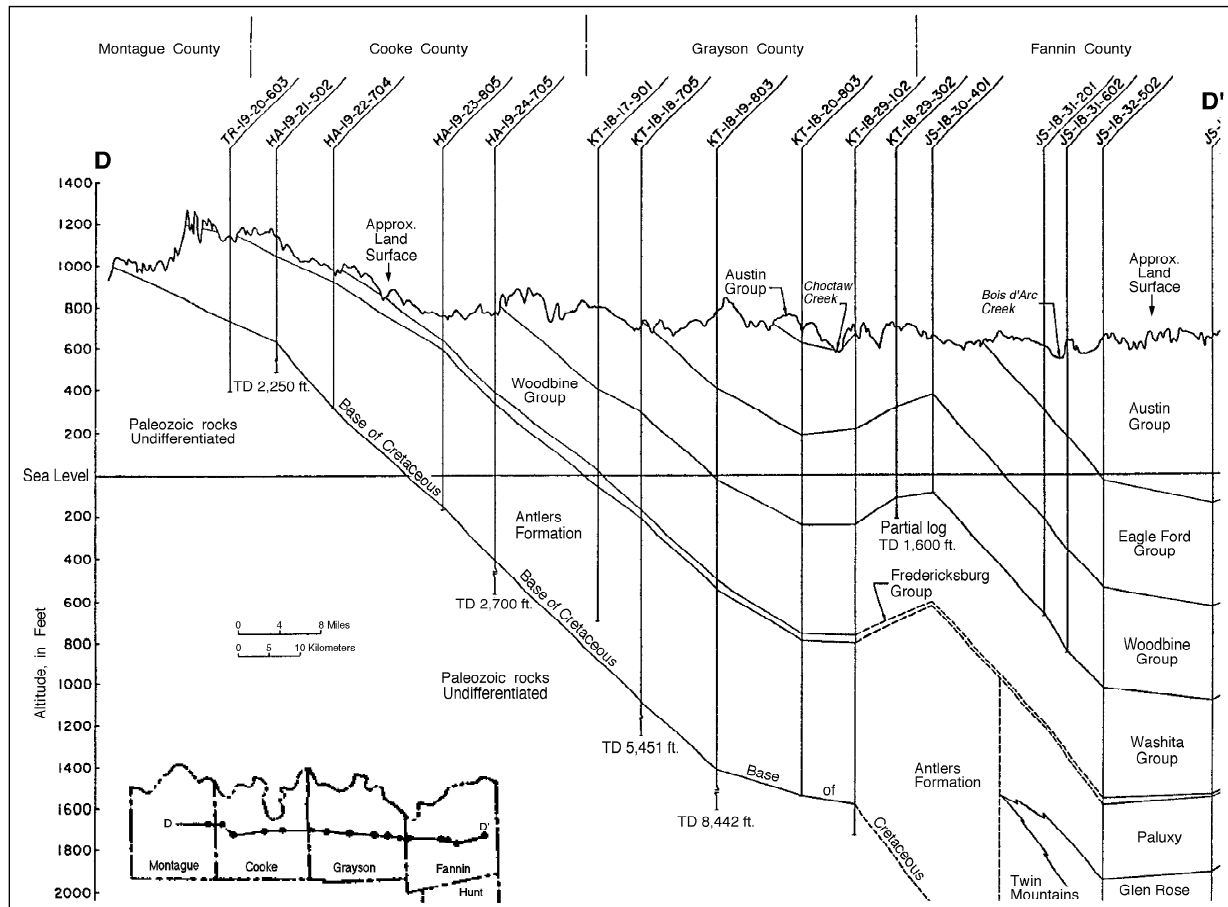
**Note:** The last 5 digits of each well's API number are labeled below the well number.

Some operators in this study area have not been diligent about filing required reports and forms to the Texas Railroad Commission concerning their operations. For this reason, other producing and improperly plugged wells may exist in this study area which are not known. Also, some of the map's plugged oil wells, which are not marked as improperly plugged, may be improperly plugged.

<p><b>1/4 Mile Area of Review (AOR)</b> Circles for 8 Injectors or Salt Water Disposal Wells (SWD's) around ..... WIW #6</p>
<p>A - *** , * , * , * , * Co. Survey Cooke County, Texas</p>
<p>Cooke County Regular Field Texas Railroad Commission District 9</p>
<p>Map Scale: 1 inch = 600 feet</p>
<p>Well locations, lease boundaries and abstract lines are approximate. Some well numbers, well locations and lease boundaries are estimates based on well/drilling records found in the Central Records Department of the Texas Railroad Commission. Abstract lines and other well numbers and locations are based on the Texas Railroad Commission's computer database map.</p>
<p>Prepared by: David Voorhis of David Voorhis &amp; Associates Austin, Texas</p>
<p>Date: January 20, 1997</p>



**Figure 4:** Base of Cretaceous Age Rock Contours for the Region (Approximate Base of Usable Quality Ground Water, adapted from Nordstrom<sup>7</sup>)



**Figure 5: Cross-section of Ground Water Aquifers in the Region**  
(adapted from Nordstrom<sup>7</sup>)



**Table C.3:** Suspected or Known Improperly Plugged Wells around the ..... (Lease #.....) Well No. 6, Project No. F....., Cooke County Regular Field, Texas

Fig. No.	Current TRRC Lease No. Location	Current Lease Name Location	Estimated Original Lease Name when Drilled/Plugged	Well No.	Approximate Distance from ..... WIW No. 6 (ft)	Estimated Date Plugged	Estimated Total Depth (ft)	Estimated Base of Useable Quality Water (Depth in ft)	Injection/Disposal Operations Plugged Status
C.3	.....	.....	.....	1	740	May-36	1800	670	Suspected Improperly Plugged
C.4	.....	.....	.....	4	1,420	10/15/51	1611	670	Improperly Plugged
C.5	.....	.....	.....	9	660	9/29/54	1919	670	Improperly Plugged
C.6	.....	.....	.....	10?	360	unknown	1864	670	Suspected Improperly Plugged
C.7	.....	.....	.....	3	2,980	12/12/50	1680	700	Suspected Improperly Plugged
C.8	.....	.....	.....	3	2,490	10/8/53	1960	850	Suspected Improperly Plugged
C.9	.....	.....	.....	5	2,370	5/30/54	1826	700	Suspected Improperly Plugged
C.10	.....	.....	.....	2(SCS)	1,200	prior to 3/24/41	1655	670	Suspected Improperly Plugged
C.11	.....	.....	.....	3	530	Feb-52	1995	670	Suspected Improperly Plugged
C.12	.....	.....	.....	4	800	Nov-53	1756	670	Suspected Improperly Plugged
C.13	.....	.....	.....	6	not applicable	WIW	1800	670	Project No. F.....
C.14	.....	.....	.....	1-B	1,080	3/24/41	1867	670	Improperly Plugged Well
C.15	.....	.....	.....	1	1,890	2/6/52	1488	700	Suspected Improperly Plugged
C.16	.....	.....	.....	2-A	1,390	unknown	1847	850	Suspected Improperly Plugged
C.17	.....	.....	.....	4	1,820	unknown	unknown	700	Suspected Improperly Plugged
C.18	.....	.....	.....	3	1,350	unknown	unknown	850	Suspected Improperly Plugged
C.19	.....	.....	.....	4	1,675	unknown	unknown	850	Suspected Improperly Plugged
C.20	.....	.....	.....	4-A	1,210	3/22/64	unknown	850	Suspected Improperly Plugged
C.21	.....	.....	.....	4A	680	11/26/37	unknown	850	Suspected Improperly Plugged
C.22	.....	.....	.....	5A	1,520	11/22/75	1695	850	Improperly Plugged Well
C.23	.....	.....	.....	5B(old?)	825	1954 or 1955	1600	850	Suspected Improperly Plugged
C.24	.....	.....	.....	1	2,480	unknown	unknown	700	Suspected Improperly Plugged
C.25	.....	.....	.....	1-C	1,120	est. April 1951	2072	700	Suspected Improperly Plugged
C.26	.....	.....	.....	2	2,235	7/9/51	1990	700	Suspected Improperly Plugged
C.27	.....	.....	.....	5	2,315	8/11/51	1985	700	Suspected Improperly Plugged
C.28	.....	.....	.....	1	3,670	6/16/48	1351	700	Improperly Plugged Well
C.29	.....	.....	.....	1	3,340	1/5/52	2143	700	Improperly Plugged Well
C.30	.....	.....	.....	1	3,250	Jun-36	1153	700	Suspected Improperly Plugged
C.31	.....	.....	.....	2	1,370	Oct-36	1636	700	Suspected Improperly Plugged
C.32	Unknown	Unknown Lease	Unknown	7	2,850	unknown	unknown	850	Suspected Improperly Plugged