# Highlights of Technical Analysis for TexCom's Permit Application WDW-410 Class I Well

An Oversight Exercise by EPA, Region 6

November, 2012

EPA, Region 6
Dallas, Texas

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# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## A Discussion on Relevant Parameters, Parameter Values, Injection Reservoir Pressure Build Up Modeling, Aquifer Contamination Risk Assessment for Permitted Operation and UIC Program Performance Assessment

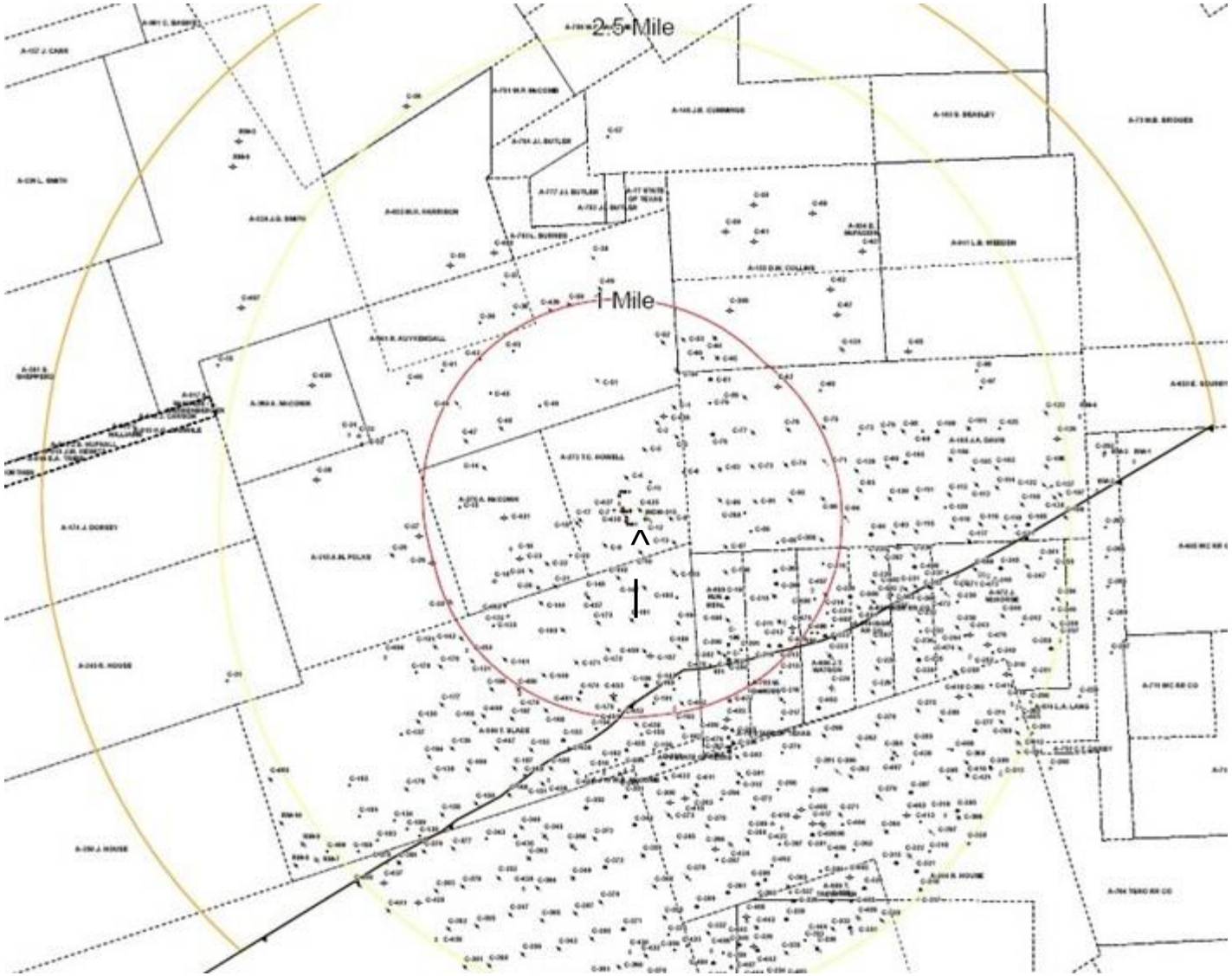
Ms Lorrie: This discussion on the engineering data associated with the processing of the permit application for TexCom's WDW-410 well, and the technical analysis of these data, seeks to provide an insight on the reasons behind EPA R6's determination that the approval of TexCom's application is cause for concern.

This discussion attempts to provide fine details of the engineering evaluation of the permitted injection operation carried out by me, José E. Torres, in my capacity of Delegated UIC Program Manager, at the request of my superiors, following the numerous complaints sent to R6 by citizens of Montgomery County.

Details of the engineering evaluation are provided in order to assist TCEQ's UIC Team better understand the basis for the views expressed in EPA R6's Delegated UIC Program Review Reports discussed with you and other team members on October 12, 2012. It also seeks to provide TCEQ's UIC Team an opportunity to offer scientific validation for the parameters and methodology used in evaluating the TexCom application, which might justify modifying the views expressed in the above program performance reports.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Location of Conroe Oil Field Wells Within 2.5 Miles of the Permitted Injection Well




This map illustrates the location of the permit well relative to the fault found at about 4400 Ft to the South.

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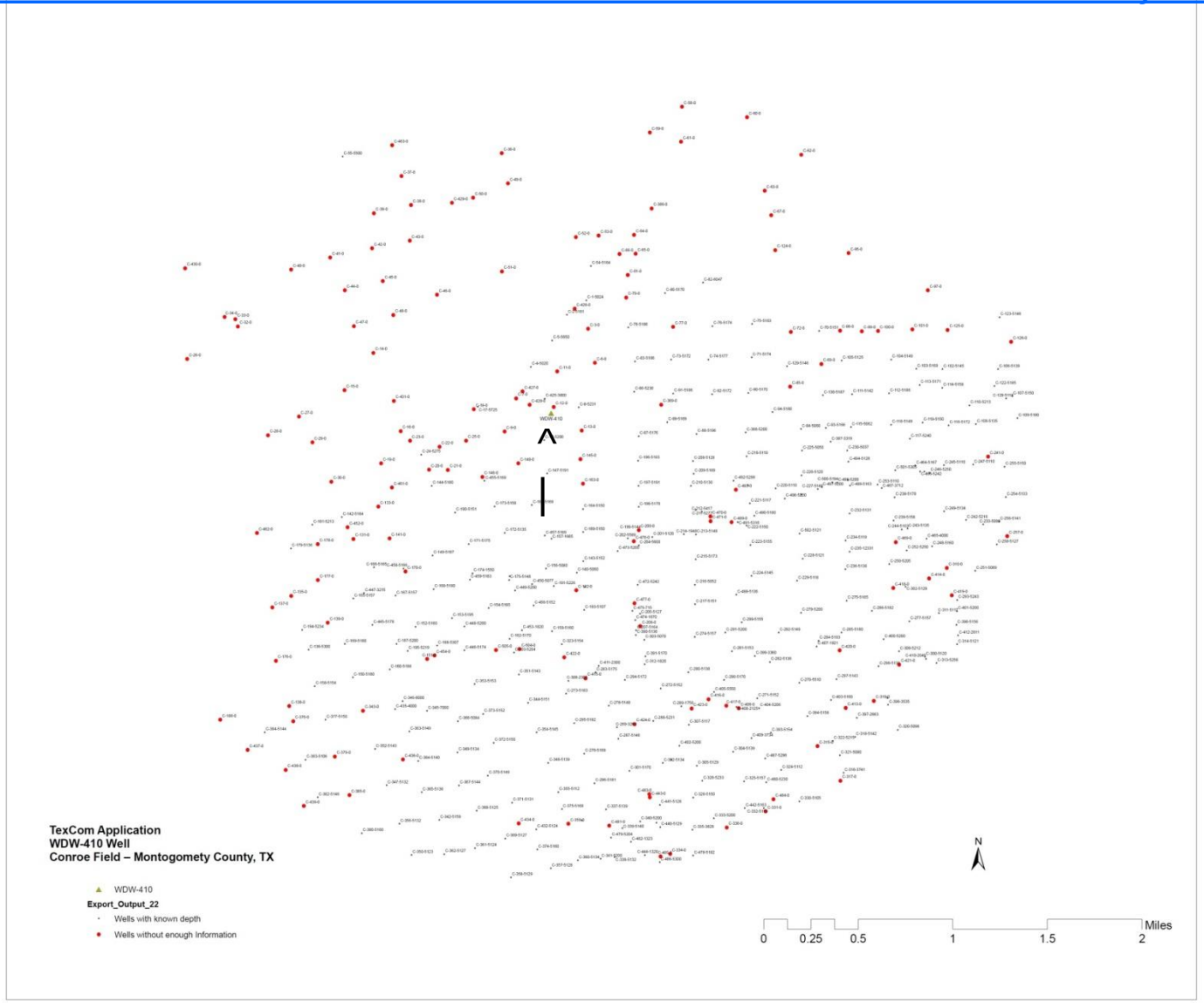


Of the 505 wells located within a 2.5 miles radius from the injector, 179 have an "unknown status" (red dots). Of these, 32 could not be spotted on the map due to a lack of location data. The arrow points to the permitted injection well's location.

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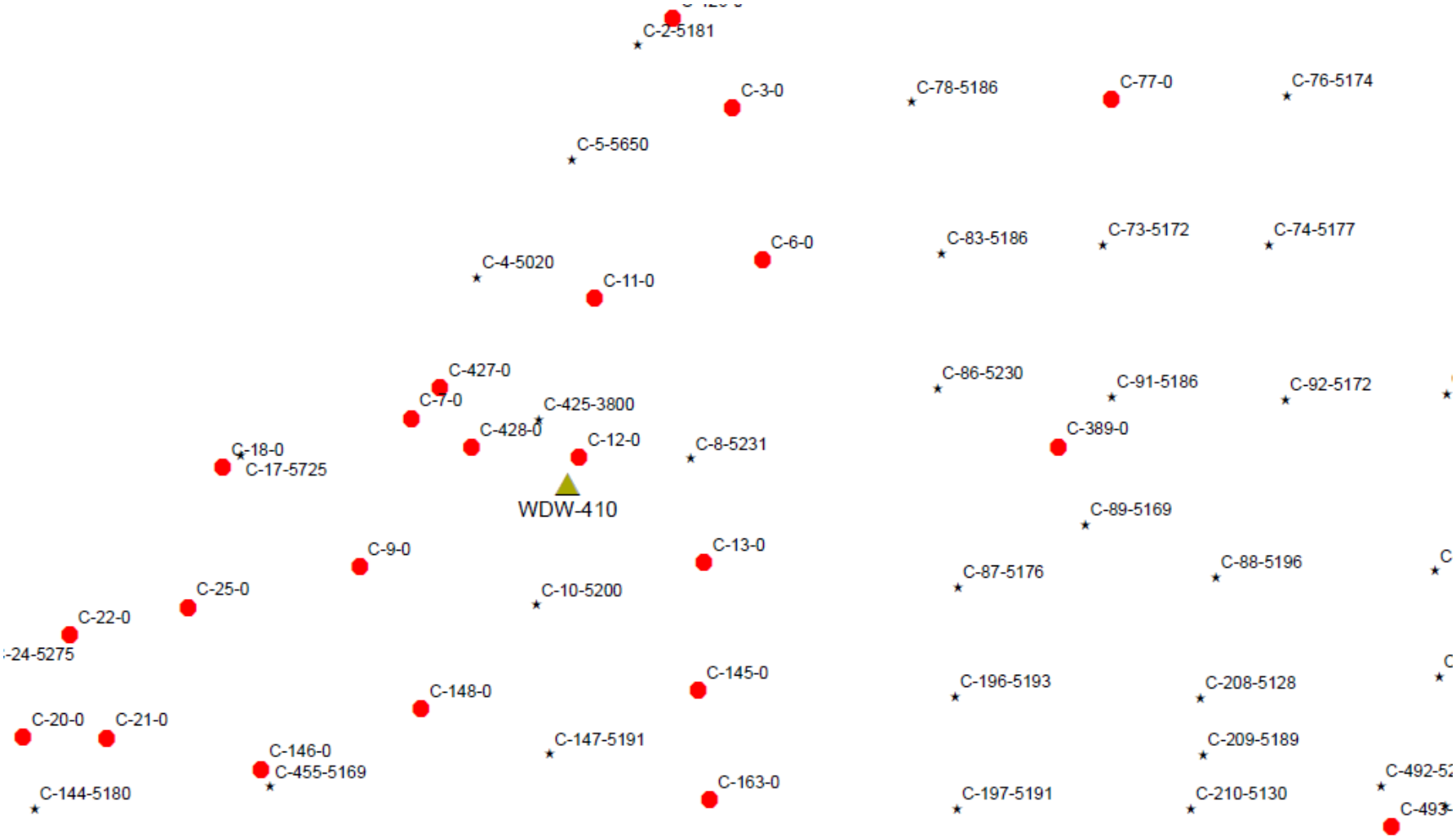
## Location of Conroe Oil Field Wells Within 2.5 Miles of the Injection Well




Above, a closer view of the WDW-410's location. The red circles represent wells with an "unknown status". The zero at the end of these wells' ID indicates that no TD data were available.

The C-12-0 well was recently plugged by the Railroad Commission. The plugging report provided no evidence that the well might have undergone "self closure".

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Wells Within a 2.5 Mile Radius From The Injector Whose Status Is Listed As "Unknown"

**Table of Approximate Distances Between WDW-410 & Wells Without Enough Information**

**Conroe Field - Montgomery County, TX**

| Map ID Number | Miles | Feet | Map ID Number | Miles | Feet | Map ID Number | Miles | Feet | Map ID Number | Miles | Feet |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WDW-410 | 0.00 | 0 | C-431 | 0.86 | 4536 | C-422 | 1.21 | 6367 | C-424 | 1.60 | 8438 |
| C-12 | 0.03 | 173 | C-66 | 0.87 | 4578 | C-131 | 1.24 | 6563 | C-98 | 1.62 | 8576 |
| C-428 | 0.12 | 656 | C-52 | 0.88 | 4633 | C-452 | 1.24 | 6567 | C-423 | 1.64 | 8683 |
| C-13 | 0.19 | 986 | C-192 | 0.88 | 4666 | C-30 | 1.24 | 6568 | C-416 | 1.65 | 8711 |
| C-427 | 0.19 | 999 | C-65 | 0.91 | 4804 | C-42 | 1.27 | 6698 | C-58 | 1.67 | 8815 |
| C-7 | 0.21 | 1082 | C-53 | 0.91 | 4813 | C-44 | 1.28 | 6740 | C-135 | 1.68 | 8860 |
| C-11 | 0.21 | 1101 | C-461 | 0.94 | 4975 | C-38 | 1.28 | 6749 | C-462 | 1.71 | 9017 |
| C-9 | 0.27 | 1428 | C-19 | 0.96 | 5064 | C-85 | 1.31 | 6901 | C-417 | 1.73 | 9126 |
| C-145 | 0.28 | 1466 | C-48 | 0.99 | 5206 | C-29 | 1.31 | 6908 | C-99 | 1.74 | 9178 |
| C-148 | 0.31 | 1614 | C-64 | 0.99 | 5209 | C-36 | 1.31 | 6911 | C-32 | 1.76 | 9287 |
| C-6 | 0.34 | 1812 | C-470 | 1.01 | 5309 | C-415 | 1.32 | 6968 | C-406 | 1.78 | 9384 |
| C-163 | 0.39 | 2051 | C-14 | 1.01 | 5349 | C-454 | 1.35 | 7145 | C-33 | 1.78 | 9403 |
| C-18 | 0.42 | 2228 | C-471 | 1.02 | 5373 | C-72 | 1.36 | 7202 | C-343 | 1.79 | 9447 |
| C-3 | 0.46 | 2434 | C-477 | 1.04 | 5495 | C-27 | 1.37 | 7253 | C-137 | 1.80 | 9478 |
| C-25 | 0.48 | 2552 | C-133 | 1.05 | 5536 | C-39 | 1.38 | 7285 | C-95 | 1.80 | 9508 |
| C-146 | 0.49 | 2584 | C-493 | 1.07 | 5671 | C-151 | 1.39 | 7328 | C-60 | 1.81 | 9538 |
| C-426 | 0.53 | 2800 | C-141 | 1.08 | 5678 | C-37 | 1.42 | 7522 | C-100 | 1.82 | 9631 |
| C-389 | 0.60 | 3167 | C-170 | 1.11 | 5878 | C-178 | 1.43 | 7530 | C-34 | 1.84 | 9719 |
| C-21 | 0.63 | 3320 | C-489 | 1.12 | 5909 | C-41 | 1.43 | 7534 | C-62 | 1.86 | 9842 |
| C-22 | 0.63 | 3331 | C-45 | 1.12 | 5936 | C-124 | 1.46 | 7710 | C-436 | 1.89 | 9973 |
| C-79 | 0.70 | 3700 | C-15 | 1.13 | 5974 | C-59 | 1.48 | 7832 | C-176 | 1.93 | 10206 |
| C-20 | 0.72 | 3809 | C-50 | 1.14 | 6040 | C-69 | 1.49 | 7869 | C-483 | 1.95 | 10308 |
| C-200 | 0.75 | 3948 | C-386 | 1.15 | 6057 | C-61 | 1.51 | 7986 | C-420 | 1.96 | 10337 |
| C-51 | 0.75 | 3950 | C-43 | 1.15 | 6059 | C-177 | 1.51 | 7993 | C-443 | 1.97 | 10396 |
| C-476 | 0.78 | 4095 | C-49 | 1.16 | 6105 | C-67 | 1.54 | 8154 | C-469 | 1.98 | 10457 |
| C-23 | 0.78 | 4124 | C-47 | 1.16 | 6108 | C-28 | 1.55 | 8162 | C-26 | 2.00 | 10560 |
| C-77 | 0.79 | 4159 | C-206 | 1.16 | 6108 | C-463 | 1.58 | 8337 | C-101 | 2.01 | 10605 |
| C-81 | 0.80 | 4211 | C-429 | 1.17 | 6171 | C-40 | 1.58 | 8359 | C-359 | 2.03 | 10695 |
| C-16 | 0.82 | 4354 | C-504 | 1.18 | 6207 | C-139 | 1.60 | 8428 | C-138 | 2.03 | 10718 |
| C-46 | 0.85 | 4503 | C-505 | 1.21 | 6366 | C-63 | 1.60 | 8434 | C-434 | 2.03 | 10719 |

Seen here is a partial list of the wells with "unknown status". As shown below, the inter-well distance information in this Table made it possible to analyze the injection pressure effects at the location of some of these wells with "unknown status".

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Permitted Injection Zone

**Table V.B.1.4: Local Stratigraphic Column**

| Local Stratigraphic Column<br>TexCom Facility, Montgomery County, Texas | | | | |
|---|---|---|---|---|
| SYSTEM | STAGE | GROUP or FORMATION | | Regulatory/Hydrostratigraphic Unit |
| Quaternary | Pleistocene | Gulf Coast Aquifer System | | Aquifers |
| Tertiary (Part) | Pliocene | | | |
| | Miocene | | | |
| | Oligocene | Catahoula Formation (Frio/Vicksburg) | | Buffer and Aquiclude<br>Base of Lowermost USDW |
| | Eocene (Part) | Jackson Formation | | Upper Confining Zone |
| | | Cockfield Formation | Upper Member | Injection Zone |
| | | | Middle Member | |
| | | | Lower Member | |
| | | | Shale Member | Lower Confining Zone |

The application document clearly identifies the injection zone as consisting of the three members of the Cockfield Formation, including the oil producing Upper Cockfied, currently operated by Denbury Onshore, LLC.

Ms. Lorrie:

The argument was made that no remedial measures were necessary regarding the potential for vertical migration of fluids through the large number of wells that could potentially provide a pathway out of the injection zone, because those wells would have undergone “natural closure”.

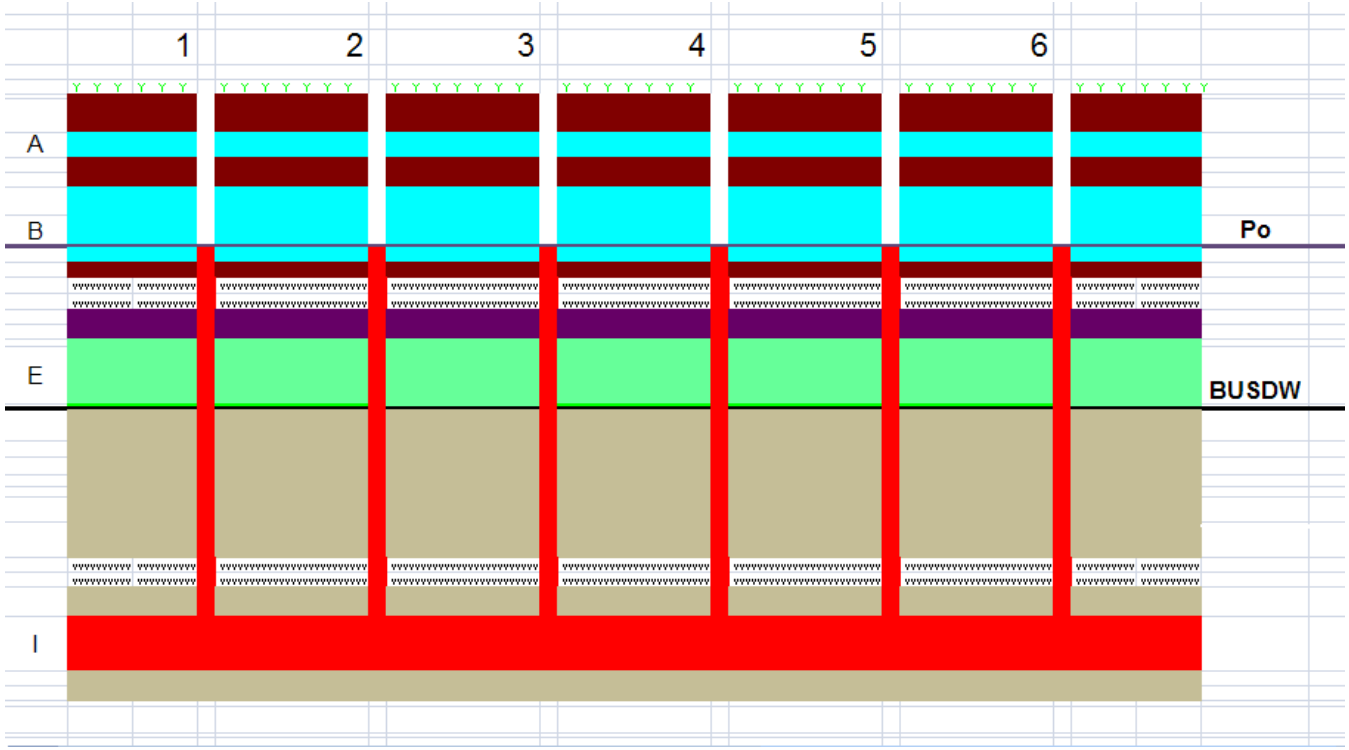
My assessment is that, without data on “natural closure”, specific to Montgomery County, the argument on well “natural closure” would appear to be an unproven hypothesis.

As a result, no scientific data seem to be available on which to base an important decision such as that of not requiring the plugging of wells which might potentially allow the injected fluids, and native fluids to leak out of the injection zone under pressure.

As noted, the Upper Cockfield is an oil producing horizon, and it has been made part of the injection zone. Waste injected into the Upper Cockfield is bound to find its way out of this zone through producing wells.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Conceptual Reservoir Fluid Mechanics Model for WDW-410 Prior to Injection




The above generic cross section illustrates the presence of several USDWs: A through E. Wells 1 through 6 penetrate, and are in hydraulic communication with, deeper Aquifer I. All areas of Aquifer I are hydraulically connected.

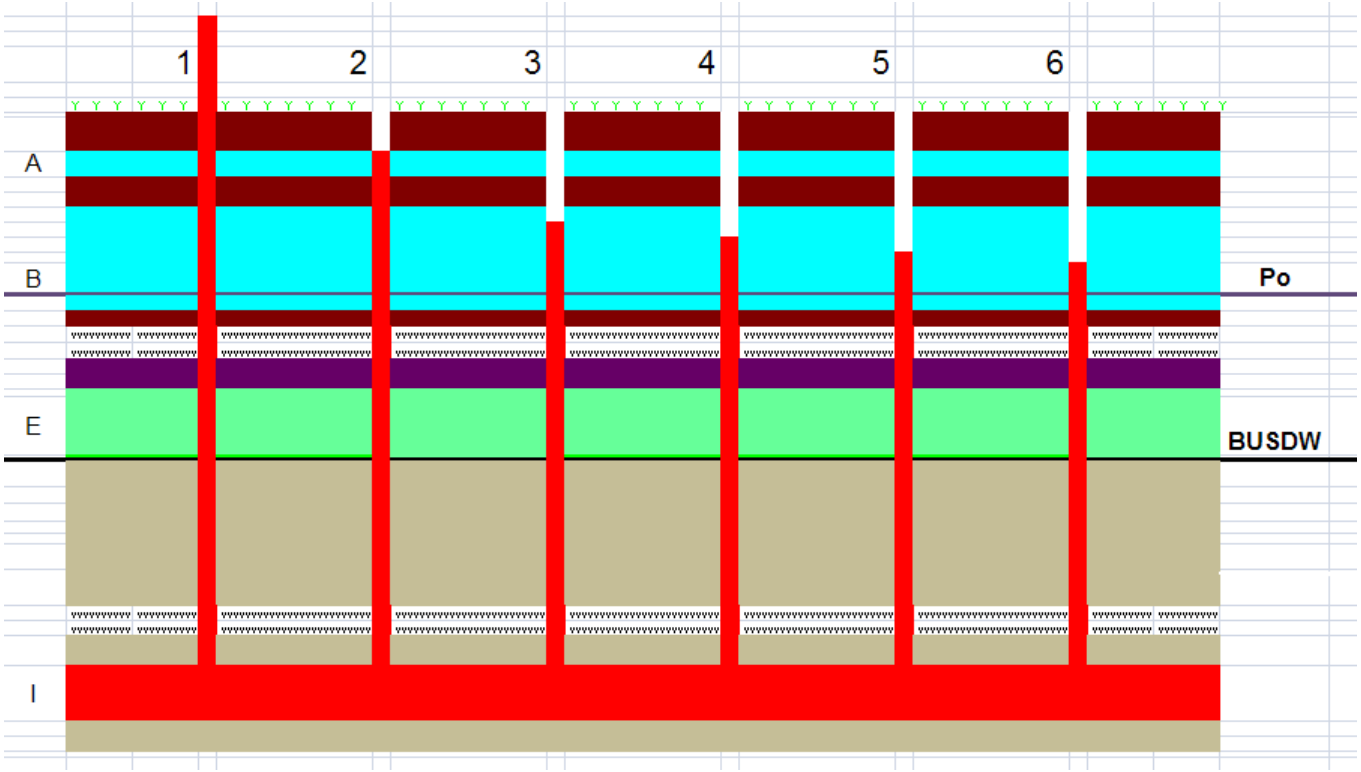
The fluid level (hydrostatic column) in these wells attests to the initial reservoir pressure, Po, in Aquifer I.

Po is of such magnitude that it places the piezometric surface of Aquifer I **above the base of the USDWs** (BUSDW). Fluids in Aquifer I could potentially flood the existing USDWs, per the above model.

The TexCom provided field data indicate that **the initial static condition of the target injection zone in the WDW-410 well Is similar to the situation illustrated above,** as far as the disposal system's initial fluid mechanics is concerned.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Conceptual Reservoir Fluid Mechanics Model for WDW-410 During Injection




The above graph illustrates how the initial static pressure conditions seen in the previous Slide are disturbed by injection of fluids into Well 1 (the injection pressure at this well may correspond to a hydrostatic column extending well above ground level).

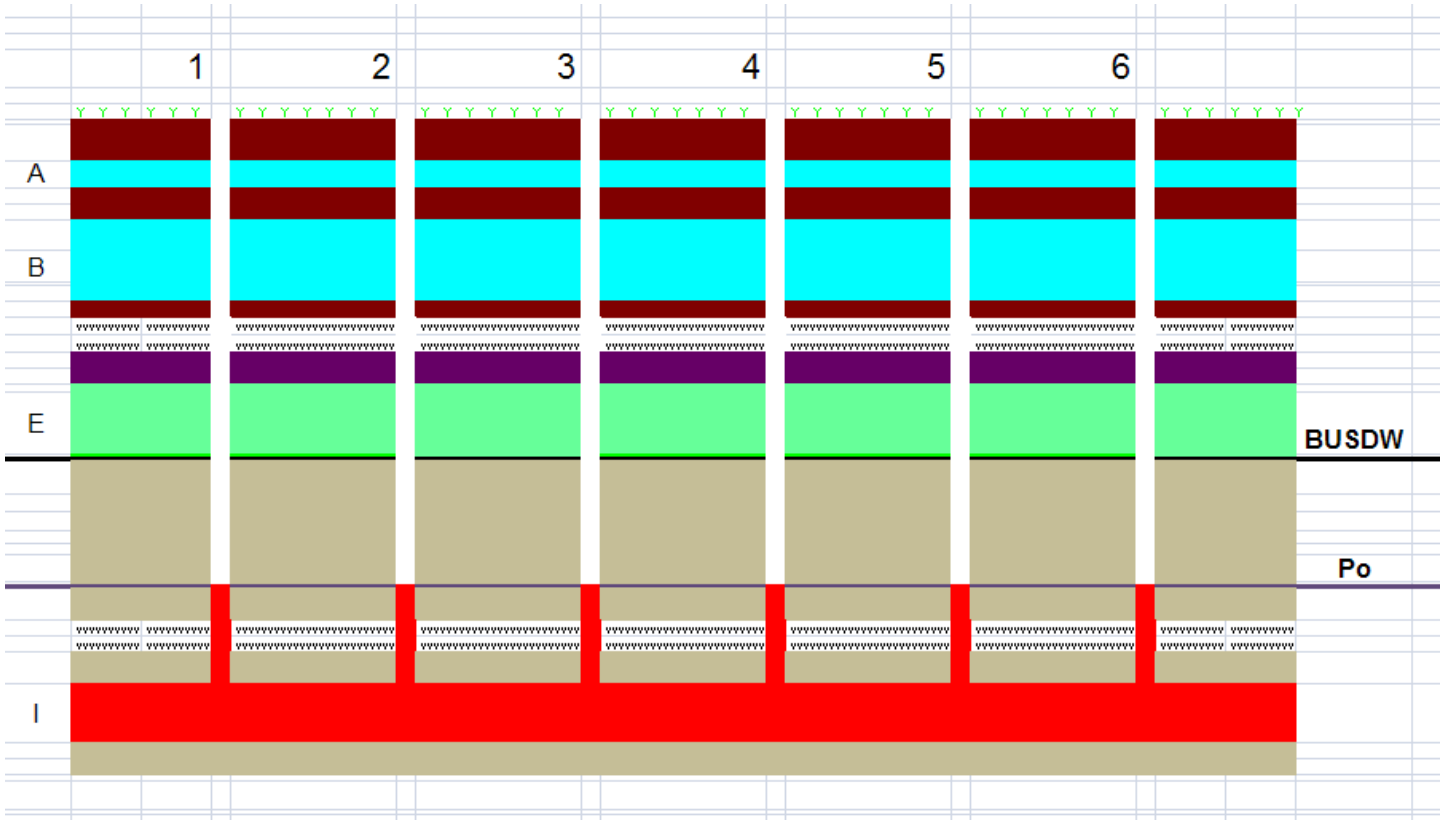
It can be seen that the reservoir pressure at the location of wells 2 through 6 increases as injection proceeds, causing the hydrostatic column in these wells to rise closer to the ground surface.

Fluids inside Aquifer I could now potentially become in contact with, and contaminate, other shallower USDWs.

The above graph illustrates how waste disposal injection into a well could increase the risk of USDW degradation at every point inside an already pressurized disposal reservoir (**i.e.: a reservoir with an infinite Radius of Endangerment, RE**).

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## A Conceptual Reservoir Fluid Mechanics Model Prior to Injection




The above cross section is similar to the first presented cross section. The only difference here is that the illustrated reservoir pressure, Po, in Aquifer I is of a lower magnitude and, as a result, the piezometric surface for this Aquifer is found below the base of the USDWs (BUSDW).

In this model, and prior to injection, the risk for movement of fluids from Aquifer I into the USDWs is zero.

This is basically the model used by all parties that argued in favor of the approval of the TexCom permit application, with Po set, for all practical purposes, at 0.0 psi.

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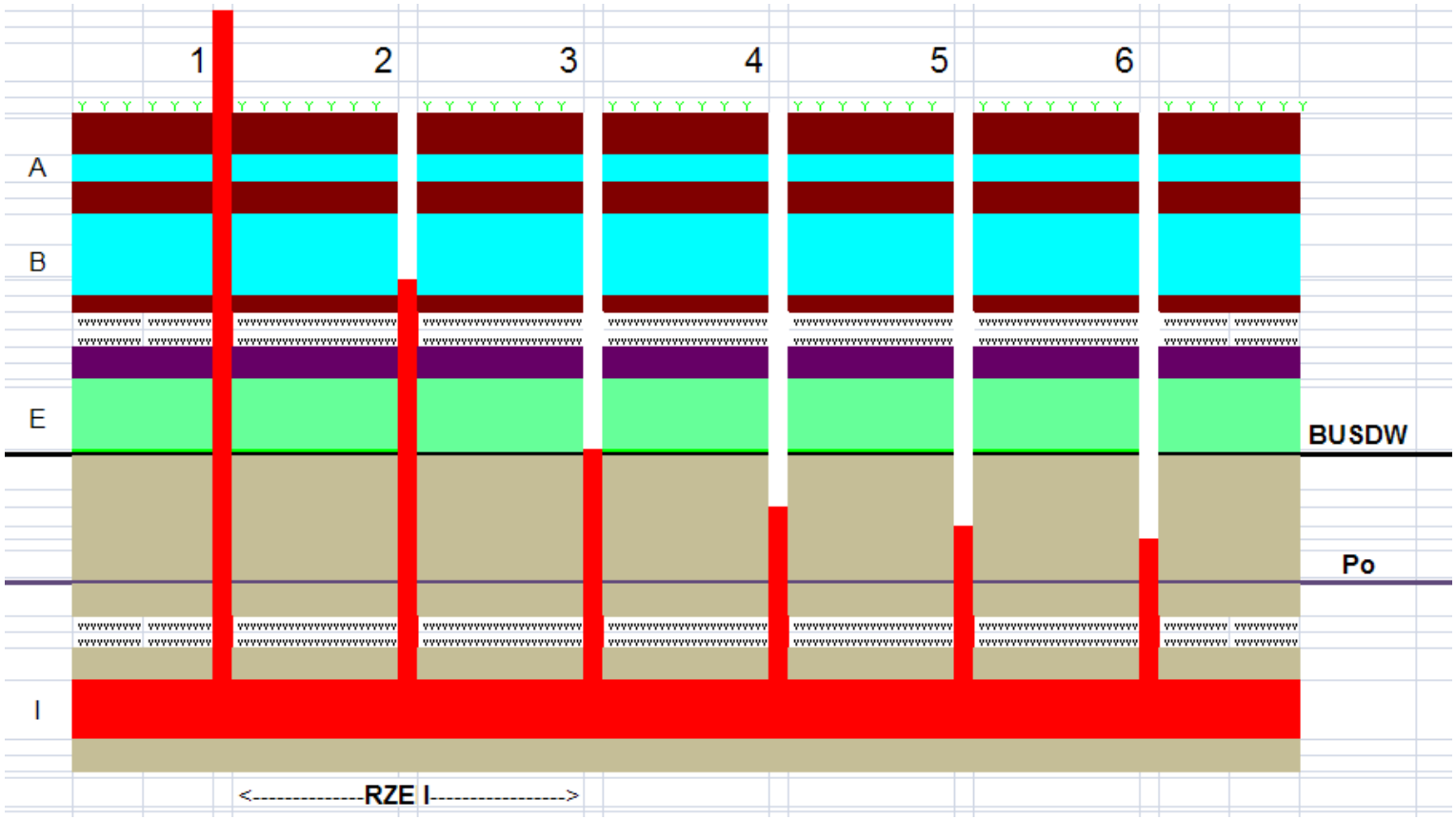
## A Conceptual Reservoir Fluid Mechanics Model During Injection




This cross section also illustrates the pressure effect of injection into Aquifer I, through injection Well 1, over a certain period of time.

It can be seen that, as a result of injection, the reservoir pressure at Well 3 is of such magnitude that it may cause liquids inside Aquifer I to potentially flood (contaminate) USDWs.

The distance between Well 1 and Well 3 Is called the Radius of the Zone of Endangering Influence (RZEI), or Radius of Endangerment, RE (slight variations of this model may result from consideration of other well and aquifer conditions).

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Modeling the Reservoir Pressure Response Effected by Injection

The mathematical model below is often used to evaluate the risk of contamination that an injection operation might induce. This model lends itself for what has been called by some "back of the envelope" computations.

**Evaluating this risk is at the heart of the technical review of a permit application for injection operations.**

In exercising its oversight authority, EPA R6 carefully reviewed, among other things, the process for obtaining the parameters relevant to the technical evaluations submitted by the parties, along with the proposed parameter values.

$$p = p_e + \frac{q\mu B_o}{14.16\ kh} Ei\left[\frac{-r^2}{4\ \eta t}\right]$$

As can be seen in the above mathematical model, the initial reservoir pressure, Pe*, the fluid viscosity, μ, the injection interval thickness, h, the injection zone permeability, k and porosity, ¢, are some of the parameters of interest.

The discussion that follows focuses in part on the results of EPA R6's review of these parameters as they relate to TexCom's permit application for injection well WDW-410.

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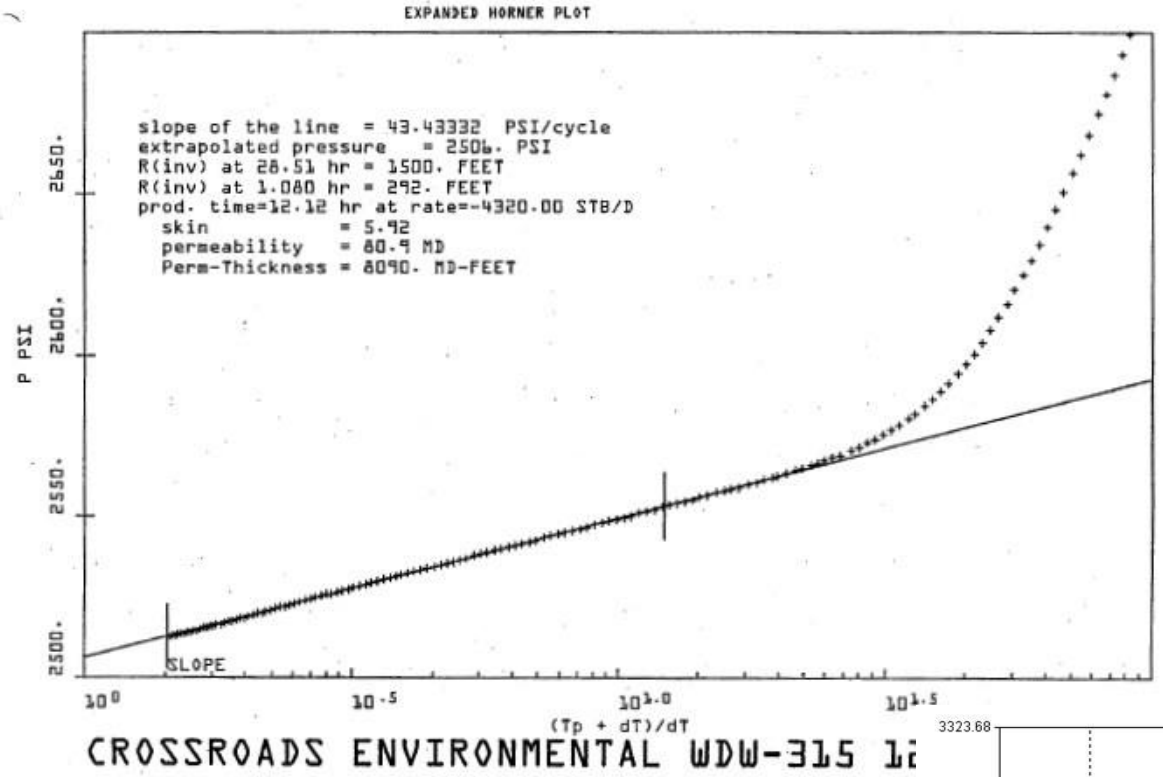
* Pe in the equation above is identical to Po posted on the schematic cross sections previously presented.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well




[Initial Reservoir Pressure Pe in the Permitted Injection Interval: The Lower Cockfield Sand]

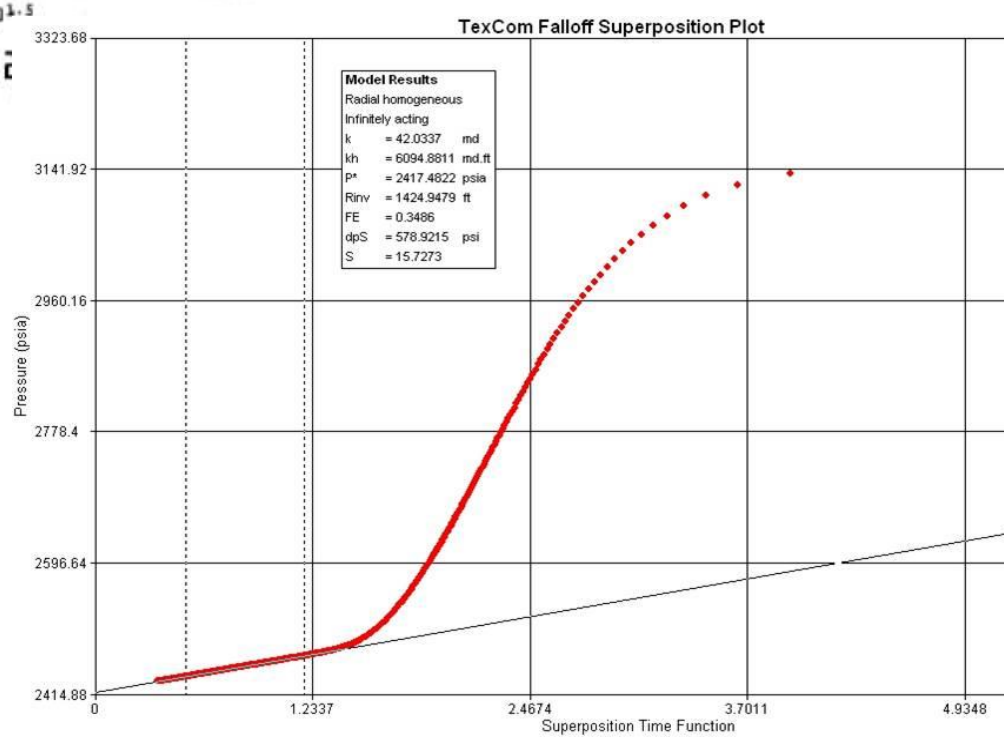
The base of the USDWs in the WDW-410 well has been estimated at 4088 Ft.

The 1999 Fall-Off Test indicated a static reservoir Pressure of 2506 psia at 6200 Ft

The 2009 Fall-Off Test indicated a static reservoir Pressure of 2417.5 psia at 6000 Ft

These pressure readings put the fluid level inside the permit well at roughly 690 Ft from the surface.

Since factual data show that Pe is not zero, and that, if given a flow path, the Lower Cockfield's fluids can migrate upward, beyond the base of the USDWs, it seems appropriate to say that the first two discussed cross sections model the fluid mechanics at WDW-410.



Ms. Lorrie:

It appears that, during the permit approval proceedings, no scientific justification was provided for having adopted the fluid mechanics reservoir model depicted in the last two cross sections shown in this discussion.

However, during the program review meeting of October 12, 2012, it was clear that Ms. Goss was upset with any reference in the review report to the location of the Piezometric Surface, as if it was irrelevant.

I am not a law major so, I can only attest to the importance of the selected model and its characteristics from an engineering standpoint. On that basis, I have said that the model with Pe set at zero psia is not applicable to the technical analysis of the WDW-410 permit.

Perhaps Ms. Goss may wish to shed some light as to why, from an attorney's perspective, the location of the piezometric surface in the aquifer in question falls outside the scope of the technical review of the subject permit, or the Review Report, for that matter. I look forward to hearing her explanation during the discussions I anticipate we will hold in the near future.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Permeability k in the Lower Cockfield

OMNI Laboratories, Inc.

### SUMMARY OF ROUTINE CORE ANALYSES RESULTS

Routine Samples

Crossroads Environmental
WDW 315 No. 1
East Conroe Field

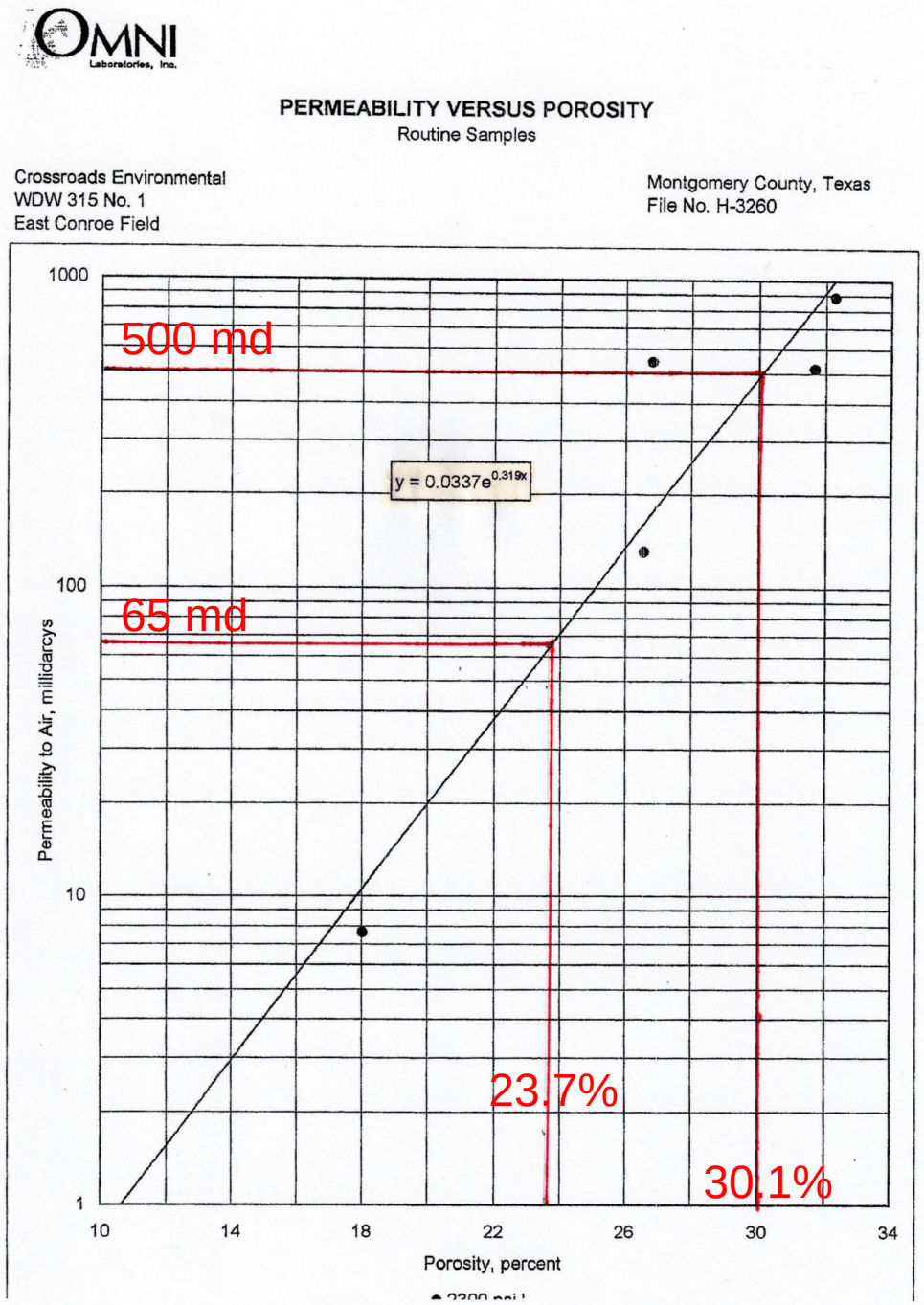
Montgomery County, Texas
File No. H-3260

| Core Number | Sample Number | Sample Depth, feet | Permeability, millidarcys to Air 2000 psi | Permeability, millidarcys Klinkenberg 2000 psi | Porosity, percent 2000 psi | Porosity, percent Ambient | Grain Density, gm/cc |
|---|---|---|---|---|---|---|---|
| 2 | 1 | 6071.52 | 518. | 485. | 31.7 | 34.1 | 2.66 |
| 2 | 2 | 6073.25 | 882. | 836. | 32.3 | 33.4 | 2.65 |
| 2 | 3 | 6077.55 | 545. | 511. | 26.8 | 27.7 | 2.64 |
| 2 | 4 | 6080.20 | 131. | 117. | 26.6 | 27.8 | 2.66 |
| 2 | 5 | 6082.96 | 7.63 | 6.00 | 18.0 | 19.3 | 2.69 |
| | | Average values: | 417. | 391. | 27.1 | 28.5 | 2.66 |

A 14 foot core from the Lower Cockfield was available for the WDW-410 well.

The shown excerpt from the lab report suggests that five core plugs were analyzed for air permeability and other parameters.

There is no evidence that results for whole core analysis are available.




# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Permeability k in the Lower Cockfield From Core and Log Data

The shown Porosity-Permeability cross-plot was provided by the applicant. It appears that the air permeability values were spotted in this cross-plot.

A review of the available porosity logs indicates that the average density porosity across the Lower Cockfield in the WDW-410 well is about 23.7 %. This porosity value corresponds to an air permeability of about 65 md, according to the cross-plot on hand.

This permeability value, derived from core and log data, appears to be compatible with the order of magnitude of the permeability values obtained through fall-off tests in the permit well.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Permeability k in the Lower Cockfield From Core and Log Data

**TABLE VII-3**
**Model Input Parameters**

| Zone | Layer TOP Depth (ft, bls)* | Net Layer Thickness (ft) | Porosity %** | Permeability (md) | md-ft | Temperature (F) |
|---|---|---|---|---|---|---|
| 1 | 6045 | 145 | 24 | 500 | 72,500 | 181 |
| 2 | 5546 | 401 | 27.6 | 500 | 200,500 | 166 |

* At Wellbore location.
** For initial modeling effective considered same as total.

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In its application package (Table VII-3), the operator reported an average porosity of 24% for the Lower Cockfield (Zone 1 in the application document), which is in good agreement with the value shown in the previous slide.

However, the operator proposed a corresponding value of 500 md for the permeability in this zone. Now, speaking solely from an engineering standpoint, while it is true that some of the tested core plugs showed permeabilities in the range of 500 md, extrapolating this value across the entire Lower Cockfield can not be supported with the cross-plot and porosity log data available.

In addition, assuming that the available cross-plot is valid for the Middle Cockfield, a permeability value of 500 md for this zone can not be supported with the cross-plot data available either. The permeability value corresponding to a Middle Cockfield porosity of 27.6 % is 225 md, per the available cross-plot.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

Reservoir Permeability k in the Lower Cockfield From Core and Log Data

## VII.B.4 Permeability and Skin

Permeability is the capacity of porous media to transmit fluids. An averaged homogenous permeability of 80.9 md was determined from a well testing event performed after the initial well completion in December 1999. Based on review of the perforation record, log analysis, and core analysis performed on the well it is believed that the derived permeability from the well test analysis is not representative of the reservoir conditions. Estimates of reservoir permeability has been as high as 1,400 md based on literature review. Core analysis conducted on the Lower Cockfield indicated a permeability range of 550 md to 850 md for the portion of the formation planned for perforating after permit approval. A reservoir permeability of 500 md was used in the modeling effort based on the review of logs and core analysis. This value is believed to be more representative of the injection zone and still considered to be a conservative number.

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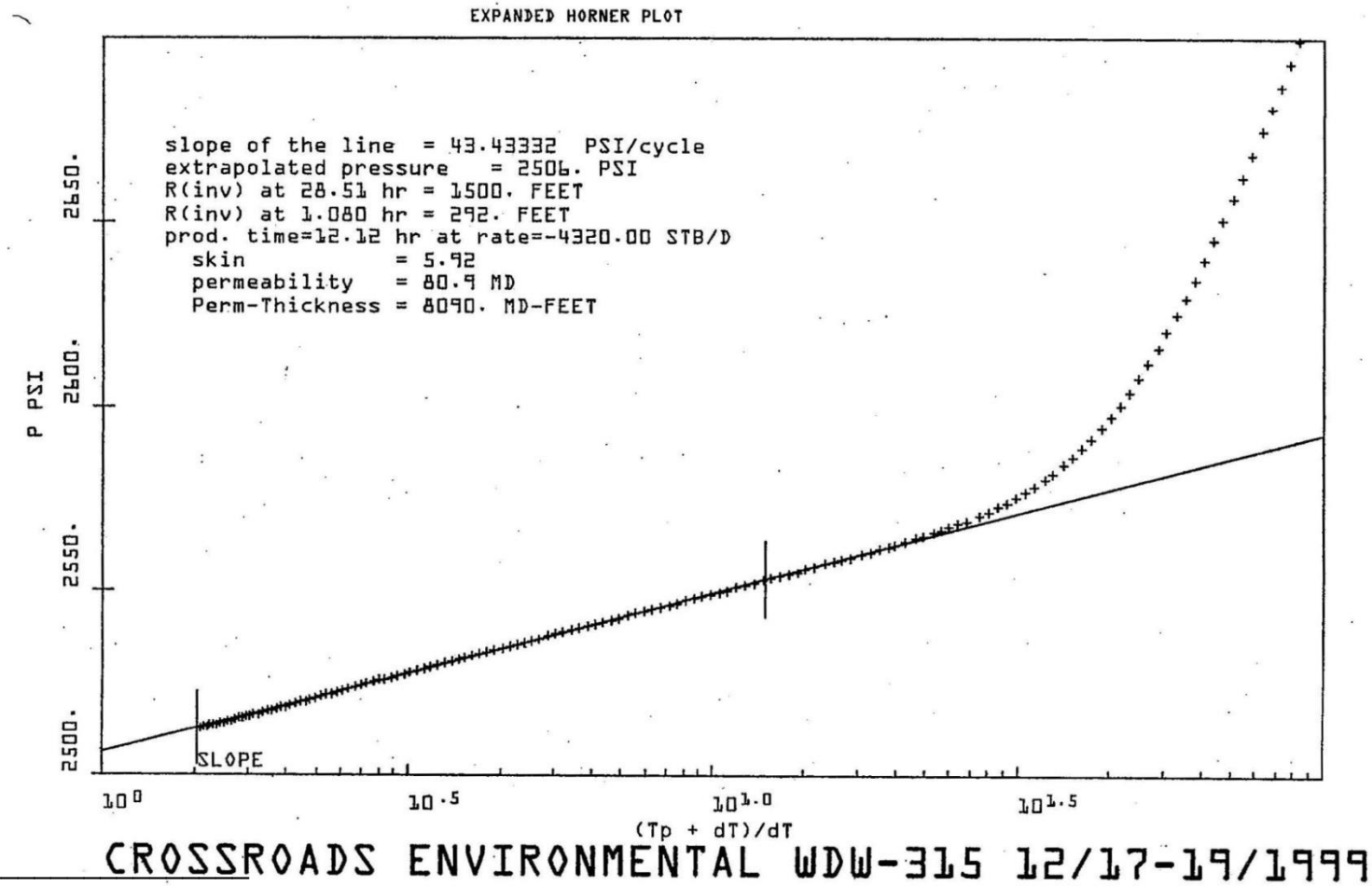
The above excerpt from the application package illustrates efforts to legitimize the use of a permeability of 500 md in the assessment of the risk of contamination for the proposed injection operation. Similar arguments were presented as expert testimony.

However, as seen in the available cross-plot, a permeability value of 500 md corresponds to a porosity of about 30.1%. The discussions on porosity presented below show that the available engineering data do not validate an average porosity of 30.1% for the injection interval in the Lower Cockfield.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Permeability k in the Lower Cockfield From Fall-Off Test Data




The Fall-Off test conducted in the WDW-410 well in 1999 indicated a permeability of 80.9 md for the tested 100 Ft perforated interval in the Lower Cockfield. A viscosity of 0.5 cp was used in the analysis of the data gathered during the test. As shown below, a viscosity value of about 0.39 cp would have been more representative.

Apparently, an accurate description of the perforated interval was not available at the time the permit application was prepared, which led to some, seemingly unwarranted, qualification of the 1999 fall-off test results by the applicant.

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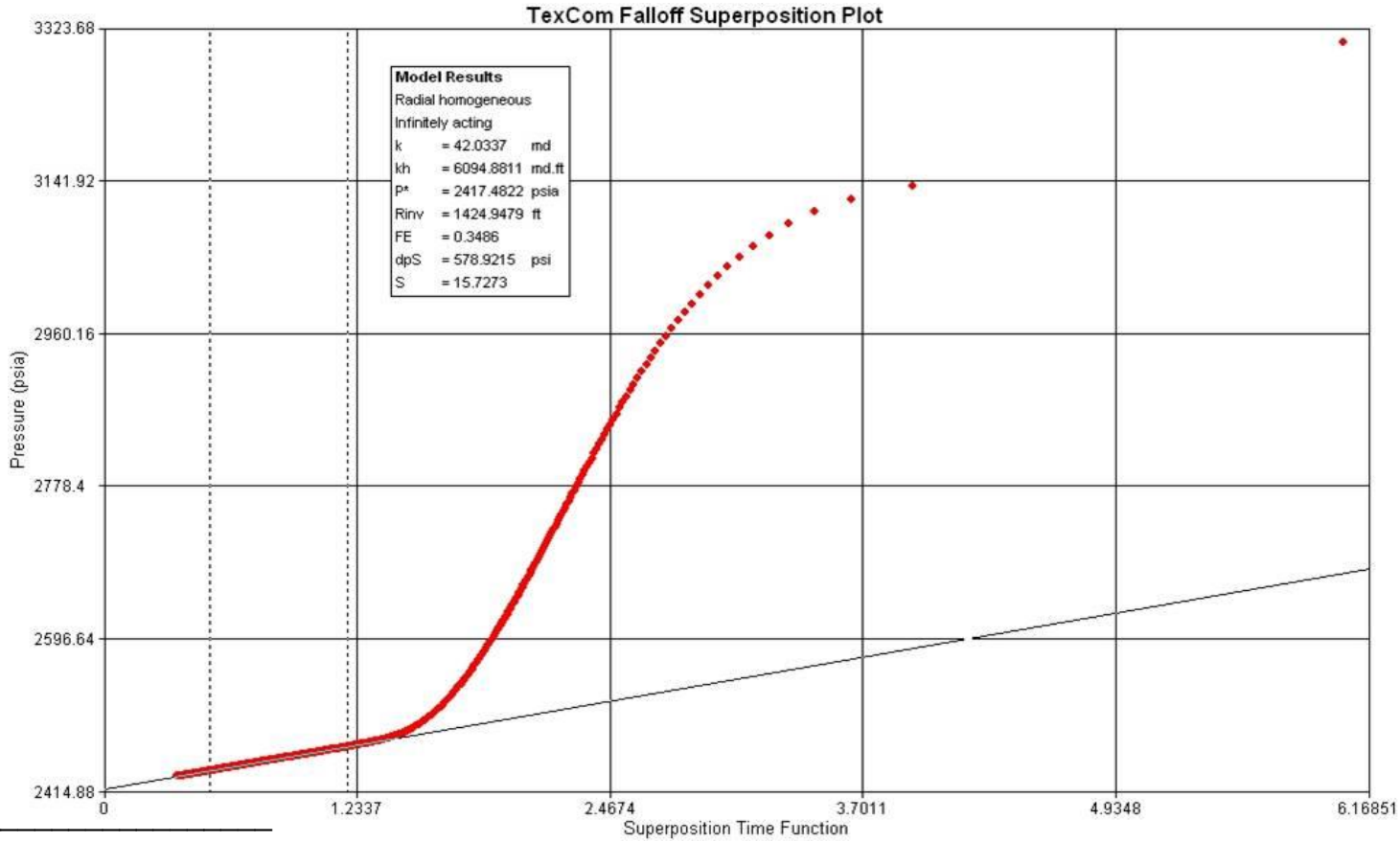
## Reservoir Permeability k in the Lower Cockfield From Fall-Off Test Data




The WDW-410 well was worked over in September, 2009. New perforations were added above the existing perforations, bringing the total thickness of the injection interval to 145 Ft. A fall-off test followed, and the results of the test analysis (illustrated above) indicated a permeability of 42 md for the Lower Cockfield tested interval.

Region 6's Pansystem software was used to analyze the test data, which estimated the viscosity of the reservoir water at 0.364 cp, based on the observed bottom hole temperature and input water salinity of 80,000 ppm.

EPA considered the test results to be representative, and recommended they be honored.

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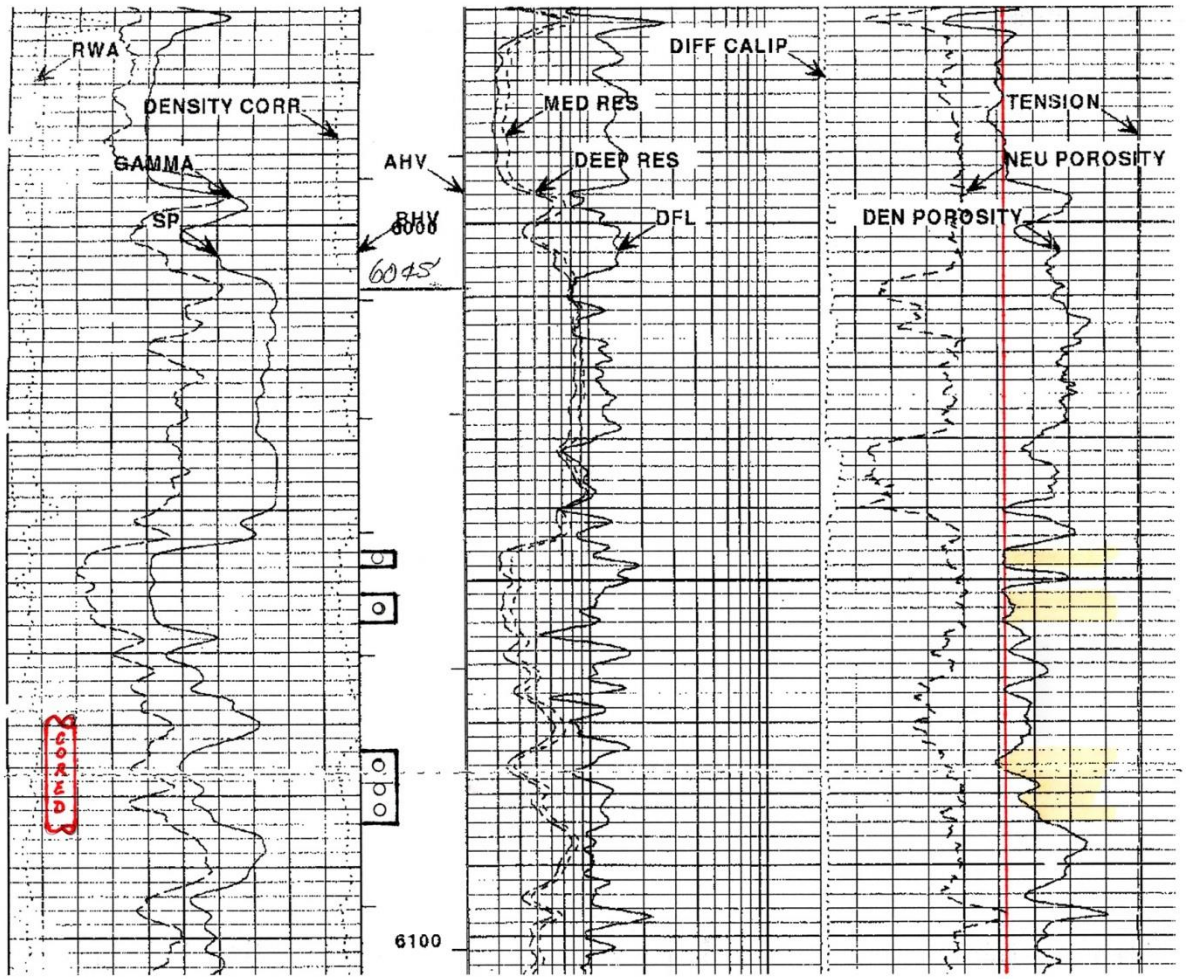
## Reservoir Porosity ¢ in the Lower Cockfield From Log Data




A composite well log was available for the WDW-410 well from the operator. A Lower Cockfield segment of this log is illustrated above. The red line amid the Neutron-Density porosity curves marks the 29 % porosity to emphasize the deviation of the density porosity from this value across the entire thickness of the Lower Cockfield, the injection zone. The following two slides show the log segments for the remainder of the Lower Cockfield.

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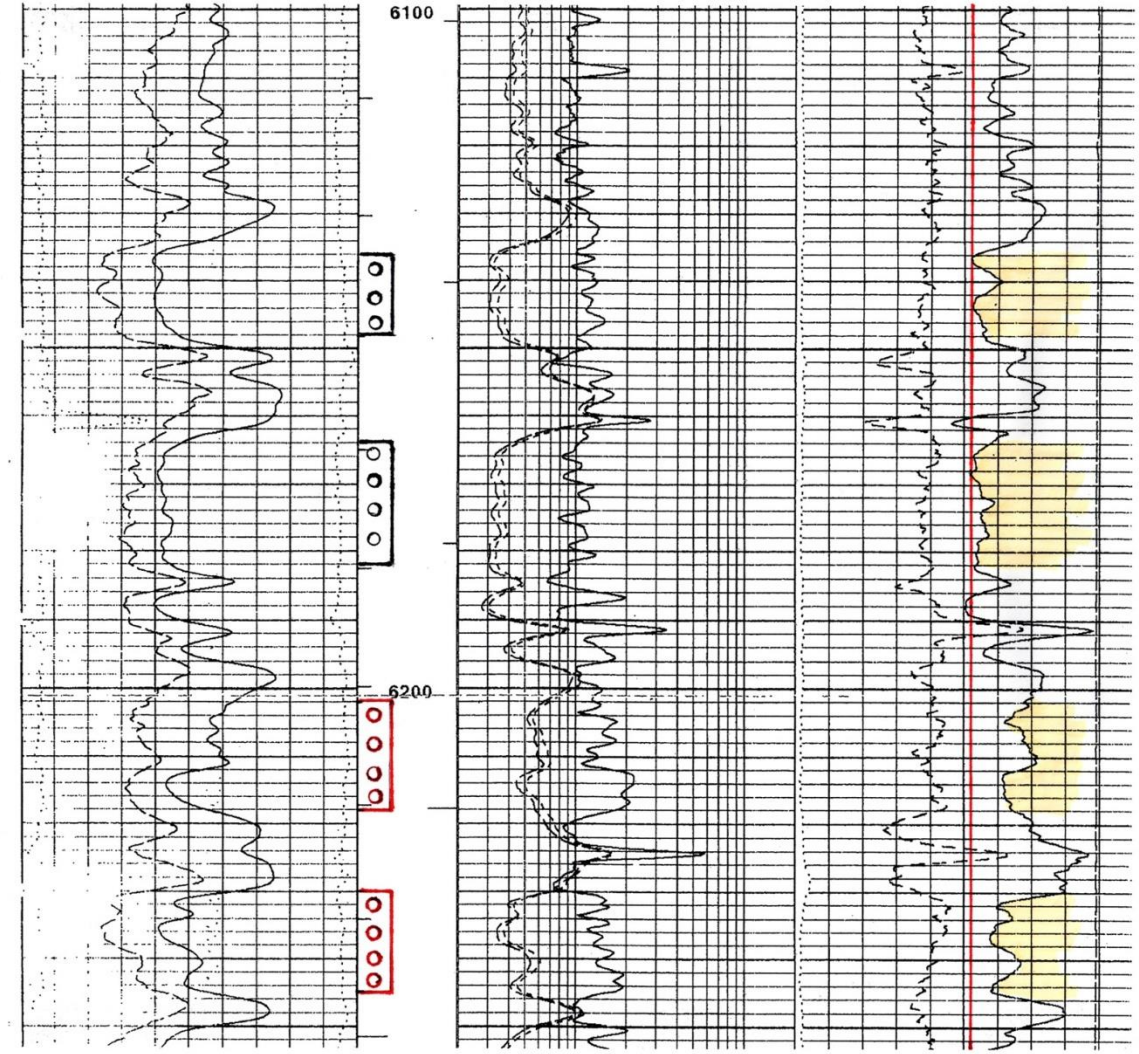


The perforated intervals are marked in the "Depth" track of the log. The red marks represent the original completion perforations, and the black marks represent the perforations added in 2009.

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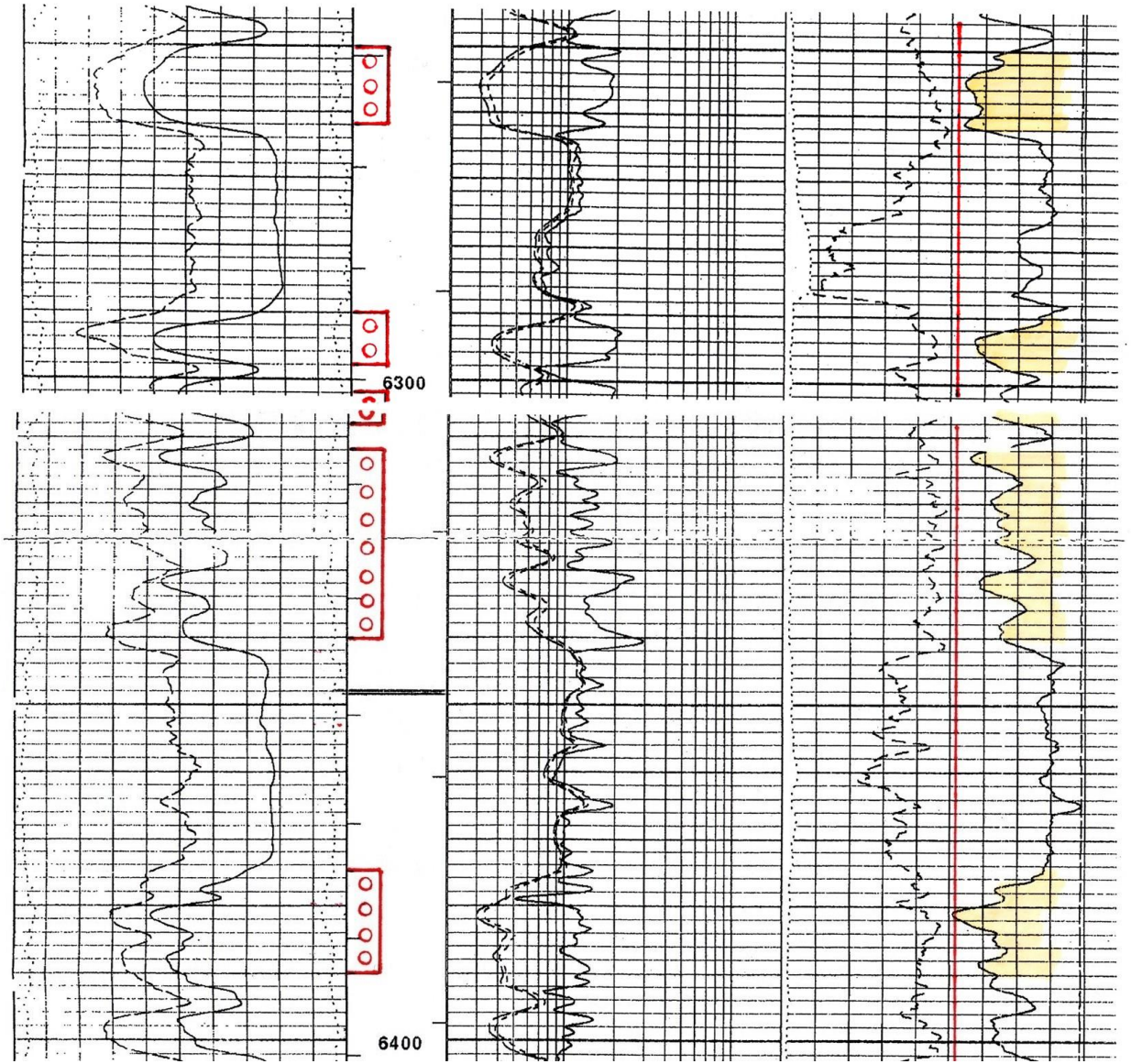
## Reservoir Porosity ¢ in the Lower Cockfield From Log Data




In the above log segments, the Lower Cockfield porosity rarely reaches a value of 30.1 %. Segments of the composite log were digitized for the three components of the Cockfield formation for use in quantitative analysis.

| 1 | WDW-315 - LOWER COCKFIELD | | | | |
|---|---|---|---|---|---|
| 2 | | DEPTH FEET | DENS POR-% | NEUT POR-% | PERM MD |
| 15 | | 6056 | 28.9 | 36.4 | 337.8 |
| 16 | | 6057 | 26.8 | 37.2 | 174.0 |
| 17 | | 6058 | 24.7 | 38.8 | 89.6 |
| 18 | | 6059 | 26.0 | 38.5 | 134.8 |
| 19 | | 6060 | 27.8 | 39.9 | 236.3 |
| 20 | | 6061 | 26.5 | 39.3 | 157.1 |
| 21 | | 6062 | 23.1 | 37.7 | 53.8 |
| 22 | | 6063 | 21.5 | 38.3 | 32.3 |
| 23 | | 6064 | 23.8 | 40.2 | 66.0 |
| 24 | | 6065 | 27.9 | 42.3 | 248.7 |
| 25 | | 6066 | 28.2 | 42.5 | 275.4 |
| 26 | | 6067 | 25.4 | 43.0 | 112.7 |
| 27 | | 6068 | 24.8 | 41.8 | 91.9 |
| 28 | | 6069 | 25.1 | 41.1 | 101.8 |
| 29 | ^ | 6070 | 24.8 | 43.8 | 91.9 |
| 30 | \| | 6071 | 24.5 | 43.2 | 83.0 |
| 31 | \| | 6072 | 25.3 | 42.2 | 107.1 |
| 32 | | 6073 | 25.9 | 41.1 | 131.4 |
| 33 | C | 6074 | 27.4 | 39.5 | 208.0 |
| 34 | | 6075 | 29.4 | 39.7 | 403.9 |
| 35 | O | 6076 | 30.2 | 39.0 | 521.3 |
| 36 | | 6077 | 28.6 | 38.1 | 312.9 |
| 37 | R | 6078 | 25.4 | 37.0 | 112.7 |
| 38 | | 6079 | 22.9 | 36.2 | 49.8 |
| 39 | E | 6080 | 25.6 | 36.3 | 118.6 |
| 40 | | 6081 | 26.4 | 36.6 | 153.1 |
| 41 | D | 6082 | 24.6 | 37.3 | 87.3 |
| 42 | | 6083 | 23.2 | 39.7 | 55.2 |
| 43 | \| | 6084 | 22.4 | 36.8 | 42.7 |
| 44 | v | 6085 | 19.0 | 38.1 | 14.6 |
| 45 | | 6086 | 16.8 | 38.2 | 7.2 |
| 46 | | 6087 | 14.9 | 37.4 | 3.9 |
| 47 | | 6088 | 15.5 | 37.0 | 4.8 |
| 48 | | 6089 | 17.8 | 36.5 | 9.7 |
| 49 | | 6090 | 18.1 | 36.2 | 10.8 |

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Porosity ¢ in the Lower Cockfield From Log Data

Porosity log readings at one foot intervals from the digitization exercise, and their corresponding estimated permeabilities, are Illustrated here for a segment of the Lower Cockfield.

Similar tables were developed for all injection target zones as part of R6 evaluation of the application.

This table documents how the variances in the porosity values across these formations are carried forward to the permeability values.

Data obtained through this exercise helped estimate several average reservoir parameter values previously discussed.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Porosity ¢ in the Lower Cockfield From Log Data

| | | | | |
|---|---|---|---|---|
| | LOWER COCKFIELD | | | |
| | 7' | 28.7% | 320.4 md | kh= 2243 md-Ft |
| | 14' | 28.3% | 283.6 md | kh= 3970 md-Ft |
| | 173' | 22.9% | 50.5 md | kh= 8737 md-Ft |
| | 194 Feet | | | |

The above schematic illustrates the porosity and permeability stratification in the permeable segments of the Lower Cockfield in the WDW-410 well. It was prepared using the available core and log data, before a complete description of the perforated interval became available, therefore the shown greater total thickness value of 194 Ft.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Thickness h in the Lower Cockfield

**TABLE VII-1**
**Injection Reservoir Layer**

| Formation | Layer Top Depth (ft, bls)* | Gross Layer Thickness (ft) | Net Layer Thickness (ft) | Porosity (percent) |
|---|---|---|---|---|
| Middle Cockfield (past fault) | 5546 | 794 | 401 | 29 |
| Lower Cockfield | 6045 | 345 | 145 | 24 |

* At Wellbore location.

### VII.B.2 Layer Thickness

To determine appropriate thickness values of the injection reservoir geophysical logs were used. A total net layer zone thickness of 145 feet was identified for injection into the Lower Cockfield at the well location. (See Table VII-1) For the area past the fault identified in the geology review, a net thickness of 401 feet for the Middle Cockfield Sand was used for the model parameters.

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The above excerpt from the permit application documents the operator's choice of formation thickness for the risk analysis for the, at the time, proposed injection.

An estimated thickness of 401 feet in the Middle Cockfield, at a location several thousand feet from the permit well was used in the initial modeling work and defended at the discussions held during the permitting process.

The target injection interval is located in the Lower Cockfield, not the Middle Cockfield.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Thickness h in the Lower Cockfield

A complete description of the perforated interval finally became available after the well was worked over in 2009 (see illustration).

It showed that the bottom perforations were at 6390 Ft, not at 6372 Ft.

This information helped establish that the md-Ft for the injection interval is:

42 md * 145 Ft

=

6090 md-Ft

This is the figure EPA Region 6 recommended be used for the evaluation of the contamination risk from this injection.

Ms. Lorrie:

The discussion on permeability just presented demonstrates why a permeability value of 500 md doesn't come even close to being representative of the permeability of the injection interval. Concerns over such misrepresentation of the character of the injection interval are more than justified. This permeability value should have never been taken into consideration in the risk analysis. TCEQ stopped advocating its use only after Dr. Shaw acknowledged that 80.6 md was a more representative value.

The use of an injection reservoir thickness of 401 Ft was also defended by the operator and TCEQ early in the hearings, and it was also cause for concern. The reason being that the use of this thickness value, as was the case with the permeability value just mentioned, can not be validated through the applicable engineering principles and practices.

The zone to which these permeability and thickness values are attributed, the Middle Cockfield, is located at roughly 4400 Ft from the injection well. A large portion of reservoir is being injected into, north of the fault.

Fortunately, even though the use of a reservoir thickness of 401 Ft passed unchallenged for some time, in the end, the correct thickness of 145 Ft (see previous Slide) was adopted. However, the md-Ft value defended by the parties continued to be off, by a lot.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Fluid Viscosity μ in the Lower Cockfield

| | | | | |
|---|---|---|---|---|
| Rm @ BHT | 0.588 @ 188 F | @ | @ | @ |
| Time Since Circ. | 5:00 11-23 | | | |
| Time on Bottom | 2:30 11-24 | | | |
| Max. Rec. Temp. | 188 F @ 6584' | @ | @ | @ |
| Equip. \| Location | 53261 FRESNO | \| | \| | \| |
| Recorded By | N.WINTERS | | | |
| Witnessed By | MARK [illegible] | FRED DUFFY | TOM ROTH | |

| CROSSROADS ENVIRONMENTAL WDW-315 | | |
|---|---|---|
| INJECTIVITY/FALLOFF TEST DATA DEC. 17-19, 1999 | | |
| | BHP | BHT |
| hours | psia | Deg F |
| 2.19983 | 2502.21 | 185.86 |
| 2.20264 | 2502.21 | 185.85 |
| 2.20544 | 2502.21 | 185.86 |
| 2.20828 | 2502.21 | 185.86 |
| 2.35267 | 2502.22 | 185.85 |
| 2.35547 | 2502.22 | 185.85 |
| 2.35828 | 2502.22 | 185.85 |
| 2.36108 | 2502.22 | 185.85 |
| 2.36372 | 2502.22 | 185.85 |

Page 5

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The viscosity of a fluid is a function of temperature. And temperature in a well is a function of depth.

The information above was obtained from a log header and from a fall-off test report, and it helped find a temperature gradient in the Lower Cockfield.

It was then possible to estimate a reservoir temperature at the midpoint of the perforated interval and, based on the above provided data, that temperature value is 186 ºF at a depth of 6218 Ft.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Fluid Viscosity μ in the Lower Cockfield

TABLE V

ANALYSIS OF TYPICAL SALT WATER FROM THE CONROE FIELD

| SUN COMPANY'S STEWART NO. 3 | |
|---|---|
| Primary salinity | 89.66 |
| Secondary salinity | 9.78 |
| Primary alkalinity | none |
| Secondary alkalinity | 0.56 |
| Per cent $rSO_4$ in $rSO_4$ plus rCl | 0.06 |
| Ratio $rCO_3$ to $rSO_4$ | 9.33 |
| *Constituents in Parts per Million* | |
| Sodium | 27,620.2 |
| Calcium | 1,865.0 |
| Magnesium | 553.5 |
| Iron and aluminum oxides | 20.0 |
| Sulphate | 42.4 |
| Chloride | 47,100.0 |
| Carbonate | 288.0 |
| Silica | 22.0 |
| Total | 77,451.1 |

Viscosity is also a function of the salinity of the water.

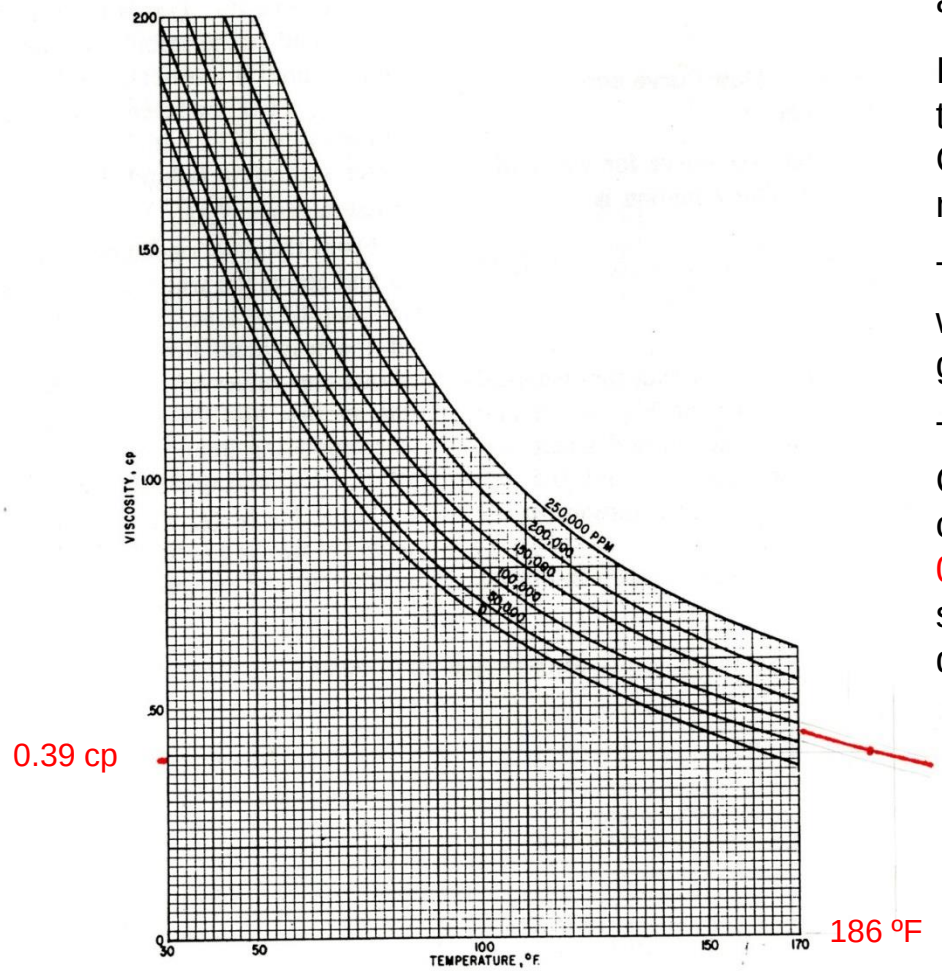
The shown water analysis is for water produced at the Conroe oil field, possibly from the Upper Cockfield sand. This analysis is provided in the 1936 paper on the Conroe Field by Michaux and Buck.

The provided total salinity figure has been rounded to 80,000 ppm for use in the R6 engineering evaluation of the injection operations at the WDW-410 well.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Fluid Viscosity μ in the Lower Cockfield

Fig. D.13 is taken from
"How Temperature Affects Viscosity of Salt Water", *World Oil* (Aug. 1, 1967) 68.




Now, the shown graph depicts how water viscosity varies with temperature and salinity.

In order to accommodate the higher temperature value for the Lower Cockfield, some extrapolation has been necessary.

The estimated viscosity for 80,000 ppm water at 186 ºF is 0.39 cp, per the shown graph.

This estimated value for the Lower Cockfield at the WDW-410 well compares favorably with that of 0.364 cp estimated by R6's Pansystem software, previously referenced in this discussion.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Fluid Viscosity μ in the Lower Cockfield

| | |
|---|---|
| Injection Rate, bpd | 4320 bpd (3 bpm) |
| Net thickness, feet | 100 |
| Porosity, % | 31 |
| Total formation compressibility, $psi^{-1}$ | $7.0 \times 10^{-6}$ |
| Fluid viscosity, cp | 0.5 |
| Wellbore radius, feet | 0.318 |
| Static Reservoir Pressure, psia | 2502.28 (prior to injection) |
| Gauge Depth, feet K.B. | 6200 |
| Skin Factor | 5.92 |
| Permeability, md | 80.9 |

The above Table documents the use of a reservoir fluid viscosity of 0.5 cp in the analysis of the 1999 fall-off test in the WDW-410 well. No justification for this value appears to have been provided by the analyst.

But, this value could be considered more in line with the viscosity values just discussed, compared to the other below proposed viscosity value.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## Reservoir Fluid Viscosity μ in the Lower Cockfield

| FIGURE 2 | | |
|---|---|---|
| **Reservoir and Test Properties** | | |
| Property | Value | Source |
| Viscosity of injected fluid, μ | 1.26 cp | Derived from correlations based on temperature, pressure and Specific Gravity of injectate |
| Temperature | 97.6° F | Measured |
| Specific Gravity of injectate | 1.18 | Measured, 9.9 ppg brine |
| Formation Volume Factor, B | 1.00 RB/STB | Assumed due to conditions |
| Net Pay, Injection Interval Thickness, h | 145 ft | Determined from perforations |
| Radius of Wellbore, $r_w$ | 3.5 in | From well construction |
| Porosity of Formation, $\phi$ | 24 % | From Permit Application |
| Total Compressibility, $c_t$ | $6.0 \times 10^{-6}$ $psi^{-1}$ | From Correlations |
| Pressure at beginning of Well Injection, $p_i$ | 2437.2 psig | Measured during test @ 6,000' |
| Pressure at beginning of Well Shut In, $p_{ws}$ ($p_{wf}$) | 3306.2 psig | Measured during test @ 6,000' |

The above Table shows that the applicant, through its consultant, set the reservoir fluid viscosity at 1.26 cp. This viscosity value is reported for a 9.9 ppg brine at 97.6 ºF, which can be characterized as a 240,000 ppm brine.

With these numbers, the operator justified a Lower Cockfield permeability of 190 md following the 2009 fall-off test.

These values may be hard to validate with the available data and applicable engineering practices and principles.

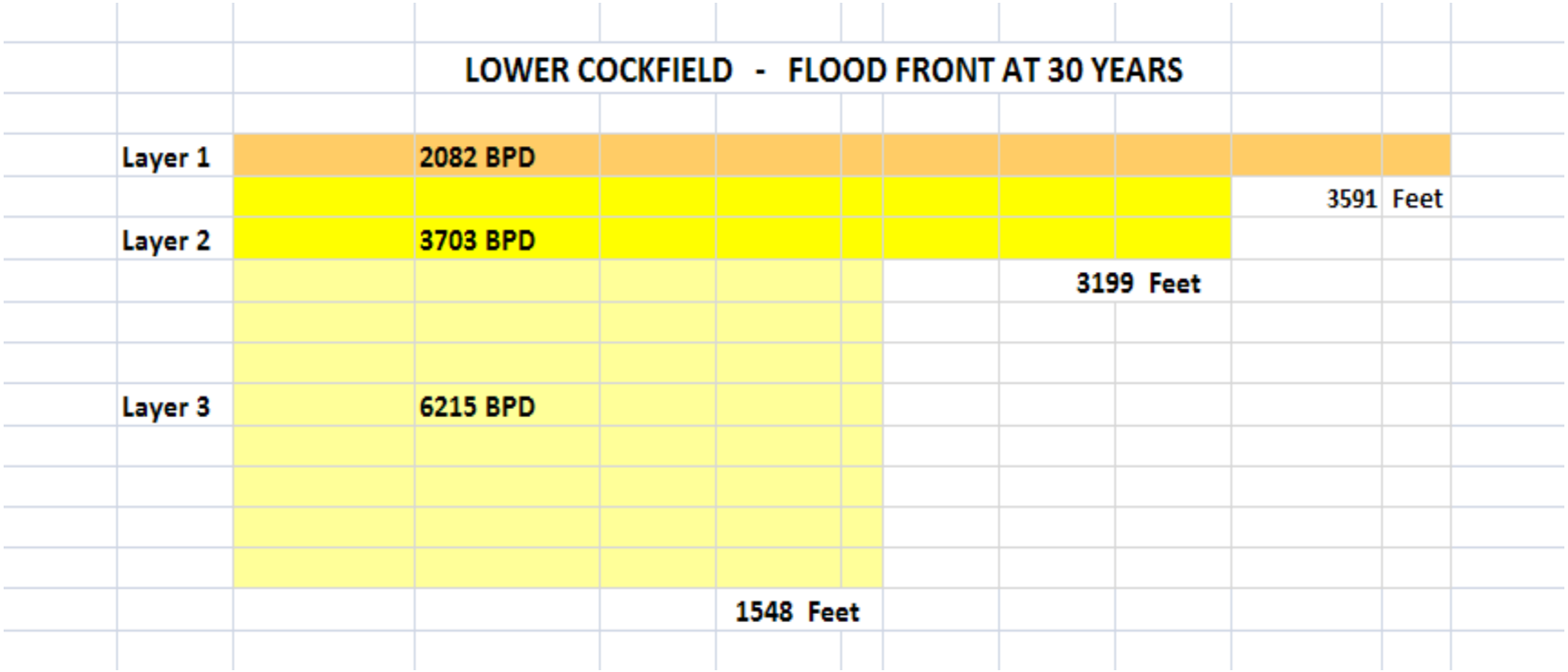
Ms. Lorrie:

The previous discussion on viscosity of fluids in a reservoir shows why the viscosity value of 1.26 cp proposed by the operator for the Lower Cockfield in the Conroe field can not be validated with engineering principles and practices or supported with the available data. I am not sure that anyone challenged this piece of information, though I know that there were comments stating that our proposed value was too low. However, I never got to see a justification for such comment.

The reservoir fluid viscosity is a very important factor in the outcome of the reservoir pressure build up predictions and in the assessment of the risk posed by an injection operation. I believe every effort should be made to arrive at the correct value.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Reservoir Pressure Response Modeling Work for the Lower Cockfield




Injected fluid distribution estimates using the mathematical model introduced earlier in this discussion, along with the stratified reservoir model and the R6 derived parameter values, resulted in the illustrated preliminary fluid distribution profile for the fluids injected into the Lower Cockfield.

It can be seen that the injected waste could travel a considerable distance through the most permeable, thinner strata in the reservoir, increasing the probability for its intersection of a flow pathway out of the injection zone. The presence of wells that may not be properly plugged, and transmissive faults, increase the risk of leakage from the injection interval in the Lower Cockfield.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Reservoir Pressure Response Modeling Work for the Lower Cockfield

| Well's C Number | Feet From WDW-410 | Days To CP* |
|---|---|---|
| C-12 | 173 | 12.5 |
| C-428 | 656 | 179 |
| C-427 | 999 | 416 |
| C-145 | 1466 | 894 |
| C-163 | 2051 | 1752 |
| C-426 | 2800 | 3285 |
| C-470 | 5309 | 11680 |

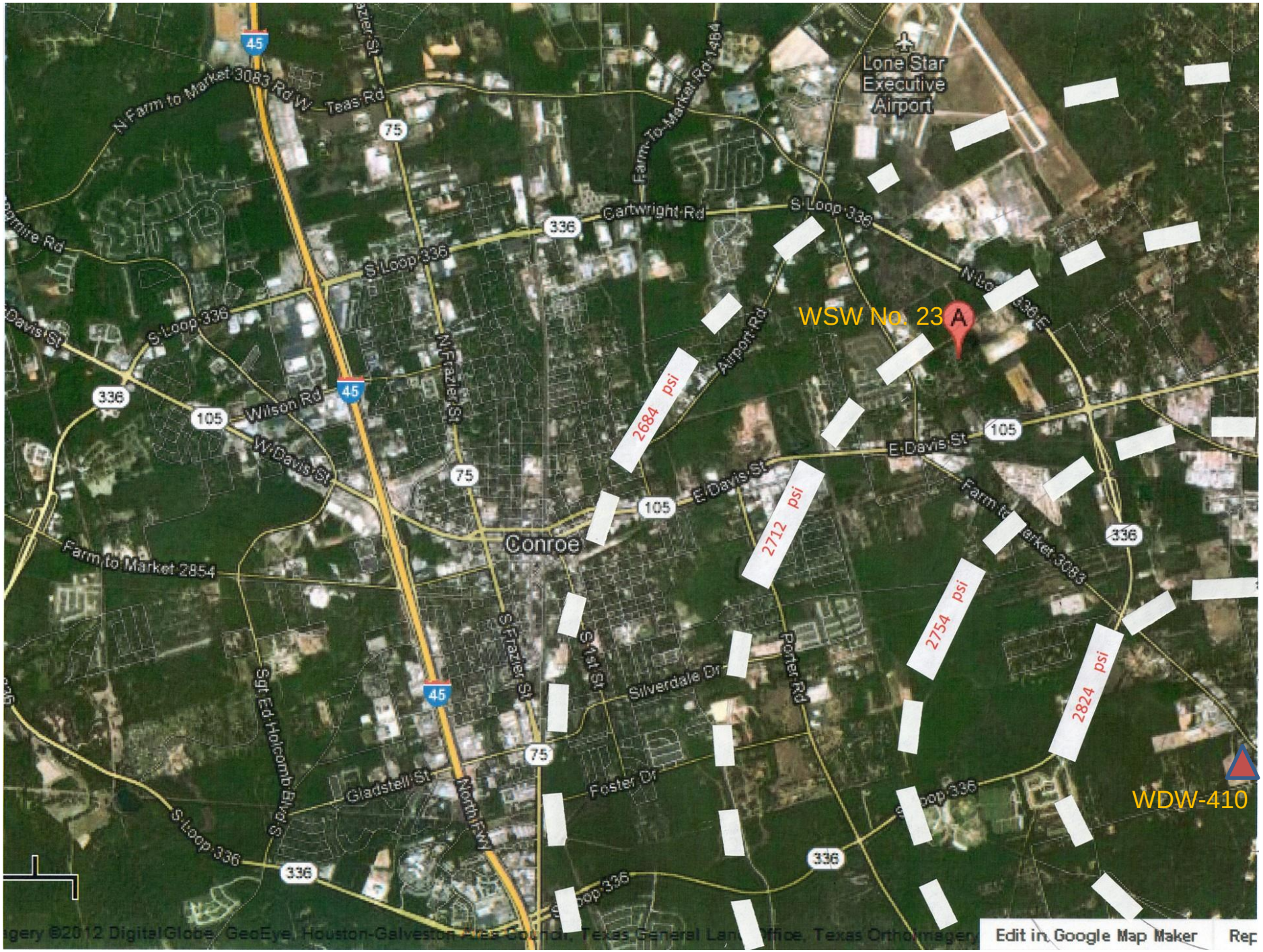
* Critical Pressure: Fluid Level at Surface: 2827 psia

The above Table illustrates results of estimates of reservoir pressure build up in the Lower Cockfield at the location of some of the identified abandoned wells with an unknown mechanical condition. A single layer reservoir was used this time.

The computations assumed a constant injection rate of 12,000 BPD, as requested, and aimed at finding the number of days that it would take for the reservoir pressure to build up enough to cause the fluid level in a potentially unplugged well to reach the surface.

The previously introduced mathematical model was used along with all the parameter values estimated by Region 6.

Well C-12 was recently plugged by the Railroad Commission. It was not found to experience any "self closure" phenomenon.


Lone Star Executive Airport
N Farm to Market 3083 Rd W
Teas Rd
Farm To Market Rd 1484
Cartwright Rd
S Loop 336
N Loop 336 E
WSW No. 23
A
Airport Rd
N Frazier St
Wilson Rd
W Davis St
E Davis St
Farm to Market 3083
Farm to Market 2854
Conroe
S Frazier St
S 1st St
Silverdale Dr
Porter Rd
Sgt Ed Holcomb Blvd S
Gladstell St
Foster Dr
North Fwy
2684 psi
2712 psi
2754 psi
2824 psi
WDW-410
Edit in Google Map Maker

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Reservoir Pressure Response Modeling Work for the Lower Cockfield

Ms. Lorrie:

The contour lines on the aerial view in the previous Slide show my predicted injection interval pressure values at locations at 1, 2, 3 and 4 miles from the WDW-410 well at the end of 30 years of injection.

The pressure at these points is high enough to bring a hydrostatic column to within 12 Ft from the surface at the one mile marker, and to within 320 Ft from the surface at the four mile marker.

The red "A" marker on the map points to the City of Conroe Public Works' WSW No. 23, scheduled to be placed in line, serving 3333 domestic connections, in early 2013.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Reservoir Pressure Response Modeling Work for the Lower Cockfield

| FLOW OF FLUIDS IN POROUS MEDIA | TexCom's WDW-410 | | |
|---|---|---|---|
| Reservoir Pressure Effects Computations | | | |
| Production Rate (STBbl/Day) | -12000 | **Compute Diffusivity Factor** | |
| Time of Operation (Days) | 12.5 | | |
| Initial Reservoir Pressure (psia) | 2514.2 | Numerator | 0.26544 |
| Injected Fluid Viscosity (cp) | 0.364 | Denominator | 5.18E-07 |
| Formation Volume Factor (ResBbl/STBbl) | 1 | | |
| Formation Porosity (Percent) | 23.7 | **Diffusivity Factor =** | 5.13E+05 |
| Formation Permeability (md) | 42 | | |
| Formation Interval Thickness (Ft) | 145 | | |
| Formation Compressibility (1/psi) | 6.00E-06 | **Compute "x"** | |
| Specified Radius (Ft) | 173 | | |
| Computed Pressure Change @ Specified Radius (psia) | **312.89** | Numerator | 29929 |
| Resulting Reservoir Pressure @ Specified Radius (psia) | **2827.1** | Denominator | 2.56E+07 |
| | | **x =** | 1.17E-03 |
| | | **Compute Ei(-x)** | |
| | | | 3.406E-07 |
| | | | 8.835E-11 |
| | | | 1.934E-14 |
| | | | 3.611E-18 |
| | | **Ei(-x)** | -6.18 |

This Table illustrates the computer routine used by R6 to predict the reservoir pressure response to the permitted injection, using the proposed mathematical model.

The illustrated computation shows that reservoir fluids could potentially reach the surface at the location of the C-12 well after 12.5 days of injection.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Reservoir Pressure Response Modeling Work for the Lower Cockfield

**FIGURE VII-6**
**Pressure Year 30**
*Pressure contours after 30 years of modeled injection.*

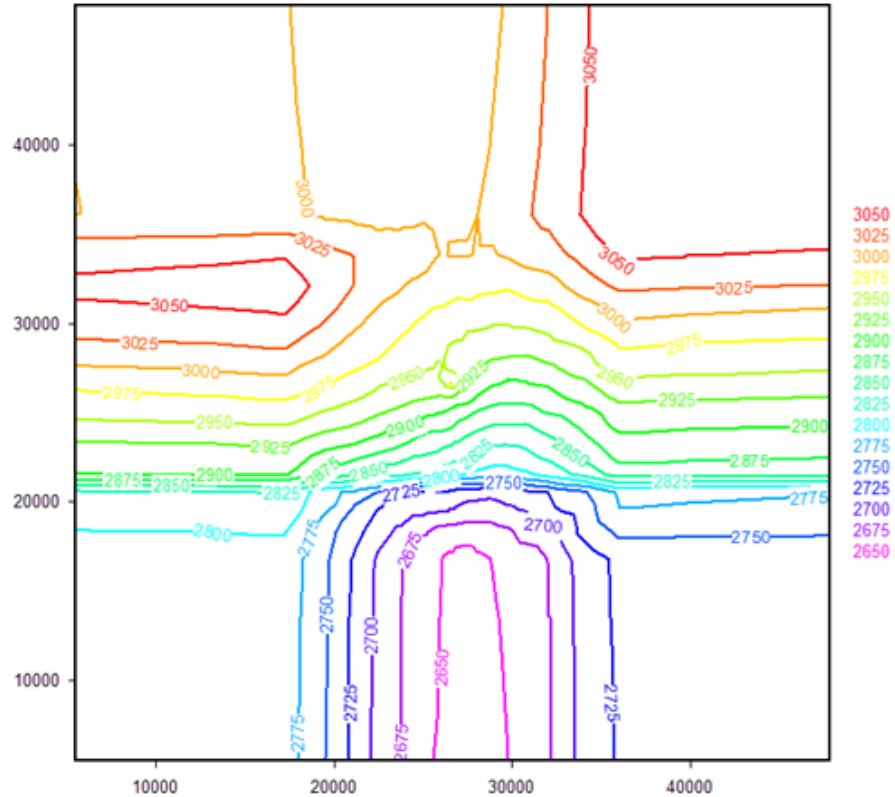



Figure VII-6 in the application package was intended to illustrate the reservoir pressure profile at the en of the project's life. The iso-potential lines in this Figure suggest reservoir flow patterns associated with lines of Injectors (line drive patterns) rather than the typical radial flow pattern around one single injection well, or a closely spaced cluster of injection wells. The point in bringing up this Figure for discussion is to illustrate situations that ought to have triggered questioning the validity of submitted information in a case like this. Apparently, no red flags were raised because of this anomalous piece of information.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Reservoir Pressure Response Modeling Work for the Lower Cockfield

As already shown in this discussion, the 2009 fall-off test in the WDW-410 permit well indicated a permeability of 42 md, which corresponds to a md-Ft value of 6090 in the recompleted well. However, subsequent to the above test, discussions during the permitting process continued to address an injection interval permeability value of 80.9 md, in effect assigning to the modified injection interval a md-Ft value of:

80.9 md * 145 Ft = 11,730.5 md-Ft

In other words, in assessing the risk of contamination for the proposed injection operations, some of the parties, TCEQ included, went along with the use of a md-Ft figure that is 92.6 % higher than that indicated by factual field data. Gathering the data that led to the 42 md permeability value cost a lot of resources, and their meticulous analysis was done according to sound engineering principles and practices. These data, however, were shelved without apparent explanation.

While arriving at the 80.9 md permeability figure also took a lot of resources, its value as a representative reservoir parameter was lost when perforations were added to the tested interval in 2009. Its continued use in analyzing a recompleted well can not be validated with the applicable engineering principles and practices.

Also, in assessing the risk of contamination of the now permitted injection operations, the parties favoring permit approval arrived at a host of values for the Radius of Endangerment (RE). This was possible because the model adopted for the flow system's fluid mechanics basically assumed an initial reservoir pressure, Pe, of zero psi, and due to the variances in the relevant parameter values given by the parties. RE values ranged from 0.0 Ft (the operator's), to 150 Ft (TCEQ's initial expert testimony), to a few thousand feet.

Field data show that the risk of endangerment of the USDWs by the permitted operation is present all over the Conroe field since the current Pe value for the Lower Cockfield is large enough to lift reservoir fluids past the base of the USDWs. Michaux and Buck presented in their paper data documenting the continuity of the Lower Cockfield and the transmissivity of the faults in the Conroe field. RE is infinite, for all purposes.

Ms. Lorrie:

The sole goal of the preceding discussion is to illustrate how EPA R6 has implemented its oversight duties as it reviewed the technical evaluation of TexCom's application for a permit to inject waste into the Lower Cockfield.

In carrying out this legitimate oversight task, R6 has found numerous issues that are cause for concern, and offers comments in a spirit of collaboration, with the best intention of assisting a delegated UIC Program with the task of carrying out the Agency's mission of protecting human health and the environment.

Some of the language in the delegated program Review Reports is solely intended to point to the fact that there have been opportunities for the Region to provide technical assistance with program implementation, and in my view, there are no reasons for anyone to feel insulted by that. This discussion on the technical analysis for TexCom's application points to a number of examples of those opportunities, which call for collaboration between TCEQ and EPA R6 to ensure accomplishing a goal, the goal of carrying out the Agency's mission.

In closing this discussion I would like to call to your attention to the last Slide.

The last Slide illustrates recent efforts by Montgomery County to better manage its water resources while faced with the detrimental effects of a drought. In seeking alternate sources of water, ASWs, the LSGCD has drilled and completed a number of wells in portions of the Catahoula aquifer at depths ranging from 1800 Ft to nearly 3000 Ft below the surface. These wells are projected to produce up to 2,000 gpm to satisfy the needs of a large number of households with good quality ground water, while helping slow the depletion rate for other aquifers in use in the area.

The information reviewed so far in connection with the TexCom permit shows that there are reasons to be concerned with the risk of contamination of the overlying aquifers, the Catahoula Aquifer included.

# Highlights of Technical Analysis for TexCom's Application – WDW-410 Class I Well

## The Reservoir Pressure Response Modeling Work for the Lower Cockfield

Lone Star Water Conservation District (LSGCD), Montgomery County, TX

Alternative Sources of Water (ASW)

| Well Owner | Well Name | Latitude | Longitude | TD | Perforated Interval | Aquifer Name | Number Svc. Connections | Date First Production | TDS mg/L | Well Site Address |
|---|---|---|---|---|---|---|---|---|---|---|
| City of Conroe Public Works | No. 24 | 30.34217100 | -95.4749200 | 3000 | 2258 - 2276<br>2299 - 2317<br>2355 - 2405<br>2586 - 2622 | Catahoula | 3333 | 04/13 | 945 - 2500 | 2499 N. Frazier |
| City of Conroe Public Works | No. 23 | 30.32959700 | -95.4153840 | 3000 | 1926 - 1965<br>2026-2060<br>2088-2108<br>2218 - 2234<br>2395 - 2410<br>2419 - 2435 | Catahoula | 3333 | Apr-13 | 1300 - 1550 | 2915 Beasley Rd. |
| City of Panorama Village | No. 4 | 30.37994444 | -95.4954722 | 2000 | | Catahoula | 2100 | 06/11 | 804 | 99 Hiwon Drive |
| Stanley Lake Municipal Utility District | No. 3 | 30.38055556 | -95.6455556 | 2700 | 2260 | Catahoula | 1181 | 01/12 | | 10719 Twin Circles |
| Montgomery County Utility District No. 3 | No. 1 | 30.36888889 | -95.6158333 | 2607 | 2134 | Catahoula | 2919 | 04/11 | | 49 April Waters South |
| Montgomery Co. Municipal Utility District No. 18 | No. 3 | 30.43583333 | -95.6405556 | 2480 | 1833 - 2453 | Catahoula | | 2012? | 444 | 18529 FM 1097 West |
| Montgomery Co. Municipal Utility District No. 8 | No. 1 | 30.39229983 | -95.6169000 | 3000 | 2174 - 2660? | Catahoula | | 06/12 | 430 - 950 | 12649 Browning Dr. |

The above Table lists some of the water supply wells recently completed, and soon to be completed. The Catahoula drilling began near the shores of Lake Conroe and will soon be within three miles of the permitted injection.