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Reference 3

http://www.epa.gov/superfund/sites/npl/hrsres/tools/scdm.htm
Last updated on Wednesday, March 17, 2010

National Priorities List (NPL)

You are here: EPA Home Superfund Sites National Priorities List (NPL) HRS Toolbox
Superfund Chemical Data Matrix (SCDM)

Superfund Chemical Data Matrix (SCDM)

The Superfund Chemical Data Matrix (SCDM) is a source for factor values and benchmark values applied when evaluating potential National Priorities List (NPL) sites using the Hazard Ranking System (HRS). Factor values are part of the HRS mathematical equation for determining the relative threat posed by a hazardous waste site and reflect hazardous substance characteristics, such as toxicity and persistence in the environment, substance mobility, and potential for bioaccumulation. Benchmarks are environment- or health-based substance concentration limits developed by or used in other EPA regulatory programs. SCDM contains HRS factor values and benchmark values for hazardous substances that are frequently found at sites evaluated using the HRS, as well as the physical, chemical, and radiological data used to calculate those values. The accompanying SCDM Methodology report describes how data are selected or calculated for inclusion in SCDM and how SCDM data, HRS factor values, and benchmarks are presented in formatted printouts.

On January 28, 2004, EPA released an updated SCDM with many revisions to the HRS factor values and benchmarks. These revisions were necessary both because of updates in the SCDM procedures used to assign HRS factor values and benchmarks and because of revisions to pertinent standards and criteria for individual hazardous substances and their associated characteristics.

Disclaimer

The Superfund Chemical Data Matrix (SCDM) is a database containing factor values and benchmark values used for applying the Hazard Ranking System (HRS) [40 CFR Part 300 Appendix A, 55 FR 51583] to evaluate potential National Priorities List (NPL) sites. The physical, chemical, toxicological, and radiological parameters used to calculate the factor values and benchmarks contained in SCDM are obtained from references listed in Chapters 2 and 3 of the SCDM Methodology. The references and the data extracted from them were selected to meet specific HRS requirements and conditions which may not be applicable or representative for other uses. In addition, the parameter values are updated only on an "as needed" basis. As a screening tool, the HRS and SCDM are used for quickly assessing sites at the screening stage and data used to perform this task may not be applicable for other site specific purposes.

The parameter values in SCDM should be used for HRS and NPL purposes only.

You will need Adobe Acrobat Reader to view some of the files on this page. See EPA's PDF page to learn more about PDF, and for a link to the free Acrobat Reader.

Superfund Chemical Data Matrix Report

- SCDM Methodology Report PDF
  - Part 1 - Table of Contents and Introduction (PDF) (5 pp, 283K)

030001

HAZARD RANKING SYSTEM
Hazardous Substance Factor Values

			Ground Water Mobility				Persistence		Bioaccumulation				Ecotoxicity					
			Liquid		Non-Liquid				Food Chain		Environment							
Substance Name	CAS Number	Toxicity	Karst	Non-Karst	Karst	Non-Karst	River	Lake	Fresh	Salt	Fresh	Salt	Fresh	Salt	Air Gas Migration	Air Gas Mobility	Gas	Part
Carbon disulfide	000075-15-0	10	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.4000	0.4000	500.0	500.0	500.0	500.0	100	10*	17	1.0000	Yes	No
Carbon tetrachloride	000056-23-5	1000	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.4000	1.0000	50.0	50.0	500.0*	500.0*	100	10*	17	1.0000	Yes	No
Cesium	007440-46-2	0	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.0000	1.0000	5.0*	50.0*	5.0*	50.0*	0	0	...	...	No	Yes
Chlordane	000057-74-9	10000	1.00E+00	1.00E-02	2.00E-03	2.00E-05	1.0000	1.0000	5000.0*	5000.0*	50000.0	5000.0*	10000	10000	6	0.0020	Yes	Yes
Chlordane, alpha-	005103-71-9	10000*	1.00E+00	1.00E-02	2.00E-03	2.00E-05	1.0000	1.0000	50000.0*	50000.0*	50000.0*	50000.0*	10000	10000	11*	0.0200*	Yes*	Yes
Chlordane, gama-	005566-34-7	10000*	1.00E+00	1.00E-02	2.00E-03	2.00E-05	1.0000	1.0000	50000.0	50000.0	50000.0*	50000.0*	0*	0*	6*	0.0020*	Yes*	Yes
Chlorobenzene	000108-90-7	100	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.0007	0.0700	50.0	50.0	5000.0*	5000.0*	10000*	100	17	1.0000	Yes	No
Chloroform	000067-66-3	100	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.4000	1.0000	5.0	5.0	500.0*	500.0*	100*	10	17	1.0000	Yes	No
Chromium	007440-47-3	10000	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.0000	1.0000	500.0*	500.0	500.0*	500.0	10000*	100	...	...	No	Yes
Chromium(III)	016065-83-1	1	1.00E+00	1.00E-04	1.00E+00	1.00E-04	1.0000	1.0000	500.0	500.0	500.0	500.0	100*	100*	...	...	No	Yes
Chromium(VI)	018540-29-9	10000	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.0000	1.0000	5.0	500.0	5.0	500.0	100	100	...	...	No	Yes
Chrysene	000218-01-9	10	1.00E+00	1.00E-04*	2.00E-05	2.00E-09*	1.0000	1.0000	5.0*	5.0*	5000.0	500.0	1000	1000	6	0.0002	Yes	Yes
Cobalt	007440-48-4	10*	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.0000	1.0000	5000.0*	5000.0*	5000.0	5000.0	0	0	...	...	No	Yes
Copper	007440-50-8	0	1.00E+00	1.00E-02	1.00E+00	1.00E-02	1.0000	1.0000	500.0*	50000.0	5000.0*	50000.0	1000*	1000*	...	...	No	Yes
Cumene	000098-82-8	10*	1.00E+00	1.00E-02*	2.00E-01	2.00E-03*	0.4000	0.4000	500.0	500.0	500.0	500.0	100	1	17	1.0000	Yes	No

* Indicates difference between previous version of chemical data (JUN 96) and current version of chemical data (JAN04).
** Indicates new hazardous substance in current version of chemical data (JAN04).

003002

HAZARD RANKING SYSTEM
Hazardous Substance Benchmarks

Substance Name	CAS Number	Ground Water/Surface Water Pathway Drinking Water			Surface Water Pathway Food Chain			Surface Water Pathway Environmental			
		MCL/MCLG (mg/L)	Reference Dose Screen Conc (mg/L)	Cancer Risk Screen Conc (mg/L)	FDAAL (ppm)	Ref. Dose Screen Conc (mg/kg)	Cancer Risk Screen Conc (mg/kg)	Acute CMC (µg/L) *		Chronic CCC (µg/L) *	
								Fresh	Salt	Fresh	Salt
Carbazole	000086-74-8	...	...	4.3E-3	...	...	1.6E-1	...	...	...	...
Carbon disulfide	000075-15-0	...	3.7E+0	...	...	1.4E+2	...	...	...	...	...
Carbon tetrachloride	000056-23-5	5.0E-3	2.6E-2	6.6E-4	...	9.5E-1	2.4E-2	...	...	...	...
Cesium	007440-46-2	...	...	...	...	...	...	...	...	...	...
Chlordane	000057-74-9	2.0E-3	1.8E-2	2.4E-4	3.0E-1	6.8E-1*	9.0E-3	2.4E+0[G]	9.0E-2[G]	4.3E-3[G, aa]	4.0E-3[G, aa]
Chlordane, alpha-	005103-71-9	...	1.8E-2*	2.4E-4*	...	6.8E-1*	9.0E-3*	...	...	...	...
Chlordane, gama-	005566-34-7	...	1.8E-2*	2.4E-4*	...	6.8E-1*	9.0E-3*	...	...	...	...
Chlorobenzene	000108-90-7	1.0E-1	7.3E-1	...	...	2.7E+1	...	...	...	...	...
Chloroform	000067-66-3	...*	3.6E-1	...*	...	1.4E+1	...*	...	...	...	...
Chromium	007440-47-3	1.0E-1	1.1E-1*	...	...	4.1E+0*	...	...	...	...	...
Chromium(III)	016065-83-1	...	5.5E+1*	...	...	2.0E+3*	...	5.7E+2[D, E, K]	...	7.4E+1[D, E, K]	...
Chromium(VI)	018540-29-9	...	1.1E-1*	...	...	4.1E+0*	...	1.6E+1[D, K]	1.1E+3[D, bb]	1.1E+1[D, K]	5.0E+1[D, bb]
Chrysene	000218-01-9	...	...	1.2E-2	...	...	4.3E-1	...	...	...	...

* Indicates difference between previous version of chemical data (JUN 96) and current version of chemical data (JAN04).
** Indicates new hazardous substance in current version of chemical data (JAN04).

003013

Reference 4

Reference 4-

Reserved Reference

Reference 5

NCR 112 SI LOG BOOK #1

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RECYCLED CONTENT

7/20/2009

Shane Ames URS
FADEI Malakieh URS
April Palmie TCEQ
Dani Soule TCEQ
Mike Cave TCEQ

at 7:15 AM in the hilton lobby M. Cave conducted the HISR Meeting. The following people were in attendance:

Weather → 79°F, slight breeze, partly cloudy. 20% chance of rain

Arrived at the staging area at 8am located at the corner of SCR 1205 and WCR 110.

The field parameter meter used was the Ultra meter II.

Calibration Standards	Range	Standards
Conductivity	10-200 mS/cm	— 660 PPM
Resistivity	10 KΩ	— 660 PPM
TDS	10-200 PPT	→ 510 ppm NaCL
pH	0-14 pH	→ 7 pH
ORP	−1000 mV − +1000 mV	→ 7 pH
Temp	0-71°C / 32-160°F	→ 25°C

Danielle Soule 7/20/09

7/20/09

GW-22 - Groundwater background Sample

3004 SCR 1207 - Robert White

photo one : N facing photo of well and sample location of GW-22 - photo by D. Soule

~~Temp~~ Time	Temp	TDS	Cond.	~~DO~~	pH	ORP
910	21.7	1053	1484		6.02	107
924	21.4	1071	1505		7.08	98
929	21.3	1067	1500 1495		7.07	97
934	21.3	1067	1500		7.07	97
939	21.3	1066	1498		7.09	93
942	21.4	1071	1505		7.12	93

Well was purged from closes faucet to the well located after a small pressure tank.

Samples were collected from faucet located after pressure tank. VOC's were collected followed by Total metals. Samples were collected by Chase Ames at 9:45AM.

Danielle Soule 7/20/09

Danielle Soule 7/20/09

US 003

GW-20

This groundwater sample location has an anion exchang filtration system connected to the well.

HE	TDS	Temp	Cond.	pH	ORP
30	1958	23.1	2638	591	205
145	1961	23.9	2627	693	331
150	1958	24.4	2637	6.99	328
155	1950	24.2	2636	7.04	327
1200	1932	24.7	2612	7.04	318

GW-20 ~~samples~~ VOC's and TM's were collected in that order at 1201 samples were collected ~~to~~ by F. Malakien.

Danielle Soule 7/20/09

7/20/09 at 12:20 PM
GW-28/GW-37 Duplicate
2700 W CR 112

Well depth at 70 feet

photo #7 - N. facing photo of the effluent port where ~~gw-28/37~~ gw was purged.

photo #8 - N facing photo of the influent port where gw-28/37 was collected.

photo 7 and 8 where collected by D. Soule

Time	TDS	Temp	Cond.	pH	ORP
1220	2308	29.1	3124	7.10	237
1235	2306	30.1	3125	7.25	296
1240	2309	28.68	3201	7.313	269.2
1245	2310	27.6	3120	7.31	269
1250	2315	26.2	3115	7.30	269
1253	2326	25.8	3121	7.33	230
1256	2327	25.1	3122	7.21	232

GPS file 20720177B - GPS Coord. Collected by D. Soule

Danielle Soule 7/20/09

2

Time	TDS	Temp	Cond	pH	ORP
1510	1908	45.5	2650.	7.21	137
1525	1905	30.01	2607	7.52	145
1530	1910	28.4	2597	7.35	141
1535	1911	27.9	2598	7.28	139
1540	1914	27.4	2604	7.27	141
1543	1911	27.6	2605	7.24	142

F. MALAKEN collected GW-14 at 1545

Water water collected was a medium yellow [illegible]

DAG 7/20/09

Danielle Sorle 7/20/09

05 007

7/20/2009 @ 1600

GW-31 - Well depth at
2514 W CR112
Acosta

* This sample site contains an anion exchange filtration system on the well

* groundwater was purged from the effluent part of the filtration system

Time	Temp	TDS	Cond.	pH	ORP
1602	28.6	1667	2393	7.46	135
1617	23.7	1636	2252	7.40	137
1622	22.8	1627	2235	7.38	142
1627	22.7	1601	2196	7.36	142
1636	22.7	1599	2192	7.35	141

* groundwater samples were collected for VOC's & TM's VOC's were collected [illegible] followed by TM's.

GW-31 was collected by F. Malaken at 1634

Dan Sorle

7/21/09 @ 800 AM

- Shane Ames, Fadie Malakien, A. palmie, Mani Soule, and M. Cave attended the H&S meeting at the stadging area onsite at 8:15 AM.

The two Ultrameter II were calibrated

Standards	ultra meter (1)		UltraMeter II
pH 7	7	6.99	6.92
pH 4		4.03	3.92
Cond.	1035	1034	1029

Clear morning w/ slight breeze. The temperature was 80°F.

7/21/09

0

TIME	TDS	Temp	Cond	pH	ORP
855	1956	23.0	2640	5.35	172
910	1951	22.5	2641	5.4	153
915	1950	22.3	2630	6.82	155
920	1949	22.3	2625	6.85	158
925	1947	22.5	2626	6.90	160

05 011

Malakien was collected gw-33/40 at 928 / & 945, respectively. VOCs followed by TM's were collected. GW samples were collected from the closes faucet to the well before the pressure tank.

7/21/09

7/21/09 at 1000

GW-12
2714 WCR114
Dickens

The well at this location contains an aion exchange filtration system.

The well was purged from effluent port of the filtration system

TIME	TDS	Temp	Cond.	pH	ORP
1005	2032	22.0	2754	6.90	132
1020	2035	24.8	2741	7.28	155
1025	2032	23.5	2732	7.23	162
1030	2031	23.7	2736	7.33	171
1035	2032	23.0	2732	7.21	176

F. MALAKIEN collected gw-12 from the influent port on the anion exchang filtration system at 1040

7/21/09

7/21/09 - GW-08

* GPS file #: 20712116B

gps coord. collected by D. Soule

photo ~~#5~~ 23 ~~93~~ : S facing photo of the anion exchange filtration system w/ port #3 (effluent where gw was purged) and port #1 where (influent) gw-08 was collected

05 013

Danielle Soule 7/21/09

7/21/09 at ~~2108~~ 1208

GW-03

2602 W CR 114

The well at this location has an ~~ax~~ aion exchange filtration system.

groundwater was purged from the effluent port of the filtration syst.

Time	TDS	Temp	Cond.	pH	ORP
1208	1672	31.3	2304	7.30	161
1223	1629	29.8	22~~0~~64	7.59	205
1228	1639	28.7	2278	7.41	203
1233	1651	28.4	2284	7.48	
1238	16~~6~~8 5	27.9	2282	~~7.48~~ 7.41	216

F. MALAKLIEN collected gw-03 sample from the influent port He collected VOC's followed by TM's. Collection Time was 1240.

[signature]

* GPS file # Z0721198
GPS Coordinates collected
by D. Soule

photo 27 of effluent
port where gw was
purged

photo 28 of influent
port where gw-116 sample
was collected

photos collected by
D. Soule

7/21/09

05 015

7/21/09 at 1500
GW-01
2805 W CR 110
Ramirez

The well at this location has an
anion exchange filtration system.

The groundwater was purged from effluent.

Time	TDS	Temp	Cond.	pH	ORP
1508	1761	24.4	2400	7.49	132
1525	1770	23.2	2402	7.46	139
1528	1765	22.7	2401	7.38	147
1533	1775	22.7	2406	7.40	146
1538	1767	22.5	2401	7.41	152

F. MALAKIEN collected GW-01 samples
from the influent port on the
filtration system. He collected VOC's
followed by TM's. Samples
were collected at 1540.

7/21/09

2

7/22/09 at 8:36AM

Shane Ames, FADIE MALAKIEN, Dani Soule, April PAMLE, Mike CAVE, and Lloyd Johnson attended the HBS meeting lead by M. CAVE.

Two Ultrameter II were calibrated

Standards	Meter 1	Meter 2
7 pH	6.99	7.00
4 pH	4.00	3.96
Cond. 1035	1033	1027

- Overcast w/ slight breeze at 75°F

Danielle Soule 7/22/09

7/22/09 at 9:05

GW-11

2604 SCR 1200

*Well depth 80 ft

The well located at the GW-11 site contains an ~~air~~ ~~aion~~ anion exchange filtration system.

Groundwater was purged from the effluent port of filtration sys.

TIME	TDS	Temp	Cond	pH	ORP
910	1613	22.0	2206	4.28	273
925	1614	21.4	2206	4.86	245
930	1615	21.3	2205	4.90	242
935	1610	21.3	2199	4.90	247
940	1599	21.3	2184	4.95	247

F. MALAKIEN collected groundwate sample #11 from the influent port of the filtration system. He collected the VOC's followed by TM's. Collection time was 9:42 AM

05 017

GPS file # : 2072215A
Collected by D. Soule

photo # 34 at 1048
is an ~~est~~ east facing photo of the filtration system at the GW-26 site. The photo shows port A (inflnent) where gw-26 was collected

US 015

7/22/09

7/22/2009 at 1250 Well is 76' deep
GW-15 MS/MOS
3000 S CR 1200
A

The well at this gw location contains an anion exchange system.

Groundwater was purged from the effluent port of the filtration system.

Time	TDS	Temp	Cond	pH	ORP
1254	1480	21.2	2034	7.08	142
1309	1485	21.0	2040	7.13	139
1314	1486	21.1	2041	7.06	140
1319	1485	21.1	2041	7.09	141
1324	1485	21.1	2040	7.05	142

F. Malakien collected the gw sample from the site. The sampler collected from the inflnent port of the filtration system. He collected VOCs followed by TMS. Samples ~~wer~~ collected at 1326

7/22/09

GPS file #: 20722 19A
Collected by D. Soule

E Photo facing photo 38 of the filtration system where gw-3A ~~where~~ was collected from the effluent port.

05 021

7/22/09

7/22/2009
Returned to the field from sampling. 1450 and ceased field gw sampling.

Packed samples in cooler for shipping. after metals were preserved by + Palmic.

1600 - Met w/ Lloyd Johnson TCEQ's QA/QC Tech specialist. Mr. Johnson conducted initial audit findings

~~1650~~

1630 - left for federal express with all coolers sealed w/ custody seals

7/22/09

05 023

7/23/09

7/23/09 at 0858
SO-4 - background
3004 SCR 1207

A surface soil background sampling was collected in the east side of the property located at 3004 SCR 1207.

A decon. spoon and bowl were used to collect the a 4 in ~~surce~~ surface soil sample.

Shane Ames collected SO-04. He collected VOC's followed by TM's.

GPS file: 2072314A
Collected by A. Palmie

Photo ~~34~~ 41 DAS due down in the east direction where SO-04 was collected.
Photo taken by A. PALMIE.

Danielle Sorle 7/23/09

7/23/09

7/23/2009 at 0958
SO-02 / SO-03 (Dup.)
2604 W CR 112

SO-02 and SO-03 (Dup.) are surface soil samples collected from an old pit that was once filled w/ debris and 55-gallon drums. The new property owners removed the debris and drums recently, and filled in the pit.

S. Ames collected a 3 to 4 inch surface sample at 1000 (SO-02). He collected VOC's followed by TM's. After collecting SO-02 he collected SO-03, which was timed at 1015 on the sample tag.

SO-02 and SO-03 were collected with a sealed spoon and bowl (metal) that was decon prior to the sampling event.

GW-44 - was a field blank
Collected by SO-02 & SO-03
Nas 10.12.09

7/23/09

7/23/09

05 0227

7/23/2009 at ~~1120~~ 1115

GW-45
Rinesate for Soil Augur ~~#~~ #2
After following field decon. instructions on pg. 51a stream of ultra deionized was poured on the auger tip. A VOC and TM sample were collected.

S. Ames collected the samples at 1120.

Soil auger #2 was used at SO-01.

7/23/09

Jamille Saule 7/23/09

05 029

Reference 6

WCR 112 SI LOGBOOK #2

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WCR 112 GROUNDWATER PLUME 7/20/9

0715 HEALTH SAFETY MTG AT HILTON
FULL NOTES IN LOG BOOK #1 KEPT BY DANIELLE SATTMAN SOULE

0800 PROCEED TO SITE. 0800 BEGIN SET UP STAGING AREA AT PETROPLEX, CALIBRATION NOTES IN BOOK #1
80° OVERCAST CALM
NOTES ON SAMPLING. READINGS - 30 MIN REQUIRED INITIAL, 3 1st in 15 MINS, 3 more at 5 min (up to 30 MINS), 30-45 min at 3 min INTERVALS if not stable.

3 measurements w/in following interval
pH +/- 0.5
cond +/- 10%
tem +/- 0.5°C

0900 PROCEED TO GW-22 ROBERT WHITE 3004 SCR 1207
BEGIN PURGE ~~0910~~ 0909

	TIME	TDS	TEMP	COND	PH	ORP
INITIAL	09:10	1053	21.7	1484	6.02	107
1st	09:24	1071	21.4	1505	7.08	98
2nd	09:29	1063	21.3	1495	7.06	97
3rd	09:34	1067	21.3	1500	7.07	97
4th	09:39	1066	21.3	1498	7.09	93
5th	09:44	1071	21.4	1505	7.12	93

SAMPLE TIME 0945 Shane AMES - SAMPLER
VOAs collected before metals
SAMPLES TAGGED + CUSTODY SEALED. PUT ON ICE. PROCEED TO TRACE

7/20/09

7/20/09

1000 TO TRACE ENGINES 3000 I-20 GW-10
BACKGROUND SAMPLE
COLLECT SAMPLE FROM FAUCET IN WELL HOUSE
WELL IS ON WEST SIDE OF MAIN
TRACE ENGINES BUILDING

PHOTO 2: TRACE WELL GW-10
DUE EAST, APRIL PALMIE, 1000

BEGIN PURGE FROM FAUCET IN WELL HOUSE
AT ~~10:23~~ 10:08

Reading	Time	TDS	Temp	Cond	PH	ORP
INITIAL	10:10	1859	22.1	2514	7.07	97
1st	10:25	1845	21.8	2501	7.10	101
2nd	10:30	1844	21.6	2494	7.05	97
3rd	10:35	1849	21.6	2502	7.07	91
4th	10:40	1857	21.6	2510	7.10	90
5th	10:43	1862	21.5	2517	7.09	93
6th	10:46	1862	21.5	2516	7.08	94

GPS 20720158 GW-10 PALMIE
SAMPLER SHANE AMES, VOCS collected before metals, TAG + SEAL
SAMPLE TIME 10:48 GW-10, PUT ON ICE
TO STAGING AREA, DROP SAMPLES
1105 BACK TO GW-22 TO COLLECT GPS READING
GPS 20720164 GW-22 PALMIE

1110 BACK TO STAGING AREA

7/20/2009

1118 TO GW-19 2710 W CRUZ BOWERS 7/20/9

MS/MSD WILL COLLECT TRIPLE VOL VOAS + DOUBLE METALS

NOTE: STRONG SMELL OF PESTICIDES IN WELL BUILDING

PHOTO 3: DUE NORTH, GW-19, PALMIE

GPS FILE 20720116B

BEGIN PURGE FROM EFFLUENT PORT (C)
AT 11:27

READING	TIME	TDS	TEMP	COND	PH	ORP
INITIAL	11:28	2863	25.3	3797	7.02	125
1st	11:43	2624	24.1	3496	6.99	134
2nd	11:48	2568	23.6	3422	6.98	133
3rd	11:53	2501	23.4	3339	6.99	133
4th	11:58	2461	23.3	3290	6.98	132
5th	12:01	2441	23.6	3273	6.95	133

SAMPLER SHANE AMES, VOAS THEN METALS COLLECTED
SAMPLE TIME 12:03 GW-19 from Port A influent
TAG + SEAL, PUT ON ICE.

TRAVEL TO STAGING AREA

BOOK #3

7/20/9

1220 TO GW-27 MOFFIT 2615 W CR 112

1234 Start purge from effluent port (C)

PHOTO 6 DUE N, GW-27 well, PALMIE

GPS FILE 20720170 GW-27

Reading	Time	TDS	Temp	Cond	PH	ORP
Initial	1235	1896	25.4	2549	7.12	113
1st	1250	1909	25.0	2598	7.11	122
2nd	1255	1922	22.8	2601	7.12	125
3rd	1300	1945	22.5	2619	7.09	130
4th	1305	1946	22.3	2623	7.09	128

vocs then metals collected

Sample collected from port A influent by Shane Ames GW-27 SAMPLE Time 1307, tag + seal + put on ice, back to staging area

1330 Break for lunch + set up computer / printer

1505 TO GW-21 SHELDON + DEBBIE JOHNSON 2601 N CR 112

begin purge from port C (effluent) at 1514

PHOTO 11, DUE N of GW-21, PALMIE

GPS FILE 20720208 GW-21

7/20/9

GW-21 CONT Began purge 1514

Time	Reading	TDS	Temp	COND	PH	ORD
1515	initial	1573	27.2	2181	7.03	77
1530	1st	1518	26.3	2119	7.30	112
1535	2nd	1543	25.2	2126	7.25	124
1540	3rd	1514	24.5	2091	7.23	121
1545	4th	1514	24.2	2086	7.31	121

Sample collected 1547 GW-21 by Shane Ames
FROM PORT A influent VOAS then metals
SAMPLE tagged + sealed + put on ice.
~~TIME READING TDS TEMP COND PH ORD~~ AP

1605 TO GW-29 Cimtons 2502 WCR 112

Begin Purge at 1609 from effluent port (C)

Reading	Time	TDS	TEMP	COND	PH	ORD
Initial	1610	1638	31.0	2269	7.20	126
1st	1625	1640	27.5	2245	7.13	128
2nd	1630	1639	26.2	2306	7.07	133
3rd	1635	1660	24.4	2270	7.05	137
4th	1640	1657	24.3	2280	6.98	139
5th	1643	1663	23.6	2281	6.98	140
6th	1646	1661	23.7	2280	7.00	141
7th	1649	1660	23.4	2278	6.97	142

PHOTO 12 DUE N, PALMIE

GPS FILE 20720214 GW-29

7/20/9

GW-29 CONT

SAMPLED ~~FOR~~ ab FROM PORT A INFLUENT AT 1651. VOAS collected first, then Metals SAMPLER SHANE AMES. SAMPLE Tagged and Sealed and put on ice.

1700 TO STAGING AREA & PRESERVE METALS + Prepare samples to ship.

1737 COLLECT ~~FB~~ ab Field Blank GW-41 at staging area, by S. Ames DANI, FADI, + SHANE TRANSPORT SAMPLES TO FEDEX MINE + APRIL STAY AT STAGING AREA TO PACK UP

1845 DEPART ~~SIT~~ ab SITE.

END DAY 1

900 90

7/20/9

200 90

7/21/09

0745 DEPART FOR SITE STAGING AREA (PETROPLEX)

0800 MEET CONTRACTORS, GAIN ACCESS TO YARD FOR SET UP. WEATHER APPROX 80°F, light breeze, up to mid 90's by end of day

0815 SAFETY MTG CONDUCTED BY MIKE CAVE. HEAT, INSECTS, ANIMALS, SLIPS, TRIPS, FALLS

0845 TO GW-07 2718 W CR 114 JOSE URANGA MS/MSD

BEGIN PURGE AT 0853 FROM EFFLUENT PORT C

Reading	TIME	TDS	TEMP	COND	PH	ORP
Initial	8:54	1852	25.0	2516	5.81	162
1st	9:09	1844	22.2	2498	7.02	164
2nd	9:14	1844	21.6	2495	7.05	160
3rd	9:19	1845	21.5	2495	7.07	159
4th	9:24	1846	21.4	2496	7.09	162

Samples collected at 925 from Port A influent by Shane Ames. VOAs collected before metals. samples tagged & sealed & put on 16

PHOTO 17 DUE N, PALMIE of well GW07
GPS FILE Z072114B, PALMIE

PHOTO 18 DUE N, PALMIE of filter at GW-07

900 90

7/21/09

BOOK #2

7/21/09

0945 TO GW-13 2708 W CR114 Elder

Began purge from Effluent Port C at 0949

GPS FILE Z072115A , PALMIE
PHOTO 19 DUE W, PALMIE of filter GW-13
PHOTO 20 DUE N, Palmie of well at GW-13

Reading	Time	TDS	Temp	Cond	pH	ORP
Initial	0950	2003	26.6	2704	7.13	150
1st	1005	1989	23.9	2681	7.18	157
2nd	1010	1992	23.3	2680	7.16	161
3rd	1015	1995	23.0	2683	7.14	159
4th	1020	1990	22.7	2676	7.17	159
5th	1023	1990	22.6	2676	7.17	158
6th	1026	1991	22.5	2677	7.17	159

Sample time 1028 collect from influent port 14 by Shane Ames. VOAs before metals samples tagged + sealed + put on 14

1030 TO STAGING AREA FOR SAMPLE DROP OFF + PICK UP NEW SAMPLES

600 90

7/21/09

7/21/09

1115 TO 2701 W CR 114 GW-05 FRANKLIN HOWARD

1119 Begin Purge from effluent port C

~~Purge~~ Reading	Time	TDS	Temp	Cond	pH	ORP
Initial	1120	1761	23.8	2404	7.16	139
1st	1135	1830	23.2	2480	7.44	138
2nd	1140	1807	22.9	2456	7.36	136
3rd	1145	1801	22.6	2447	7.26	134
4th	1150	1787	23.1	2433	7.26	128
5th	1153	1787	22.8	2431	7.26	128
6th	1156	1788	22.9	2431	7.30	129

GPS FILE Z072116A, PALMIE
PHOTO 22 DUE E, PALMIE, GW-05 filter + well

SAMPLE TIME 1158 COLLECTED BY SHANE AMES FROM INFLUENT PORT A. VOAS BEFORE METALS samples tagged + sealed + put on ice

1205 TO GW-04 2500 W CR 114 TOMMIE MITCHELL

BEGIN PURGE 1209

GPS FILE Z072117A PALMIE

PHOTO 24 ~~16~~ + ~~17~~ DELETED OR, PALMIE, DUE North, well + filter

Camera malfunctioning, put photos between older shots - CROSS OUTS INDICATE CORRECT NUMBER + ORDER OF PHOTOS

06 010

7/21/9

7/21/9

1210 GW-04 CONT

Reading	Time	TDS	Temp	Cond	PH	ORP
Initial	1210	2087	26.6	2847	7.26	136
1st	1225	2006	26.5	2716	7.53	123
2nd	1230	2003	25.0	2705	7.51	123
3rd	1235	1973	25.3	2675	7.58	121
4th	1240	1961	25.8	2649	7.50	118
5th	1243	~~1961~~ 1951	24.7	2645	7.57	121
6th	1246	1946	24.2	2639	7.52	118
7th	1249	1946	24.6	2638	7.50	115

Sample collected by Shane Amos at 1250 FROM INFLUENT PORT A. VOAS BEFORE METALS

Samples tagged + custody sealed, put on ice

255 TRAVEL TO STAGING area, drop of samples

1300 Break for lunch

1400 TO WCR114

1405 TO GW-02 LUIS VILLANUEVA 2605 WCR114

1409 Begin purge

GPS FILE Z072119A, PALMIE
PHOTO ~~19~~ 26 OR DUE W ~~DUE~~ S, PALMIE, (1423)

7/21/19

1410 GW-02 cont

Reading	Time	TDS	Temp	Cond	PH	ORP
Initial	1410	1846	26.7	2509	7.44	91
~~1410~~ 1st	1425	1860	25.2	2541	7.35	118
~~14~~ 2nd	1430	1860	23.8	2529	7.26	131
3rd	1435	1840	23.1	2496	7.22	140
4th	1440	1825	23.1	2482	7.20	138
5th	1443	1825	22.8	2479	7.17	138
6th	1446	1819	22.7	2473	7.17	137

Sample collected at 1448 from port A influent by Shane Ames. VOAs before metals. Sample was tagged, custody sealed + put on ICE

1455 PROCEED TO GW-09 + DUP GW-20
DELLA HOLIEDY 2404 W CR 114

PHOTO ~~22~~ 29 DUE E, PALMIE 1457
GPS FILE 2072119C, PALMIE

Begin purge at 1503 from Effluent Port C

7/21/19

06 012

1505 GW-09 CONT

Reading	Time	TDS	Temp	Cond	pH	orp
Initial	1505	1619	24.2	2216	7.30	137
1st	1520	1644	23.4	2243	7.31	145
2nd	1525	1641	22.8	2245	7.32	148
3rd	1530	1645	22.8	2250	7.30	149
4th	1535	1649	22.5	2254	7.31	150

GW-09 Sample collected at 15:37 by Shane Ames from Influent Port A

GW-34 Duplicate sample collected at 15:52 by Shane Ames from Influent Port A

SAMPLES TAGGED, CUSTODY SEALED + put on IC

1553 TO STAGING AREA FOR SAMPLE PREP, METAL PRESERVATION

1700 HEAD TO FEDEX TO SHIP SAMPLES. DISCUSS AUDIT WITH LLOYD

1745 DEPART FOR HOTEL

END DAY 2

06 013

7/21/9

7/22/9

0745 Meet to travel to site. Car troubles

0836 Meet at staging area for s Health + Safety Mtg. Staff Mike Cave, Dan, April, Shane, Fadi, Lloyd (auditing today)

0909 TO GW-06 2524 COTTON FLAT RD, ALCOCER ~~ADN~~ AND GW-35 DUPLICATE

BEGIN PURGING FROM PORT C EFFLUENT AT 0914

READING	TIME	PH	TEMP	COND	ORP	TDS
Initial	9:15	5.62	21.9	2651	162	1972
1st	9:30	7.15	21.0	2755	147	2061
2nd	9:35	7.09	20.9	2765	151	2070
3rd	9:40	7.01	20.9	2732	154	2042
4th	9:45	7.00	20.9	2691	156	2009
5th	9:48	~~7.00~~ 7.01	20.9	2662	159	1984
6th	9:51	6.98	20.8	2641	159	1967

SAMPLE GW-06 collected at 0952 by Shane Ames from Port A influent.
Duplicate GW-35 collected from Port A influent at 1007 By Shane Ames

Tagged, custody sealed + put on ice

GPS FILE Z072214B, PALMIE

PHOTO ~~26~~ 33 OR, DUE N, PALMIE, TIME 9:58

Weather overcast, chance of rain temp to 80s

06 014

7/21/09

7/22/09

1005 Back to staging area.
Shane + April will sample GW-17+18 by staging area.

1019 Shane collects field blank GW-43 adjacent to GW-18 at 1019

1025 TO GW-17 2801 + 2803 WCR111 RIGNET

Begin purge at 1034 from Effluent Port C

Reading	Time	PH	Temp	Cond	ORP	TDS
Initial	1035	7.03	28.7	2777	167	2039
1st	1050	6.99	24.2	2710	178	2013
2nd	1055	6.93	23.9	2706	177	2011
3rd	1100	6.93	23.1	2704	180	2011
4th	1105	6.91	22.8	2697	180	2008
5th	1108	6.92	22.7	2697	182	2007

Sample collected at 11:10 from Port A Influent VOAs before metals.

SAMPLE tagged + custody sealed

1130 [PHOTO ~~28~~ 35 ar, DUE W, PALMIE, TIME 1135]
GPS FILE Z0722116A, PALMIE WENT BACK FOR AT 11:30

~~1120~~ 1140 [TO ~~GW-18~~ GW-18 ar ~~36~~ ar Petroplex 2802 W CR111
GPS FILE Z0722116B, Palmie &
Photo 36, Due N, Palmie TIME 11:42

Book #2

7/22/19

1144 Begin purge of GW-18 from Effluent Port C

Reading	Time	~~Cond~~	pH	Temp	Cond	ORP	TDS
Initial	1145	3285	6.98	24.3	3285	175	2457
1st	1200	3255	7.06	21.7	3255	179	2443
2nd	1205	(W)	7.04	21.3	3236	180	2429
3rd	1210		7.05	21.0	3231	184	2426
4th	1215		7.02	20.8	3230	186	2426

RAINING THROUGHOUT SAMPLE PURGE + COLLECTION TIME, LIGHTNING / THUNDER INTERVAL APPROX 16-18 secs meaning lightning is far from site. Safe to sample. April held umbrella over Shane while we sampled.

Sample collected at 1219 from Influent Port C by Shane Ames. VOAs before metals.

Samples were tagged, custody sealed, + put on ICE

1245 Break for lunch

1315 Return to staging area. Still raining.

7/22/19

7/22/9

1400 TO GW-25 2605 W CR 110 Mendoza

1401 Begin purging GW-25 from Effluent Port C

Reading	Time	PH	Temp	Cond	ORP	TDS
Initial	1405	7.04	26.5	2710	172	1995
1st	1420	7.16	23.9	2642	178	1960
2nd	1425	7.09	23.1	2635	180	1956
3rd	1430	7.09	22.7	2634	180	1956
4th	1435	7.08	22.3	2633	181	1956

Sample collected at 1437 from PORT A Influent by Shane Amos. Samples were tagged, custody sealed & put on ice.

GPS ~~Reading~~ File 20722198, PALMIE

PHOTO ~~3239~~ 3239 DUE SE, PALMIE TIME 1449

1450 Return to staging area for sample prep, metal preservation, & shipping prep.

1600 MET W/ LLOYD TO DISCUSS PRELIM AUDIT RESULTS (DAN, MIKE, APRIL, LLOYD)

1630 TRAVEL TO FEDERAL EXPRESS TO SHIP SAMPLES

END OF DAY 3

7/22/9

06 012

7/23/09

0745 MEET IN HOTEL LOBBY

0810 TO STAGING AREA FOR PRED

OFFICIAL LOG IN BOOK #1. SOIL SAMPLE PHOTOGRAPHIC + GPS DOCUMENTATION IN BOOK #1 ALSO WITH SAMPLE NOTES

SO-05 GPS FILE 2072313A, PALMIE
PH#40 PHOTO ~~33~~ 40 DUE DOWN + EAST, PALMIE, 09:49
SAMPLE TIME 08:47

SO-04 GPS FILE, 2072314A, PALMIE
PH#41 PHOTO ~~34~~ 41 DUE DOWN + EAST, PALMIE, 09:09

SO-01 GPS FILE, 2072314C, PALMIE
PH#42 PHOTO ~~35~~ 42 DUE DOWN + EAST, PALMIE TIME 9:59
SAMPLE TIME 0955

SO-02/DUP SO-03
GPS FILE, 2072315A PALMIE
PH#43 PHOTO ~~36~~ 43 DUE DOWN + EAST, PALMIE TIME 10:07
SAMPLE TIME SO-02 10:00, DUP SO-03 10:15

END FIELD LOG BOOK #2 FOR WCR 112
GROUNDWATER PLUME SI
COMPLETE DAY 3
FIELD NOTES CONTAINED IN BOOK #1 KEPT
BY DANIELLE SAMMAN SOULE

APRIL PALMIE

7/23/9

Reference 7

GEOLOGIC HISTORY AND HYDROGEOLOGIC SETTING OF THE EDWARDS-TRINITY AQUIFER SYSTEM, WEST-CENTRAL TEXAS

By Rene' A. Barker, Peter W. Bush, and E.T. Baker, Jr.

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94–4039

Austin, Texas
1994

07 001

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

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07 003

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CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY UNIT

Multiply	By	To obtain
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft^2/d)	0.09290	meter squared per day
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
mile squared (mi^2)	2.590	kilometer squared

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Water-quality unit:

mg/L, milligram per liter

Geologic History and Hydrogeologic Setting of the Edwards-Trinity Aquifer System, West-Central Texas

By Rene´ A. Barker, Peter W. Bush, *and* E.T. Baker, Jr.

Abstract

The Edwards-Trinity aquifer system underlies about 42,000 square miles of west-central Texas. Nearly flat-lying, mostly Comanche (Lower Cretaceous) strata of the aquifer system thin northwestward atop massive pre-Cretaceous rocks that are comparatively impermeable and structurally complex. From predominately terrigenous clastic sediments in the east and fluvial-deltaic (terrestrial) deposits in the west, the rocks of early Trinitian age grade upward into supratidal evaporitic and dolomitic strata, intertidal limestone and dolostone, and shallow-marine, open-shelf, and reefal strata of late Trinitian, Fredericksburgian, and Washitan age. A thick, downfaulted remnant of mostly open-marine strata of Eagleforgian through Navarroan age composes a small, southeastern part of the aquifer system.

The Trinity Group was deposited atop a rolling peneplain of pre-Cretaceous rocks during three predominately transgressive cycles of sedimentation that encroached upon the Llano uplift. The Fredericksburg and Washita Groups were deposited above the Trinity Group mostly in the lee of the Stuart City reef trend, a shelf margin ridge that sheltered depositional environments in the study area. The Washita Group subsequently was covered with thick, mostly fine-grained Gulf strata.

During late Oligocene through early Miocene time, large-scale normal faulting formed the Balcones fault zone, where the Cretaceous strata were downfaulted, intensively fractured, and differentially rotated within a series of northeast-trending fault blocks. In addition to fracturing the rocks in the fault zone and extending the depth of freshwater diagenesis, the faulting vertically displaced the terrain, which steepened hydraulic gradients and maintained relatively high flow velocities near the surface. A shallow regime of dynamic ground-water flow evolved that promoted dissolution and enhanced the transmissivity of the Edwards Group in the Balcones fault zone. Cementation, recrystallization, and mineral replacement—caused by deeper, comparatively sluggish ground-water circulation—combined to diminish the transmissivity of the underlying Trinity Group, as well as most Cretaceous strata in the Hill Country, Edwards-Plateau, and Trans-Pecos.

The Trinity, Fredericksburg, and Washita strata compose a regional aquifer system of three aquifers, whose water-transmitting characteristics generally are continuous in the lateral direction, and two hydraulically tight confining units. The aquifers are the Edwards aquifer in the Balcones fault zone, the Trinity aquifer in the Balcones fault zone and Hill Country, and the Edwards-Trinity aquifer in the Edwards Plateau and Trans-Pecos. The Navarro-Del Rio confining unit overlies the subcrop of the Edwards aquifer, and the Hammett confining unit lies within the updip, basal part of the Trinity aquifer and a small southeastern fringe of the Edwards-Trinity aquifer. The confining units are mostly calcareous mudstone, siltstone, and shale of low-energy terrigenous and open-shelf marine depositional environments. The aquifers mainly result from fractures, joint cavities, and porosity caused by the dissolution of evaporites and unstable carbonate constituents.

07 005

Because the diagenetic effects of cementation, recrystallization, and mineral replacement diminish the hydraulic conductivity of most rocks composing the Trinity and Edwards-Trinity aquifers, transmissivity values average less than 10,000 feet squared per day over more than 90 percent of the study area. However, the effects of tectonic fractures and dissolution in the Balcones fault zone cause transmissivity values to average about 750,000 feet squared per day in the Edwards aquifer, which occupies less than 10 percent of the study area.

INTRODUCTION

The Edwards-Trinity aquifer system, underlying about 42,000 mi^2 of west-central Texas, was studied as part of the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) program. The Geological Survey began the RASA program in 1978 to define the hydrogeology of large aquifer systems in the United States. The Edwards-Trinity RASA is one of 28 RASA projects nationwide that were identified for study under the program (Weeks and Sun, 1987, fig. 1).

Available data on the hydrogeology of west-central Texas generally cover smaller areas than the regional scale of this RASA project. Therefore, the contents of this report were synthesized primarily from the published work of investigators in colleges and universities, in agencies of local and Federal governments, and in industry. Chief contributors are the U.S. Geological Survey, the Bureau of Economic Geology of the University of Texas at Austin, the Texas Water Development Board, and the Texas Natural Resource Conservation Commission. Publications of the American Association of Petroleum Geologists and the Geological Society of America, and some unpublished dissertations and theses from the University of Texas (Austin and Arlington) also were useful.

Purpose and Scope

This report summarizes the geologic history and hydrogeologic setting of the rocks that compose the Edwards-Trinity aquifer system. Pertinent depositional, tectonic, and diagenetic events are reviewed in the section "Geologic History." The "Hydrogeologic Setting" section relates the regional aquifers and confining units to their chronostratigraphic and lithostratigraphic counterparts and summarizes ground-water conditions in the study area.

Acknowledgment

Much of the geologic information provided in this report for the western part of the study area was summarized from unpublished maps and notes volunteered by Dr. C.I. "Ike" Smith, Chairman, Department of Geology at the University of Texas at Arlington. The authors are greatly indebted to Dr. Smith for his generous contributions.

Aquifer-System Boundaries

The study area of the Edwards-Trinity RASA comprises the Edwards-Trinity aquifer system plus contiguous hydraulically connected units (fig. 1). The contiguous hydraulically connected units are between the boundary of the Edwards-Trinity aquifer system and the natural or assumed boundaries of the regional ground-water-flow system, where the two are not coincident.

The Edwards-Trinity aquifer system contains three major aquifers and two major confining units (fig. 2). From east to west, the aquifers are the Edwards aquifer, Trinity aquifer, and Edwards-Trinity aquifer. The aquifers are laterally adjacent except in the southeastern part of the system, where the downdip part of the Trinity aquifer is overlain by the Edwards aquifer. The Navarro-Del Rio confining unit overlies the subcrop of the Edwards aquifer, and the Hammett confining unit lies within the updip, basal part of the Trinity aquifer and a small southeastern fringe of the Edwards-Trinity aquifer.

The boundary of the Edwards-Trinity aquifer system (fig. 2) is the limit of conterminous Cretaceous strata that are the principal source of ground water. This boundary has been defined on the basis of geologic and hydrologic considerations.

Geologic boundaries delineate the northern and western limits of the aquifer system from west-central Travis County in the east to eastern Brewster County in the west. The northern boundary between west-central Travis County and the northwestern corner of Ector County is the approximate updip limit of Cretaceous

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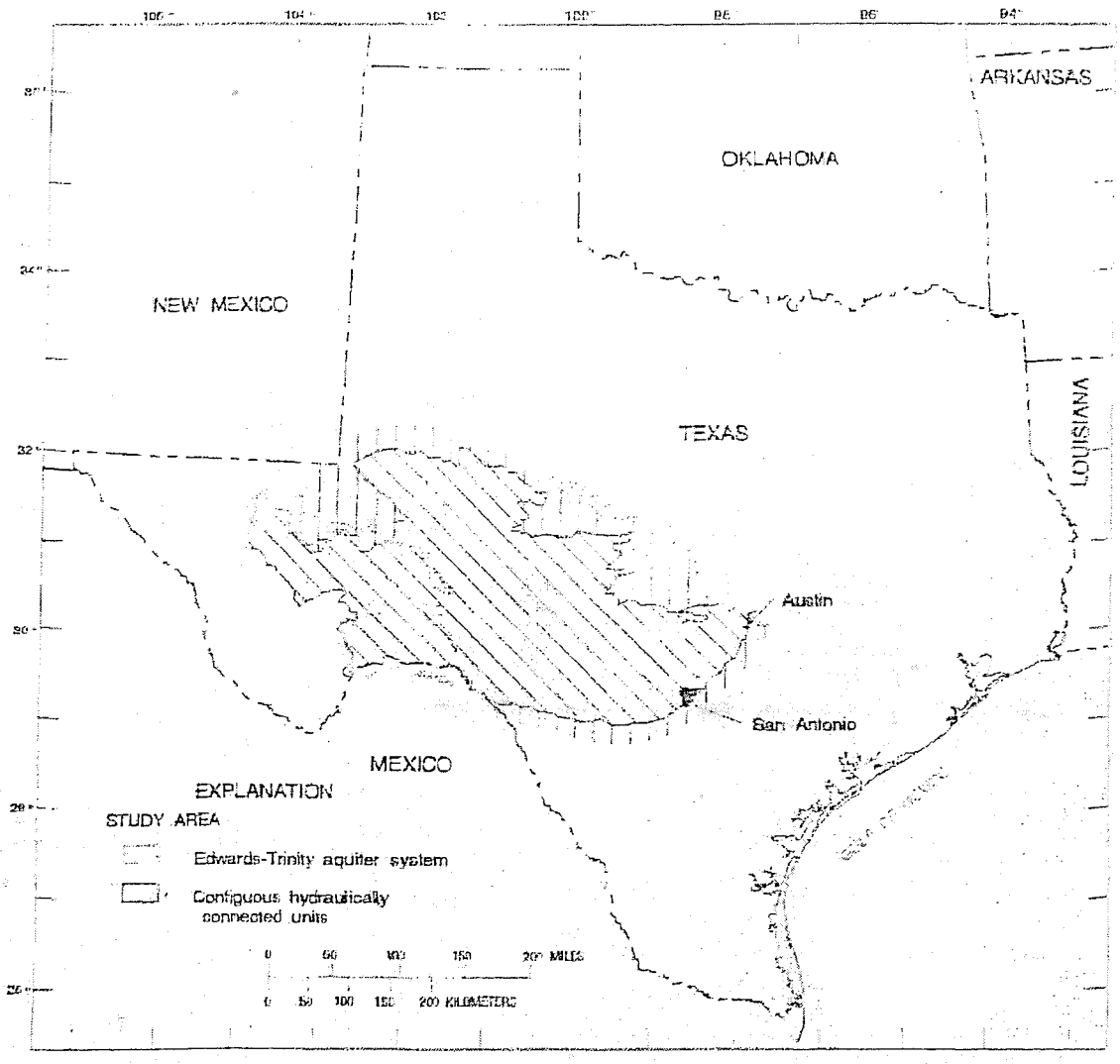

Figure 1. Location of the study area of the Edwards-Trinity Regional Aquifer-System Analysis.

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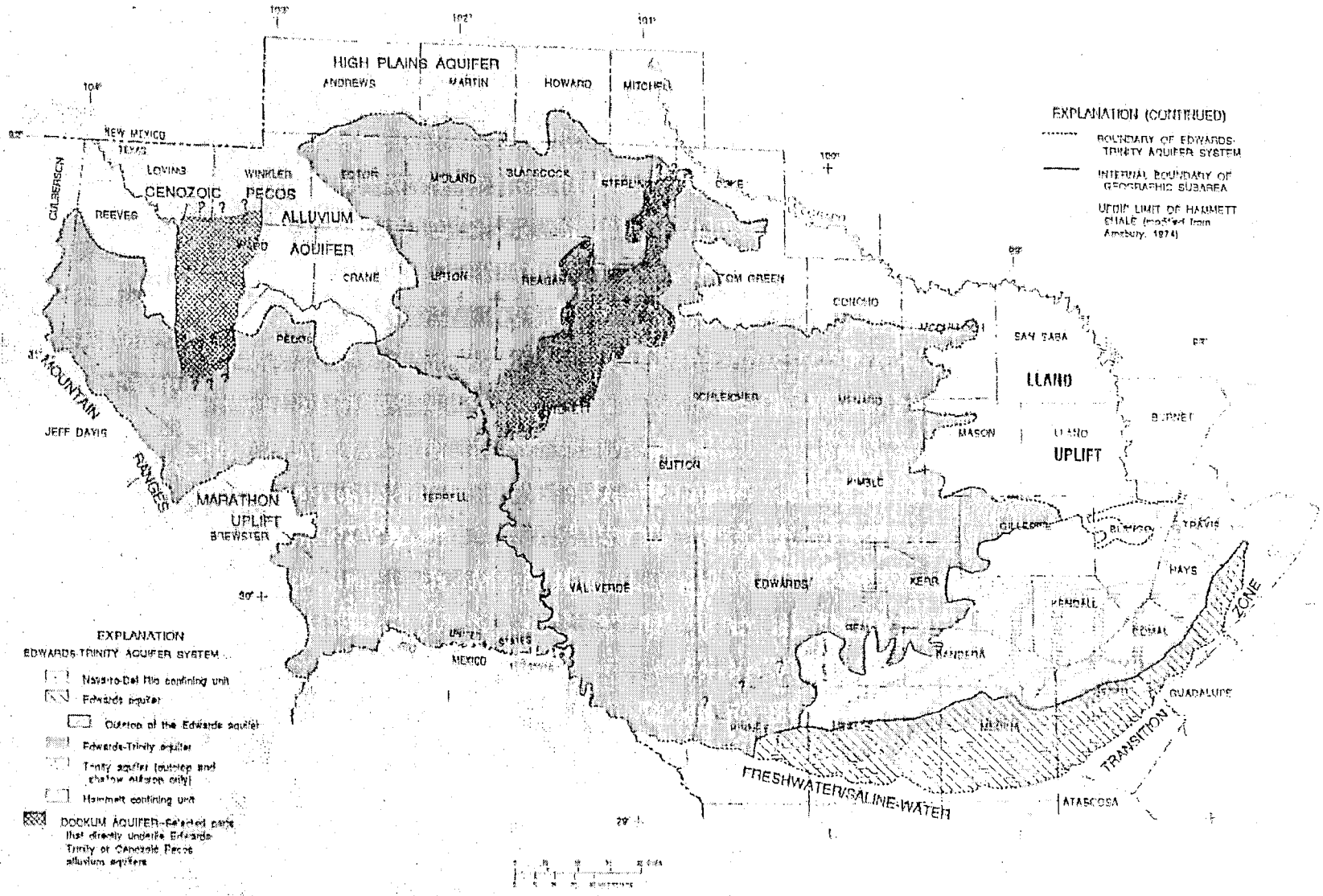

Figure 2. Location of the aquifers and confining units in the Edwards-Trinity aquifer system and of selected adjacent aquifers.

rocks (University of Texas, Bureau of Economic Geology, 1974b; 1975; 1976a; 1981a; Ashworth and Flores, 1991, fig. 1). In some areas, the boundary is indicated topographically by a low escarpment facing away from the aquifer system. The boundary is drawn arbitrarily between central Howard County and northwestern Ector County because sandy intervals of the High Plains aquifer (Weeks and others, 1988) are virtually indistinguishable from the sand unit that comprises most of the Edwards-Trinity aquifer system in that area (Mount and others, 1967, p. 45). Between northwestern Ector County and Culberson County, the boundary of the Edwards-Trinity aquifer system is where Cretaceous rocks abut the Cenozoic Pecos alluvium (University of Texas, Bureau of Economic Geology, 1976b; Rees and Buckner, 1980, fig. 2). The western boundary between Culberson County and the Rio Grande in Brewster County is defined by the eastern flanks of several mountain ranges where the Cretaceous rocks pinch out, are structurally detached, or are virtually impermeable (Rees and Buckner, 1980, fig. 2).

Hydrologic boundaries were used to delineate the southern and eastern limits of the aquifer system between eastern Brewster County and west-central Travis County. Because hydraulic-head data indicate that the Rio Grande is a regional ground-water drain (E.L. Kuniansky, U.S. Geological Survey, oral commun., 1987), the southern extent of the aquifer system between eastern Brewster County and southeastern Val Verde County coincides with the Rio Grande. Between the Rio Grande in southeastern Val Verde County and the Colorado River in central Travis County, the aquifer system is bounded by a well-defined, freshwater/saline-water transition zone (fig. 2) that minimizes the downdip flow of freshwater from the Edwards aquifer. The aquifer system boundary coincides here with the updip edge of the transition zone, defined by the line of 1,000-mg/L (milligrams per liter) dissolved solids (Maclay and others, 1980, fig. 7). A freshwater/saline-water transition zone also is in the Trinity aquifer beneath the Edwards aquifer. Dissolved-solids data from the Trinity aquifer are too sparse to define lines of equal dissolved solids. However, limited data indicate that the transition zone in the Trinity aquifer approximately coincides, in plane view, with the transition zone in the Edwards aquifer (Brune and Duffin, 1983, fig. 12; Duffin, 1974, fig. 18).

The Colorado River forms the northeastern boundary of the aquifer system through west-central Travis County. Although Cretaceous rocks extend north beneath the Colorado River, the river is a regional discharge boundary except near the freshwater/saline-water transition zone, where the Edwards aquifer is confined hundreds of feet below land surface.

The study area (fig. 1) was extended beyond the boundary of the Edwards-Trinity aquifer system to account for the hydraulic connection with contiguous rock units around the southeastern, northeastern, and northwestern edges of the system (fig. 2). The southeastern limit of the study area was drawn arbitrarily to coincide with the estimated location of the 10,000-mg/L line of equal dissolved solids, based on data from Maclay and others (1980, p. 13). The study area is bounded on the northeast by the Colorado River, a regional discharge boundary (Kuniansky, 1990) for the aquifers in the contiguous pre-Cretaceous rocks that underlie the river (Mount and others, 1967, pl. 4). The northwestern limit of the study area overlaps the Cenozoic Pecos alluvium aquifer (Ashworth, 1990, fig. 5) and the southernmost part of the High Plains aquifer (Weeks and others, 1988, fig. 1).

Western and central parts of the Edwards-Trinity aquifer system locally are overlain directly by the Del Rio Clay or Buda Limestone. Together, these relatively impermeable units comprise the lower 10 to 20 percent of the Navarro-Del Rio confining unit (fig. 2), which confines downdip parts of the Edwards aquifer in the southeastern part of the study area (fig. 3). The base of the Edwards-Trinity aquifer system is formed of Paleozoic and Triassic rocks that are mostly impermeable (Barker and Ardis, 1992). Where adjacent Paleozoic and Triassic rocks are permeable, they form "contiguous hydraulically connected units" (fig. 1).

Geographic Setting

The extent of the Edwards-Trinity aquifer system was divided into four geographic subareas (fig. 3) based on distinct physiographic, climatic, and geologic characteristics. The subareas, from largest to smallest, are the Edwards Plateau, the Trans-Pecos, the Hill Country, and the Balcones fault zone south of the Colorado River (hereafter referred to as the Balcones fault zone). By definition, the Edwards-Trinity aquifer is coincident with the Edwards Plateau and Trans-Pecos. The Trinity aquifer is the principal aquifer in the Hill Country, and the Edwards aquifer is the principal aquifer in the Balcones fault zone.

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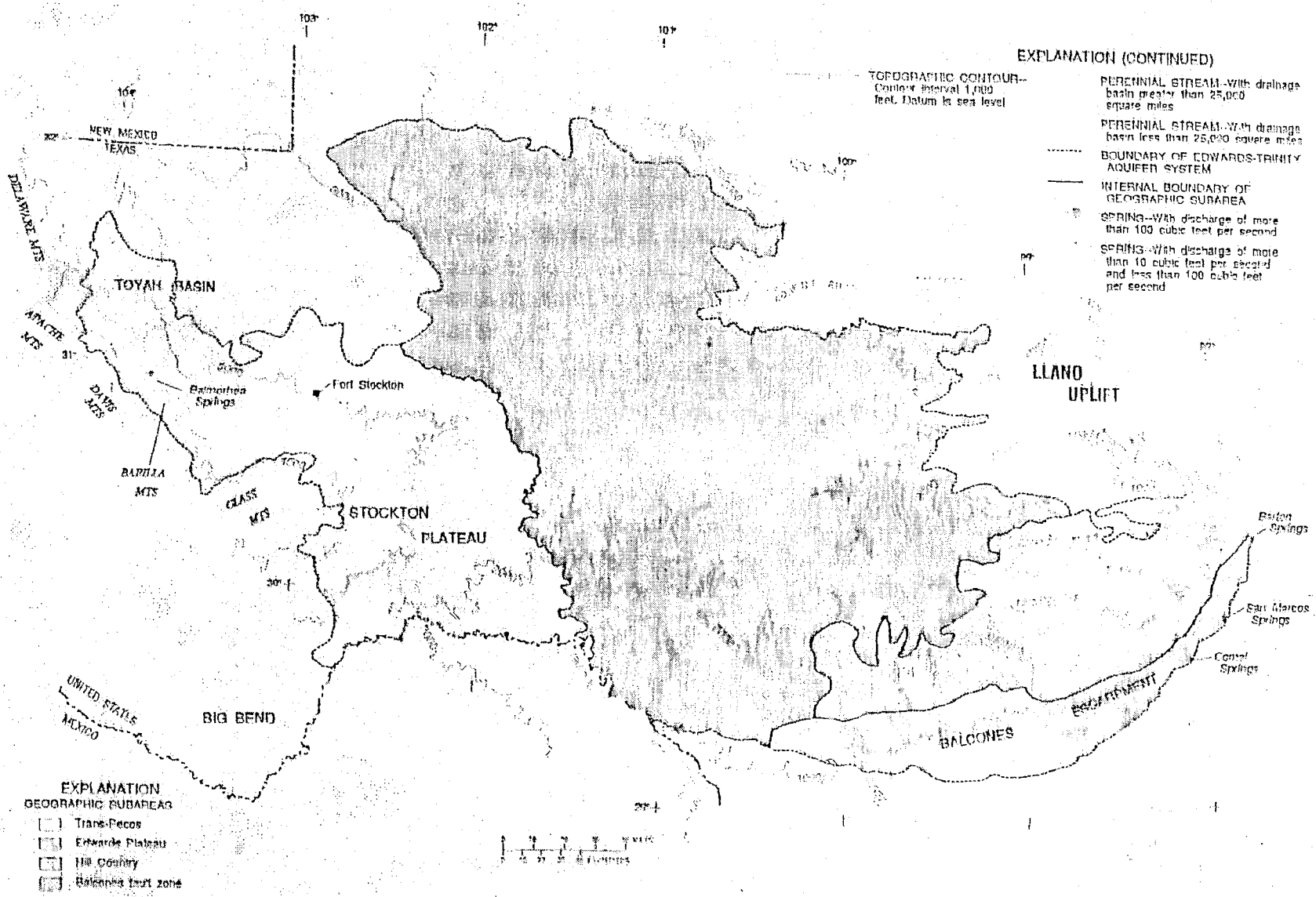

Figure 3. Location of geographic subareas of the Edwards-Trinity aquifer system and the major springs and streams.

Balcones fault zone by an en echelon network of mostly down-to-the-southeast, high-angle normal faults that strike generally southwest to northeast (Maclay and Small, 1986, p. 5). Broken and downfaulted by these faults, the Cretaceous rocks exhibit a steeper southeastward dip in the Balcones fault zone.

The Balcones faults are the principal structural features of the study area, and they greatly influence ground-water flow. The Edwards Group in this area contains the most transmissive rocks in the study area, those composing the Edwards aquifer of the Balcones fault zone. The Trinity Group, which comprises the Trinity aquifer, is deeply buried and relatively impermeable in the Balcones fault zone.

The boundary between the Hill Country and the Balcones fault zone (fig. 3) was determined by linking the updip edge of major faults that juxtapose the Trinity Group on the west against the Edwards Group (or stratigraphic equivalent) on the east. This delineation was based on fault locations provided by the University of Texas, Bureau of Economic Geology (1974a; 1977; 1983), and was substantiated by water-level records (Kuniansky, 1990) and data on the base of the Edwards Group (G.E. Groschen, U.S. Geological Survey, written commun., 1988).

The boundary between the Edwards Plateau and the Balcones fault zone (fig. 3) was determined from well-log and transmissivity data. The data were used to separate the area where the Edwards-Trinity aquifer is the principal aquifer from the area where the Edwards aquifer is the principal aquifer.

The topography of the Balcones fault zone smooths gulfward in a southeastward direction from the Balcones escarpment (fig. 3), a major physiographic divide that locally separates the Great Plains from the Gulf Coastal Plain. The Balcones escarpment approximately coincides with the 1,000-ft topographic contour. Although the Edwards aquifer crops out in the updip part of the Balcones fault zone, the downfaulted strata and steepening structural dip cause the aquifer to be progressively more deeply buried and confined south of the outcrop area (fig. 4).

The broad stream valleys in downgradient parts of the Hill Country narrow where the streams enter the Balcones fault zone and flow atop the relatively permeable Edwards Group (Wermund and Woodruff, 1977, p. 342). The streambeds lose appreciable quantities of water to the Edwards aquifer as they traverse the faulted outcrop area of the Edwards Group. Hydraulic heads in confined parts of the Edwards aquifer are above land surface near the freshwater/saline-water transition zone, resulting in several large springs. Comal and San Marcos Springs (fig. 3) discharge at rates averaging more than 100 ft^3/s.

Mean annual (1951–80) precipitation averages about 20 in/yr over the Edwards-Trinity aquifer system (Riggio and others, 1987, fig. 11). Most precipitation occurs as moisture-laden air from the Gulf of Mexico moves inland and cools. The distribution of perennial streams (fig. 3) attests that considerably less precipitation falls on the western part of the aquifer system than on the eastern part. An increasing distance from the Gulf of Mexico (the principal source of moisture) causes a general westward decrease in the amount of precipitation (Carr, 1967, p. 2). The steepening terrain northwest of the Balcones escarpment superimposes an orographic effect on precipitation over the Hill Country. Mean annual (1951–80) precipitation is about 28 in/yr over the Balcones fault zone, about 30 in/yr over the Hill Country, about 19 in/yr over the Edwards Plateau, and about 13 in/yr over the Trans-Pecos (Riggio and others, 1987).

May and September generally are the months of greatest precipitation in the Balcones fault zone, Hill Country, and Edwards Plateau. In the Trans-Pecos, precipitation mostly occurs during convective showers and thunderstorms in July, August, and September (Carr, 1967, p. 14; Linsley and others, 1975, p. 61).

GEOLOGIC HISTORY

The depositional, tectonic, and diagenetic characteristics of the rocks of the Edwards-Trinity aquifer system are different from those of the underlying, comparatively impermeable pre-Cretaceous rocks. Relatively thin, nearly flat-lying Cretaceous strata of the aquifer system typically dip southeastward atop generally massive Paleozoic and Triassic units that generally dip westward (fig. 4). The unconformity between the Cretaceous rocks of the aquifer system and the pre-Cretaceous complex (Barker and Ardis, 1992) marks a major change in the geologic history of the study area. This hiatus spans a transition from the deposition of terrestrial red beds during Late Triassic time to the deposition of terrigenous clastic and shallow-marine carbonate sediments during Early Cretaceous time, transcending about 60 million years of crustal warping and erosion during the Jurassic Period. This section summarizes the geologic history of the pre-Cretaceous rocks upon which the Cretaceous seas encroached and

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The Edwards Plateau, which covers about 23,750 mi^2, is a resistant carbonate upland of nearly flat-lying limestone and dolostone, which typically are veneered with loose, thin soils. Caprock mesas, broad alluvial fans, and dry arroyos are the most prominent features on the near-featureless plain. The topographic contours in figure 3 indicate a gradual northwest to southeast slope of land-surface altitude from about 3,000 to about 1,000 ft above sea level.

In contrast to interior parts of the Edwards Plateau, the eastern and southern margins of the Plateau are topographically rugged. High-velocity headwaters have cut narrow, steep-walled canyons into the carbonate terrain around the eastern and southern margin of the plateau. Watercourses that are intermittent in the higher elevations of the Edwards Plateau evolve downstream into perennial streams, as their channels intersect the water table and gain base flow (Kuniansky, 1989).

Most of the carbonate strata in the eastern part of the Edwards Plateau belong to the Edwards Group (Rose, 1972). The Edwards Group and its western equivalents, the Fredericksburg Group and lower part of the Washita Group, are hydraulically connected to terrigenous clastic and carbonate sediments of the underlying Trinity Group. The name "Edwards-Trinity" aquifer thus was adopted for all the permeable Cretaceous rocks on the Edwards Plateau.

The Trans-Pecos covers approximately 9,750 mi^2 west of the Pecos River (fig. 3). Southeast of Fort Stockton, in the Stockton Plateau (Fenneman, 1931, p. 47), the Trans-Pecos terrain is an extension of the Edwards Plateau. North and west of Fort Stockton, the Trans-Pecos occupies much of what Fenneman (1931, p. 48) called the Toyah basin, which is the southernmost part of a long, trough-like alluvial valley of the Pecos River. The Toyah basin is topographically flatter than the Stockton Plateau. The Toyah basin is covered with alluvium ranging in thickness from a few feet near the northern edge of the Stockton Plateau to more than 1,000 ft beneath the Pecos River valley. Thus, the Edwards-Trinity aquifer in the Trans-Pecos is exposed or nearly so in the southern part of the subarea and is partly buried under alluvial sediments of varying thickness in the northern part.

Land-surface altitudes in the Trans-Pecos decrease from greater than 4,000 ft in the foothills of mountains that bound the aquifer system on the west to about 1,100 ft near the confluence of the Pecos River and Rio Grande (fig. 3). The Pecos River and Rio Grande are the only perennial streams in the Trans-Pecos. Between the mountain front and the Pecos River, the land surface is characterized by intermittently flowing stream channels. From well-defined headwater valleys in the western foothills, the intermittent streams drop onto gently inclined lowlands. The stream channels broaden into shallow arroyos as they leave the foothills and enter the alluvial-filled Toyah basin, and nearly disappear as they approach the Pecos River (Armstrong and McMillion, 1961, p. 13–14). Valleys in the Stockton Plateau generally are most clearly defined where they cut through dense carbonate rock. The Pecos River and Rio Grande flow through deep, steep-walled canyons of nearly flat-lying limestone along the eastern and southern boundaries of the Stockton Plateau.

The streams that originate along the southeastern margin of the Edwards Plateau and their downstream tributaries largely are responsible for the high topographic relief of the Hill Country (fig. 3), which covers approximately 5,500 mi^2. Headward erosion by southeast-flowing streams has stripped all but a few thin remnants of the Edwards Group and its equivalents from the Hill Country, exposing the Trinity Group at land surface; thus, the name "Trinity" was given to the principal aquifer in the Hill Country. The Trinity aquifer in the Hill Country is an extension of the lower part of the Edwards-Trinity aquifer of the Edwards Plateau, with the Edwards Group and its equivalents mostly removed. The boundary between the Edwards Plateau and the Hill Country was delineated from the outcrop configuration of the Trinity rocks (University of Texas, Bureau of Economic Geology, 1977; 1981a; 1983).

The major streams descend steep gradients as they flow through the Hill Country. Many upgradient reaches are contained within deep, narrow canyons characterized by nearly vertical walls. Although most of these canyons widen downstream into broad, flat-bottomed valleys, they typically retain their nearly vertical walls. Attributing the widening of the steep-walled canyons to a condition known as "spring sapping," Fenneman (1931, p. 53) stated that the effect of spring discharge in the area was "*** to sap the strong rocks of the canyon walls which thereupon retreat and separate."

The Balcones fault zone, to the south and east of the Hill Country, covers about 3,000 mi^2 (fig. 3). The relatively gentle southeastward dip of the rocks that compose the Edwards-Trinity aquifer system in the Edwards Plateau and Hill Country is interrupted in the

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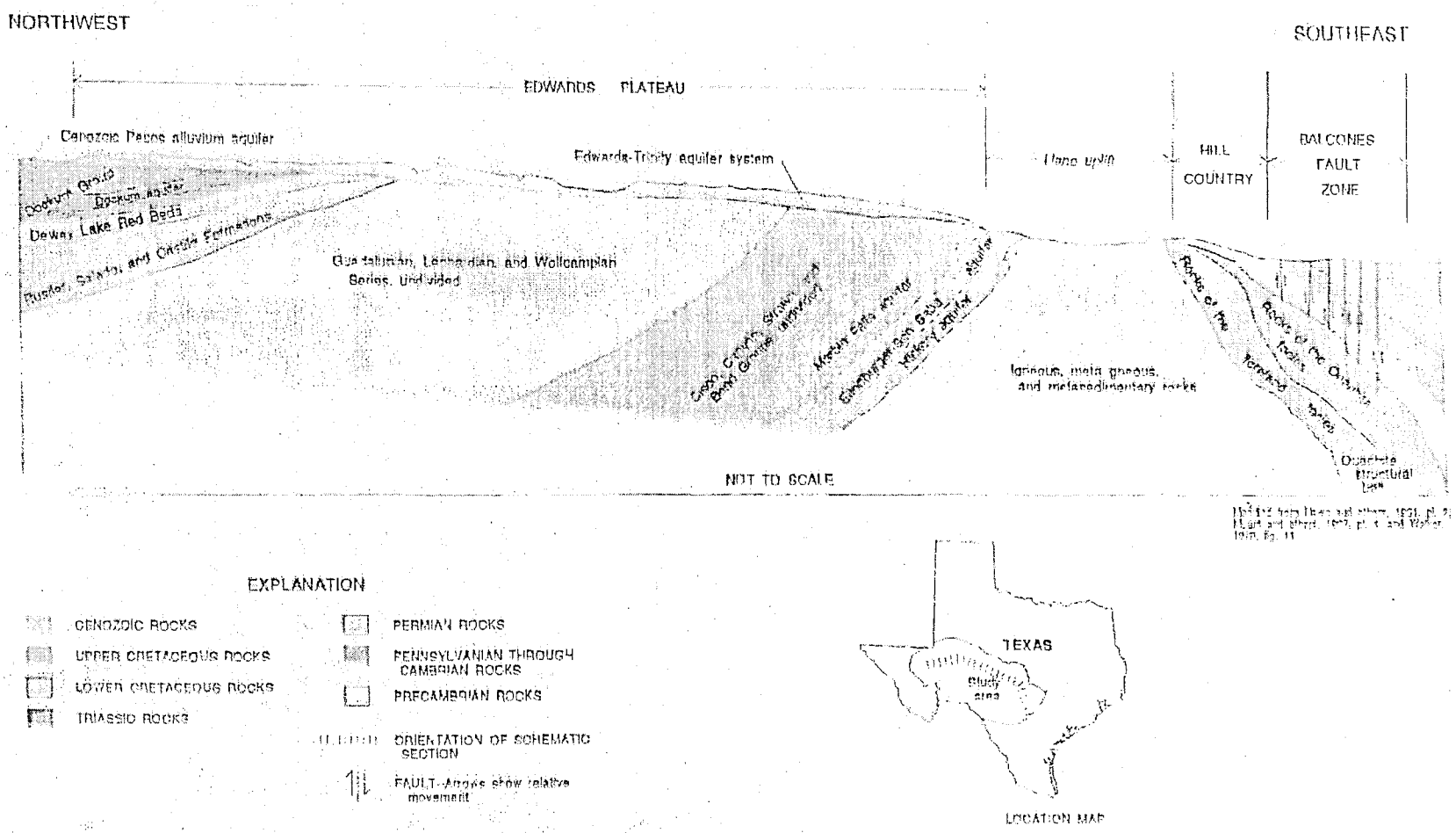

Figure 4. Generalized relation between the Edwards-Trinity aquifer system and the pre-Cretaceous rocks and hydrogeologic units that form the base of the system.

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reconstructs the depositional, tectonic, and diagenetic events between the beginning of Cretaceous time and the present day that appear to most affect conditions within the Edwards-Trinity aquifer system.

Paleozoic Era

The Paleozoic history of west-central Texas was dominated by: (1) the Ouachita geosyncline, an elongated depositional trough that bordered the ancestral North American continent; (2) land masses south and east of the geosyncline; and (3) shallow inland seas across a stable continental foreland, north and west of the geosyncline. Presently, the Ouachita geosyncline is represented by the mostly buried Ouachita structural belt (fig. 5). From southeastern Oklahoma, the Ouachita geosyncline curved around the southeastern and southern margins of the Llano and Devils River uplifts, respectively, to the Marathon and Solitario uplifts of southwestern Texas (Flawn and others, 1961). The Llano and Devils River uplifts were resistant promontories of Precambrian crystalline rock on the southeastern perimeter of ancestral North America. Until Late Permian time, deposition in the broad foreland area was mainly of an organic or chemical nature and was only partly clastic, while clastic deposition prevailed in the geosyncline (Sellards, 1935, p. 18). Intermittent tectonic pulses maintained prominent land areas near the southern and eastern margins of the geosyncline, which supplied the subsiding trough with sediment throughout early and middle Paleozoic time.

Following about 400 million years of mainly uplift and erosion during the late Precambrian and through Early Cambrian time (Flawn, 1956, p. 68–71), about 5,000 ft of Ordovician, Silurian, Devonian, and Mississippian strata were deposited upon an unevenly eroded surface of Precambrian igneous and metamorphic rocks. Depositional rates that increased during the Pennsylvanian Period continued through most of the Permian Period, when more than 5,000 ft of marine sandstone, limestone, and shale were deposited in the foreland area of west-central Texas. The bordering geosyncline continued to subside under the weight of coarse clastic sediment and attained depths of more than 20,000 ft (Sellards, 1933, p. 134). The Ouachita geosyncline was finally overwhelmed by a tectonic upheaval that profoundly affected the geologic history of the study area.

During the Ouachita orogeny, which climaxed between Late Pennsylvanian and Early Permian time, the geosynclinal deposits were uplifted, thrust faulted, and intensively folded into a late Paleozoic mountain range. From the southeastern part of the United States, the ancestral Ouachita Mountains extended through the present Ouachita Mountains of Arkansas and Oklahoma to the Marathon and Solitario uplifts of Texas (fig. 5). The Llano and Devils River uplifts responded as resistant buttresses against which the Ouachita facies were thrust from the south, shearing and folding intervening rocks of the foreland. A complex foreland structure resulted (Webster, 1980), creating petroleum traps that are recognized as some of the most productive oil and gas reservoirs in the world. Interior segments of the Ouachita structure underwent varying degrees of metamorphism—producing slate, phyllite, and metaquartzite—as blocks of early Paleozoic rocks were thrust northward across younger strata.

During the waning stages of the Ouachita orogeny, the Permian Basin (fig. 5) developed in west Texas beneath a broad, shallow sea. The sea became increasingly saline as the basin became more isolated from the open ocean about the middle of Late Permian time, a time of intense aridity and restricted water circulation (King, 1942, p. 711–763). Detrital influx to the basin ceased and the predominant sediments became gypsum, anhydrite, halite, and potash. Following differential uplift and erosion, fresher-water conditions returned. As the connection with the open ocean improved near the end of the Permian Period, the super-saline water became fresher, and fine-grained clastic sediments washed in from surrounding high ground, covering the evaporitic strata with a thin red-bed unit. The Permian sea withdrew as the region was again uplifted at the close of the Paleozoic Era.

Mesozoic Era

Triassic and Jurassic Periods

The retreat of the Permian sea was followed by a long interval of nondeposition, crustal warping, and erosion during Early and Middle Triassic time. While uplift continued in the Llano area and erosion planed down the central basin platform (fig. 5), a closed continental basin formed in west Texas. This basin was partly filled during Late Triassic time with easily erodible Paleozoic sediments that were redeposited as red

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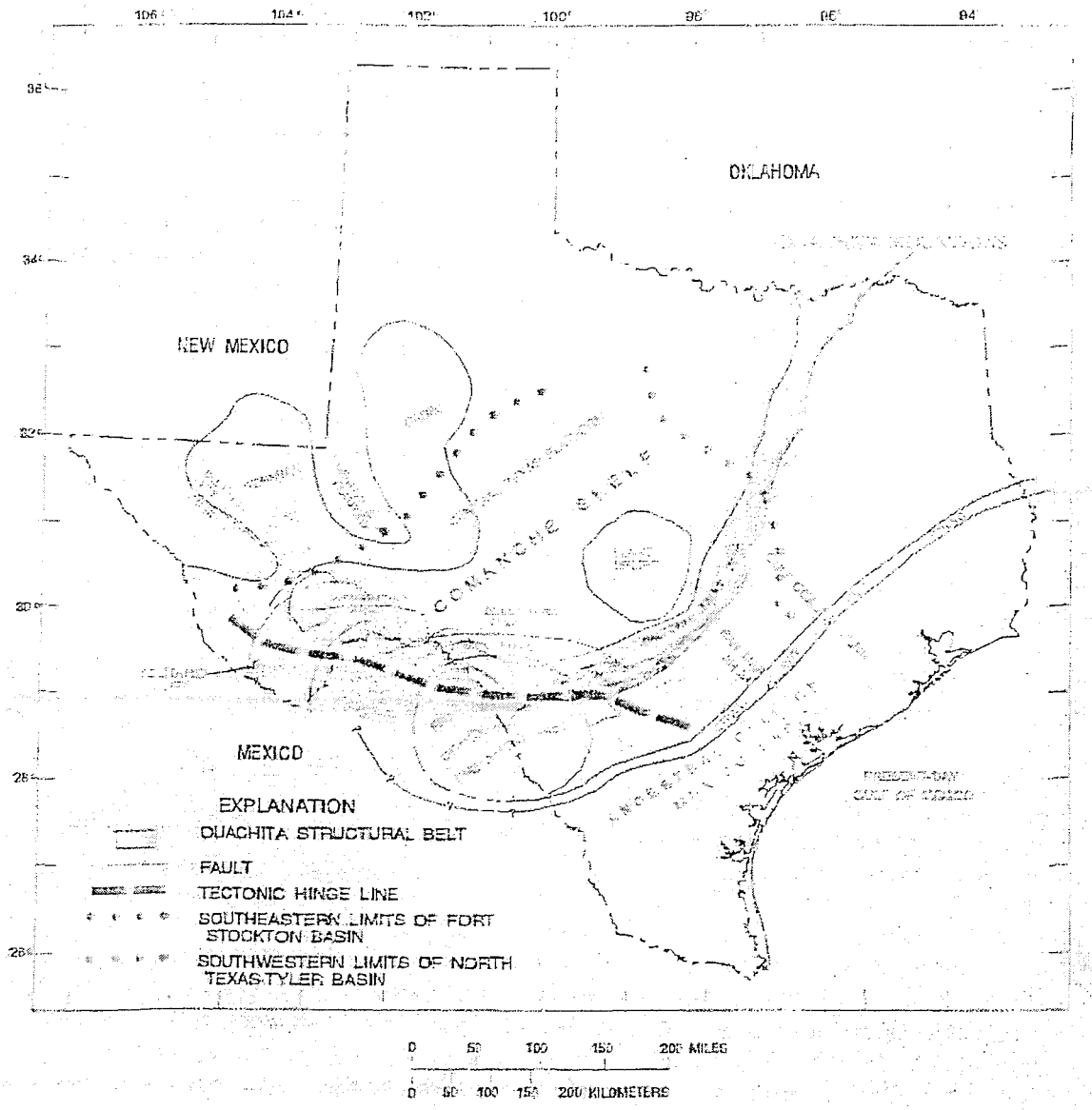

Figure 5. Paleogeographic and structural features in west-central Texas and parts of adjacent States and northern Mexico.

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beds of the Dockum Group under fluvial, deltaic, and lacustrine conditions (McGowen and others, 1979).

Most of west-central Texas was above sea level during the Jurassic Period. During this time, the study area was tilted toward the southeast and eroded to a rolling peneplain characterized by broad river valleys and low ridges of resistant rocks (Hill, 1901). The ancestral Ouachita Mountains mostly were removed by erosion through central Texas, and the remnants sank as the Gulf of Mexico opened (Flawn, 1964, p. 271–274). The land surface tilted southeastward, causing a reversal in the direction of surface drainage. The reversal in drainage, which may have begun during Permian time, was completed by the end of the Jurassic Period so that the earlier pattern of northwestward drainage toward inland seas was superseded by southeastward drainage into a westward-advancing Cretaceous sea (Sellards, 1933, p. 24).

Cretaceous Period

Rifting and subsidence in the ancestral Gulf of Mexico basin (fig. 5) continued into the Cretaceous Period (Wood and Walper, 1974). A broad continental shelf formed around the rim of the basin, bridging the Yucatan Peninsula and the southeastern part of the United States with the Bahamas (Bebout and Loucks, 1974, p. 2). The Comanche and Gulf strata of the Edwards-Trinity aquifer system (table 1) formed atop the landward margin of this shelf under predominately shallow-marine conditions of relatively low wave and current energy. The Llano uplift was a dominant structural element through late Trinitian time. During Trinitian time, islands of Precambrian metamorphic and igneous rocks and Paleozoic sedimentary rocks stood high on the uplift and shed clastic debris into nearby fluvial and terrigenous environments (Stricklin and others, 1971, p. 7). By Fredericksburgian time, the Llano uplift was a negligible contributor of sediment; however, a southeastward extension of the Llano uplift, the San Marcos arch (Adkins, 1933, p. 266), continued as a structural ridge between the north Texas-Tyler basin on the northeast and the Rio Grande Embayment on the southwest.

Comanchean Epoch: Trinitian Age

Subsidence in the ancestral Gulf of Mexico basin (fig. 5), coupled with an overall rise in sea level, caused the Early Cretaceous sea to advance slowly westward upon the peneplained surface of folded and faulted pre-Cretaceous rocks (Hill, 1901). The Trinity rock record indicates a cyclic, but persistent pattern of transgression; the regressive phases of deposition were relatively short lived and left comparatively little sediment. The regressions may have been triggered by decreasing rates of subsidence, an overall lowering of sea level, increases in the supply of clastic sediment from rising inland source areas, or some combination of these conditions (McFarlan, 1977, p. 10). While terrestrial deposition prevailed on alluvial plains landward of the advancing shoreline, terrigenous and restricted shallow-marine environments dominated the gently inclined upper shelf, over which warm, generally clear seawater circulated. Contacts between the resulting lithofacies are diachronous (time-transgressive) toward the Llano uplift (fig. 5), reflecting the effects of shallower water and shoreline advancement toward the northwest.

The lateral and vertical distributions of the rock units that compose the Trinity Group (table 1) are shown in figures 6 and 7, respectively. The gradational nature of the Trinity rock units is indicated on the southern flank of the Llano uplift (fig. 7a), where basal terrestrial sediments were overlapped by marine deposits as the Early Cretaceous sea encroached upon the feature (Amsbury, 1974).

The Trinity rock units were deposited on the southern flank of the Llano uplift during three complete transgressive-regressive cycles of sedimentation (Stricklin and others, 1971). Each cycle is represented by a lithogenetic, time-stratigraphic sequence characterized by terrigenous clastic deposits near the base and marine carbonate sediments near the top. The rock record of each cycle, or "terrigenous clastic/marine carbonate couplet," is separated from the succeeding cycle by a disconformity. Each couplet generally onlaps rocks of the previous cycle and documents a major advance of the Early Cretaceous sea, terminated by an overall drop in sea level or some kind of equilibrium between land and sea. In depositional order, these couplets include: (1) the Sycamore Sand (Hosston Formation, downdip) and Sligo Formation; (2) the Hammett Shale (Pine Island Shale Member, downdip) and Cow Creek Limestone (Cow Creek Limestone Member, downdip); and (3) the Hensel Sand (Bexar Shale Member, downdip) and Glen Rose Limestone.

While detrital sand and gravel of the Sycamore Sand were deposited by aggrading streams on the southern flank of the Llano uplift (Inden, 1974),

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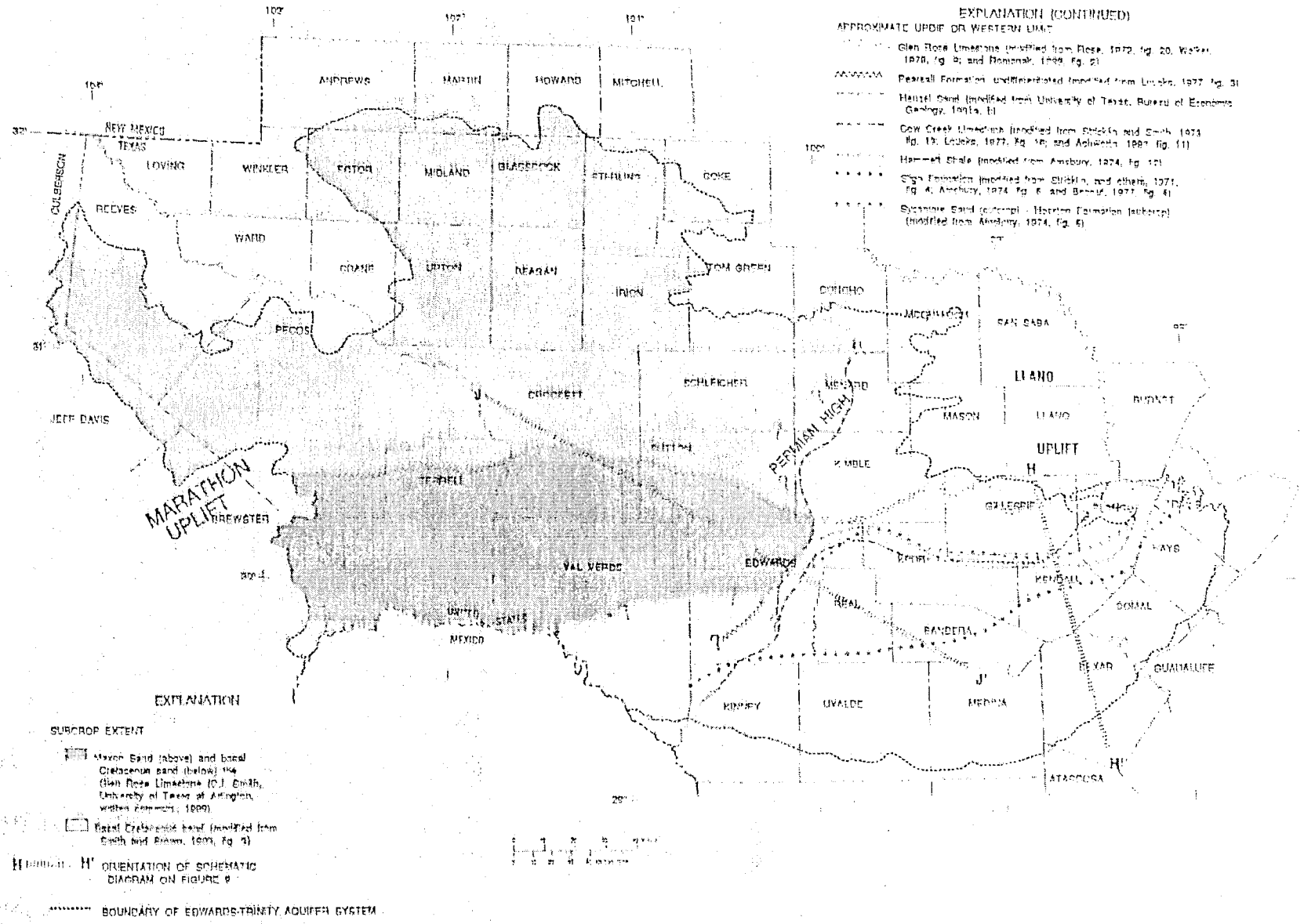

Figure 6. Lateral distribution of Trinity rock units in west-central Texas.

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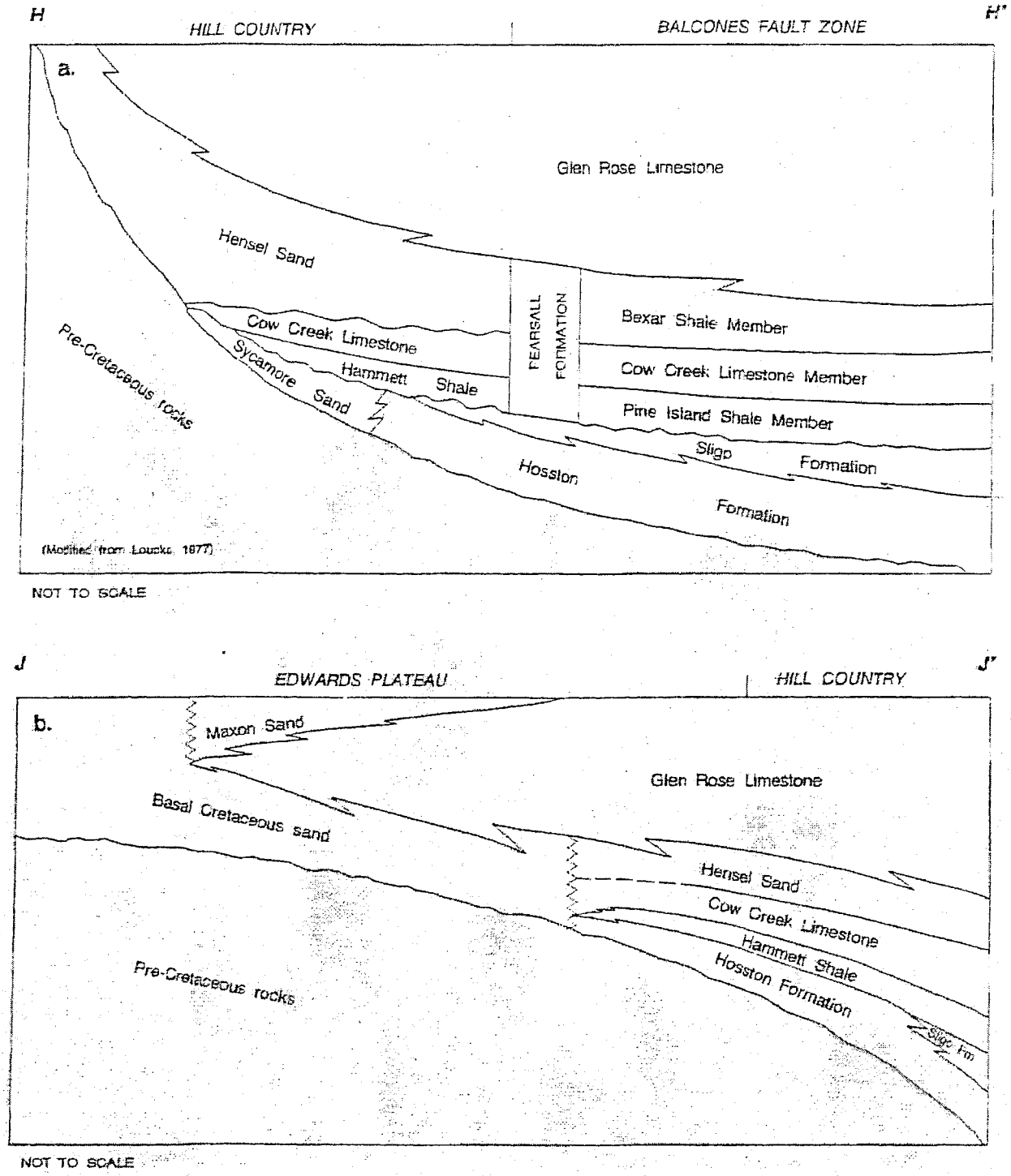

Figure 7. Vertical distribution of Trinity rock units in west-central Texas and their relation to geographic subareas. (See fig. 6 for orientation of diagrams.)

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calcareous mud and silt of the Hosston Formation (Bebout and others, 1981) accumulated offshore in a transgressing sea. Dolomitic siltstone and rhythmically bedded mudstone of the overlying Sligo Formation (Stricklin and others, 1971) were deposited in shallow, brackish water of a regressive sea with a shoreline that did not reach the updip limit (present outcrop area) of the Sycamore Sand (fig. 6).

Following a period of subaerial exposure and widespread cementation, the Trinity sea rapidly returned (Stricklin and others, 1971, p. 14). The argillaceous Hammett Shale was deposited atop slightly eroded upper surfaces of the Sycamore Sand and Sligo Formation. The dominant depositional environment of the Hammett Shale (and the downdip equivalent Pine Island Shale Member of the Pearsall Formation) was a wide, relatively unrestricted body of quiet water whose salinity ranged from normal marine to brackish (Amsbury, 1974).

The Cow Creek Limestone mostly formed as high-energy, beach-dominated environments prograded seaward from the Llano uplift (Stricklin and Smith, 1973). Lower parts of the unit appear to have been deposited offshore under gradually shoaling conditions. Coquina in the upper parts of the unit probably formed within a shoreline reentrant, where mollusk shells furnished by slackened longshore currents were sorted by waves refracted against the curved shoreline of the reentrant. High-gradient streams transported Precambrian igneous and metamorphic detritus and Paleozoic sedimentary rock fragments from the Llano uplift to the shoreline, where it mixed with the shell debris and extended the land area. As the reentrant filled and the shoreline stabilized, upper parts of the beach became subaerially exposed. An irregular topography and pockets of caliche developed atop parts of the Cow Creek Limestone, as unconsolidated sediments were redistributed by the wind and storm waves and meteoric water alternately leached and precipitated carbonate minerals.

Further subsidence in the ancestral Gulf of Mexico basin initiated the third and final major transgression of the Trinity sea. The Bexar Shale Member of the Pearsall Formation (Forgotson, 1957, p. 2,347) formed as a mixed, terrigenous clastic/carbonate facies in the "*** fine-grained distal part of a deltaic system" that prograded seaward from the Llano uplift (Loucks, 1977, p. 106). The Hensel Sand was deposited in the updip part of that system upon alluvial fans that coalesced into a lower-lying coastal plain, which merged on the south and east with the shallow-marine environment of the Bexar Shale. About this time, the basal Cretaceous sand (Romanak, 1988) began to form west of the Llano uplift as braided stream deposits accumulated atop the peneplained surface of Paleozoic and Triassic rocks (figs. 6, 7b).

As sandy red beds of the updip Hensel Sand formed in terrestrial settings on the flanks of the Llano uplift, the Glen Rose Limestone accumulated to the southwest (above the basal Cretaceous sand) and south (above the Bexar Shale) in comparatively low-energy, shallow-marine environments. During early Glen Rose time, rudist reefs flourished in pockets of highly circulated water of less than normal salinity (Perkins, 1974; Petta, 1977). The reefal structures vanished as hypersaline conditions dominated late Glen Rose time, in response to reduced water circulation and increased aridity (Stricklin and Amsbury, 1974). The upper member of the Glen Rose Limestone was deposited in restricted environments dominated by broad tidal flats in the lee of an incipient Stuart City reef trend (fig. 5) that began to build along the shelf edge during middle to late Trinitian time.

The rate of regional subsidence during middle to late Trinitian time was greatest toward the south. As a result, the thickness of the Glen Rose Limestone triples between central Sutton County and southern Kinney County. Jager (1942, p. 384) attributed this southward thickening to a rapidly sinking northern flank of the Rio Grande embayment (fig. 5). Trinity rocks in the study area were deposited on the northern flank of the Rio Grande Embayment (Murray, 1961, p. 128).

The sea withdrew from the study area during late Trinitian time. As the shoreline receded toward the south and east, the carbonate-producing marine environments of the Glen Rose Limestone were replaced in the southwestern part of the study area by a fluvial-deltaic system that deposited the Maxon Sand (King, 1980, p. 21). While the Maxon Sand accumulated atop the Glen Rose Limestone between southern Pecos County and eastern Edwards County (fig. 6), a large mudflat dominated depositional conditions east of Edwards County. Thin beds of evaporitic, dolomitic, and marly strata accumulated on the mudflat in environments characterized by long periods of subareal exposure and cementation. Mudcracks, algal structures, ripple marks, dinosaur tracks, and mollusk borings characteristic of these environments were preserved near the top of the Glen Rose Limestone. About the end of Trinitian time, the shoreline withdrew

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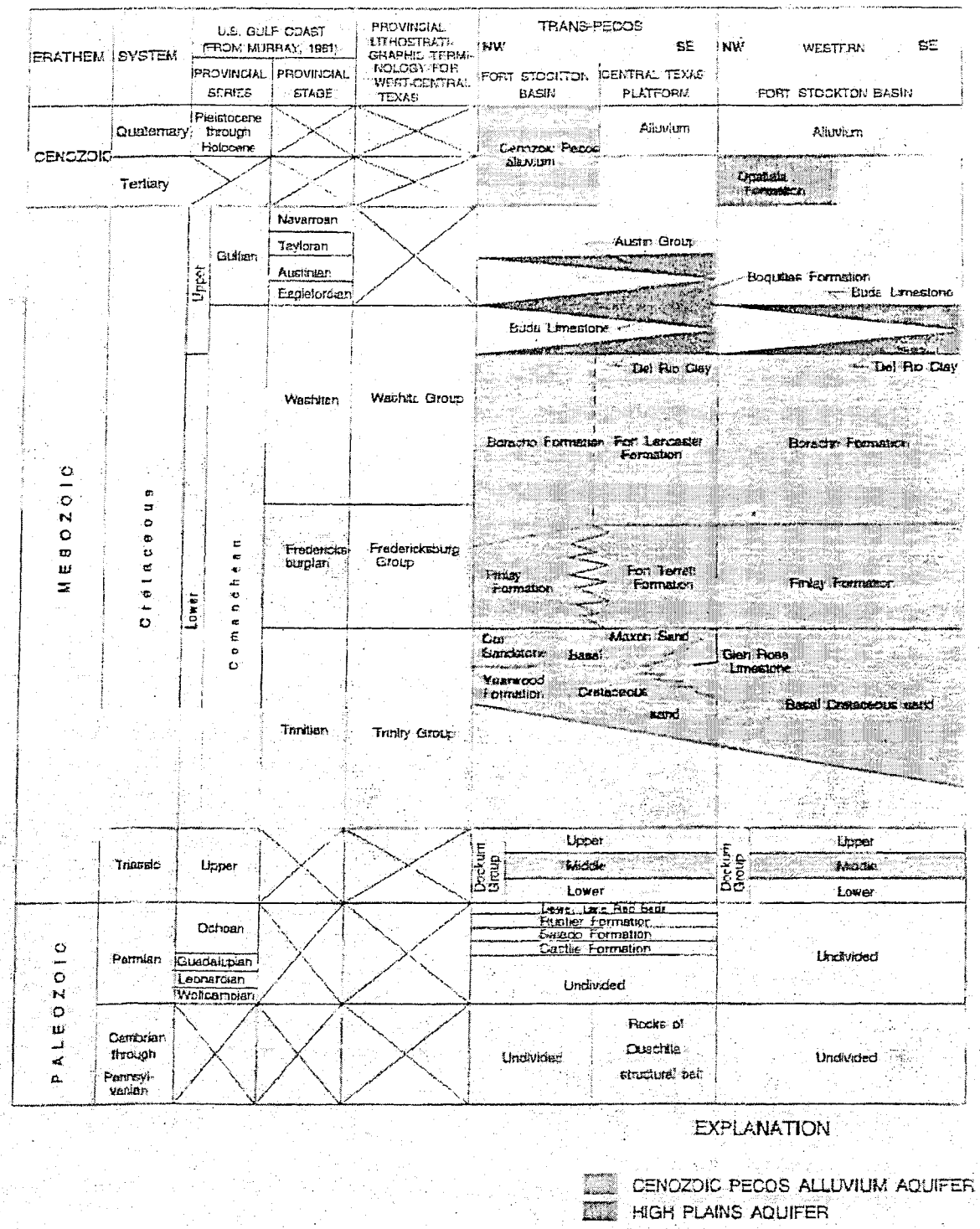
Table 1. Correlation chart showing the chronostratigraphic, lithostratigraphic, and regional hydrogeologic units in



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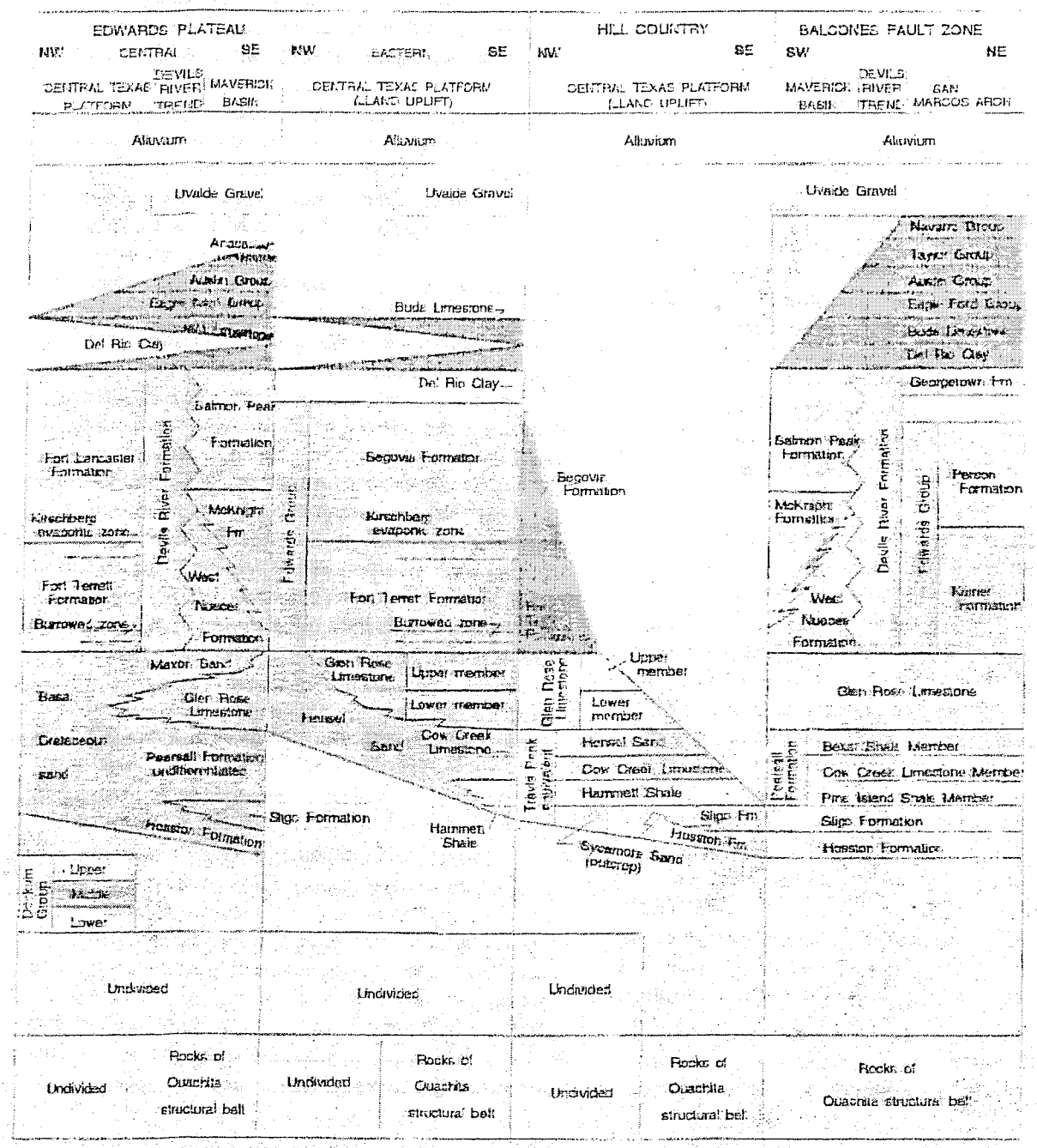
the Edwards-Trinity aquifer system, west-central Texas



EXPLANATION (CONTINUED)

EDWARDS-TRINITY AQUIFER SYSTEM

- Navarro-Del Rio confining unit
- Edwards aquifer
- Edwards-Trinity aquifer
- Trinity aquifer
- Hammett confining unit
- DOCKUM AQUIFER
- CRETACEOUS ROCKS NOT PART OF EDWARDS-TRINITY AQUIFER SYSTEM BECAUSE THEY ARE DISCONTINUOUS, UNSATURATED, OR RELATIVELY IMPERMEABLE
- ROCKS ABSENT

07 021

to a position parallel to and slightly north of the present day Balcones fault zone (Lozo and Smith, 1964, p. 291).

Comanchean Epoch: Fredericksburgian and Washitan Ages

By early Fredericksburgian time, an offshore bioherm of rudists, corals, and carbonate deposits had grown to an almost continuous reef/island ridge along the seaward edge of the continental shelf in the ancestral Gulf of Mexico basin (Bebout and Loucks, 1974, p. 6). This shelf margin ridge, called the Stuart City reef trend (fig. 5), extended from northern Mexico across nearly 500 mi of southeastern Texas (Winter, 1962). The aggressive upward growth of the Stuart City reef trend during early Fredericksburgian time probably resulted from a rapid rise in sea level that may have been triggered by an increase in the rate of seafloor spreading (Bay, 1977, p. 17).

The Stuart City reef trend sheltered depositional environments in the study area from the deep, open-marine conditions in the ancestral Gulf of Mexico basin. While water depths exceeded 1,000 ft in the basin, they ranged from a few feet to generally less than 100 ft on the landward margin of the continental shelf, or carbonate platform, where depositional environments were sheltered from strong wave and current forces. While dark, argillaceous sediments containing planktonic foraminifera accumulated basinward under generally reducing conditions, calcareous strata containing warm-water organisms formed in shallow-marine environments on the carbonate platform (Bebout and Loucks, 1974, p. 2–6). Evaporitic and dolomitic strata formed over higher parts of the carbonate platform on tidal flats, which frequently were subjected to subaerial exposure, oxidation, and erosion.

The Fredericksburg Group and most of the Washita Group of west-central Texas (table 1) were deposited leeward of the Stuart City reef trend upon a broad expanse of sea floor known as the Comanche shelf (Rose, 1972). According to C.I. Smith (University of Texas at Arlington, oral commun., 1989), sedimentation on the Comanche shelf was controlled by the (1) climate, (2) influx of terrigenous clastic sediment, (3) distribution of tectonic subsidence and uplift, and (4) energy level of wave and current action. The resulting lithofacies determined the stratigraphy and, together with the effects of subsequent tectonics and diagenesis, the hydraulic characteristics of rocks that today compose the Edwards-Trinity aquifer system.

Elements of the Comanche shelf that most strongly affected Fredericksburg and Washita deposition are shown schematically in figure 8. The lateral and vertical distributions of the resulting rock units are shown in figures 9 and 10, respectively.

The central Texas platform was an elongated mound on the Comanche shelf that extended from northwest of the Llano uplift to approximately the San Angelo area (figs. 8, 9). The San Marcos arch, a comparatively narrow structural high, extended southeast from the Llano uplift to the Stuart City reef trend. By early Fredericksburgian time, the Llano uplift had eroded to a much less prominent feature on the central Texas landscape than it had been during Trinitian time. Because the central Texas platform and San Marcos arch merged across the Llano uplift, however, depositional environments in the study area generally were isolated from those of north Texas. The Maverick basin was a semioval depression near the southern margin of the Comanche shelf. The Devils River trend was a narrow carbonate bank composed largely of rudists and reefal debris that developed around the northern and western margins of the Maverick basin during middle Fredericksburgian through early Washitan time. The Devils River trend, together with the Stuart City reef trend, restricted the circulation of seawater and isolated depositional conditions in the Maverick basin. The Fort Stockton basin was a slowly subsiding, deep-water embayment that extended across the northwestern part of the Comanche shelf from northern Mexico.

During Fredericksburgian through early Washitan time, the central Texas platform was dominated by supratidal, intertidal, and restricted shallow-marine depositional environments. During periods of especially low sea level and extreme aridity, the crest of the central Texas platform became a broad, sabkha-type mudflat where evaporites, dolostone, and thin-bedded dolomitic limestone were deposited (Fisher and Rodda, 1966). Comparatively thick-bedded, rudist-bearing, bioclastic carbonate strata were deposited on the southwestern flank of the central Texas platform in mostly open shallow-marine to open-shelf environments. Here, the water typically was deeper and the circulation generally was less restricted than in the tidal flat environments that prevailed over the crest of the central Texas platform. Marly carbonate strata were deposited at this time in the Fort Stockton basin, an open-marine embayment of moderately deep, quiet water.

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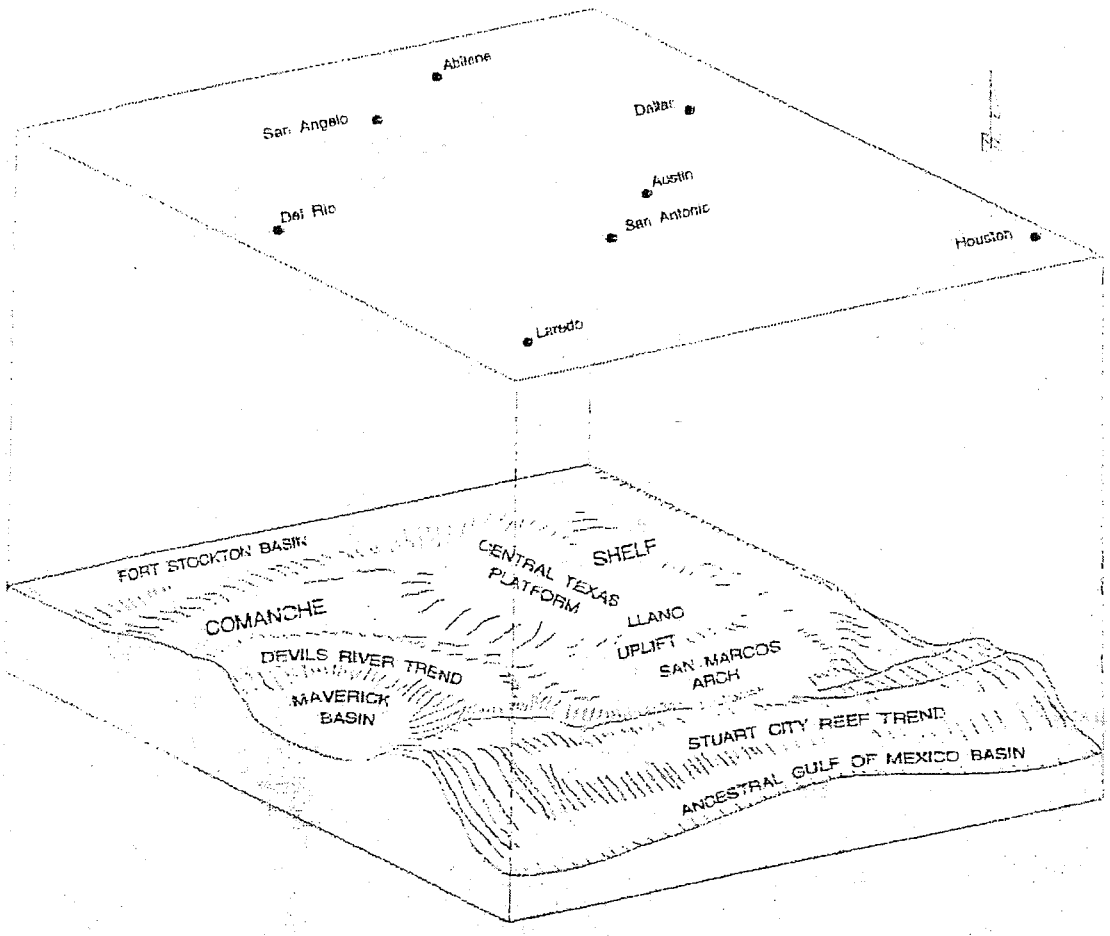

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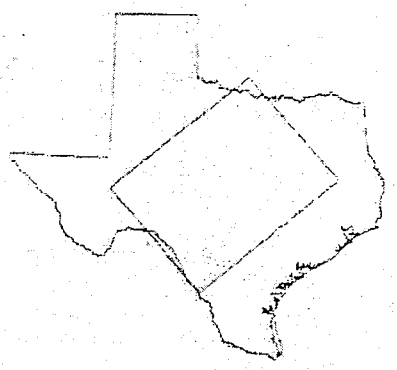

LOCATION MAP

Figure 8. Structural controls on the deposition of Fredericksburg and Washita strata of the Edwards-Trinity aquifer system. (Modified from Rose, 1972, fig. 2.)

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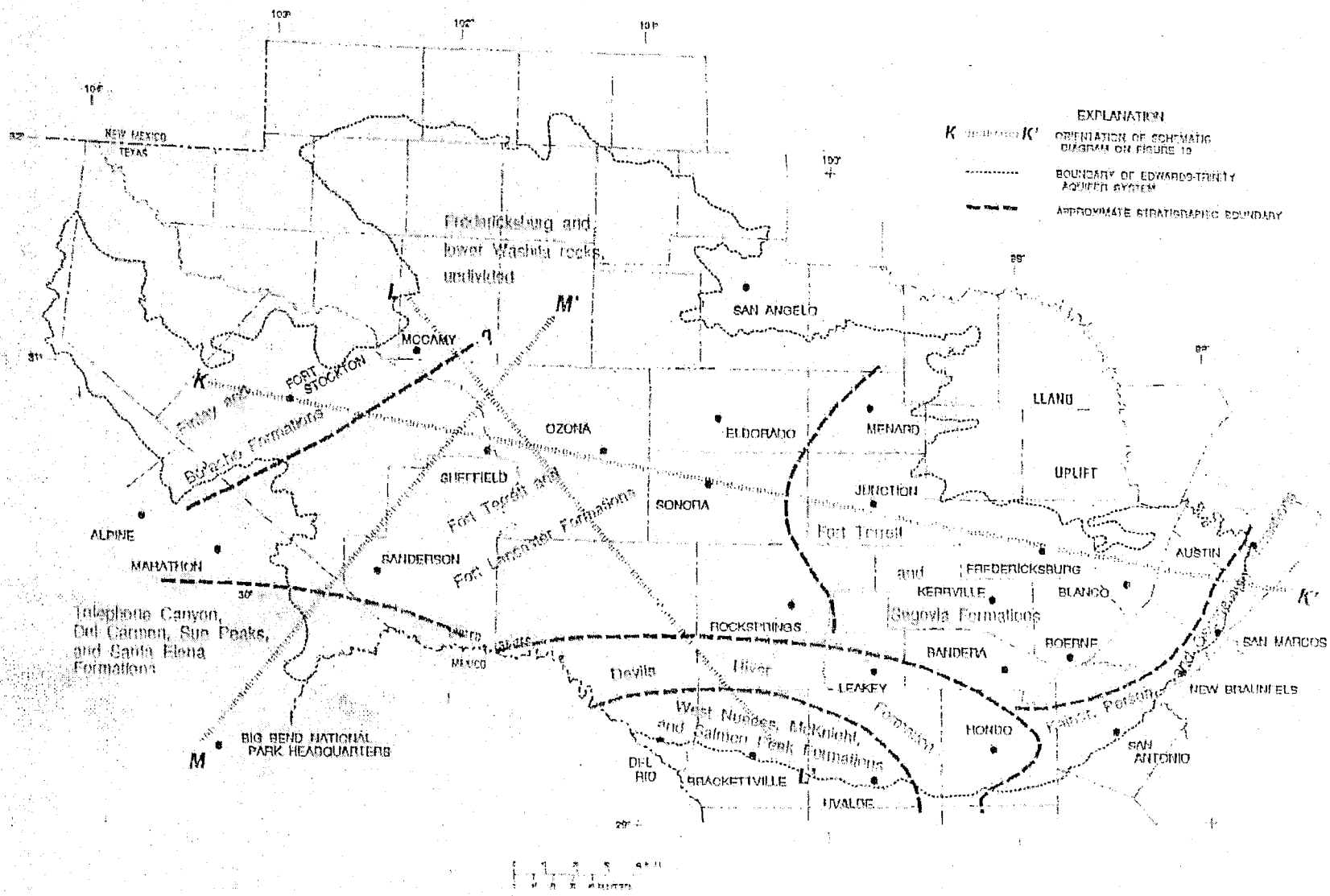

Figure 9. Lateral distribution of Fredericksburg and lower Washita rock units in west-central Texas. (Modified from Smith and Brown, 1983.)

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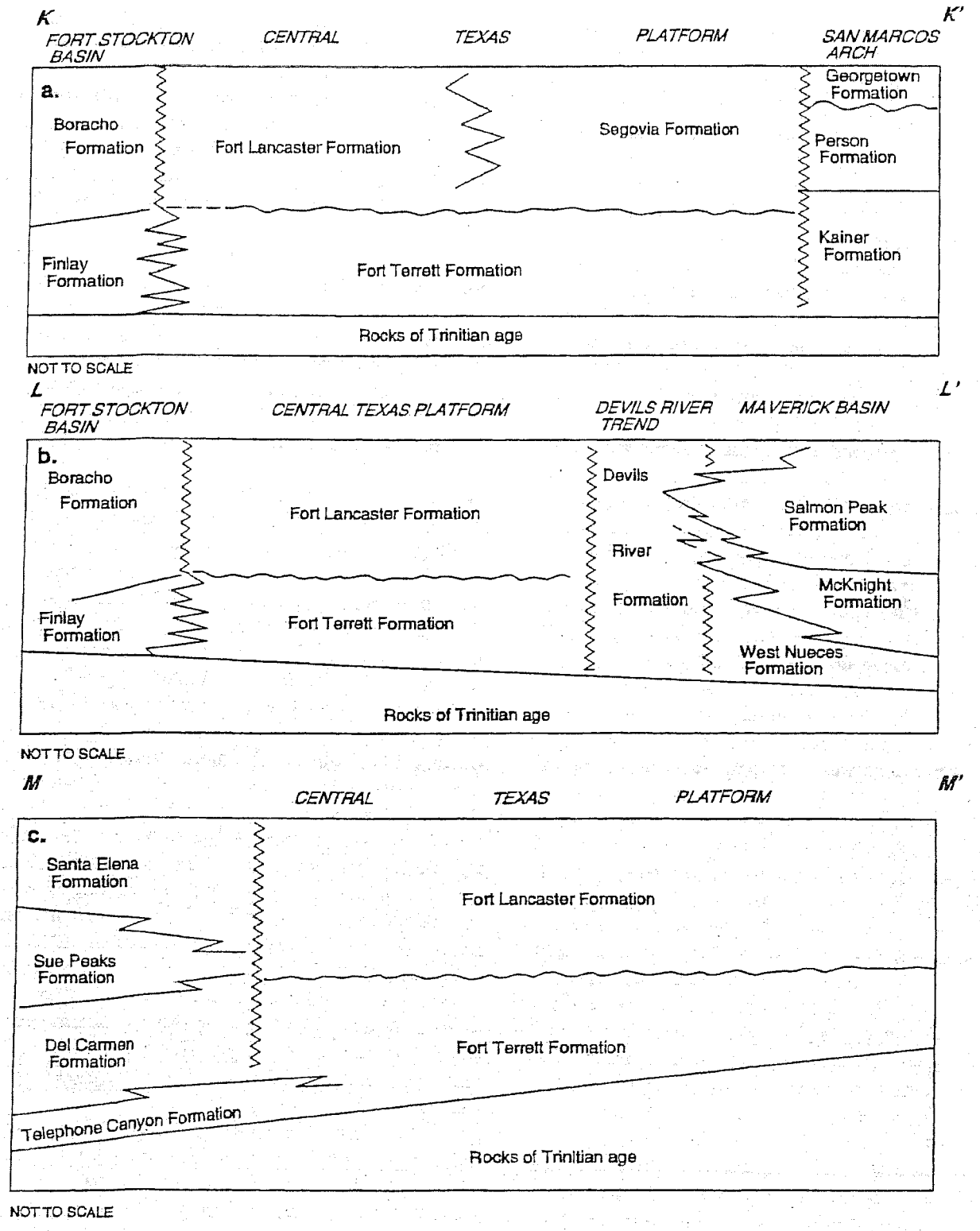

Figure 10. Vertical distribution of Fredericksburg and lower Washita rock units in west-central Texas (modified from Smith and Brown, 1983) and their relation to depositional environments. (See fig. 9 for orientation of diagrams.)

07 025

The eastern part of the Fort Terrett Formation and the Segovia Formation (Rose, 1972) formed near the crest of the central Texas platform in mostly supratidal to restricted shallow-marine environments. The western part of the Fort Terrett Formation and the Fort Lancaster Formation (Scott and Kidson, 1977) formed in mostly open shallow-marine to open-shelf environments transitional to the central Texas platform and Fort Stockton basin.

The Finlay Formation, a cliff-forming limestone with quartz sand in the lower part and rudists in the upper part (Reaser and Malott, 1985), formed during Fredericksburgian time in the Fort Stockton basin when it mostly was a shallow, open lagoon. The Boracho Formation (Brand and Deford, 1958) was deposited later in a deeper, shelf-basin environment that received fine-grained terrigenous sediment from west of the study area. The fine-grained, siliciclastic nature of the Boracho Formation inhibited the precipitation of calcium carbonate and growth of rudists in the Fort Stockton basin during Washitan time (C.I. Smith, University of Texas at Arlington, oral commun., 1989).

The San Marcos arch was dominated by tidal flats and shallow water deposits that frequently underwent uplift, subaerial exposure, and erosion. The Kainer and Person Formations (Rose, 1972) that formed over this arch are characterized by lateral facies changes, structural thinning, and erosional surfaces.

While depositional environments on the central Texas platform and San Marcos arch mostly got shallower during Fredericksburgian through early Washitan time, major subsidence south of a tectonic hinge line (fig. 5) kept parts of southwestern Texas and northern Mexico more deeply submerged. The tectonic hinge line (Smith, 1981, p. 4) extended from the San Marcos arch westward across Medina, Uvalde, Kinney, and Val Verde Counties (fig. 2) to the Big Bend area of Texas (fig. 3). Greater rates of subsidence south of the hinge line triggered fundamental differences between the stratigraphy of rocks deposited on the central Texas platform and those deposited in the Maverick basin (C.I. Smith, University of Texas at Arlington, oral commun., 1989).

In contrast to many depositional breaks north of the tectonic hinge line, the persistently submerged Maverick basin received sediment almost continuously during Fredericksburgian and Washitan time. The typically restricted basin environments generally were isolated from those to the north by an intervening zone of comparatively good water circulation, moderate to high wave and current energy, and aggressive reef growth; the resulting bank of carbonate sediment and reefal debris is known as the Devils River trend (fig. 5). The Devils River trend, on the west and north, together with the Stuart City reef trend, on the east and south, nearly encircled the Maverick basin and thereby limited the extent of three lithofacies that are unique to the basin: the West Nueces, McKnight, and Salmon Peak Formations.

Bioclastic limestone of the West Nueces Formation (Lozo and Smith, 1964) formed mostly below wave base, generally under open-marine conditions of normal salinity. Evaporites near the base of the McKnight Formation (Miller, 1984) were deposited in slightly restricted intertidal and subtidal environments on a broad mudflat that sloped inland from the Stuart City reef trend. As the rate of subsidence increased south of the tectonic hinge line (fig. 5) and the water deepened toward the center of the Maverick basin, gypsiferous deposits that compose lower parts of the McKnight Formation prograded northward. Thin-bedded, finely laminated middle parts of the McKnight Formation formed in an euxinic lagoonal environment (Carr, 1987, p. 70) that produced raw sulfur, petroliferous shale, and dark organic-rich limestone. After the water freshened slightly, thin beds of anhydrite and clayey, lime mudstone accumulated in water approximately 150 to 200 ft deep and formed upper parts of the McKnight Formation (C.I. Smith, University of Texas at Arlington, oral commun., 1989). The McKnight Formation was covered with thick beds of relatively pure lime mudstone that characterize the lower two-thirds of the Salmon Peak Formation (Humphreys, 1984). The lower few hundred feet of Salmon Peak Formation amassed in open to slightly restricted basinal environments, where the water was approximately 300 to 600 ft deep. Conditions became less restricted toward the end of Salmon Peak deposition (middle Washitan time), as the Stuart City reef trend began to disintegrate and the connection between the Maverick basin and the open sea improved (C.I. Smith, University of Texas at Arlington, oral commun., 1989).

Concurrent with deposition inside the Maverick basin, the surrounding Devils River trend produced a stratigraphically undifferentiated bank of partly to completely dolomitized miliolid, shell-fragment, and rudist-bearing limestone (Lozo and Smith, 1964, p. 291–297). Nodular, burrowed, dolomitic, and evaporitic rock sequences that compose the lower half of the Devils River Formation (Miller, 1984) were laid down

07 026

during Fredericksburgian time. During most of Washitan time, rudist reefs flourished around the northern perimeter of the Maverick basin in open, shallow-marine environments of moderate to high wave and current energy. These reefs may have stood above sea level intermittently during middle to late Washitan time when extensive leaching, dolomitization, and recrystallization occurred here, as well as in other parts of the study area (R.W. Maclay, U.S. Geological Survey, written commun., 1987).

Most of the central Texas platform was exposed subaerially, following a widespread withdrawal of the sea toward the end of early Washitan time in response to an upwarping of the Comanche shelf (Rose, 1972, p. 71). Approximately 100 ft of lower Washita strata were eroded from the crest of the San Marcos arch, where upper surfaces of the remaining rocks were karstified (Maclay and Small, 1983, p. 130). Soil and caliche horizons developed toward the north and west over emergent parts of the central Texas platform (Smith and Brown, 1983, p. 23). Freshwater marl and limestone (Halley and Rose, 1977, p. 213–215) formed in marshy, lower-elevation environments toward the south and east. Caverns and other karstic features in the Edwards Plateau (Kastning, 1983, fig. 3) and in the Balcones fault zone (Hammond, 1984, fig. 15) probably began to form during this middle Washitan exposure to meteoric conditions (fig. 11). The local regimes of freshwater circulation suggested by Ellis (1986, p. 110) would have helped flush soluble constituents from the shallow subsurface.

The open sea eventually returned and covered the San Marcos arch with the Georgetown Formation, a nodular, slightly argillaceous, generally thin-bedded limestone. Upper parts of the Segovia and Fort Lancaster Formations were deposited at this time over the central Texas platform, as bioclastic lime sand and mud were laid down in relatively shallow, agitated water (Rose, 1972, p. 71). A shoaling-upward pattern of deposition prevailed around the northern margin of the Maverick basin. As a result of higher wave and current energy and a greater reworking of sediments near the Devils River reef bank, a tongue of relatively pure lime grainstone prograded southward into the Maverick basin, forming the upper part of the Salmon Peak Formation. The rate of reef growth at this time probably exceeded the rate of subsidence in the Maverick basin (Humphreys, 1984, p. 56).

Following regional uplift during late Washitan time and additional erosion of sediments from the crest of the central Texas platform, the open sea once again returned to west-central Texas. The Comanche shelf was blanketed with silt, clay, and marly limestone of the Del Rio Clay. This relatively thin (table 2), open-marine terrigenous deposit topped the Maverick basin, which by late Washitan time was no longer characterized by distinct depositional environments. Carbonate sedimentation abated as the suspended sediment obstructed the feeding of carbonate-producing organisms in environments no longer sheltered within the Maverick basin or behind the Stuart City reef trend (C.I. Smith, University of Texas at Arlington, oral commun., 1989).

Additional uplift and emergence of the central Texas Platform just before the end of Washitan time caused erosion to strip some, and in places all, of the upper Washita strata from the study area. The Washitan age ended as the deep sea returned and blanketed the entire study area with a thin sheet of open-shelf lime mudstone, known as the Buda Limestone.

Gulfian Epoch: Eaglefordian Through Navarroan Ages

During Eaglefordian (early Gulfian) through Navarroan (late Gulfian) time, the Buda Limestone was covered with 2,000 to perhaps 4,000 ft of sandstone, shale, marl, and chalk (Waters and others, 1955, p. 1,831). Except for Eagle Ford sediments in western parts of the study area, most Gulf strata formed under low-energy, open-shelf conditions. Most Gulf strata in the study area are fine-grained, strongly cemented, and virtually impermeable.

The study area was uplifted at the close of the Cretaceous Period, in response to the Laramide orogeny of northern Mexico and the southwestern part of the United States (Ewing, 1991, p. 24). Extensive erosion subsequently removed most Gulf sediments from the study area. The remaining rocks include those of Late Cretaceous age that dip steeply below land surface east of the Ouachita structural belt (fig. 4) and thin, sparse remnants of the Austin Group and Boquillas Formation atop the Edwards Plateau and Trans-Pecos. The Cretaceous System of the study area thus is separated from the Cenozoic Erathem by a major unconformity (Adkins, 1933, p. 517).

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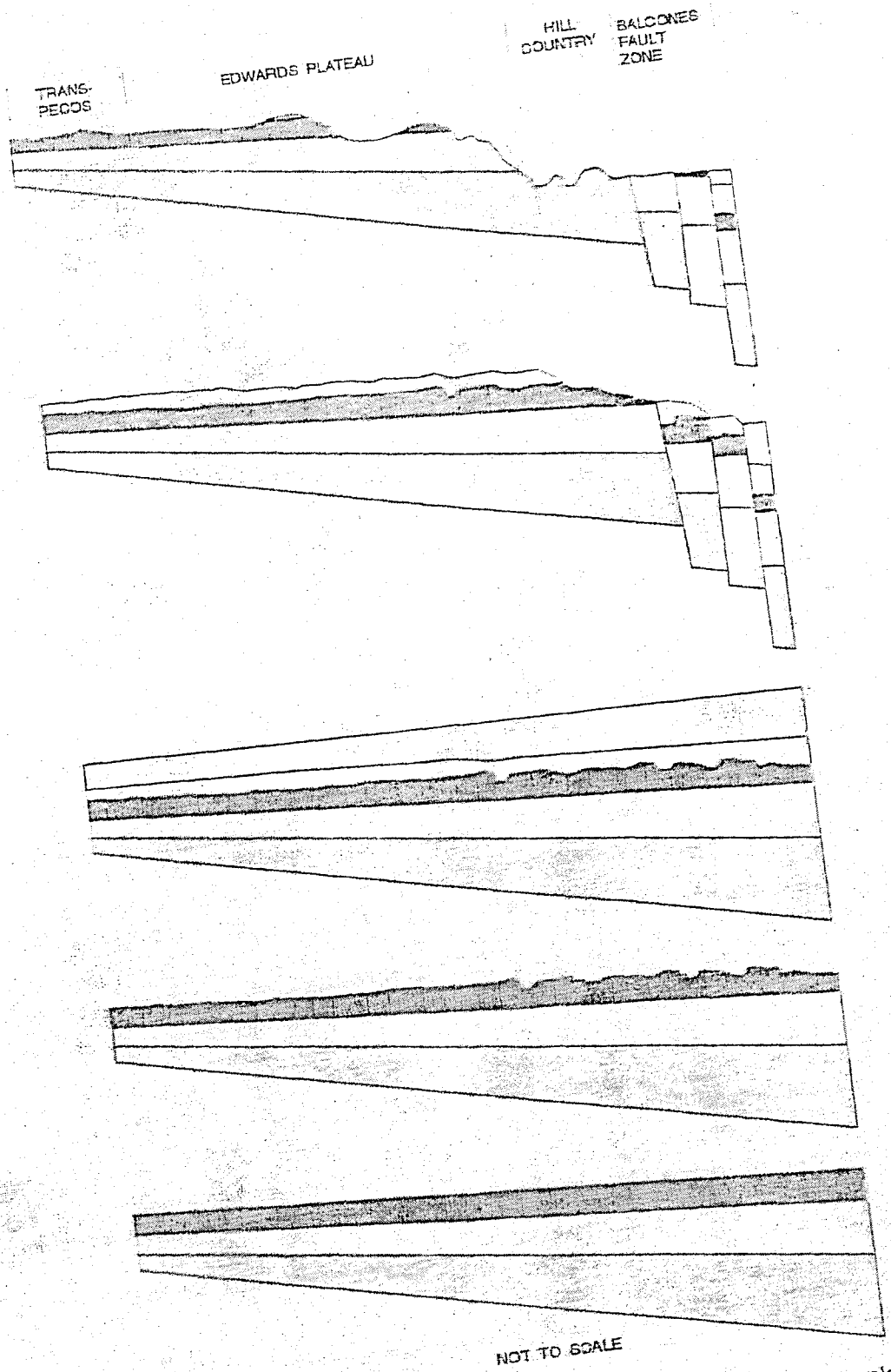

Figure 11. Progression of major depositional, tectonic, and diagenetic events affecting the development of the Edwards-Trinity aquifer system.

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QUATERNARY

Base level of surface drainage lowers as streams erode deeper into uplifted strata west of Balcones fault zone; Hill Country stripped of most post–Trinity strata; hydraulic conductivity of strata outside fault zone decreases through cementation, recrystallization, and replacement; hydraulic conductivity of Edwards Group inside fault zone increases through dissolution and dedolomitization; joint cavities, solution channels, and honeycombed zones continue to enlarge—increasing the transmissivity of Edwards aquifer; dynamic equilibrium between freshwater and saline water reached across freshwater/saline-water transition zone.

TERTIARY: Oligocene – Miocene Epochs

Cretaceous strata displaced vertically as much as 1,200 feet in Balcones fault zone by high-angle normal faults, culminating tensional buildup in strata above Ouachita structural belt, as Gulf of Mexico subsides; fractures in fault zone widen as erosional unloading progresses; ground-water flow diverted toward northeast by barrier faults; hydraulic conductivity increases through dissolution of previously buried evaporites, magnesium calcite, and aragonitic constituents as meteoric water enters faulted terrain and circulates through fractures and downdropped paleokarst; dolomite replaced by calcite through dedolomitization; micrite recrystallizes to coarse microspar and pseudospar; headward erosion toward upthrown Edwards Plateau initiates dissection of terrain west of fault zone; Gulf strata eroded and redeposited gulfward.

LATE CRETACEOUS

Karst, marl, soil, and caliche surfaces buried by upper Washita strata (following regional subsidence) and Gulf strata (following collapse of Stuart City reef trend); calcite cementation abates; karst development ceases; carbonate sediments undergo compaction, with stylolitization in deeply buried facies.

LATE–EARLY CRETACEOUS: Following middle Washitan uplift

Lower Washita strata exposed subaerially following uplift of Comanche shelf; approximately 100 feet of strata eroded from crest of San Marcos arch; San Marcos arch and central Texas platform locally karstified; primary porosity enlarged through dissolution of evaporitic and calcareous constituents in shallow zones of freshwater circulation, with carbonate cementation downgradient; freshwater marl, soil, and caliche horizons formed over central Texas platform.

EARLY CRETACEOUS

Trinity, Fredericksburg, and lower Washita strata deposited mainly in terrestrial, supratidal, intertidal, and shallow marine environments on slowly subsiding carbonate platform in lee of Stuart City reef trend; aragonitic constituents, high-magnesium calcite, and evaporites leached early by locally circulated meteoric water; breccia zones formed by collapse of overlying beds; supratidal carbonate deposits dolomitized and gypsum precipitated; aragonite and magnesian calcite cements formed in marine environments.

EXPLANATION

GULF ROCKS

Eagleford Through Navarro age

COMANCHE ROCKS

Late Washitan age

Early Washitan age

Fredericksburgian age

Trinitian age

Figure 11. Continued.

07 029

Table 2. Approximate maximum thickness of lithostratigraphic units that compose the Edwards-Trinity aquifer system, west-central Texas

Lithostratigraphic unit	Thickness (feet)	Sources of thickness data
Navarro Group	500	Maclay and Small, 1986, table 1
Taylor Group	500	Do.
Austin Group	350	Do.
Eagle Ford Group	250	Do.
Buda Limestone	200	Small and Ozuna, 1993, table 1
Del Rio Clay	170	C.I. Smith, written commun., 1989
Georgetown Formation	60	Rose, 1972, fig. 16
Salmon Peak Formation	500	Humphreys, 1984, fig. 2
Devils River Formation	700	Maclay and Small, 1986, table 1
Boracho Formation	410	Brand and DeFord, 1958, fig. 2
Fort Lancaster Formation	405	C.I. Smith, written commun., 1989
Segovia Formation	380	Rose, 1972, fig. 23
Person Formation	260	Rose, 1972, fig. 15
McKnight Formation	285	Carr, 1987, p. 21
Finlay Formation	165	Small and Ozuna, 1993, table 1
Fort Terrett Formation	300	Rose, 1972, fig. 21
West Nueces Formation	260	Miller, 1984, p. 9
Kainer Formation	400	Rose, 1972 fig. 14
Maxon Sand	200	C.I. Smith, written commun., 1989
Glen Rose Limestone	1,530	Welder and Reeves, 1964, table 1
Cox Sandstone	170	Brand and DeFord, 1958, fig. 2
Yearwood Formation	180	Do.
Basal Cretaceous sand	395	Romanak, 1988, p. 21; Wessel, 1988
Hensel Sand/Bexar Shale Member of Pearsall Formation	210	Imlay, 1945, table 2
Cow Creek Limestone/Cow Creek Limestone Member of Pearsall Formation	88	Do.
Hammett Shale/Pine Island Shale Member of Pearsall Formation	130	Amsbury, 1974, fig. 12
Sycamore Sand	50	DeCook, 1963, table 3
Sligo Formation	240	Imlay, 1945, table 2
Hosston Formation	880	Do.

Cenozoic Era

The majority of Cenozoic deposition in Texas (Wilhelm and Ewing, 1972) occurred southeast of the study area in the ancestral Gulf of Mexico basin (fig. 5). During the Cenozoic Era, a thick succession of offlapping deltaic deposits built the Gulf Coastal Plain with detritus eroded from Paleozoic and Mesozoic rocks on the uplifted continental interior (Wilhelm and Ewing, 1972). The most important Cenozoic units in the study area are: (1) narrow streambeds of Holocene alluvium; (2) sparse remnants of Pleistocene terrace deposits; and (3) thick deposits of Tertiary and Quaternary alluvium along the Pecos River. Only the thick alluvium along the Pecos River markedly affect the Edwards-Trinity aquifer system.

A large volume of Cretaceous strata was removed from the study area as a result of post-depositional dissolution, structural collapse, and stream erosion along the present course of the Pecos River (fig. 2).

07 030

During the late Mesozoic and early Cenozoic Laramide deformation (Henry and Price, 1985), large solution cavities formed in the underlying Permian strata as halite, gypsum, and anhydrite were dissolved by ground water (Maley and Huffington, 1953). The entry of meteoric water was enhanced by the effects of a general crustal instability and the mobility of massive salt deposits in the region (Wessel, 1988, figs. 11–14). As the overlying Triassic and Cretaceous strata collapsed into the solution cavities, two elongated troughs (Barker and Ardis, in press, pl. 2) formed between the southeastern corner of New Mexico and the northwestern part of Pecos County (Ashworth, 1990, fig. 5). The troughs filled during Tertiary and Quaternary time with more than 1,500 ft of talus and alluvial fill, known as the Cenozoic Pecos alluvium.

Since late Mesozoic time, mountain-building forces in the Trans-Pecos have uplifted western parts of the study area, while sediments east of the Ouachita structural belt mostly have subsided (Walper and Miller, 1985). Tensile stresses accumulated in the Cretaceous strata where they stretched over a sunken, but structurally rigid Ouachita structural belt (Flawn, 1956, p. 32). The crustal tension culminated during the Tertiary Period with a series of discontinuous, generally en echelon, mostly down-to-the-southeast, normal faults (figs. 4, 5). Although the majority of large-scale faulting probably was during late Oligocene through early Miocene time (Weeks, 1945, p. 1,736), some Late Cretaceous (or earlier) movement on some faults is possible (Murray, 1961, p. 176).

The Balcones fault zone is aligned with the curvature, and approximately with the axis, of the Ouachita structural belt (fig. 5). The Balcones faults disrupt Lower Cretaceous through Paleocene strata at the surface (Murray, 1961, p. 176) and appear to extend into and displace rocks of the underlying structural belt (Maclay and Small, 1986, fig. 2). The alignment of the Balcones faulting probably was influenced by lines of weakness in the Ouachita structural belt (Flawn and others, 1961, p. 190). Maximum displacements occurred over the San Marcos arch in Bexar, Comal, Hays, and Travis Counties. Weeks (1945, p. 1,734) estimated the total displacement across the Balcones fault to be about 1,200 ft near San Antonio and about 900 ft near Austin.

The Balcones faulting (fig. 11) disrupted the lateral continuity of the Cretaceous strata and initiated hydrogeologic conditions that ultimately produced one of the most transmissive and productive aquifers in the Nation: the Edwards aquifer of the Balcones fault zone (Maclay and Small, 1986). The Cretaceous strata in this area were downfaulted, intensively fractured, and differentially rotated within a series of northeast-trending fault blocks. Ground-water flow shifted toward the northeast in response to high-angle barrier faults that impeded or completely blocked southeastward flow. Flowpaths became increasingly ingrained toward the northeast as evaporites and unstable carbonate constituents dissolved from the fractured terrain and discharged in that direction through springs and deeply entrenched streams (Abbott, 1975).

Springs originated in topographically low areas, where barrier faults intercepted the lateral flow of confined water at depth and diverted it to the surface along avenues of least resistance (Abbott, 1977). Aquifers developed as flowpaths converged toward spring outlets, and the rocks became more permeable through dissolution. Solution channels spread outward from the springs, and zones of honeycombed and cavernous porosity evolved into major conduits of ground-water flow (Woodruff and Abbott, 1986, p. 77). The major springs (fig. 3) persisted and control modern potentiometric levels and discharge patterns (Bush and others, 1993).

Gulf-bound streams, that had been low-gradient, meandering features before the faulting, were out of equilibrium with the faulted topography (Woodruff and Abbott, 1986, fig. 5). Although most of the pre-fault watercourses had flowed generally eastward, headward erosion by newly formed (post-fault) streams progressed quickly northwestward across the Balcones escarpment toward the Edwards Plateau (Woodruff and Abbott, 1986). Many of the older, east-trending streams were pirated by the younger, higher-gradient streams that developed normal to the escarpment. According to Woodruff and Abbott (1986, p. 87), greater rates of stream incision began after piracy when more discharge became available from the newly acquired headwaters. Once the rejuvenated stream network breached the overburden of low-permeability Gulf rocks and cut into the relatively permeable Comanche rocks, the streams became discharge areas for developing aquifers.

Erosion eventually removed all but minor remnants of the Fredericksburg and Washita strata (mostly of the Edwards Group) from a 20- to 50-mile-wide area between the Balcones fault zone and the Edwards Plateau (fig. 3). The extensively dissected Hill Country is characterized by expansive outcrops of Glen Rose

07 031

Limestone (of the Trinity Group). Because the rocks in the Hill Country generally were excluded from the vertical displacement, intensive fracturing, and subsequent dissolution that characterize those in the Balcones fault zone, the hydraulic properties of the Hill Country more closely resemble those of the Edwards Plateau and Trans-Pecos.

Outside the Balcones fault zone, the dominant effects of carbonate diagenesis (Bathurst, 1975) on the hydraulic characteristics of the Edwards-Trinity aquifer system result most importantly from cementation, recrystallization, and neomorphism. Neomorphism is a comprehensive term to describe processes of recrystallization and replacement where the mineralogy may have changed or it is impossible to distinguish between the mechanism of change. Most of the primary intergranular porosity partly or completely filled through cementation, and much of the original intercrystalline porosity decreased through successive stages of recrystallization. Unstable minerals, such as high-magnesium calcite and aragonite, mostly were replaced by relatively stable low-magnesium calcite. Because cementation, recrystallization, and replacement typically reduce or obliterate the porosity of carbonate rocks (Choquette and Pray, 1970, p. 209), the hydraulic conductivity of most rocks in the study area decreased over geologic time. The trend of decreasing hydraulic conductivity with increasing age is typical of carbonate rocks (Jakucs, 1977, p. 69; fig. 16).

Within the Balcones fault zone, however, the hydraulic conductivity generally has increased through the effects of tectonic fracturing and freshwater diagenesis in humid, post-Cretaceous environments (Maclay and Small, 1986, p. 28–32). In addition to creating porosity (Howard and David, 1936), the fractures enhanced hydraulic conductivity by interconnecting existing pores. The subsequent dissolution of unstable carbonate constituents resulted in vugs, channels, caverns and various kinds of fabric-selective porosity (Choquette and Pray, 1970, fig. 2) that additionally enhanced hydraulic conductivity. Because fractures typically close with increasing depth below land surface and dissolution is most active within the shallower zones of water-level fluctuation (LeGrand and Stringfield, 1971, p. 1,286), the increases in hydraulic conductivity generally are limited to rocks nearest the land surface.

A shallow, freshwater-flow regime probably has existed in the Balcones fault zone since Miocene time (Ellis, 1986), when large-scale faulting ruptured the thick overburden of hydraulically tight Gulf strata and exposed the more permeable upper Comanche strata to meteoric conditions (fig. 11). Previously leached strata (paleokarst) provided an incipient network of groundwater circulation that fostered aquifer development (Hammond, 1984, p. 149). The concentration of high-angle faults and associated fractures facilitated the percolation of carbon-dioxide-enriched meteoric water, extending the depth of freshwater diagenesis. The partial pressure of the dissolved carbon dioxide, derived from the atmosphere and soil, increased the solubility of carbonate minerals. The vertically displaced terrain provided steep hydraulic gradients that maintained relatively large flow velocities near the surface and helped flush dissolved constituents. Hydraulic conductivity increased as evaporites (principally anhydrite and gypsum) and unstable carbonate constituents (aragonite and high-magnesium calcite) dissolved along fractures, bedding planes, and burrows (Abbott, 1975, p. 255–267).

The hydraulic conductivity of dolostone in the Balcones fault zone increased through dedolomitization (Maclay and Small, 1986, p. 31), a form of incongruent dissolution, where dolomite in combination with dissolved gypsum is replaced by calcite. Dedolomitization, by itself, does not increase hydraulic conductivity. However, the resulting "calcite after dolomite," or dedolomite, can be more soluble than the original dolomite; subsequent dissolution can then increase hydraulic conductivity. The presence of dedolomite to depths of about 600 ft on the freshwater side of the freshwater/saline-water transition zone (fig. 2) is evidence that most dedolomitization in the Balcones fault zone occurred since Miocene time—after a dynamic, freshwater-flow regime was established (Ellis, 1986, p. 109). Most dedolomite in the area of the Edwards aquifer formed during the last 15 to 20 million years, according to R.W. Maclay of the U.S. Geological Survey (written commun., 1990).

The transmissivity of the Edwards aquifer is much greater than that of the other aquifers in the study area. Whereas transmissivity values for the Edwards aquifer (covering less than 10 percent of the study area) average about 750,000 ft^2/d, transmissivity values for the Trinity and Edwards-Trinity aquifers (covering more than 90 percent of the study area) average less than 10,000 ft^2/d (E.L. Kuniansky, U.S. Geological Survey, written commun., 1990).

The difference between the transmissivity of the Edwards aquifer and the transmissivity of the Trinity

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aquifer in the Balcones fault zone is attributable to the effects of fractures that close with increasing depth below land surface and a history of larger flow velocities near the surface. The Balcones faulting steepened hydraulic gradients and initiated a shallow, dynamic flow system that promoted dissolution, which enhanced the transmissivity of the Edwards aquifer. In contrast, cementation, recrystallization, and mineral replacement—caused by deeper, comparatively sluggish ground-water circulation—combined to diminish the transmissivity of the underlying Trinity aquifer, as well as most strata outside the fault zone.

The transmissivity of the Trinity aquifer in the Hill Country and the Edwards-Trinity aquifer in the Edwards Plateau and Trans-Pecos, likewise, is small compared with the transmissivity of the Edwards aquifer in the Balcones fault zone. Secondary calcite fills most of the original pores in the carbonate rocks outside the Balcones fault zone, where joint cavities and solution channels associated with large-scale normal faulting and subsequent dissolution are relatively sparse. Variations in transmissivity outside the fault zone probably result more from differences in saturated thickness (Ardis and Barker, 1993) than from diagenetic and post-depositional tectonic activity.

HYDROGEOLOGIC SETTING

The Cretaceous rocks of the Edwards-Trinity aquifer system thin toward the northwest atop massive, comparatively impermeable and structurally complex pre-Cretaceous rocks. From predominately terrigenous clastic sediments in the east and fluvial-deltaic (terrestrial) deposits in the west, the rocks of early Trinitian age grade upward into supratidal evaporitic and dolomitic strata, intertidal limestone and dolostone, and shallow-marine, open-shelf, and reefal strata of late Trinitian, Fredericksburgian, and Washitan age. A thick, downfaulted remnant of mostly open-marine strata of Eaglefordian through Navarroan age composes a small, southeastern part of the aquifer system.

The correlation chart on table 1 shows the relation between stratigraphic units in the study area and the hydrogeologic units of the Edwards-Trinity aquifer system. The correlation chart combines pertinent chronostratigraphic and lithostratigraphic nomenclature with aquifer terminology recommended in the Texas Water Plan (Texas Water Development Board, 1990). The stratigraphic nomenclature was selected from the results of stratigraphic research by colleges and universities, agencies of local and Federal governments, and industry.

Stratigraphy

Trinity Group

The stratigraphy of the Trinity Group in the study area was synthesized for table 1 from several publications. The correlation of the Trinity rock units is based primarily on descriptions by Forgotson (1956), Lozo and Stricklin (1956, fig. 4), Brand and Deford (1958, fig. 2), Loucks (1977, fig. 4), and Smith and Brown (1983, fig. 3). The lateral and vertical distributions of the Trinity rock units are summarized in figures 6 and 7, respectively.

Sediments in the Trinity outcrop between the top of Paleozoic rocks and the base of the Glen Rose Limestone were originally called the Travis Peak Formation (Taff, 1892; Hill and Vaughan, 1898; and Hill, 1901). After finding key disconformities and an additional shale unit within the Travis Peak sequence, Lozo and Stricklin (1956) raised each member of the original Travis Peak Formation to formational rank. Lozo and Stricklin (1956, p. 68) recommended that Travis Peak nomenclature be "*** deleted from modern stratigraphic terminology or reserved for use by laymen." However, in recognition of usage that continues locally, the term "Travis Peak equivalent" is applied in this report to the outcrop and shallow subcrop of Trinity strata in the Hill Country, to represent the combined Sycamore Sand, Hammett Shale, Cow Creek Limestone, and Hensel Sand (table 1).

The Pearsall Formation was defined by Imlay (1945, p. 1,441) to include sediments above the Sligo Formation and below the Glen Rose Limestone that represent "*** the subsurface equivalents of the Travis Peak formation of the outcrop." The Pearsall Formation is applied in this report to the subcrop of Trinity strata in the Balcones fault zone, where it contains the Pine Island Shale, Cow Creek Limestone, and Bexar Shale Members and to the south-central part of the Edwards Plateau (southeastern Edwards County; fig. 6),where the formation is not differentiated into members (table 1).

The Hosston Formation typically is a siliciclastic siltstone and sandstone in updip areas and a dolomitic mudstone and grainstone in downdip areas. The downdip dolomitic sediments grade upward into supratidal

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evaporites and intertidal limestone and dolostone of the Sligo Formation (Bebout and others, 1981). From a shallow-marine carbonate lithofacies in downdip areas, the Sligo Formation grades updip, toward the Llano uplift (fig. 6), into the terrigenous clastic lithology of the Hosston Formation (fig. 7). Farther updip, the Hosston Formation grades into the Sycamore Sand (Lozo and Stricklin, 1956) of the outcrop area. The Sycamore Sand is a clastic unit composed predominately of quartzose sand and gravel, with some feldspathic and dolomitic detritus that was eroded from the Llano uplift and deposited on its flanks by aggrading streams (Amsbury, 1974, p. 6).

The Hammett Shale (Lozo and Stricklin, 1956) in the Hill Country has the same stratigraphic position as the genetically similar Pine Island Shale Member of the Pearsall Formation (Forgotson, 1956) in the Balcones fault zone (table 1); the different nomenclature reflects the preferred usage in each area (Murray, 1961, p. 308–309). The Pine Island Shale Member extends eastward from the Balcones fault zone and is one of the most persistent Lower Cretaceous rock units of east Texas. The updip Hammett Shale typically is a highly burrowed mixture of clay, terrigenous silt, lime mud, silt-sized dolomite, and other carbonate particles (Amsbury, 1974). The downdip Pine Island Shale Member is primarily a gray to black calcareous shale interbedded with dense gray limestone (Forgotson, 1957). The Hammett Shale and the Pine Island Shale Member interfinger vertically with the overlying Cow Creek Limestone and Cow Creek Limestone Member, respectively (fig. 7a).

The Cow Creek Limestone (Lozo and Stricklin, 1956) is a regressive beach sequence on the southern flank of the Llano uplift (Stricklin and Smith, 1973). The lower part of the Cow Creek Limestone generally is a fine- to coarse-grained calcarenite, with large oyster fragments. The middle part is a silty calcarenite, containing carbonate concretions and fine quartz sand. The upper part is a crossbedded beach coquina, composed primarily of oyster-shell detritus with poorly sorted quartz grains and scattered chert pebbles. The updip part of the Cow Creek Limestone generally is overlain by the Hensel Sand, and the Cow Creek Limestone Member of the Pearsall Formation (Forgotson, 1956) generally is overlain by the Bexar Shale Member (fig. 7a).

The Bexar Shale Member of the Pearsall Formation (Forgotson, 1956) typically is a mixture of dark mudstone, clay, and shale. The name is derived from Bexar County, where the unit produces a distinct pattern on electric logs (Forgotson, 1957, p. 2,347). In this report, the Bexar Shale Member applies to the gray to black calcareous shale with intermixed thin beds of dense, finely crystalline limestone present between the Cow Creek Limestone Member and the Glen Rose Limestone throughout the Balcones fault zone. The Bexar Shale Member has been interpreted as the fine-grained, marine equivalent of the near-shore, terrigenous facies of the Hensel Sand (Loucks, 1977, p. 106).

The Hensel Sand (Lozo and Stricklin, 1956) comprises a weakly cemented mixture of ferruginous clay, quartz and calcareous sand (crossbedded in places), and chert and dolomite pebbles, which typically form a basal conglomerate (Inden, 1974). The clastic sediments of this time-transgressive unit weather to a distinctive nonuniform, rusty-yellow hue. The downdip part of the Hensel Sand grades northwestward into the genetically similar basal Cretaceous sand (fig. 7b). The updip Hensel Sand, on the southern flank of the Llano uplift (fig. 7a), has been interpreted as the clastic, shoreward equivalent of the Glen Rose Limestone (Stricklin and others, 1971).

The Glen Rose Limestone (Lozo and Stricklin, 1956) is a sandy, fossiliferous limestone and dolostone characterized by repetitious interbeds of calcareous marl, clay, and shale with laterally persistent stringers of gypsum and anhydrite. The (informal) lower member of the Glen Rose Limestone comprises mostly medium-thick beds of limestone, dolostone, and dolomitic limestone with diverse mollusk assemblages and local rudist reefs (Perkins, 1974). The (informal) upper member of the Glen Rose Limestone is predominately a thin- to medium-bedded sequence of nonresistant marl alternating with resistant beds of dolostone, lime mudstone, and bioclastic limestone (Stricklin and others, 1971). The upper member generally contains one or more evaporite stringers and shows no evidence of reef formation. The alternating beds of different lithology within the Glen Rose Limestone provide an uneven resistance to erosion, resulting in a characteristic "stairstep" topography over much of its outcrop area in the Hill Country.

The calcareous, shallow-marine lithology of the Glen Rose Limestone grades northward into a quartzose clastic, terrestrial lithology characteristic of the Hensel Sand in the eastern part of the study area and the basal Cretaceous sand in the western part (fig. 6). The location of this carbonate-to-clastic facies transition, known as the Glen Rose pinchout, is approximated in

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figure 6 by a zigzag pattern between northern Blanco and southern Pecos Counties. In the southern parts of the Edwards Plateau and Trans-Pecos, the Glen Rose Limestone generally is overlain by the Maxon Sand.

The Maxon Sand (King, 1980, p. 21) predominately is a brownish, well indurated, coarse- to medium-grained, crossbedded sandstone, with lesser quantities of conglomerate, mudstone, and limestone (Butterworth, 1970, p. 4). The sandstone is composed mainly of quartz with minor quantities of feldspar and heavy (metallic) minerals eroded from Permian and Triassic rocks northwest of the study area. The constituents generally are consolidated with calcite, hematite, and kaolinite cements. The Maxon Sand forms conspicuous ledges atop the Glen Rose Limestone where these units crop out along escarpments east of the Marathon uplift in southern Pecos County (fig. 6). From Terrell County eastward, the Maxon Sand is covered by the Fort Terrett Formation.

The (informal) basal Cretaceous sand (Smith and Brown, 1983) is the only Trinity rock unit in the northern part of the study area (table 1, fig. 6). The basal Cretaceous sand underlies the updip wedge of Glen Rose Limestone in southwestern parts of the study area, where it is stratigraphically equivalent to the Hosston Formation, Hammett Shale, Cow Creek Limestone, and Hensel Sand (fig. 7b). North of the updip limit of Glen Rose Limestone, the basal Cretaceous sand underlies either the Finlay or Fort Terrett Formations of Fredericksburgian age and includes sediments equivalent to the Maxon Sand. The basal Cretaceous sand is identical to the "basement sands," "Trinity sand," and "basal Cretaceous sandstone" of previous reports and incorporates the Yearwood Formation and Cox Sandstone of Brand and Deford (1958).

The basal Cretaceous sand, largely of a fluvial-deltaic origin, generally consists of varying mixtures of sandstone, siltstone, and conglomerate. The major constituents are well-rounded fragments of quartz, chert, and feldspar derived from Permian and Triassic red beds. Calcite is the dominant cement, but dolomite, ankerite, silica, kaolinite, and hematite are prevalent cements locally (Romanak, 1988, p. 27). This diverse, areally extensive unit generally is unfossiliferous and varies vertically and laterally in color, texture, composition, and degree of cementation. The lower part of the unit generally is coarse-grained, and a fine- to medium-grained sandstone replaces a basal conglomerate in places. The finer grained, variegated middle part of the unit is crossbedded in places and indurated locally with calcareous cement. The upper part of the unit contains small quantities of limestone and thin, calcareous shale interbeds.

Fredericksburg and Washita Groups

The stratigraphy of the Fredericksburg and Washita Groups in the study area (table 1) was modified from reports by Brand and Deford (1958), Lozo and Smith (1964), Rose (1972), and Smith and Brown (1983). The correlation chart links: (1) the Edwards Group of Rose (1972) in the northeastern part of the Balcones fault zone and eastern part of the Edwards Plateau; (2) the Devils River, West Nueces, McKnight, and Salmon Peak Formations of Lozo and Smith (1964) in the southwestern part of the Balcones fault zone and south-central part of the Edwards Plateau; (3) the Finlay and Boracho Formations of Brand and Deford (1958) in the northwestern part of the Trans-Pecos and western part of the Edwards Plateau; and (4) the Fort Terrett and Fort Lancaster Formations of Smith and Brown (1983) in the southeastern part of the Trans-Pecos and north-central part of the Edwards Plateau. The lateral and vertical distributions of the Fredericksburg and lower Washita rocks are summarized in figures 9 and 10, respectively.

The Fredericksburg Group and lower part of the Washita Group are superseded in the northeastern part of the Balcones fault zone and eastern part of the Edwards Plateau by the Edwards Group of Rose (1972). In the northeastern part of the Balcones fault zone, the Edwards Group consists of the Kainer and Person Formations (fig. 9). In the eastern part of the Edwards Plateau, the Edwards Group consists of the Fort Terrett and Segovia Formations.

Across the western part of the Balcones fault zone, the southwestern part of the Hill Country, and the southern part of the Edwards Plateau, the Fort Lancaster, Fort Terrett, Kainer, Person, and Segovia Formations lose their identities against a narrow, semioval carbonate bank that is known as the Devils River trend (figs. 5, 10b). The Devils River trend wraps around the northern part of the Maverick basin (Winter, 1962), which also is bounded by the Stuart City reef trend on the south and by the San Marcos arch on the east. The Devils River trend, represented stratigraphically by the Devils River Formation (Miller, 1984), is a composite of dolostone, fossiliferous limestone, and reefal debris (Lozo and Smith, 1964, p. 290–296). The lower part of the Devils River Formation is stratigraphically

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continuous with lower, dolomitic parts of the Fort Terrett and Kainer Formations. However, because the Devils River Formation is relatively homogeneous from top to bottom, it is impractical to subdivide this formation stratigraphically except to recognize informally the lower (dolomitic) and upper (limestone) parts.

The Fredericksburg and lower Washita units of the Maverick basin (Lozo and Smith, 1964) are the West Nueces, McKnight, and Salmon Peak Formations. The West Nueces Formation is a transgressive lithofacies that closely resembles the nodular, shell-fragment limestone at the base of the Fort Terrett Formation and in lower parts of the Devils River Formation (Smith, 1979, p. 15). According to Maclay and Small (1983, p. 132), the McKnight Formation is a predominately euxinic deposit that "*** grades upward from thin-bedded carbonate mudstones to petroliferous shales and evaporites and terminates in a layer of pelleted grainstones." The Salmon Peak Formation (Humphreys, 1984) predominately is a dense, thick-bedded, deep-water mudstone that grades upward to a crossbedded, rudist-shell grainstone (Smith, 1979, p. 16).

Smith and Brown (1983) extended the Fort Terrett Formation (Rose, 1972) to include Fredericksburg strata in the central and western parts of the Edwards Plateau and in most of eastern Pecos and Terrell Counties of the Trans-Pecos (fig. 9). The Fort Terrett Formation exhibits strong lateral continuity, featuring a basal transgressive unit overlain by a distinctive burrowed zone, which is in turn overlain by thin- to medium-bedded bioclastic limestone and dolomitic strata. Although the effects of dolomitization and neomorphic alteration within the Fort Terrett Formation are prevalent in the eastern part of the Edwards Plateau (Rose, 1972, p. 29–46), these effects are much less common in the western part. Interbedded gypsum of the "Kirschberg evaporite zone," or a collapse breccia resulting from dissolution of the gypsum, is most common in the northeastern part of the Edwards Plateau.

The Fort Terrett Formation grades into the Finlay Formation near the western limits of the study area (figs. 9, 10a), where the Finlay Formation (Brand and Deford, 1958) unconformably overlies the basal Cretaceous sand of Trinitian age. The Finlay Formation is composed mostly of gray, massive to thick-bedded, cherty and marly limestone, with interbeds of gray to brown quartz sandstone and shale near the base and thin- to thick-bedded fossiliferous limestone near the top (Reaser and Malott, 1985). The Fort Terrett Formation grades southward (figs. 9, 10c), through the Big Bend area of Texas, into the Telephone Canyon and Del Carmen Formations of northern Mexico (Smith, 1970).

The Boracho Formation, which unconformably overlies the Finlay Formation, includes all the Fredericksburg and Washita strata between the Finlay Formation and the Del Rio Clay, or the Buda Limestone where the Del Rio Clay is absent. The Boracho Formation (Brand and Deford, 1958) characteristically is limestone and marl, with the exception of the basal part, which predominately is thinly laminated, yellowish shale. This shale unit weathers to a distinctive slope-forming horizon characteristic of basal Washita strata throughout the Edwards Plateau.

The Fort Lancaster Formation (Smith and Brown, 1983), composed of uppermost Fredericksburg and lowermost Washita strata in the north-central part of the Edwards Plateau and eastern part of the Trans-Pecos, is equivalent to the Segovia Formation on the east and the Boracho Formation on the west (figs. 9, 10a). The Fort Lancaster Formation was deposited mostly in open shallow-marine to open-shelf environments (Scott and Kidson, 1977, p. 174) on the southwestern flank of the central Texas platform in water that deepened toward the Fort Stockton basin (fig. 5). Relatively thick-bedded, rudist-bearing limestone helps distinguish eastern parts of the Fort Lancaster Formation from the generally thinner-bedded, dolostone and dolomitic limestone of the Segovia Formation that formed concurrently in intertidal and restricted shallow-marine environments atop the central Texas platform. The Fort Lancaster Formation thickens toward the west and south and shows a decreasing density of rudists and miliolid and shell-fragment grainstones toward the west and north, with an increasing incidence of ammonites, pelecypods, and marly sediments (C.I. Smith, University of Texas at Arlington, oral commun., 1989). The Fort Lancaster Formation grades southward (figs. 9, 10c), through the Big Bend area of Texas, into the Sue Peaks and Santa Elena Formations of northern Mexico (Smith, 1970).

The marly, nodular limestone that composes basal parts of the Fort Lancaster and Sue Peaks Formations erodes to a distinctive grass-covered slope over much of the Edwards Plateau and Trans-Pecos (Smith and Brown, 1983, p. 19). The characteristic outcrop of this ammonite-bearing horizon has helped geologists map the Fredericksburgian-Washitan boundary in the field for more than 100 years.

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The Del Rio Clay on the San Marcos arch consists of dark bluish-gray, calcareous, pyritic bentonitic clay and shale, with scattered mollusk fragments and pelagic foraminifera (Rose, 1972, p. 27). In the eastern part of the Edwards Plateau, the Del Rio Clay is a yellowish-brown, soft calcareous clay containing thin, reddish-brown silty streaks and coquinoid lenses of small oysters (Rose, 1972, p. 43). In the Trans-Pecos and western part of the Edwards Plateau, the unit is fossiliferous (with some ammonites) and consists mostly of interbedded calcareous and siliceous flagstones and marly limestone (Adkins, 1933, p. 388–396). The Del Rio Limestone almost everywhere contains pyrite that, upon weathering to limonite (iron oxide), renders a characteristic yellowish-brown tint to the outcrop. From a maximum thickness of about 170 ft near the town of Del Rio (fig. 9), the formation thins in all directions. Only thin, scattered remnants exist in the western part of the Edwards Plateau.

The Buda Limestone on the San Marcos arch is a light gray, porcellaneous limestone with pelagic foraminifera, fragile mollusk fragments, and microspherulites (Rose, 1972, p. 27). In the eastern part of the Edwards Plateau, this open-shelf limestone consists of nodular micrite, mollusk-fragment biomicrite, and marly interbeds (Rose, 1972, p. 43). In the Trans-Pecos, where the unit typically is exposed atop mesas as a light gray to white caprock, the Buda Limestone is slightly argillaceous, locally crossbedded, and extremely hard (Brand and Deford, 1958, p. 385). Fractured surfaces of Buda Limestone generally are hackly or conchoidal and weathered surfaces typically are nodular.

The Del Rio Clay and Buda Limestone of Washitan age (Comanchean Series) are overlain in the Balcones fault zone by Eagle Ford, Austin, Taylor, and Navarro sediments of the Gulfian Series (table 1). The Eagle Ford-Navarro rock sequence is thickest in the Balcones fault zone where it forms the bulk of the Navarro-Del Rio confining unit, which typically is thicker than 1,000 ft (table 2). The Eagle Ford, Austin, Taylor, and Navarro Groups consist primarily of interbedded shale, siltstone, limestone, chalk, and marl (University of Texas, Bureau of Economic Geology, 1974a, 1983).

Regional Aquifers and Confining Units

The Cretaceous strata in the study area are divided into three major aquifers and two major confining units (table 1). These divisions are based on regional contrasts in hydraulic conductivity that determine the relative capacity of the different rock units to transmit ground water over large areas. The hydraulic conductivity of the strata mostly was inferred from aquifer-test and specific-capacity data, and an inherent relation between stratigraphy and hydraulic conductivity. The aquifer-test and specific-capacity data were obtained mainly from Walker (1979), Rees and Buckner (1980), Ashworth (1983), Baker and others (1986), and Maclay and Small (1986).

The relation between stratigraphy and hydraulic conductivity results from the fact that the stratigraphy reflects the lithology and distribution of the various rock units or formations. Each formation is the result of a relatively consistent set of depositional, tectonic, and diagenetic conditions; hydraulic conductivity evolved from these conditions. Therefore, the hydraulic conductivity of strata for which hydraulic data were not available was inferred from the relation between stratigraphy and hydraulic conductivity where that relation was known.

The regional aquifers are composed of strata that are permeable mainly as the result of fractures, joint cavities, and porosity caused by the dissolution of evaporites and unstable carbonate constituents. The confining units comprise comparatively impermeable strata that are continuous over more than 100 mi^2 and affect regional patterns of ground-water flow and storage. The confining units are mostly calcareous mudstone, siltstone, and shale of low-energy terrigenous and open-shelf depositional environments. Because of the regional scope of the RASA study and the need to generalize from site-specific data, the aquifers include some confining strata, and the confining units contain some strata permeable enough to supply small amounts of water to a few wells in limited areas.

From east to west (fig. 2), the three major aquifers are the Edwards aquifer in the Balcones fault zone, the Trinity aquifer in the Balcones fault zone and Hill Country, and the Edwards-Trinity aquifer in the Edwards Plateau and Trans-Pecos. The Navarro-Del Rio confining unit covers about 70 percent of the Balcones fault zone, and the Hammett confining unit subcrops beneath about 80 percent of the Hill Country and less than 10 percent of the Edwards Plateau.

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The Hammett confining unit is restricted to the Hill Country and southeastern margin of the Edwards Plateau, where structural displacement of the hydraulically tight Hammett Shale has been minor (Barker and Ardis, in press, pls. 3, 7, and 8). Vertical displacement of the Pine Island Shale Member of the Pearsall Formation prevents the downdip-equivalent of the Hammett Shale from being an effective regional confining unit within the Balcones fault zone.

In contrast, the Navarro-Del Rio confining unit is restricted to the Balcones fault zone (Barker and Ardis, in press, pls. 3, 7). From top to bottom, this confining unit includes the Navarro Group, Taylor Group, Austin Group, Eagle Ford Group, Buda Limestone, and Del Rio Clay. Although vertically displaced within the Balcones fault zone, the combined thickness (approximately 1,500 ft) of these rock units typically is more than 10 times the maximum thickness of the Pine Island Shale Member (130 ft; table 2). Despite the fault displacement, the Navarro-Del Rio confining unit is comparatively continuous within the Balcones fault zone, where it is effective as a confining medium atop the Edwards aquifer.

Thin, scattered remnants of the Del Rio Clay and Buda Limestone, plus minor outcrops of Gulf strata, overlie parts of the Edwards Plateau and Trans-Pecos. None of these rocks is known to yield water to wells. However, the rocks are not regarded as confining units west of the Balcones fault zone because none is directly underlain by saturated rock.

Ground-Water Hydrology

From a minimum thickness of less than 1,000 ft in the outcrop area, the wedge of Cretaceous sediments thickens downdip to more than 10,000 ft near the ancestral shelf edge (McFarlan, 1977, p. 5). The Edwards-Trinity aquifer system is in the updip, western half of this wedge where terrigenous clastic and terrestrial sediments of early Trinitian age grade upward and gulfward into marine carbonate rocks of late Trinitian, Fredericksburgian, and Washitan age. The ground-water conditions in these rocks are summarized below for each of the four geographic subareas beginning with the Balcones fault zone, the most transmissive part of the study area.

Balcones Fault Zone

The Edwards aquifer in the Balcones fault zone (fig. 3) is one of the most productive reservoirs of potable ground water in the Nation. The aquifer exists within intensively fractured and extensively leached Washita and Fredericksburg strata (table 1); the hydraulic conductivity of the underlying Trinity strata is negligible by comparison. The U.S. Environmental Protection Agency has declared the Edwards aquifer a sole-source aquifer in the San Antonio area, where it serves the domestic, public-supply, industrial, and agricultural needs of more than 1 million people. The economy of Medina and Uvalde Counties, southwest of San Antonio, primarily is based on farming and ranching activities that depend on water from the Edwards aquifer. Toward the northeast, between San Antonio and Austin, the Edwards aquifer discharges to Barton, Comal, and San Marcos Springs (fig. 3), which help support the local recreation and tourism industries.

Ground-water conditions in the Edwards aquifer have evolved from tectonic and diagenetic events superimposed upon depositional products of the San Marcos arch (Rose, 1972), Devils River trend (Lozo and Smith, 1964), and Maverick basin (Winter, 1962). The part of the Edwards aquifer that formed on the San Marcos arch and in the Devils River trend extends from the Colorado River through eastern Uvalde County (fig. 2). The part of the Edwards aquifer that formed in the Maverick basin extends from west-central Uvalde County through east-central Kinney County. This section of the report discusses ground-water conditions in the Edwards aquifer east of central Uvalde County (figs. 2, 5, and 9) in rocks that formed on the San Marcos arch (Georgetown, Person, and Kainer Formations) and in the Devils River Trend (Devils River Formation). Ground-water conditions in equivalent rocks that formed in the Maverick basin (Salmon Peak, McKnight, and West Nueces Formations) are discussed in the "Edwards Plateau" section, as the hydraulic conditions in west-central Uvalde through east-central Kinney Counties (at the westernmost end of the Balcones fault zone) are most like those in the Edwards-Trinity aquifer in the southern part of the Edwards Plateau.

The Edwards aquifer is hydraulically unconfined in the outcrop area of the Georgetown, Person, and Kainer Formations and in the outcrop areas of the Devils River, Salmon Peak, McKnight, and West Nueces Formations across parts of Kinney, Uvalde, and

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Medina Counties (figs. 2, 9). The Edwards aquifer is confined in downdip areas beneath the Navarro-Del Rio confining unit. The confined part of the aquifer is bound on its downdip (gulfward) side by a freshwater/saline-water transition zone of brackish water. The concentrations of dissolved solids downdip of the transition zone exceed 1,000 mg/L (Maclay and others, 1980, p. 13) and rapidly increase in a gulfward direction to more than 250,000 mg/L (Maclay and Land, 1988, p. A12) near the Stuart City reef trend (fig. 5). The concentration of dissolved solids in the Edwards aquifer updip of the transition zone ranges from about 250 to 300 mg/L (Pavlicek and others, 1987, p. 3).

Ellis (1986, p. 101) attributes diagenetic differences between rocks of the saline-water zone and those of the Edwards aquifer to the effects of vastly different pore-water chemistry since the Miocene Epoch, when the majority of the normal (down-to-the-southeast) faulting in the Balcones fault zone probably occurred. Although the saline-water zone is saturated with respect to calcite, dolomite, gypsum, celestite, strontianite, and fluorite, the Edwards aquifer is saturated only with respect to calcite (Pearson and Rettman, 1976, p. 19). The rocks of the highly permeable Edwards aquifer are calcitic, typically recrystallized to coarse microspar and pseudospar, and extensively dedolomitized. The nearly impermeable saline-water zone mostly consists of dolomitic rocks containing unoxidized organic material, including petroleum and accessory minerals such as pyrite, gypsum, and celestite (Maclay and Small, 1986, p. 28). The negligible hydraulic conductivity of the saline-water zone results from minimal connection between interparticle pores caused by a diagenetic history dominated by cementation in a saline-water environment.

The extraordinarily large values of hydraulic conductivity in the Edwards aquifer result from the freshwater diagenesis of intensively fractured carbonate rocks. After large-scale normal faulting fractured the terrain and increased hydraulic gradients, large quantities of meteoric water entered previously buried strata and initiated the evolution of a dynamic ground-water-flow system (Abbott, 1975). The preferential leaching of evaporites and soluble minerals, fossil parts, and burrow fillings has provided a honeycombed, or "Swiss cheese," appearance to much of the outcrop area. Much of the subcrop area is riddled with joint cavities and solution channels that formed as fractures and bedding planes widened through dissolution and erosional unloading.

Ground-water flow in the Edwards aquifer largely is controlled by an anisotropic pattern of hydraulic conductivity. The anisotropy primarily results from barrier faults, which displace rocks vertically such that permeable strata are juxtaposed against impermeable strata (Barker and Ardis, in press, pls. 2, 6, and 7), blocking or impairing transmissivity in directions normal to the faults. The dominant direction of transmissivity approximates a N. 60° E. trend, along which transmissivity values compare with those normal to the trend by ratios ranging from 1:0 to 1:1 (Maclay and Land, 1988, fig. 20), depending upon the extent of aquifer displacement (Small, 1986). Transmissivity values along the principal direction of ground-water flow range from about 200,000 to about 2,000,000 ft^2/d (Maclay and Small, 1986, p. 61). The anisotropy is so dominant in the subcrop of the Edwards aquifer in Bexar County (Arnow, 1963, p. 29–31) that most of the confined ground-water flow is nearly parallel to generalized equipotential lines on regional potentiometric maps of the San Antonio area (Maclay and Small, 1986, fig. 23).

The barrier faults generally block southeastward flow in the Edwards aquifer and divert ground water toward the northeast along flowpaths aligned with the fault zone (Arnow, 1963). In some places, a secondary network of transverse faults obstructs the major northeast-trending flowpaths, imposing internal boundaries that further divert or compartmentalize the flow system (Maclay and Small, 1993, p. 135–145). As a result, local patterns of ground-water flow can be extremely complex, making predictions about future responses to prolonged drought or additional pumping difficult to determine for specific sites.

The Edwards aquifer primarily is recharged by the (1) discharge of streams draining the Hill Country where they flow onto the highly permeable outcrop of the Edwards Group and Devils River Formation; (2) infiltration of precipitation in the outcrop area; (3) subsurface inflow across the updip margin of the Balcones fault zone, where the Trinity aquifer is laterally adjacent to downfaulted Edwards strata (Barker and Ardis, in press, pl. 3); and (4) diffuse upward leakage from the underlying Trinity aquifer. Recharge rates vary considerably with time, depending upon antecedent conditions and the frequency and intensity of precipitation. Although the actual rates of recharge cannot be measured, estimates of recharge routinely are made for water management purposes.

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Estimates of total recharge to the Edwards aquifer (Nalley, 1989, table 2) range from less than 50,000 acre-ft in 1956 to more than 2,000,000 acre-ft in 1987. (Precipitation was about 50 percent less than the long-term average in 1956, and was about 20 percent greater than the average in 1987.) Recharge probably has averaged about 675,000 acre-ft/yr since the mid-1930's, not including water entering laterally from the Trinity aquifer in the Hill Country. The quantity of water entering laterally from the Hill Country is unknown; however, a preliminary estimate (assuming an average hydraulic gradient of 20 ft/mi and an average transmissivity of 5,000 ft^2/d) indicates that this inflow could total more than 100,000 acre-ft/yr. The quantity of diffuse upward leakage from the Trinity aquifer also is unknown; however, the preliminary results of computer simulation (E.L. Kuniansky, U.S. Geological Survey, written commun., 1992) indicate a long-term average rate of about 10,000 acre-ft/yr.

From upgradient parts of the recharge area, ground water generally flows downdip in a southward or southeastward direction. This water typically is diverted northeastward along joint cavities and solution channels that have developed upgradient of the barrier faults. Most ground-water discharge occurs as either: (1) springflow; (2) withdrawals through irrigation, public-supply, and industrial wells; (3) leakage to the Colorado River; or (4) diffuse upward leakage to Upper Cretaceous strata.

Springflow has averaged about 400,000 acre-ft/yr since the mid-1930's (Nalley, 1989, table 3; Slade and others, 1986, p. 69). Well withdrawals have steadily increased from about 100,000 acre-ft/yr during the 1930's to about 470,000 acre-ft/yr during the 1980's (Nalley, 1989, table 3). The rates of leakage to the Colorado River and Upper Cretaceous strata are unknown; however, they are considerably smaller than the rates of springflow and well withdrawal.

The major center of public-supply pumpage is San Antonio, where water levels in an observation well open to confined parts of the aquifer have varied between 612.5 ft above sea level in 1956 and 703.2 ft above sea level in 1992 (G.M. Nalley, U.S. Geological Survey, written commun., 1992). Despite public concern about occasional periods of flooding or drought, long-term hydrographs for the San Antonio area indicate no net rise or decline in water levels over the last 85 years (R.W. Maclay, U.S. Geological Survey, written commun., 1990).

Hill Country

The Trinity aquifer, in rocks of the Trinity Group (table 1), dominates the ground-water hydrology of the Hill Country (fig. 3). As a result of the Balcones faulting and subsequent erosion, most of the Fredericksburg and practically all of the Washita strata have been removed from the Hill Country. However, a few domestic- and stock-supply wells are completed in the Fort Terrett Formation in interstream areas of northwestern Bandera, northern Kendall, and eastern Kerr Counties; likewise, the Devils River Formation contributes locally to the water supply in southern Real and northern Uvalde Counties.

The Trinity aquifer in the Hill Country is composed of three relatively permeable zones that are separated vertically by two relatively impermeable intervals. The upper Trinity permeable zone comprises the upper member of the Glen Rose Limestone. The middle Trinity permeable zone comprises the lower member of the Glen Rose Limestone, the Hensel Sand, and the Cow Creek Limestone. The lower Trinity permeable zone comprises the Sycamore Sand (updip) and the Sligo and Hosston Formations.

The upper Trinity permeable zone is separated from the middle Trinity permeable zone by thin- to medium-bedded, hydraulically tight sediments within the upper and middle parts of the Glen Rose Limestone. These nearly impermeable intervals (Ashworth, 1983, p. 33) typically are composed of "*** laterally continuous, alternating resistant and nonresistant beds of blue shale, nodular marl, and impure fossiliferous limestone." Because of their relatively high stratigraphic position, these beds generally are above the regional potentiometric surface (Kuniansky, 1990) of the topographically rugged Hill Country.

The lower Trinity permeable zone is separated from the middle Trinity by the Hammett (Shale) confining unit. Because of its depth below land surface and fine-grained composition, the Hammett Shale is areally continuous and relatively impermeable throughout most of the Hill Country, except where it has been disrupted by faults or breached by the Pedernales River and Cypress Creek drainages (Stricklin and Amsbury, 1974, pl. 6). Displacement of the downdip-equivalent Pine Island Shale Member by high-angle normal faults disrupts the confining effect of the shale in the Balcones fault zone; therefore, the Hammett confining unit is limited to the Hill Country and the southeastern edge of the Edwards Plateau (fig. 2; table 1).

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The hydrology of the Hill Country varies greatly in response to diverse geologic conditions and wide-ranging topographic effects. Although ground water in the deeper strata generally is confined, unconfined conditions prevail within a few hundred feet of the surface. The leaching of evaporites and unstable carbonate constituents has enhanced the hydraulic conductivity of some upgradient, outcrop (recharge) areas; however, the precipitation of stable minerals has diminished the hydraulic conductivity of most downgradient, subcrop areas. The transmissivity of the Trinity aquifer is highly variable because the saturated thickness varies with both hydraulic head (Bush and others, 1993) and the altitude of underlying pre-Cretaceous rocks (Barker and Ardis, 1992).

The quartzose clastic deposits that dominate the Sycamore Sand, updip parts of the Hensel Sand, and basal parts of the Hosston Formation are some of the most permeable sediments in the Hill Country. Outcrop surfaces of the Cow Creek Limestone characteristically are riddled with moldic porosity and are highly permeable; most of the outcrop area is particularly receptive to recharge. Although the initial hydraulic conductivity of the Cow Creek Limestone was large because it resulted from a high-energy (beach) depositional environment, the hydraulic conductivity today is comparatively small, except near the outcrop, because most primary voids are filled with calcitic cement. Lower parts of the Glen Rose Limestone are highly permeable, especially in the outcrop and shallow subcrop areas, where the unit is locally karstic as the result of meteoric diagenesis. Sinkholes atop the Glen Rose Limestone in western parts of the Hill Country intercept surface water and provide passageways for substantial quantities of recharge to the Trinity aquifer (Ashworth, 1983, p. 10).

Vertical differences in hydraulic head are common within the Trinity aquifer. The greatest and most widespread head differences generally occur across downdip parts of the Hammett Shale, an areally extensive confining unit that attains a thickness of about 40 to 80 ft over most of the Hill Country (Amsbury, 1974, p. 18). Ashworth (1983, figs. 16–18) reports that differences in hydraulic head across the Hammett Shale exceed 100 ft over parts of eastern Bandera, Kendall, and eastern Kerr Counties. Water levels in the Glen Rose Limestone near the southeastern corner of Edwards County are more than 200 ft higher than those in the underlying Hosston Formation. Differences in hydraulic head above the Hammett Shale generally are caused by strongly cemented (but commonly thin) interbeds of claystone, marl, and shale that are interspersed throughout the upper and middle permeable zones of the Trinity aquifer, but most commonly within the Glen Rose Limestone.

The strongly cemented, relatively impermeable interbeds in upper and middle parts of the Glen Rose Limestone generally impede the downward percolation of precipitation. Meteoric water that infiltrates the interstream areas circulates laterally above the dense, hydraulically tight interbeds more readily than it percolates vertically through them. Shallow zones of perched ground water commonly are present above the base level of adjacent streams. Ground water discharges from springs and seeps atop the interbeds where they are exposed on the hillsides in the Hill Country. Thus, instead of percolating to the regional flow system, much of the shallow ground water in interstream segments of the Hill Country discharges to perennial streams that drain the area (fig. 3).

Perennial streams in the Hill Country gain water as they intercept springflow and base flow from the upper and middle permeable zones of the Trinity aquifer (Ashworth, 1983, p. 47). Streams that gain water in the Hill Country typically lose all of their discharge to the downstream recharge area of the Edwards aquifer; this generally occurs where the streams cross major faults and flow onto the relatively permeable outcrop of the Edwards Group in the Balcones fault zone.

In addition to discharging as springflow and base flow from the upper and middle permeable zones, water discharges from the Trinity aquifer through well withdrawals and lateral, subsurface inflow to the Balcones fault zone. Discharge from the lower Trinity permeable zone occurs primarily through water wells and diffuse upward leakage to the middle Trinity permeable zone. Much of the diffuse upward leakage eventually discharges laterally to the Balcones fault zone. During the mid-1970s, well withdrawals are estimated to have totaled between 10,000 to 15,000 acre-ft/yr (Lurry and Pavlicek, 1991, table 1). The Trinity aquifer is recharged, in order of importance, by the (1) lateral inflow of ground water from the Edwards Plateau, (2) infiltration of precipitation on the outcrop area, and (3) surface-water leakage from shallow, tributary streams in upland areas.

Long-term hydrographs of water levels measured from observation wells in the Hill Country indicate that water levels can vary greatly over short periods. Between winter highs and summer lows, water

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levels typically vary 50 ft or more. The seasonal variances are most striking in wells less than about 250 ft deep. Because transmissivity values generally are small in the Hill Country and the demand for pumping is strongly dependent on weather conditions, the Trinity aquifer in this area is more susceptible to the effects of drought than the Edwards aquifer in the Balcones fault zone.

Transmissivity values derived from pumping tests and specific-capacity data (Ashworth, 1983, p. 55–155) range from less than 1,000 ft^2/d to about 50,000 ft^2/d for the Trinity aquifer in the Hill Country. Transmissivity values appear to average about 5,000 ft^2/d, according to the results of a regional ground-water-flow model (E.L. Kuniansky, U.S. Geological Survey, written commun., 1990).

Edwards Plateau

The Edwards-Trinity aquifer in the Edwards Plateau (fig. 3) includes all the Fredericksburg and Trinity rocks, plus all Washita rocks below the Del Rio Clay or Buda Limestone (where the Del Rio Clay is absent) or land surface. None of the rock units is uniformly permeable throughout the area. However, the rocks are combined regionally into one aquifer because no parts are substantially more or less permeable than the rest.

The Washita and Fredericksburg rocks are the primary water-producing strata throughout more than two-thirds of the Edwards Plateau. Except where the Washita and Fredericksburg rocks are absent or minimally saturated, the hydrologic characteristics of the Trinity Group largely are untested. Water wells generally do not penetrate below Fredericksburg strata, unless the Washita and Fredericksburg rocks have failed to provide sufficient water. Because the Trinity rocks thin to a negligible thickness near the Llano uplift (fig. 6) and the regional potentiometric surface (Kuniansky, 1990) is below the base of Washita rocks in northern parts of the Plateau, the Fredericksburg rocks generally are the most reliable sources of potable water in the area.

The Washita and Fredericksburg rocks are the principal water-producing zones south of northern Concho, Irion, Reagan, Tom Green, and Upton Counties (fig. 2), except where they have been breached by erosion along the valleys of the Concho, Guadalupe, Llano, Pecos, Pedernales, and San Saba Rivers (fig. 3). In these topographically low areas, the Glen Rose Limestone, Hensel Sand, and basal Cretaceous sand augment the valley alluvium as the main sources of ground water. Although the Washita rocks are used only minimally for water supply in the northern Edwards Plateau, they become more important as they thicken and become increasingly saturated toward the south. Where the Fort Lancaster Formation (west) and Segovia Formation (east) occupy the highest elevations on the Edwards Plateau, they generally are unsaturated, minimally saturated, or contain only perched water. However, the Fort Lancaster and Segovia Formations, in addition to the Devils River and Salmon Peak Formations (in the Devils River trend and Maverick basin, respectively), are important water-producing units in parts of Edwards, Kinney, and Val Verde Counties.

The Salmon Peak Formation is "moderately to very permeable" near the top (Maclay and Small, 1986, p. 18). The lower part of the Salmon Peak Formation is "almost impermeable," except where fractured. The McKnight Formation locally contains permeable pockets of leached evaporites, but mostly it is considered to have "little permeability." Although the upper part of the West Nueces Formation is "moderately permeable," the lower part is "almost impermeable."

The Devils River Formation is "very permeable and porous," especially in middle and upper parts of the unit that contain collapse breccia or vuggy zones of leached rudists (Maclay and Small, 1986). The upper and middle parts of the formation compose the principal water-producing zone in southern Edwards County and in central Val Verde County. The Devils River Formation supplies large quantities of irrigation water in western parts of the Balcones fault zone, in Medina and Uvalde Counties, where this unit is considered a major aquifer (Maclay and Small, 1986, table 1).

The Fort Terrett Formation provides most of the ground water pumped in the Edwards Plateau. The "burrowed zone" (table 1), near the base of the formation, may be the most permeable part of the Edwards Group outside the fractured terrain of the Balcones fault zone. The permeable nature of the burrowed zone results from the preferential leaching of burrow fillings, leaving a honeycombed pattern of porosity in the remaining rock (Rose, 1972, p. 34). The overlying "Kirschberg evaporite zone" (table 1) also is highly permeable, especially where it is brecciated as the result of post-depositional leaching and structural collapse. Although the zones of Kirschberg breccia west of the Balcones fault zone are mostly unsaturated, the breccia enhances recharge in eastern parts of the

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Edwards Plateau by increasing the infiltration rates of precipitation.

Except in a few areas with shallow alluvial aquifers, the basal Cretaceous sand of Trinitian age is the most important water-producing unit in Ector, Glasscock, Midland, Sterling, and Upton Counties and along the Pecos River valley in Crockett County (fig. 6). The basal Cretaceous sand is about as important as the Fredericksburg rocks for ground water in southern Irion, southeastern Reagan, and southern Tom Green Counties. Very few water wells are deep enough to penetrate the basal Cretaceous sand over most of Crockett, Edwards, Schleicher, Sutton, and Val Verde Counties.

In the southeastern part of the Edwards Plateau (northwestern Bandera, eastern Edwards, western Kerr, and northern Real Counties), the Trinity units most likely to contain potable ground water are the Hensel Sand, lower member of the Glen Rose Limestone, and Cow Creek Limestone. The hydraulic characteristics of the much deeper Pearsall (undivided), Sligo, and Hosston Formations mostly are unknown. However, the lower Trinity units in this area generally are more than 750 ft below land surface. Because ground water at this depth is perhaps completely isolated from freshwater recharge, it typically is highly mineralized (Walker, 1979, p. 93–95) and may exceed the local standards for drinking water (Texas Department of Health, 1977).

The Hammett Shale, which is physically continuous and hydraulically tight over most of the Hill Country (fig. 3), grades northwestward across Edwards County into the comparatively permeable basal Cretaceous sand (figs. 6, 7b). The confining effect of the Hammett Shale diminishes west of the Hill Country, as it grades into sand and thins to a featheredge. Therefore, the Trinity strata over most of the Edwards Plateau are connected hydraulically with the overlying Fredericksburg rocks.

Hydraulic conditions in the Edwards Plateau are mostly confined or semiconfined, except in the shallowest water-transmitting zones and near the outer margins of Fredericksburg strata where the underlying Trinity sediments crop out. Although no confining unit is mappable over large areas west of the Hammett confining unit (fig. 2), the effects of many low-permeability beds accumulate with increasing depth below land surface to confine deeper parts of the Edwards-Trinity aquifer. Unconfined conditions dominate where gaining streams cut into sandy Trinity sediments along the Concho, Guadalupe, Llano, Pecos, Pedernales, and San Saba Rivers (fig. 3). From generally unconfined or semiconfined conditions in the west, the aquifer becomes progressively more confined toward the south and east in response to an increasing thickness of sediment in those directions. Observations of diurnal changes in barometric pressure, water levels that rise above the top of water-transmitting zones, and entrapped hydrogen sulfide gas prompted Walker (1979, p. 49) to suggest that "*** water-table conditions may not be as prevalent as previously reported."

The Edwards-Trinity aquifer merges hydraulically with locally permeable Paleozoic strata around the western and southern flanks of the Llano uplift in Gillespie, Mason, and McCulloch Counties (fig. 2). Paleozoic rocks of the deeply eroded Llano uplift (fig. 4) form a subtle topographic basin where a shallow ground-water regime has developed along fractures and joint cavities. Water from the northeastern fringe of the Edwards-Trinity aquifer merges with the shallow flow regime of the Marble Falls, Ellenburger-San Saba, and Hickory aquifers (Barker and Ardis, 1992) before discharging into the Colorado River and northeastward-flowing tributaries that drain the Llano area (fig. 3).

The Edwards-Trinity aquifer directly overlies the Dockum Group of Triassic age in large parts of Crockett, Irion, Reagan, and Sterling Counties. Where middle parts of the Dockum Group are saturated and contain sufficient amounts of sand to be permeable (Barker and Ardis, 1992), they compose the Dockum aquifer (Texas Water Development Board, 1990, p. 1–6). Where upper parts of the Dockum Group are absent, the Dockum aquifer merges in places with the basal Cretaceous sand of the Edwards-Trinity aquifer (fig. 2, Barker and Ardis, in press, pl. 4). In such areas, the depth of ground-water circulation may increase a few hundred feet to the lower part of the Dockum Group, or—where the lower Dockum unit is absent—to the top of Permian red beds. Water from the Dockum aquifer varies considerably in quantity and quality. However, well yields rarely exceed a few hundred gallons per minute, and the water typically contains high concentrations of sodium, sulfate, and chloride (Ashworth and Christian, 1989), which may exceed the local standards for drinking water (Texas Department of Health, 1977).

The Edwards-Trinity aquifer pinches out below the Ogallala Formation of Tertiary age along the northwestern edge of the Edwards Plateau (Barker and Ardis, in press, pl. 3) in Andrews, Glasscock, Howard, and Martin Counties (fig. 2). Coarse sand and gravel of the Ogallala Formation, which forms the High Plains

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aquifer (Gutentag and others, 1984, p. 8–13) in northwest Texas, fill erosional channels atop the basal Cretaceous sand in the northwestern part of the study area. Water discharging in a southeastward direction from the southern part of the High Plains aquifer recharges the northwestern fringe of the Edwards-Trinity aquifer.

From the northwestern part of the Edwards Plateau, water in the Edwards-Trinity aquifer generally flows southeastward under hydraulic gradients that average about 10 ft/mi. Local exceptions to the regional pattern result from topographic and drainage variations and depressions in the potentiometric surface caused by pumpage. The maximum hydraulic head in the Edwards-Trinity aquifer occurs in northwestern Ector County at about 3,100 ft above sea level; the minimum hydraulic head, in southern Val Verde County, is about 2,000 ft above sea level (Bush and others, 1993). In the southwestern part of the Edwards Plateau, ground water discharges to the Pecos River and Rio Grande. In the northeast, ground water discharges to the Colorado River and its tributaries. In the southeast, ground water discharges to headwater reaches of the Frio, Guadalupe, Medina, and Nueces Rivers (fig. 3), and as lateral, subsurface inflow to the Hill Country.

Most recharge to the Edwards-Trinity aquifer results from the infiltration of precipitation from land surface and seepage losses through streambeds of intermittent streams. Discharge from the aquifer occurs mainly through: (1) springs on the walls of stream-dissected canyons on the northeastern and southeastern fringes of the Plateau; (2) base flow to gaining streams; and (3) well withdrawals. Recharge and discharge each average less than 1 in/yr over most of the Plateau, increasing from less than 0.5 in/yr in the west to more than 0.5 in/yr in the easternmost part of the area (E.L. Kuniansky, U.S. Geological Survey, written commun., 1990).

Water pumped from the Edwards-Trinity aquifer primarily is used for irrigation. Walker (1979, p. 76) estimated that about 72 percent of all pumpage during 1972 was for irrigation. Lurry and Pavlicek (1991, table 1) indicated that during the mid-1970's about 80 percent of the total annual pumpage from the Edwards-Trinity aquifer (about 130,000 acre-ft) was for irrigation. Irrigation pumpage from Glasscock and Midland Counties alone accounted for about one-half of all pumpage in the Edwards Plateau during 1975–76 (Lurry and Pavlicek, 1991).

Ground-water levels in the Edwards Plateau vary mostly in response to short-term fluctuations in recharge and long-term variations in discharge. Most of the fluctuations in recharge are caused by cyclic trends in precipitation, and most of the variations in discharge result from well withdrawals. Water levels have declined where the rates of recharge and natural discharge (evapotranspiration, springflow, and base flow) have not compensated for increasing rates of withdrawal.

During the last 50 years, water levels have declined more than 50 ft in northwestern parts of the Edwards Plateau, including parts of Ector, Glasscock, Midland, Reagan, Sterling, and Schleicher Counties (Walker, 1979, p. 96–100). Data from an observation well in Reagan County indicates more than 100 ft of decline since 1950 (Bush and others, 1993). The nearly continuous, long-term nature of water-level decline in many wells reflects the direct relation to a rapid increase in the number of irrigation wells that began about 1946 and continued through the 1960's.

Since the late 1970's, water levels in most parts of the Edwards Plateau have stabilized or begun to recover, reflecting the results of recent efforts to reduce the need for irrigation and to conserve water (J.B. Ashworth, Texas Department of Water Resources, written commun., 1991). Water-level hydrographs for central parts of the Edwards Plateau reflect a cyclic relation between recharge from precipitation and water-level change: (1) declining water levels during most of the 1960's, when precipitation was below normal; (2) rising water levels during most of the 1970's, when precipitation was above normal; and (3) declining water levels during most of the 1980's, when precipitation was below normal. Many of the highest recorded water levels during the past 30 years in Crockett, Edwards, Kimble, Schleicher, and Sutton Counties were during the middle-to-late 1970's.

Transmissivity values are relatively small in the Edwards Plateau, where the average is about 2 or 3 orders of magnitude less than those characteristic of the Balcones fault zone. Aquifer-test and specific-capacity data indicate transmissivity values of less than 5,000 ft^2/d for most of the Edwards Plateau (Walker 1979, p. 72–75). Exceptions are in the southern part of the Edwards Plateau, where Trinity rocks thicken southward toward the Rio Grande Embayment (fig. 5) and wells in the relatively permeable Devils River Formation yield up to 500 gal/min. Preliminary results of a ground-water-flow model indicate that transmissivity values range from about 5,000 to perhaps 10,000 ft^2/d over most of the Edwards and Val Verde Counties

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(E.L. Kuniansky, U.S. Geological Survey, written commun., 1990).

Trans-Pecos

The Edwards-Trinity aquifer in the Trans-Pecos (fig. 3) includes all Washita rocks below the Del Rio Clay or Buda Limestone (where the Del Rio Clay is absent) or land surface, plus all Fredericksburg and Trinity rocks. The hydrogeologic framework of Pecos, Reeves, and Terrell Counties is structurally complicated. The structural complexity results from the collapse of Cretaceous and Triassic rocks atop salt-laden Permian rocks and crustal deformation south and west of the area during Cenozoic time (Henry and Price, 1985). Probably less is understood about the Edwards-Trinity aquifer in the Trans-Pecos than about any other part of the Edwards-Trinity aquifer system.

The Edwards-Trinity aquifer does not dominate the ground-water-flow system in the Trans-Pecos, as it does in the Edwards Plateau. On average, the Edwards-Trinity aquifer is less permeable than the contiguous, hydraulically connected Cenozoic Pecos alluvium aquifer (fig. 2). The average hydraulic conductivity of the Edwards-Trinity aquifer probably is no greater than the most permeable part of the underlying Dockum aquifer. Therefore, the combined influence of all the interconnected permeable rocks must be considered when conceptualizing the regional flow system of the Trans-Pecos.

The hydraulic conditions of the Washita and Fredericksburg rocks in the Trans-Pecos largely are unpredictable because the available hydrogeologic data are sparse and inconclusive. Most of the Washita strata and much of the Fredericksburg strata in Pecos and Terrell Counties are unreliable sources of ground water because they are relatively impermeable, or they lie above the saturated part of the regional flow system. The hydraulic characteristics of the Washita and Fredericksburg strata in Reeves County have not been differentiated from that of the underlying Trinity rocks (Ogilbee and others, 1962). Where the Washita and Fredericksburg strata are saturated in eastern Pecos County and in Terrell County, they provide small quantities of water to stock wells. Southwest of Fort Stockton (west-central Pecos County), limestone of the Finlay Formation contains a fault-controlled network of interconnected solution channels that has yielded up to 2,500 gal/min to irrigation wells (Armstrong and McMillion, 1961, p. 59). In areas where solution channels have not developed, the equivalent strata yield considerably less water (100 to 500 gal/min) to individual wells. The discharge of many wells and springs in southwestern Pecos County has decreased over the years because ground-water withdrawals have lowered water levels below the solution channels that comprise the zones of greatest hydraulic conductivity.

Permeable Trinity strata in the Trans-Pecos include the basal Cretaceous sand, and in southern parts of Pecos and Terrell Counties, the Glen Rose Limestone and Maxon Sand (fig. 6). The Trinity Group generally is less than 500 ft thick in the Trans-Pecos, where much of it is unsaturated or marginally permeable. The availability of ground water from the Trinity Group generally is untested in Terrell County, and the Maxon Sand and upper few hundred feet of Glen Rose Limestone generally are not saturated in Brewster County. Neither the Glen Rose Limestone nor the Maxon Sand is present in Reeves County, and the hydrologic aspects of the basal Cretaceous sand have not been distinguished from that of other Cretaceous strata in this area (Ogilbee and others, 1962, p. 27). Although the basal Cretaceous sand is only about 150 ft thick near Fort Stockton (fig. 9), this coarse-grained, quartzose unit is an important source of ground water in Pecos County (Armstrong and McMillion, 1961, p. 57, 62). The basal Cretaceous sand has yielded up to 500 gal/min of water to individual industrial, irrigation, and public-supply wells in Pecos County.

The Edwards-Trinity aquifer is connected hydraulically to the Cenozoic Pecos alluvium, which fills two structural troughs in parts of Crane, Loving, Pecos, Reeves, Ward, and Winkler Counties. Much of the Edwards-Trinity strata was displaced and later eroded from the area now occupied by the alluvium, as a result of the dissolution and collapse of underlying Permian rocks (Maley and Huffington, 1953). The alluvium is predominately an unconsolidated to semi-consolidated mixture of gravel, sand, silt, clay, and caliche. Although the alluvium is highly permeable in most areas, the hydraulic conductivity varies greatly because of differences in the degree of sorting and cementation. Where the alluvium is strongly cemented with hardpan (a calcareous precipitate), ground water frequently is perched above the regional potentiometric surface. Where the alluvium is saturated and permeable, it composes the Cenozoic Pecos alluvium aquifer (Ashworth, 1990, p. 12). This aquifer (fig. 2) is the primary source of ground water for irrigation in

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northern Reeves County and in northwestern Pecos County.

The Cenozoic Pecos alluvium rests on Permian and Triassic red beds in northern Reeves County, where the alluvium is greater than 1,500 ft thick in places (Barker and Ardis, in press, pl. 2). Thinner deposits cover the north-facing flank of the southernmost trough, whose floor is composed of Cretaceous strata of the Edwards-Trinity aquifer (Ashworth, 1990, figs. 3, 5). Because the Cenozoic Pecos alluvium is connected hydraulically to the Edwards-Trinity aquifer, the base of the alluvium is considered the base of the regional ground-water-flow system where the Edwards-Trinity rocks are absent (Barker and Ardis, 1992).

The Edwards-Trinity aquifer overlies the Dockum Group of Triassic age in parts of Pecos and Reeves Counties (Barker and Ardis, in press, pl. 2). The upper part of the Dockum Group is absent in some areas, causing sand of the Dockum aquifer (middle part of the Dockum Group) to merge with the basal Cretaceous sand of the Edwards-Trinity aquifer (fig. 2). In these areas, the depth of regional ground-water flow may increase a few hundred feet below the base of the Edwards-Trinity aquifer system (Barker and Ardis, 1992). The Dockum aquifer has been the main source of public-supply water in northeastern Reeves County, where it also provides some water for livestock.

Although the Dockum aquifer directly underlies the Edwards-Trinity aquifer in western Crockett and northeastern Reeves Counties, the extent and importance of the Dockum aquifer is uncertain across Pecos County (fig. 2). The Edwards-Trinity aquifer is directly underlain in this area by Permian and Triassic red beds that have not been differentiated (Barker and Ardis, in press, pls. 2, 5). The uppermost Permian rock unit is a red siltstone cemented with gypsum and calcite that resembles the lower part of the overlying Dockum Group. The lower part of the Dockum Group is composed largely of reworked Upper Permian red-bed strata. The undifferentiated red beds in Pecos County range from 0 to about 1,500 ft thick; however, no part of the interval appears to be a particularly viable source of potable ground water. According to Armstrong and McMillion (1961, p. 37), the red beds of Permian and Triassic age yield "*** small amounts of water at various locations." If the middle Dockum unit is present in Pecos County, it may be thinner and less permeable than the Dockum aquifer of adjacent counties.

The Trans-Pecos aquifers primarily are recharged through the infiltration of storm runoff resulting from precipitation on the northern flanks of the Glass, Barilla, and Davis Mountains, and on the eastern flanks of the Apache and Delaware Mountains (fig. 3). The headwaters of the streams that drain these mountains mostly are confined to narrow channels with nearly impervious streambeds. The high-gradient headwater channels empty into comparatively low-gradient arroyos atop alluvial fans at the base of the mountains. During prolonged storms, runoff discharges from the mountain channels into the porous arroyos, which then recharge the Edwards-Trinity and Cenozoic Pecos alluvium aquifers.

Considerable recharge occurs in south-central Pecos County where the arroyos traverse the alluvial aprons that overlie cavernous limestone of the Edwards-Trinity aquifer. Sinkholes in the limestone greatly expedite the recharge process (Armstrong and McMillion, 1961, p. 46; pl. 14). Some recharge may occur as lateral subsurface inflow from strata deep within the mountains in northern Brewster and Jeff Davis Counties. However, such inflow would have to penetrate rocks that are faulted, folded, and tilted to the extent that flow would be impeded, if not blocked entirely (Rees and Buckner, 1980, fig. 3). Much of the springflow in the Balmorhea area of Reeves County (fig. 3) that follows prolonged periods of heavy precipitation has been traced to the infiltration of precipitation and storm runoff in a narrow anticlinal valley along the eastern escarpment of the Davis Mountains (White and others, 1941, p. 112). The results of more recent geochemical analyses by LaFave and Sharp (1987) indicate that a substantial part of the sustained (long-term) recharge to these springs may originate from relatively remote locations in and near the Apache Mountains.

Recharge has been induced in parts of the Trans-Pecos as the result of water-level decline caused by the withdrawal of irrigation water. In response to water-level decline in the Cenozoic Pecos alluvium aquifer, hydraulic gradients between the Pecos River and the aquifer have reversed from their predevelopment condition in parts of Pecos (Armstrong and McMillion, 1961, p. 52) and Reeves Counties (Ogilbee and others, 1962, p. 33). The Pecos River now loses streamflow to the aquifer in parts of northwestern Pecos and north-central Reeves Counties where the aquifer originally discharged to the river. Leakage from the Pecos River is not necessarily beneficial to the aquifer, as the concentrations of chloride and dissolved solids in the

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Pecos River can exceed 5,000 and 15,000 mg/L, respectively (Grozier and others, 1966).

Although, water levels declined more than 200 ft in parts of Reeves County and more than 100 ft in parts of Pecos County, decreasing rates of ground-water withdrawal since the mid-1960's have allowed water levels to recover as much as 75 ft in some wells (Bush and others, 1993). Reductions in irrigation pumpage have occurred in response to (1) prolonged periods of greater-than-normal precipitation since the mid-1970's; (2) fuel and labor costs that began to escalate during the 1970's; and (3) depressed profits in the agricultural marketplace during the last 20 years or so. An undetermined fraction of the irrigation water in shallow water-table areas percolates back to the saturated zone, thereby reducing the effect of ground-water withdrawal in some low-lying areas of the Trans-Pecos. Despite this return flow and the decreasing rates of withdrawal, water-level hydrographs indicate that water levels have not returned to predevelopment levels in Pecos County (T.A. Small, U.S. Geological Survey, written commun., 1990). Nor have water levels recovered fully in Reeves County (Sharp, 1989, p. 129).

Whereas well withdrawals in the Trans-Pecos were negligible through about 1945, withdrawal rates accelerated along with agricultural expansion following World War II. The number of irrigation wells increased annually by almost 25 percent between 1946 and the late 1950's. Irrigation pumpage from the Edwards-Trinity and Cenozoic Pecos alluvium aquifers in Pecos and Reeves Counties increased to about 550,000 acre-ft/yr by the late 1950's (Armstrong and McMillion, 1961, p. 44; Ogilbee and others, 1962, p. 34). However, withdrawals from the Edwards-Trinity aquifer decreased to about 450,000 acre-ft/yr during the mid-1970's (Lurry and Pavlicek, 1991). During this time, less than 1,250 acre-ft/yr of ground water was pumped in Terrell County, where about 1,000 acre-ft/yr was used for livestock and irrigation (Lurry and Pavlicek, 1991).

Springflow from the Trans-Pecos aquifers has decreased substantially as the result of water-level declines caused by ground-water withdrawals for irrigation. Although the combined springflow in Pecos and Reeves Counties averaged nearly 85,000 acre-ft/yr during the mid-1940's (Armstrong and McMillion, 1961, p. 43–44; Ogilbee and others, 1962, p. 28), springflow averaged less than 40,000 acre-ft/yr during the 1980's. Before 1946, about 48,000 acre-ft/yr of water discharged from springs in Pecos County; by 1958, this discharge had decreased to less than 2,000 acre-ft/yr (Armstrong and McMillion, 1961, p. 47). Despite short-term surges in springflow during 1986–88 (Small and Ozuna, 1993, fig. 13), springflow in Pecos County was negligible during 1961–90.

The development of ground water in the Trans-Pecos probably has reduced the loss of ground water to evapotranspiration. Ground-water losses through phreatophytes are locally important in the Pecos River valley, where the tap roots of salt cedar, mesquite, and alfalfa may exceed 50 ft in length.

The largest transmissivity values in the Trans-Pecos are recorded for the Cenozoic Pecos alluvium aquifer, where transmissivity probably averages about 5,000 ft^2/d. Transmissivity values reported for thicker parts of the Cenozoic Pecos alluvium aquifer in north-central Reeves County are as large as 20,000 ft^2/d (Ogilbee and others, 1962, p. 37). Transmissivity values for the Washita, Fredericksburg, and Trinity strata are variable and difficult to obtain. A few transmissivity values derived from the results of aquifer tests (Theis, 1935) are reported for Pecos and Reeves Counties by Armstrong and McMillion (1961) and Ogilbee and others (1962), respectively. Although the transmissivity of Fredericksburg strata that contain a large number of solution channels in west-central Pecos County is unknown, the results of aquifer tests in areas of relatively unaltered limestone generally indicate transmissivity values of less than 1,000 ft^2/d. The analyses of drawdown and recovery data from wells completed in the basal Cretaceous sand provide transmissivity values ranging from about 500 to 1,000 ft^2/d.

SUMMARY

The Edwards-Trinity aquifer system, which underlies about 42,000 mi^2 of west-central Texas, is composed of nearly flat-lying carbonate strata of mostly Comanchean (Lower Cretaceous) age. The Cretaceous rocks of the aquifer system thin toward the northwest atop massive, comparatively impermeable and structurally complex pre-Cretaceous rocks. From predominately terrigenous clastic sediments in the east and fluvial-deltaic (terrestrial) deposits in the west, the rocks of early Trinitian age grade upward into supratidal evaporitic and dolomitic strata, intertidal limestone and dolostone, and shallow-marine, open-shelf, and reefal strata of late Trinitian, Fredericksburgian, and Washitan age. A thick, downfaulted remnant of mostly open-marine strata of Eaglefordian through

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Navarroan age composes a small, southeastern part of the aquifer system.

The regional aquifer system is divided into three aquifers and two confining units. The aquifers are the Edwards aquifer in the Balcones fault zone, the Trinity aquifer in the Balcones fault zone and Hill Country, and the Edwards-Trinity aquifer in the Edwards Plateau and Trans-Pecos. These aquifers are laterally adjacent except in the Balcones fault zone, where the rocks are downfaulted and the Trinity aquifer is overlain by the Edwards aquifer. The two confining units are the Navarro-Del Rio confining unit, which overlies the subcrop of the Edwards aquifer, and the Hammett confining unit, which lies within the updip, basal part of the Trinity aquifer and a small southeastern fringe of the Edwards-Trinity aquifer.

The depositional, tectonic, and diagenetic characteristics of the Cretaceous rocks of the Edwards-Trinity aquifer system are strikingly different from those of the underlying pre-Cretaceous rocks. The relatively thin, nearly flat-lying Cretaceous strata of the aquifer system typically dip southeastward atop much thicker Paleozoic and Triassic units that generally dip westward. The unconformity between the Cretaceous rocks of the aquifer system and the pre-Cretaceous complex marks a major change in the geologic history of the study area. This hiatus spans a transition from the deposition of terrestrial red beds during Late Triassic time to the deposition of terrigenous clastic and shallow-marine carbonate sediments during Early Cretaceous time, transcending about 60 million years of crustal warping and erosion during the Jurassic Period.

The Early Cretaceous sea encroached slowly westward upon a peneplained surface of folded and faulted pre-Cretaceous rocks. Trinity deposition was characterized by a cyclic pattern of shoreline advances and retreats, superimposed upon an overall pattern of transgression. While terrestrial deposition prevailed on alluvial plains landward of the advancing shoreline, terrigenous and restricted shallow-marine environments dominated the gently inclined, upper part of a continental shelf over which warm, generally clear seawater circulated. The resulting lithofacies are diachronous toward the Llano uplift, reflecting the effects of shallower water and shoreline advancement toward the northwest. The Trinity Group of west-central Texas was deposited during three transgressive-regressive cycles of sedimentation. These deposits include: (1) the Sycamore Sand (Hosston Formation, downdip) and Sligo Formation; (2) the Hammett Shale (Pine Island Shale Member, downdip) and Cow Creek Limestone (Cow Creek Limestone Member, downdip); and (3) the Hensel Sand (Bexar Shale Member, downdip) and Glen Rose Limestone. The basal Cretaceous sand and Maxon Sand amassed in fluvial-deltaic settings west of the Llano uplift.

The Fredericksburg Group and most of the Washita Group of west-central Texas were deposited leeward of the Stuart City reef trend upon a broad expanse of sea floor called the Comanche shelf. The Kainer and Person Formations formed over the San Marcos arch, a comparatively narrow structural high dominated by tidal flats and shallow water deposits that frequently underwent uplift, subaerial exposure, and erosion. The eastern part of the Fort Terrett Formation and the Segovia Formation formed near the crest of the central Texas platform in mostly supratidal to restricted shallow-marine environments. The western part of the Fort Terrett Formation and the Fort Lancaster Formation formed in mostly open shallow-marine to open-shelf environments transitional to the central Texas platform and Fort Stockton basin. The Finlay Formation was deposited early in the Fort Stockton basin when it was mostly a shallow, open lagoon; the Boracho Formation was deposited later in a deeper, shelf-basin environment. The West Nueces, McKnight, and Salmon Peak Formations formed within a persistently submerged Maverick basin. Environments inside the Maverick basin generally were isolated from northern environments by the Devils River reef trend, in which the Devils River Formation formed.

During late Oligocene through early Miocene time, large-scale normal faulting created the Balcones fault zone, within which the Cretaceous strata were downfaulted, intensively fractured, and differentially rotated within a series of northeast-trending fault blocks. Ground-water flow shifted toward the northeast in response to high-angle barrier faults that impeded or completely blocked southeastward flow. Flowpaths became increasingly ingrained toward the northeast as evaporites and unstable carbonate constituents dissolved from the fractured terrain and discharged in that direction through springs and deeply entrenched streams.

Springs originated in topographically low areas, where barrier faults intercepted confined water at depth and diverted it to the surface. A rejuvenated stream network breached the overburden of low-permeability Gulf rocks, providing discharge areas for developing

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aquifers in the underlying, relatively permeable Comanche rocks.

The aquifers developed as flowpaths converged toward spring outlets, and the rocks became more permeable through dissolution. Solution channels spread outward from the springs. Zones of honeycombed and cavernous porosity evolved into major conduits of ground-water flow. The major springs persisted and control modern potentiometric levels and discharge patterns.

Erosion eventually removed most of the Fredericksburg and Washita strata between the Balcones fault zone and the Edwards Plateau, exposing Trinity strata in the extensively dissected Hill Country. The aquifers in the Hill Country, Edwards Plateau, and Trans-Pecos generally were excluded from the vertical displacement, intensive fracturing, and subsequent dissolution responsible for the hydraulic characteristics of the Edwards aquifer.

In addition to fracturing the rocks of the Balcones fault zone and extending the depth of freshwater diagenesis, the Balcones faulting vertically displaced the terrain, which steepened hydraulic gradients and maintained relatively large flow velocities near the surface. A shallow, dynamic flow system evolved, which promoted dissolution and enhanced the transmissivity of the Edwards aquifer. Cementation, recrystallization, and mineral replacement—caused by deeper, comparatively sluggish ground-water circulation—combined to diminish the transmissivity of the Trinity and Edwards-Trinity aquifers. Although transmissivity values in the Edwards aquifer average about 750,000 ft^2/d, transmissivity values elsewhere average less than 10,000 ft^2/d.

The Edwards aquifer in the Balcones fault zone is one of the most productive reservoirs of potable ground water in the Nation. The Edwards aquifer is the primary source of water in the San Antonio area, where it serves the domestic, public-supply, industrial, and agricultural needs of more than 1 million people. The Edwards aquifer comprises the Edwards Group and the Georgetown Formation in the northeastern part of the Balcones fault zone and the Devils River, West Nueces, McKnight, and Salmon Peak Formations in the southwestern part of the Balcones fault zone. Ground-water flow largely is controlled by an anisotropic pattern of hydraulic conductivity. The largest values of transmissivity are aligned with the network of en echelon faults that bend around the southeastern flank of the Llano uplift; the principal flow direction is northeastward. Transmissivity values range from about 200,000 to about 2,000,000 ft^2/d. Well withdrawals have steadily increased, averaging about 470,000 acre-ft/yr during the 1980's.

The Trinity aquifer, composed of the Trinity Group in the Balcones fault zone and Hill Country, dominates the ground-water hydrology of the Hill Country, where most of the Fredericksburg and practically all of the Washita strata are absent. Strongly cemented, hydraulically tight sediments within upper and middle parts of the Glen Rose Formation generally impede the downward percolation of precipitation, which results in shallow flowpaths above the regional flow system. Ground water is commonly perched in interstream areas above the base level of adjacent streams. Thus, much of the shallow ground water in interstream segments of the Hill Country is discharged to perennial streams that drain the area instead of percolating to the regional flow system. Streamflow gains in the Hill Country typically are lost to the downstream recharge area of the Edwards aquifer in the Balcones fault zone where the streams cross major faults and flow onto the relatively permeable outcrop of the Edwards Group. Ground-water pumpage in the Hill Country totaled between 10,000 and 15,000 acre-ft/yr during the mid-1970's. Transmissivity values range from less than 1,000 to about 50,000 ft^2/d and average about 5,000 ft^2/d.

The Edwards-Trinity aquifer in the Edwards Plateau comprises all Cretaceous sediments below the Del Rio Clay, or Buda Limestone where the Del Rio Clay is absent. Washita and Fredericksburg rocks are the principal water-producing zones in southern parts of the area, except where they are breached by erosion along the valleys of the Concho, Guadalupe, Llano, Pecos, Pedernales, and San Saba Rivers. In these topographically low areas, middle and lower Trinity units augment the valley alluvium as the main sources of ground water. The basal Cretaceous sand is the principal aquifer in northwestern parts of the area and along parts of the Pecos River valley. Hydraulic conditions in the Edwards Plateau mostly are confined or semiconfined, except in the shallowest water-transmitting zones and near the fringes of Fredericksburg strata where sandy Trinity sediments crop out. About 80 percent of the roughly 130,000 acre-ft of annual pumpage was used for irrigation during the mid-1970's. Water-level hydrographs reflect a cyclic relation between recharge from precipitation and water-level change: (1) declining water levels during most of the 1960's, when precipitation was below normal; (2) rising water levels

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during most of the 1970's, when precipitation was above normal; and (3) declining water levels during most of the 1980's, when precipitation was below normal. Although transmissivity values probably average less than 5,000 ft^2/d over most of the Edwards Plateau, they may approach 10,000 ft^2/d in southern parts of the area, where the Cretaceous sediments are thickest.

The Edwards-Trinity aquifer in the Trans-Pecos comprises all Cretaceous sediments below the Del Rio Clay, or Buda Limestone where the Del Rio Clay is absent. Water from the Edwards-Trinity aquifer is supplemented by water from the Cenozoic Pecos alluvium aquifer and the Dockum aquifer. Because of accelerating rates of ground-water withdrawal associated with agricultural expansion following World War II, water levels declined and springflow decreased sharply. After irrigation pumpage in Pecos and Reeves Counties had increased to about 550,000 acre-ft/yr by the late 1950's, total pumpage decreased to about 450,000 acre-ft/yr during the mid-1970's. Only about 1,250 acre-ft/yr of ground water was pumped in Terrell County during the mid-1970's. Springflow decreased from an average of nearly 85,000 acre-ft/yr during the mid-1940's to less than 40,000 acre-ft/yr during the 1980's. Transmissivity values in the Edwards-Trinity aquifer generally are less than 1,000 ft^2/d. The largest transmissivity values are in the Cenozoic Pecos alluvium aquifer, where values average about 5,000 ft^2/d and are as large as 20,000 ft^2/d in the thicker parts of the aquifer in north-central Reeves County.

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Reference 8

Texas Water Development Board

Report 360

Aquifers of the Edwards Plateau

edited by
Robert E. Mace,
Edward S. Angle, and
William F. Mullican, III

February 2004

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Note from the Editors:

In 2001, at the request of one of our board members at the time, Ms. Kathleen Hartnett White, the Texas Water Development Board held a conference in Alpine called "Aquifers of West Texas." The conference was a big success: good attendance, good information, and good camaraderie among Texans interested in and concerned with groundwater. The conference drew attendees from the Edwards Plateau region, several of which asked: "When is our conference?" Well, after two years (and a number of long nights and weekends) in the making: Here it is!

We are proud to have assembled a great collection of speakers and papers to present an overview of the aquifers and some groundwater issues of the Edwards Plateau. Similar to the "Aquifers of West Texas" conference, we identified topics we wanted addressed and then identified potential speakers to invite to discuss each of the topics. We also asked each of the speakers to write a chapter to include in the volume you are now holding. This volume is meant to be a stand-alone document as well as a proceedings of the conference held in San Angelo on February 9th, 2004.

Orchestrating the conference and this document was a great task, and we are thankful for the assistance of many people. First, we thank our speakers and authors for their contributions to the conference and volume and their willingness to share their knowledge. We also thank the Texas A &M University Research Extension Center, San Angelo (Dr. John Walker and Jodi Huybers) for providing the space to hold our conference. We are also thankful to Deborah Reyes (TWDB) and Carla Daws (TWDB) for publicizing the conference. We are grateful to Mike Parcher (TWDB) for his assistance in printing this volume. We also thank our Executive Administrator, J. Kevin Ward, for his support of this conference. Finally, we thank our former board member, Ms. Kathleen Hartnett White, now Chairman of the Texas Commission of Environmental Quality, for the initial idea of this conference.

If you are from one of the bordering areas of the Edwards Plateau, fear not: We plan to continue this conference series across Texas.

Robert E. Mace
Edward S. Angle
William F. Mullican, III

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Chapter 1

Aquifers of the Edwards Plateau

Robert E. Mace[1] and Edward S. Angle[1]

Introduction

The Edwards Plateau occupies the west-central part of Texas, extending from the Hill Country near Austin and San Antonio up to the mountains of West Texas and extending into the High Plains. Because of low rainfalls, the frequency of drought, and few major rivers, groundwater is an important source of water to the people and environmental resources of the Edwards Plateau area. The hydrogeologic centerpiece of the Edwards Plateau is the Edwards–Trinity (Plateau) aquifer, one of the major aquifers of the state. Around and in hydraulic connection with this centerpiece are a number of major and minor aquifers including the Capitan Reef, Cenozoic Pecos Alluvium, Dockum, Edwards (Balcones Fault Zone), Ellenburger-San Saba, Hickory, Lipan, Marble Falls, Ogallala, Rustler, and Trinity aquifers. Many towns and rural areas in the Edwards Plateau area rely on groundwater. Total groundwater usage in the area has ranged from about 500,000 to over 700,000 acre-ft per year over the past 20 years. A better understanding of how these aquifers behave is important for better understanding how to best manage the scarce water resources that do exist in the Edwards Plateau. The purpose of this paper is to present a general overview of the aquifers of the Edwards Plateau and recent scientific and planning activities concerning these aquifers.

Location, Physiography, and Climate

Our focus is on the Edwards Plateau area of Texas (Figure 1-1). This area comprises a large part of state and includes the following 51 counties: Andrews, Bandera, Blanco, Brewster, Brown, Burnet, Coke, Coleman, Concho, Crane, Crockett, Culberson, Ector, Edwards, Gillespie, Glasscock, Howard, Irion, Jeff Davis, Kendall, Kerr, Kimble, Kinney, Lampasas, Llano, Loving, Martin, Mason, McCulloch, Menard, Midland, Mills, Mitchell, Nolan, Pecos, Reagon, Real, Reeves, Runnels, San Saba, Schleicher, Sterling, Sutton, Taylor, Terrell, Tom Green, Upton, Uvalde, Val Verde, Ward, and Winkler. A total of 39 counties have populations of less than 20,000 people as of 2000 with four counties (Ector, Midland, Taylor, and Tom Green) with populations of more than 100,000 people (Table 1-1). The population in the area has grown by almost 80 percent since 1950, increasing by more than 440,000 people (Table 1-1). However, 19 counties

[1] Texas Water Development Board

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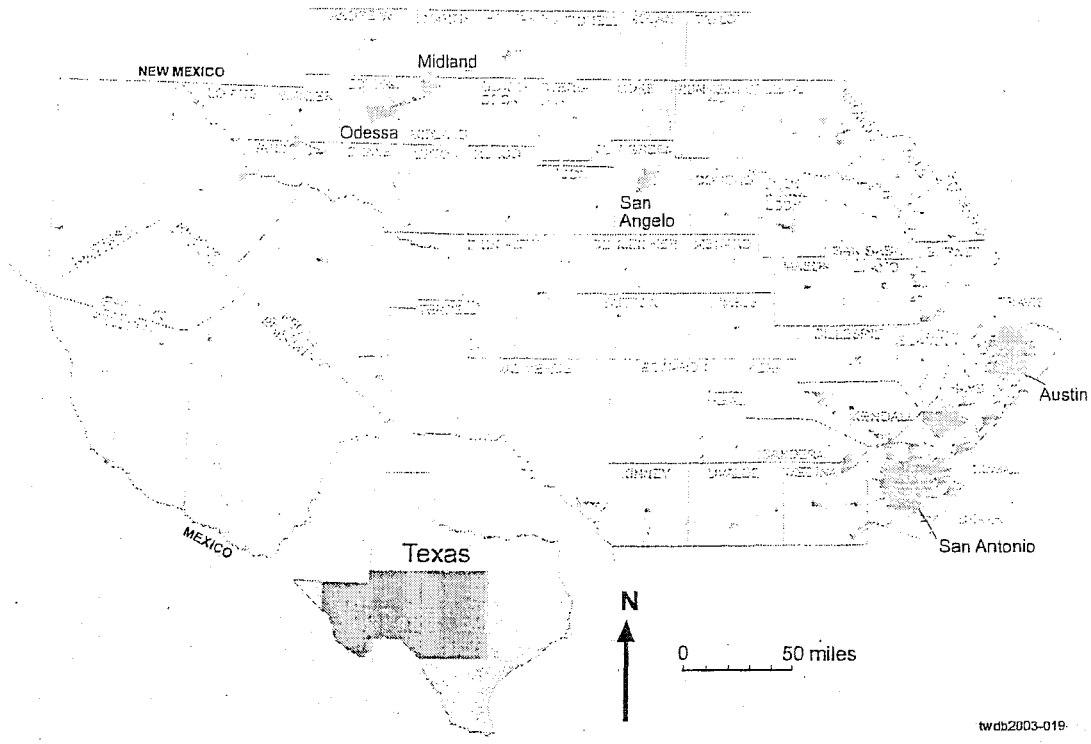

Figure 1-1: Location of the study area in the Edwards Plateau area. Bexar, Comal, Hays, Medina, Presidio, and Travis counties are shown for orientation purposes and are not considered in this paper.

have decreased in population since 1950. Total groundwater use has ranged from 443,000 to 954,000 acre-feet per year over the past twenty years (Figure 1-2). In 2000, 26 counties got more than 75 percent of their water from aquifers of the Edwards Plateau (Table 1-1).

This part of Texas is primarily located in the southern portion of Great Plains Province (Fenneman, 1931), which is characterized by asymmetric ridges or mountains and broad intervening basins (Bates and Jackson, 1984). Elevations range from 5,000 feet above sea level in the western portion of the region to 500 feet above sea level on the eastern side.

The Rio Grande and the Colorado and Pecos rivers are the major rivers than cut through the Edwards Plateau area (Figure 1-3). The headwaters of the Guadalupe, Nueces, and San Antonio rivers are also located in the Edwards Plateau area (Figure 1-3). Flow in the Rio Grande in this part of Texas is primarily controlled by inflows from the Rio Conchos near Presidio. The Pecos River is a major tributary to the Rio Grande that originates in New Mexico. The river is impounded in Red Bluff Lake in Loving County and is used for irrigation in Pecos, Reeves, and Ward counties.

Most of the study area ranges from subhumid in the eastern portion to semiarid in the western areas (Walker 1979). Average annual precipitation ranges from less than 10

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Table 1-1: Population and groundwater use for counties in the Edwards Plateau area for selected years.

	Population				Groundwater use (acre-feet)			
County	1950	1980	1990	2000	1980	1990	2000	%GW
Andrews	5,002	13,323	14,338	13,004	21,443	15,132	24,123	99.7
Bandera	4,410	7,084	10,562	17,645	1,320	1,848	2,653	85.7
Blanco	3,780	4,681	5,972	8,418	886	1,514	1,288	74.1
Brewster	7,309	7,573	8,681	8,866	3,126	2,551	3,967	92.5
Brown	28,607	33,057	34,371	37,674	1,049	1,611	2,788	13.0
Burnet	10,356	17,803	22,677	34,147	2,123	1,946	2,957	33.2
Coke	4,045	3,196	3,424	3,864	451	678	1,070	37.6
Coleman	15,503	10,439	9,710	9,235	257	113	115	4.0
Concho	5,078	2,915	3,044	3,966	1,595	3,287	3,473	91.1
Crane	3,965	4,600	4,652	3,996	2,780	2,676	2,081	59.1
Crockett	3,981	4,608	4,078	4,099	6,606	4,561	3,376	87.4
Culberson	1,825	3,315	3,407	2,975	76,119	12,580	27,030	99.9
Ector	42,102	115,374	118,934	121,123	25,144	20,551	17,546	28.4
Edwards	2,908	2,033	2,266	2,162	1,310	854	1,041	90.3
Gillespie	10,520	13,532	17,204	20,814	4,242	5,729	6,325	89.2
Glasscock	1,089	1,304	1,447	1,406	40,443	27,491	35,788	99.9
Howard	26,722	33,142	32,343	33,627	2,682	4,141	6,103	38.8
Irion	1,590	1,386	1,629	1,771	1,030	1,458	1,542	56.6
Jeff Davis	2,090	1,647	1,946	2,207	26,872	3,767	1,084	96.4
Kendall	5,423	10,635	14,589	23,743	1,748	2,322	3,499	79.6
Kerr	14,022	28,780	36,304	43,653	5,716	3,176	3,818	43.0
Kimble	4,619	4,063	4,122	4,468	1,103	845	707	25.7
Kinney	2,668	2,279	3,119	3,379	10,834	8,394	15,833	99.4
Lampasas	9,929	12,005	13,521	17,762	1,192	993	1,872	8.0
Llano	5,377	10,144	11,631	17,044	1,958	2,122	1,824	27.4
Loving	227	91	107	67	64	44	46	11.2
Martin	5,541	4,684	4,956	4,746	21,118	13,919	15,693	97.4
Mason	4,945	3,683	3,423	3,738	16,861	18,077	11,602	97.1
Mcculloch	11,701	8,735	8,778	8,205	7,515	6,060	7,137	96.2
Menard	4,175	2,346	2,252	2,360	709	767	1,132	28.4
Midland	25,785	82,636	106,611	116,009	31,975	34,173	32,945	52.3
Mills	5,999	4,477	4,531	5,151	1,340	1,245	952	19.4
Mitchell	14,357	9,088	8,016	9,698	3,611	2,249	7,103	39.1
Nolan	19,808	17,359	16,594	15,802	3,710	3,611	6,079	59.8
Pecos	9,939	14,618	14,675	16,809	111,250	67,552	78,563	97.7
Reagan	3,127	4,135	4,514	3,326	24,378	39,919	18,724	99.8
Real	2,479	2,469	2,412	3,047	632	770	480	51.1
Reeves	11,745	15,801	15,852	13,137	120,524	40,117	68,285	85.9
Runnels	16,771	11,872	11,294	11,495	2,027	1,866	973	27.8
San Saba	8,666	6,204	5,401	6,186	3,705	1,919	2,763	45.9
Schleicher	2,852	2,820	2,990	2,935	2,350	2,113	3,364	96.9
Sterling	1,282	1,206	1,438	1,393	2,245	1,814	1,813	96.1
Sutton	3,746	5,130	4,135	4,077	3,799	2,574	3,373	96.8
Taylor	63,370	110,932	119,655	126,555	2,891	914	872	2.0
Terrell	3,189	1,595	1,410	1,081	1,379	1,139	546	85.2
Tom Green	58,929	84,784	98,458	104,010	15,268	28,246	22,609	42.3
Upton	5,307	4,619	4,447	3,404	19,516	16,310	16,098	99.7

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Table 1-1 (cont): Population and groundwater use for counties in the Edwards Plateau area for selected years.

	Population				Groundwater use (acre-feet)			
County	**1950**	**1980**	**1990**	**2000**	**1980**	**1990**	**2000**	**%GW**
Uvalde	16,015	22,441	23,340	25,926	81,196	144,522	66,083	97.4
Val Verde	16,635	35,910	38,721	44,856	1,673	4,211	16,217	91.7
Ward	13,346	13,976	13,115	10,909	33,311	10,670	12,164	52.5
Winkler	10,064	9,944	8,626	7,173	8,356	3,171	5,516	99.9
Total:	255,811	549,592	660,934	754,099	621,194	310,308	447,935	63.5

% GW = percent of total water use in 1997 that was met with groundwater.
Groundwater use includes use from all aquifers, including those not discussed in this paper.

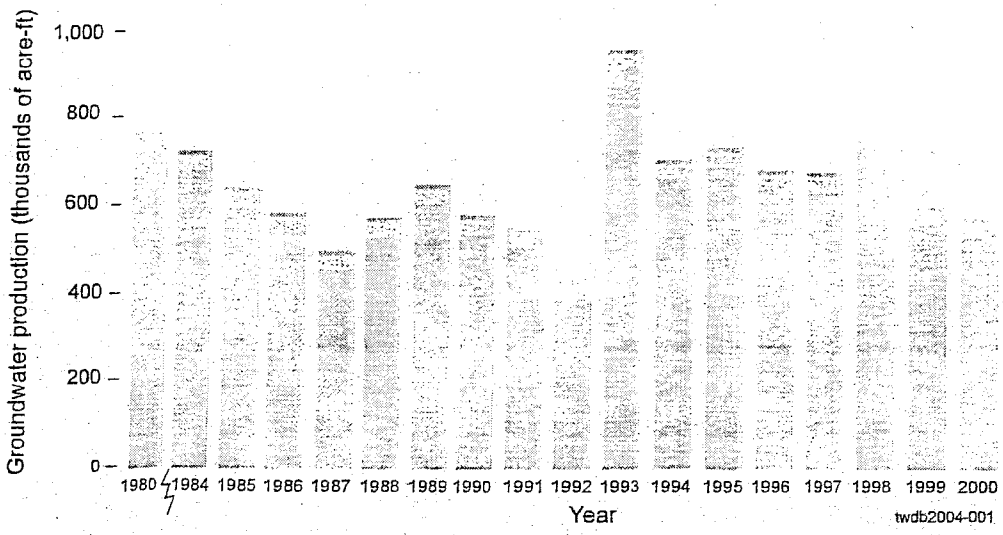

Figure 1-2: Total groundwater use for the Edwards Plateau area of Texas.

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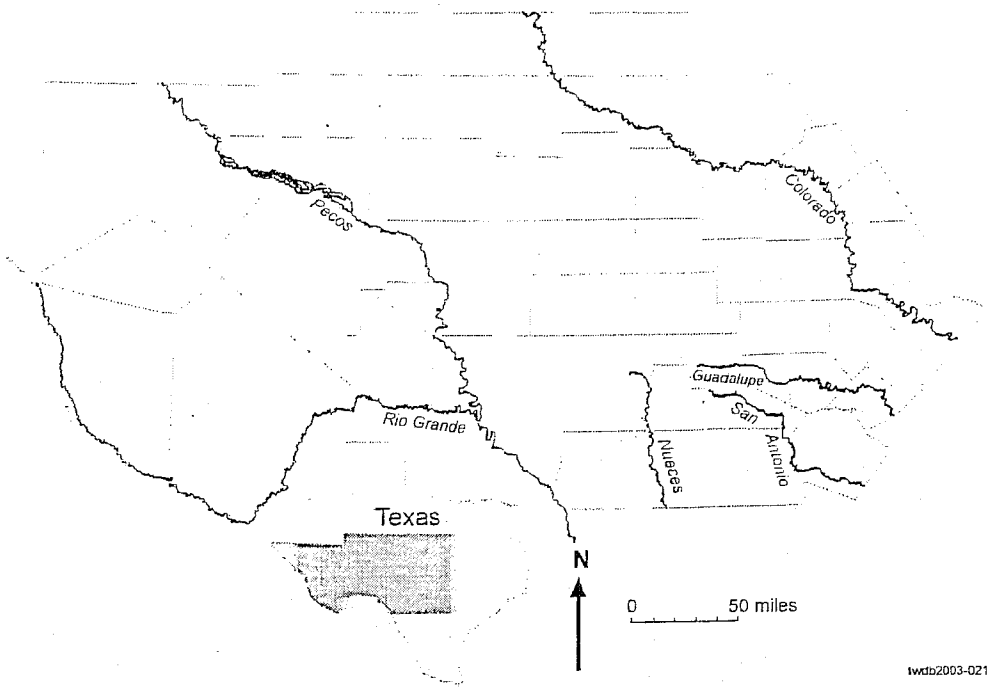

Figure 1-3: Location of major rivers in the Edwards Plateau area.

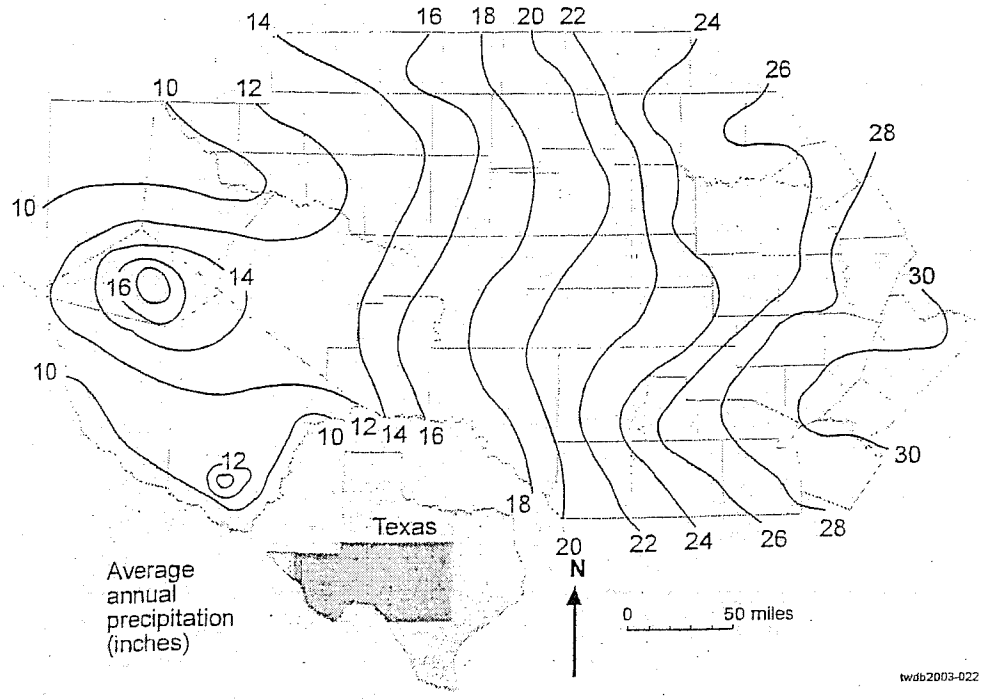

Figure 1-4: Amount of average annual precipitation in the Edwards Plateau area (after Larkin and Bomar, 1983).

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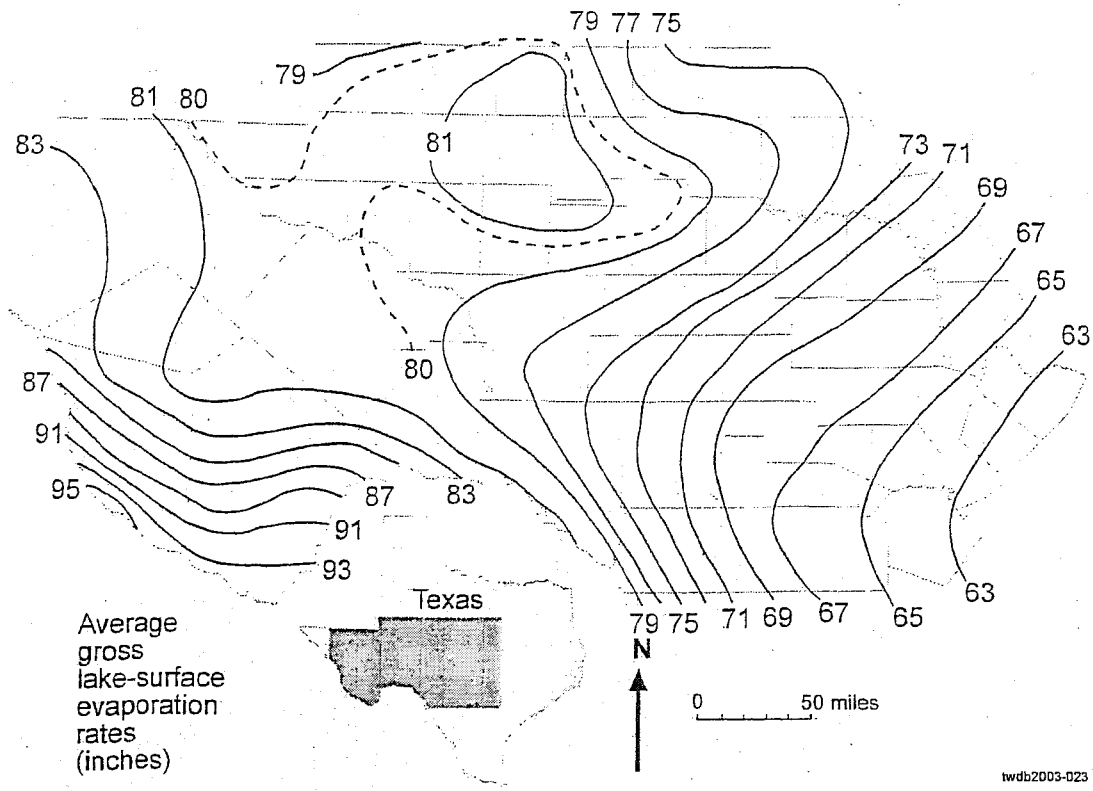

Figure 1-5: Amount of average gross lake-surface evaporation rates in the Edwards Plateau area (after Larkin and Bomar, 1983).

inches in the west to more than 30 inches in east (Figure 1-4). Late spring and early summer bring the greatest rainfalls to the eastern portion of the plateau while late summer results in the heaviest rainfall in the western areas. Average annual gross lake-surface evaporation rates range from less than 65 inches in east to more than 90 inches in west (Figure 1-5).

Aquifers of the Edwards Plateau

The Edwards Plateau area includes all or part of 12 aquifers recognized by the Texas Water Development Board (Figure 1-6). Five major aquifers, the Edwards (Balcones Fault Zone), the Edwards–Trinity (Plateau), the Cenozoic Pecos Alluvium, the Ogallala, and the Trinity are found in the area. Seven minor aquifers are also located in the area including the Capitan Reef, Dockum, Ellenburger-San Saba, Hickory, Lipan, Marble Falls, and Rustler aquifers. The Texas Water Development Board (TWDB) has assigned a major and minor status to the State's aquifers based on the quantity of water supplied by each aquifer (Ashworth and Hopkins, 1995). In addition to the aquifer recognized by the TWDB, there are several other geologic formations that locally produce water.

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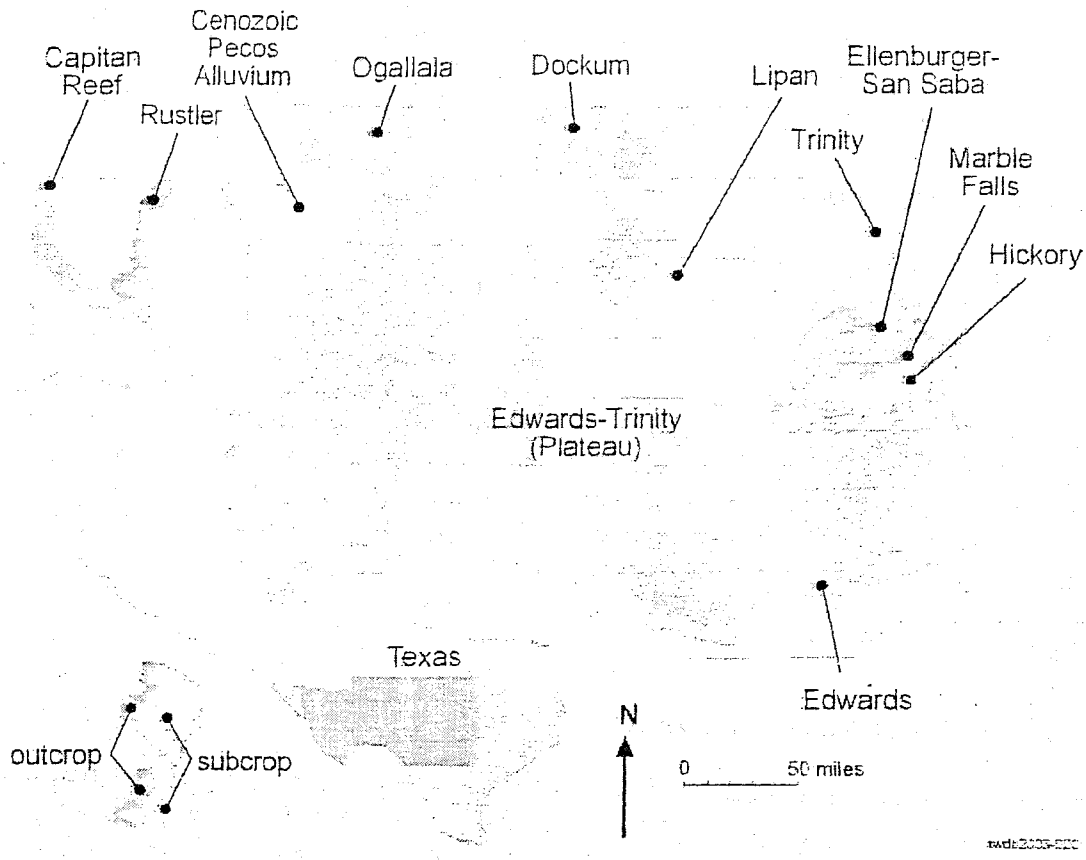

Figure 1-6: Location of recognized major and minor aquifers in Far West Texas (delineations from TWDB, map does not include the Igneous, West Texas Bolsons, and Marathon aquifers).

The major aquifers have had a number of scientific studies done on them. However, with a few exceptions in some local areas, the minor aquifers have had little to almost no groundwater studies done on them.

The general information presented below is from "Aquifers of Texas" by Ashworth and Hopkins (1995); "Aquifers of West Texas" by Mace and others (2001); the regional water plans of the Region F, Lower Colorado, South Central Texas, Plateau, and Far West Texas regions; and water-use information from TWDB surveys and estimates. Bradley and Malstaff (2004, Chapter 10 of this volume) discuss drought in the area. Paine (2004, Chapter 12 of this volume) discusses natural and oil-field contamination in an area of the Edwards Plateau, and Standen and Opdyke (2004; Chapter 11 of this volume) discuss aquifer susceptibility to contaminants. Edwards and others (2004, Chapter 13 of this volume) discuss the aquifer-dependant fishes of the Edwards Plateau. Keese and others (2004, Chapter 14 of this volume) evaluate climate, vegetation, and soil controls on groundwater recharge in Texas, including the Edwards Plateau. Arroyo and Mullican

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(2004, Chapter 15 of this volume) discuss desalination, and Hart (2004, Chapter 16 of this volume) discuss brush control. Chowdhury and others (2004, Chapter 17 of this volume) discuss the origin of flow to the San Solomon Spring system.

Capitan Reef aquifer

The Capitan Reef aquifer consists of two strips located in Brewster, Culberson, Hudspeth, Jeff Davis, Pecos, Reeves, Ward, and Winkler counties (Figure 1-6) and extends northward into New Mexico. The aquifer is an ancient reef consisting of 2,360 ft of dolomite and limestone, and, in Texas, generally has poor water quality except in the exposed areas of the aquifer. Most of the water pumped from the aquifer is in Ward and Winkler counties for water-flooding operations in oil-producing areas. A small amount water is used for irrigation in Pecos and Culberson counties. Carlsbad, New Mexico, relies on the aquifer for municipal use. Pumping from the aquifer in the Edwards Plateau area over the past twenty years has ranged from less than 30 to about 12,500 acre-ft per year (Table 1-2). Recent pumping has been less than 50 acre-ft per year. The Capitan Reef aquifer is discussed in more detail by Uliana (2001) in "Aquifers of West Texas" (Mace and others, 2001).

Cenozoic Pecos Alluvium aquifer

The Cenozoic Pecos Alluvium aquifer is located in Andrews, Crane, Crockett, Culberson, Ector, Jeff Davis, Loving, Pecos, Reeves, Upton, Ward, and Winkler counties (Figure 1-6) and extends to the north into New Mexico. The aquifer consists of sands, gravels, and clays of ancient river deposits of up to 1,500 ft thick. The aquifer is connected to the Dockum and Edwards–Trinity (Plateau) aquifers where they exist underneath the alluvium. Water quality is naturally highly variable and has also been locally impacted by past activities of the petroleum industry. Water levels have declined more than 200 ft in south-central Reeves and northwest Pecos counties but have remained somewhat steady since the 1970s with a decrease in irrigation. Lowered water levels have decreased baseflow to the Pecos River and, in some cases, now cause the river to lose water to the aquifer. Pumping from the aquifer in the Edwards Plateau area over the past twenty years has ranged from about 64,000 to about 200,000 acre-ft per year (Table 1-2). Reeves County has been the largest user of groundwater from the aquifer, using 67 percent of the total water pumped in 1997. The Cenozoic Pecos Alluvium aquifer is discussed in more detail by Jones (2004; Chapter 6 of this volume).

Dockum aquifer

The Dockum aquifer is located in Andrews, Coke, Crane, Crockett, Ector, Glasscock, Howard, Irion, Loving, Martin, Midland, Mitchell, Nolan, Pecos, Reagon, Reeves, Sterling, Tom Green, Upton, Ward, and Winkler counties in the Edwards Plateau area (Figure 1-6) and extends to the north beneath the Ogallala aquifer and to the northwest

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Table 1-2: Groundwater use for the different aquifers in the Edwards Plateau area (acre-feet). This table only includes groundwater use in the counties listed in the Location section of this paper.

	Year						
	1980	1984	1985	1986	1987	1988	1989
	1990	1991	1992	1993	1994	1995	1996
Aquifer	1997	1998	1999	2000			
Capitan Reef Complex	12,450	826	645	95	62	62	582
	181	583	156	724	642	510	398
	41	26	26	28			
Cenozoic Pecos Alluvium	199,327	127,460	102,719	93,947	75,260	79,109	106,541
	71,377	70,348	64,220	388,502	152,290	159,427	150,621
	151,371	165,084	143,806	132,456			
Dockum	12,715	12,894	14,813	10,860	10,004	10,210	9,808
	8,301	8,841	8,734	11,024	10,638	7,981	9,277
	8,432	9,196	10,019	8,260			
Edward (BFZ)	81,265	157,365	156,567	126,656	105,155	139,328	159,878
	145,346	119,805	47,592	113,493	99,221	71,447	91,970
	66,464	72,485	84,861	72,369			
Edwards–Trinity (Plateau)	184,129	205,845	163,347	171,741	149,924	153,225	168,308
	153,441	164,327	151,280	212,185	181,165	201,393	184,180
	176,708	192,717	156,151	153,371			
Ellenburger-San Saba	4,948	6,293	6,293	5,447	6,238	5,222	4,638
	6,659	6,413	6,473	6,737	7,498	5,518	5,854
	6,172	5,919	6,455	5,853			
Hickory	28,348	16,728	28,250	26,764	24,595	27,616	28,130
	26,402	26,638	20,857	24,000	23,523	22,094	20,658
	19,603	21,379	19,099	17,634			
Igneous	5,135	2,465	2,613	2,677	2,185	2,623	2,118
	2,217	2,727	2,646	2,594	2,762	2,697	2,629
	2,968	3,237	3,239	2,635			
Lipan	10,121	22,794	19,653	17,333	14,534	22,672	24,383
	24,588	20,512	13,850	63,867	60,581	76,180	35,230
	66,292	72,298	25,781	37,560			
Marble Falls	1,350	1,278	1,141	987	718	772	814
	790	749	693	702	1,524	1,601	1,647
	1,644	1,793	1,646	1,468			
Ogallala	73,283	58,124	57,240	49,075	36,434	45,606	51,249
	60,217	50,770	62,013	61,609	88,476	92,930	86,018
	76,134	83,031	83,625	73,097			
Rustler	371	539	327	297	301	251	268
	246	302	310	681	1,486	1,605	1,515
	1,584	1,728	1,542	1,380			
Trinity	14,693	12,385	13,640	13,326	12,181	13,074	14,465
	13,505	13,234	14,250	16,296	17,093	18,120	19,427
	18,765	20,465	19,940	17,296			
West Texas Bolsons	75,582	21,548	24,098	19,890	20,238	21,697	15,584
	12,752	11,788	13,987	7,936	8,818	8,968	9,387
	9,860	10,753	15,240	10,338			
Other aquifers	25,308	24,208	23,509	20,697	19,002	24,226	23,813
	15,989	18,581	16,203	23,943	18,678	20,351	16,899
	20,014	21,827	15,534	15,560			
Total	729,025	664,606	614,855	559,792	476,831	545,693	610,579
	542,011	515,618	423,264	934,293	674,395	690,822	635,710
	626,052	681,938	586,965	549,305			

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into New Mexico. The Dockum aquifer consists of up to 700 ft of sand and conglomerate with layers of silt and shale of the Dockum Group. Water quality is variable and is used for water-flooding operations in oil-producing areas of the southern High Plains. Pumping from the aquifer in the counties in the study area over the past twenty years has ranged from about 8,000 to about 15,000 acre-ft per year (Table 1-2). The Dockum aquifer is discussed in more detail by Kalaswad and Bradley (2004; Chapter 7 of this volume).

Edwards (Balcones Fault Zone) aquifer

The Edwards (Balcones Fault Zone) aquifer is located in Bexar, Comal, Hays, Kinney, Medina, Travis, and Uvalde counties in the Edwards Plateau area (Figure 1-6) and extends north into Bell and Williamson counties. The Edwards (Balcones Fault Zone) aquifer consists of the Georgetown Limestone, formations of the Edwards Group and its equivalents, and the Comanche Peak limestone where it exists. The thickness of the aquifer ranges from 200 to 400 feet. Water quality and quantity are excellent. Much of the water is used for agricultural and municipal purposes. Pumping from the aquifer in Kinney and Uvalde counties in the study area over the past twenty years has ranged from about 50,000 to about 160,000 acre-ft per year (Table 1-2). Mace and Anaya (Chapter 18 of this volume) discuss the Edwards (Balcones Fault Zone) aquifer in Kinney County in more detail. The reader is directed to Maclay and Land (1988) and Klemt and others (1979) for more detailed overviews of the aquifer. The Edwards (Balcones Fault Zone) aquifer is expected to be the focus of an upcoming Aquifers of Texas conference.

Edwards–Trinity (Plateau) aquifer

The Edwards–Trinity (Plateau) aquifer is the hydrogeologic centerpiece of the Edwards Plateau and is hydraulically connected, in one way or the other, to every other aquifer discussed in this paper. The Edwards–Trinity (Plateau) aquifer underlies Bandera, Blanco, Brewster, Coke, Concho, Crane, Crockett, Culberson, Ector, Edwards, Gillespie, Glasscock, Irion, Jeff Davis, Kerr, Kendall, Kimble, Kinney, Mason, McCulloch, Menard, Midland, Nolan, Pecos, Reagon, Real, Reeves, Schleicher, Sterling, Sutton, Taylor, Terrell, Tom Green, Upton, Uvalde, Val Verde, Ward, and Winkler counties (Figure 1-6) and extends southward into Mexico. Equivalent rocks of the Edwards-Trinity (Plateau) aquifer extend north of the Plateau area under the Ogallala aquifer are recognized as the Edwards–Trinity (High Plains) aquifer (Ashworth and Hopkins, 1995).

The Edwards–Trinity (Plateau) aquifer consists of rocks of the Comanche Peak, Edwards, and Georgetown Formations and the Trinity Group. The Trinity Group consists primarily of sands (Antlers and Maxim sands) and limestones. The Comanche Peak, Edwards, and Georgetown Formations consist primarily of limestones and dolomites. Pumping from the aquifer over the past twenty years has ranged from about 150,000 to about 200,000 acre-ft per yr (Table 1-2). The Edwards–Trinity (Plateau) aquifer is discussed in more detail by Anaya (2004) for the aquifer in Texas (Chapter 2 of this volume), by Boghici (2004) for the aquifer in Mexico (Chapter 4 of this volume), and by Nance (2004) on the

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groundwater chemistry (Chapter 3 of this volume). Mace and Anaya (2004; Chapter 18 of this volume) discuss recharge in Kinney County in greater detail.

Ellenburger-San Saba aquifer

The Ellenburger-San Saba aquifer is located in Blanco, Brown, Burnet, Coleman, Concho, Gillespie, Kendall, Kerr, Kimble, Lampasas, Llano, Mason, McCulloch, Menard, Mills, and San Saba counties (Figure 1-6). The aquifer consists of limestone and dolomite facies of Cambrian and early Ordovician age (Ashworth and Hopkins, 1995). The outcrop of the aquifer encircles the core of the Llano Uplift. The down-dip portions of the aquifer are as deep as 3,000 feet. The majority of water pumped from this aquifer is use for municipal supplies (Ashworth and Hopkins, 1995). Pumping from the aquifer over the past twenty years has ranged from about 5,000 to about 7,500 acre-ft per yr (Table 1-2). The Ellenburger-San Saba aquifer is discussed in more detail by Smith (2004; Chapter 9 of this volume).

Hickory aquifer

This Hickory aquifer is located in Blanco, Brown, Burnet, Coleman, Concho, Gillespie, Hays, Kendall, Kerr, Kimble, Lampasas, Llano, Mason, McCulloch, Menard, Mills, San Saba, Travis, and Williamson and counties (Figure 1-6). The aquifer consists primarily of sands and occurs in some of the oldest Cambrian sedimentary rocks in Texas (Ashworth and Hopkins, 1995). The outcrop areas encircle and overlie directly on the Precambrian metamorphic rocks that make up the Llano uplift. The down dip portions are as deep as 4,500 feet below land surface. Most of the water pumped from this aquifer is used for irrigation, although some high capacity wells are used for municipal supplies as well (Ashworth and Hopkins, 1995). Pumping from the aquifer over the past twenty years has ranged from about 17,000 to about 28,000 acre-ft per yr (Table 1-2). The Hickory aquifer is discussed in more detail by Smith (2004; Chapter 9 of this volume).

Lipan aquifer

The Lipan aquifer is located in Coke, Concho, Runnels, and Tom Green counties (Figure 1-6). It consists of 125 feet of alluvial sediments of the Quaternary Leona Formation (Ashworth and Hopkins, 1995). The groundwater from the Lipan usually does not meet drinking water standards but is suitable for irrigation. Pumping from the aquifer over the past twenty years has ranged from about 10,000 to about 76,000 acre-ft per yr (Table 1-2). The Lipan aquifer is discussed in more detail by Beach and Burton (2004; Chapter 8 of this volume).

Marble Falls aquifer

The Marble Falls aquifer is located in Blanco, Burnet, Kimble, Lampasas, Llano, Mason, McCulloch, Menard, and San Saba counties (Figure 1-6). The aquifer consists of Pennsylvanian-age limestones and occurs as a series of discontinuous outcrops that

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surround the Llano Uplift area (Ashworth and Hopkins, 1995). Water occurs in fractures and solution cavities in the formation. Pumping from the aquifer over the past twenty years has ranged from about 700 to about 1,800 acre-ft per yr (Table 1-2). The Marble Falls aquifer is discuss in detail by Smith (2004; Chapter 8 of this volume).

Ogallala aquifer

The Ogallala aquifer is located in Andrews, Ector, Glasscock, Howard, Martin, and Midland counties in the Edwards Plateau area (Figure 1-6). The Ogallala aquifer is composed primarily of sand, gravel, clay, and silt and generally has a saturated thickness of less than 100 ft in the Edwards Plateau area. The quality of water tends to be mixed in this part of the aquifer. The Ogallala aquifer partially overlies the Edwards–Trinity (Plateau) aquifer in the Edwards Plateau area. Pumping from the aquifer in the counties in the study area over the past twenty years has ranged from about 36,000 to about 93,000 acre-ft per year (Table 1-2). The Ogallala aquifer and its interaction with the Edwards–Trinity (Plateau) aquifer is discussed in more detail by Blandford and Blazer (2004) (Chapter 18 of this volume).

Rustler aquifer

The Rustler aquifer is located in Brewster, Culberson, Jeff Davis, Loving, Pecos, Reeves, and Ward counties (Figure 1-6). Groundwater occurs in the partially dissolved dolomite, limestone, and gypsum beds of the Rustler Formation. The water is of poor quality and is used primarily for irrigation, livestock, and for water-flooding operations in oil-producing areas. Pumping from the aquifer in the counties in the study area over the past twenty years has ranged from less than 300 to about 1,700 acre-ft per year (Table 1-2). The Rustler aquifer is discussed in more detail by Boghici and van Broekhoven (2001) in "Aquifers of West Texas" (Mace and others, 2001).

Other aquifers

There are areas along the fringes of the Edward Plateau that do not have a TWDB recognized major or minor aquifer beneath them (see white areas in Figure 1-6). This does not mean that there are no groundwater resources in these areas. These areas may have small, local aquifers that can supply water for limited purposes. According to the TWDB information, about 700 to as much as 11,000 acre-ft per year has been pumped from other aquifers in the area (Table 1-2). Further study and evaluation will increase our knowledge of water resources in these areas.

Groundwater Conservation Districts

Groundwater in Texas is governed by the rule of capture. Rule of capture allows a landowner to produce as much groundwater as the landowner chooses, absent malice or willful waste, without liability to neighbors who may claim that pumping has depleted their wells. The Legislature enabled the regulation of groundwater through the creation of

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groundwater conservation districts the first of which, the High Plains Groundwater Conservation District No. 1, was created in 1949. Groundwater conservation districts are recognized by the Legislature as the state's preferred method of managing groundwater resources. Depending on the rules and regulations of each district, absolute rule of capture does not necessarily apply within the boundary of a groundwater conservation district.

The Edwards Plateau area is home to 35 confirmed groundwater conservation districts (Figure 1-7):

1. Bandera County River Authority/Ground Water District
2. Barton Springs/Edwards Aquifer Conservation District
3. Blanco-Pedernales Groundwater Conservation District
4. Brewster County Groundwater Conservation District
5. Coke County Underground Water Conservation District
6. Cow Creek Groundwater Conservation District
7. Culberson County Groundwater Conservation District
8. Edwards Aquifer Authority
9. Emerald Underground Water Conservation District
10. Fox Crossing Water District
11. Glasscock Groundwater Conservation District
12. Hays Trinity Groundwater Conservation District
13. Headwaters Groundwater Conservation District
14. Hickory Underground Water Conservation District No. 1
15. Hill Country Groundwater Conservation District
16. Irion County Water Conservation District
17. Jeff Davis County Underground Water Conservation District
18. Kimble County Groundwater Conservation District
19. Kinney County Groundwater Conservation District
20. Lipan Kickapoo Groundwater Conservation District
21. Lone Wolf Groundwater Conservation District
22. Medina County Groundwater Conservation District
23. Menard County Underground Water Conservation District
24. Middle Pecos Groundwater Conservation District
25. Permian Basin Underground Water Conservation District
26. Plateau Underground Water Conservation and Supply District
27. Presidio County Underground Water Conservation District
28. Real and Edwards Conservation and Reclamation District
29. Santa Rita Underground Water Conservation District
30. Saratosa Underground Water Conservation District
31. Sterling County Underground Water Conservation District
32. Sutton County Underground Water Conservation District
33. Trinity Glen Rose Groundwater Conservation District
34. Uvalde Underground Water Conservation District
35. Wes-Tex Groundwater Conservation District

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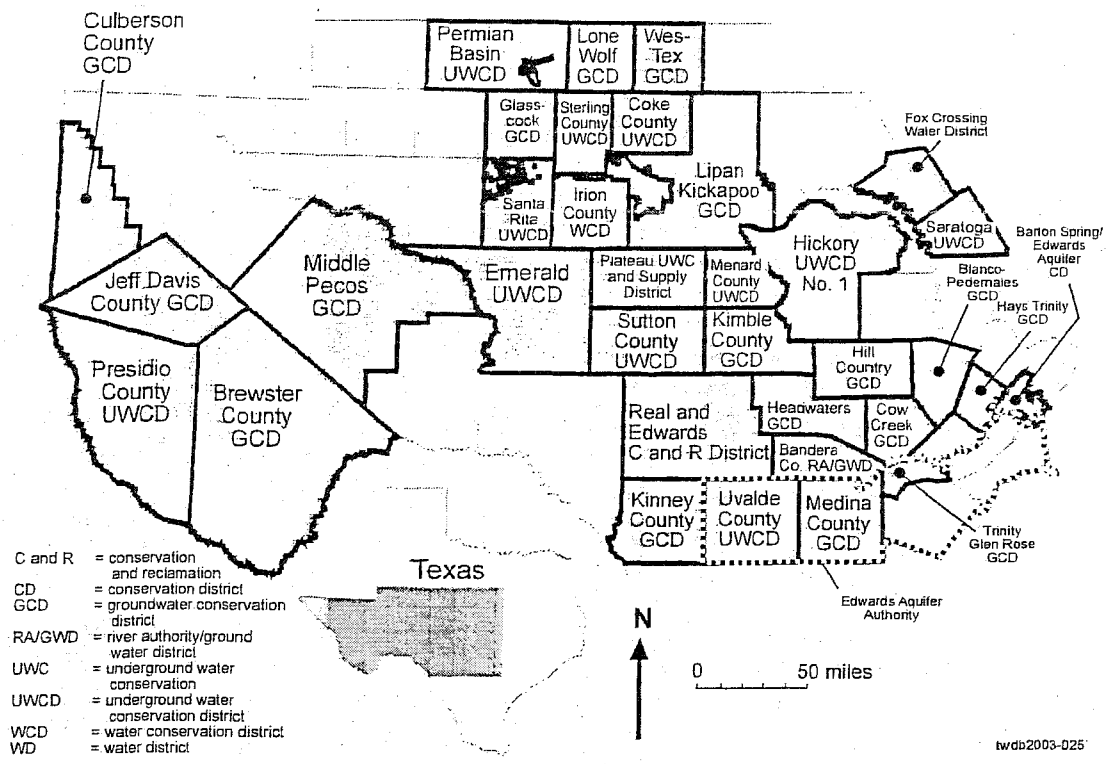

Figure 1-7: Location of confirmed groundwater conservation districts in the Edwards Plateau area.

Regional Water Planning

Through Senate Bill 1, the 1997 Legislature enacted comprehensive water management to plan for drought and meet increasing demands as population grows (Hubert, 1999). Senate Bill 1 is a "bottom up" water planning process that allows individuals representing different interest groups to serve as members of Regional Water Planning Groups. The interest groups include the public, counties, municipalities, industries, agriculture, environmental, small business, steam-electric generating utilities, river authorities, water districts, water utilities, and others selected by the Planning Groups. A total of 16 Regional Planning Areas cover the State. The Planning Groups are charged with preparing regional water plans for their respective planning areas. These plans will show, for each planning area, how to conserve water, meet future water needs, and respond to future droughts.

Each Planning Group submitted their first regional water plans in January of 2001. The TWDB integrated their individual plans into a comprehensive State Water Plan which was released on January 5, 2002. The TWDB will only provide financial assistance to those projects that are consistent with the regional water plans, and the Texas Commission on Environmental Quality will only issue water right permits for

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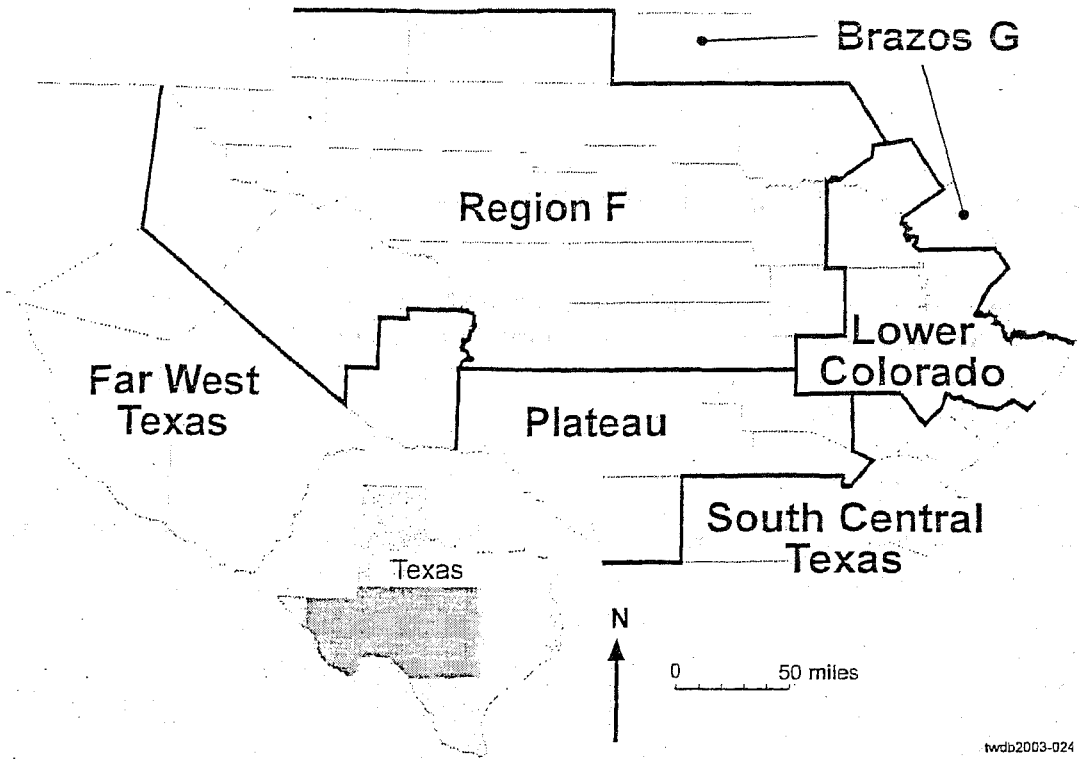

Figure 1-8: Location of regional water planning areas in the Edwards Plateau area.

municipal purposes consistent with the plan. These water plans are updated every five years.

The Edwards Plateau area includes all of Region F and parts of the Brazos G, Far West Texas, Lower Colorado, Plateau, and South Central Texas regions (Figure 1-8). All of the regions except the Far West Texas region have cities with needs by 2050. The Plateau region showed that projected water supplies exceeds projected demands, although there are specific water user groups with needs. They also noted that they need more groundwater information and that endangered and threatened species could limit future water development options. Region F showed that projected water supplies do not meet projected water demands. Over the regions, the Brazos G, Lower Colorado, and South Central Texas regions showed that projected water supplies do not meet projected water demands.

The regional water planning groups recommended a number of strategies to meet future needs for water, including:

- new groundwater,
- expanded use of existing groundwater,
- new surface water,
- expanded use of surface water,
- conservation, and
- water reuse.

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The water plans for these regions can be found on the TWDB Web page (www.twdb.state.tx.us). A statewide summary of the regional water plans is available in the 2002 State Water Plan (TWDB, 2002).

Groundwater Availability Modeling

Texas is developing new, state-of-the-art computer models of groundwater resources. In 1999, the Legislature provided initial funding for development of groundwater availability models (GAMs) for the major aquifers and in Senate Bill 2, enacted by the 77th Texas Legislature (2001), directed the TWDB to develop groundwater availability models for the minor aquifers.

There are several completed and ongoing modeling projects in the Edward Plateau area. A GAM for the Hill Country part of the Trinity aquifer that includes part of the Edwards–Trinity (Plateau) aquifer was completed in 2000 (Mace and others, 2000). A GAM for the southern part of the Ogallala aquifer was completed in early 2003 (Blandford and others, 2003). GAMs for the Cenozoic Pecos Alluvium, Edwards (Balcones Fault Zone), Edwards–Trinity (Plateau), Lipan, and northern part of the Trinity aquifers are expected to be completed in 2004. TWDB plans to develop GAMs for the Capitan Reef, Dockum, Ellenburger-San Saba, Hickory, Marble Falls, and Rustler aquifers, but development of these GAMs has not yet been scheduled.

Planning Groups and groundwater conservation districts will use the models to assess availability of groundwater in the areas or regions. These assessments will be based on the socio-economic needs of their areas and may be guided by groundwater management standards that describe the desired future condition of the aquifer, such as the quantity and quality of groundwater and the amount of springflow, baseflow, and subsidence (Mace and others, 2001, 2002).

Final reports, models, and aquifer information will be posted on the TWDB GAM Web page (www.twdb.state.tx.us/gam).

Summary

The Edwards Plateau of Texas is blessed with many aquifers but faces many challenges to meet current and future water needs. The Edwards Plateau is dry and is susceptible to drought. Because of limited surface-water resources, groundwater is often the only choice of water supply. Because of its size and ownership of the rocks that form the plateau, the centerpiece of the Edwards Plateau is the Edwards–Trinity (Plateau) aquifer. However, bordering aquifers are no less important to those that rely on them for water. In addition, the Edwards-Trinity (Plateau) aquifer is in hydraulic connection with many of its bordering aquifers.

Groundwater conservation districts, regional water planning groups, and groundwater availability models are helping to further the understanding of the aquifers and the options for meeting future water needs. However, additional study is needed, particularly

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on the less studied minor aquifers in the area and on the less studied areas of the major aquifers.

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Chapter 2

Conceptual Model for the Edwards–Trinity (Plateau) Aquifer System, Texas

Roberto Anaya[1]

Introduction

The passage of Senate Bill 1 in 1997 established a renewed public interest in the State's water resources not experienced since the drought of the 1950s. Senate Bill 1 of 1999 and Senate Bill 2 of 2001 provided state funding to initiate the development of groundwater availability models for all of the major and minor aquifers of Texas. The development and management of Groundwater Availability Models (GAMs) has been tasked to the Texas Water Development Board (TWDB) to provide reliable and timely information on the State's groundwater resources. TWDB staff is currently developing a GAM for the Edwards–Trinity (Plateau) aquifer. An essential task in the design of a numerical groundwater flow model is the development of a conceptual model. The conceptual model is a generalized description of the aquifer system that defines boundaries, hydrogeologic parameters, and hydrologic stress variables. The conceptual model helps to compile and organize field data and to simplify the real-world aquifer flow system into a graphical or diagrammatical representation while retaining the complexity needed to adequately reproduce the system behavior (Anderson and Woessner, 1992).

The first step in the development of a conceptual model is to delineate the study area and form an understanding of its physical landscape with regard to the physiography, climate, and geology. Another early step also involves the research and investigation of previous aquifer studies. Intermediate steps bring together all of the information for establishing the hydrogeologic setting which consists of the hydrostratigraphy, structural geometry, hydraulic properties, water levels and regional groundwater flow, recharge, interactions between surface water and groundwater, well discharge, and water quality. Assembling the information into organized descriptive text, maps, tables, and diagrams concludes the development of the conceptual model. The purpose of this chapter is to document the development of the conceptual model for the Edwards–Trinity (Plateau) aquifer system in central-west Texas.

[1] Texas Water Development Board

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Geographic Setting

The Edwards–Trinity (Plateau) aquifer extends over an area of about 35,000 square miles beneath all or parts of 38 counties (Ashworth and Hopkins, 1995) in central-west Texas (Figure 2-1). Most of the counties have relatively sparse populations concentrated in small towns, usually the county seats (Figure 2-2). The study area extends to the northwest to include the Cenozoic Pecos Alluvium aquifer and to the southeast to include the Trinity aquifer because of their hydraulic connection to the Edwards–Trinity (Plateau) aquifer (Figure 2-1). The Edwards–Trinity (Plateau) aquifer is also hydraulically connected to several other major and minor aquifers of the state, which is discussed later in this chapter. The study area falls within five Regional Water Planning Areas (Far West Texas, Lower Colorado, Plateau, Region F, and South Central Texas), although the aquifer is located mostly within Region F and the Plateau region (Figure 2-3). In addition to two Priority Groundwater Management Areas, there are about 29 groundwater conservation districts in the study area (Figure 2-3).

Physiography

Physiography describes the natural features of the landscape in the context of topography, landforms, surface drainage, soils, and natural vegetation, all of which reflect upon the geologic and climatic history of the region. In the United States, natural regions have been hierarchically delineated into physiographic divisions, provinces, and sections (Fenneman, 1931; Thornberry, 1965). Under this classification, the Edwards Plateau Section occupies the southern margin of the Great Plains Province, which is located within the western portion of the Interior Plains Division. The Bureau of Economic Geology (BEG) at The University of Texas at Austin has delineated the Edwards Plateau into one of seven physiographic provinces within the state of Texas (Wermund, 1996). The BEG further subdivides the Edwards Plateau Province into the Principal Edwards Plateau, the Pecos Canyons, and the Stockton Plateau sub-provinces (Figure 2-4). The LBJ School of Public Affairs delineated eleven natural regions within the state for statewide and/or regional analysis (LBJ School of Public Affairs, 1978). Many of the eleven regions also consist of two or more sub-regions. The Edwards Plateau Region includes the Live Oak-Mesquite Savanna, Balcones Canyonlands, and Lampasas Cut Plain sub-regions. The 1957 revision of Erwin Raisz's "Landforms of the United States" remains a classic hand drawn map of natural features depicting landforms and physiographic regions of the country with remarkable detail (Raisz, 1957). The landscape image on Figure 2-4 identifies natural landforms and physiographic regions of the Edwards Plateau and adjacent landscape compiled from the various classifications.

The Edwards Plateau is defined here from the perspective of the laterally contiguous sediments of the Edwards–Trinity (Plateau) aquifer system. The Balcones Fault Zone, a system of stair-stepped faults essential to the development of the Edwards Plateau, has displaced the aquifer sediments and juxtaposed them against younger and less resistant sediments of the Gulf Coastal Plains. The resulting fault displacements have formed the Balcones Escarpment, a feature so prominent, that the effects on the landscape along the

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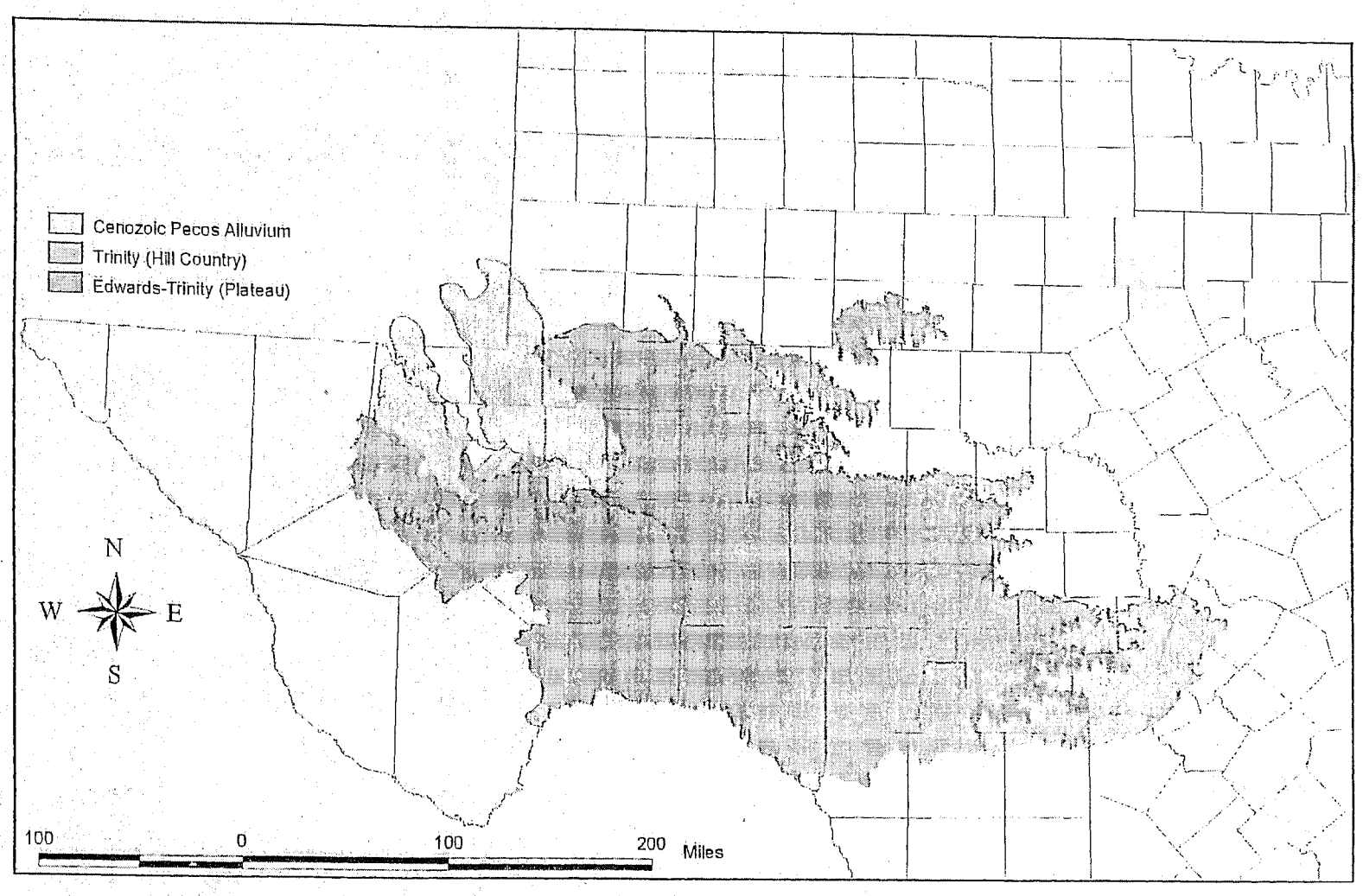

Figure 2-1: Areal extent of the Edwards–Trinity (Plateau) aquifer and the study area.

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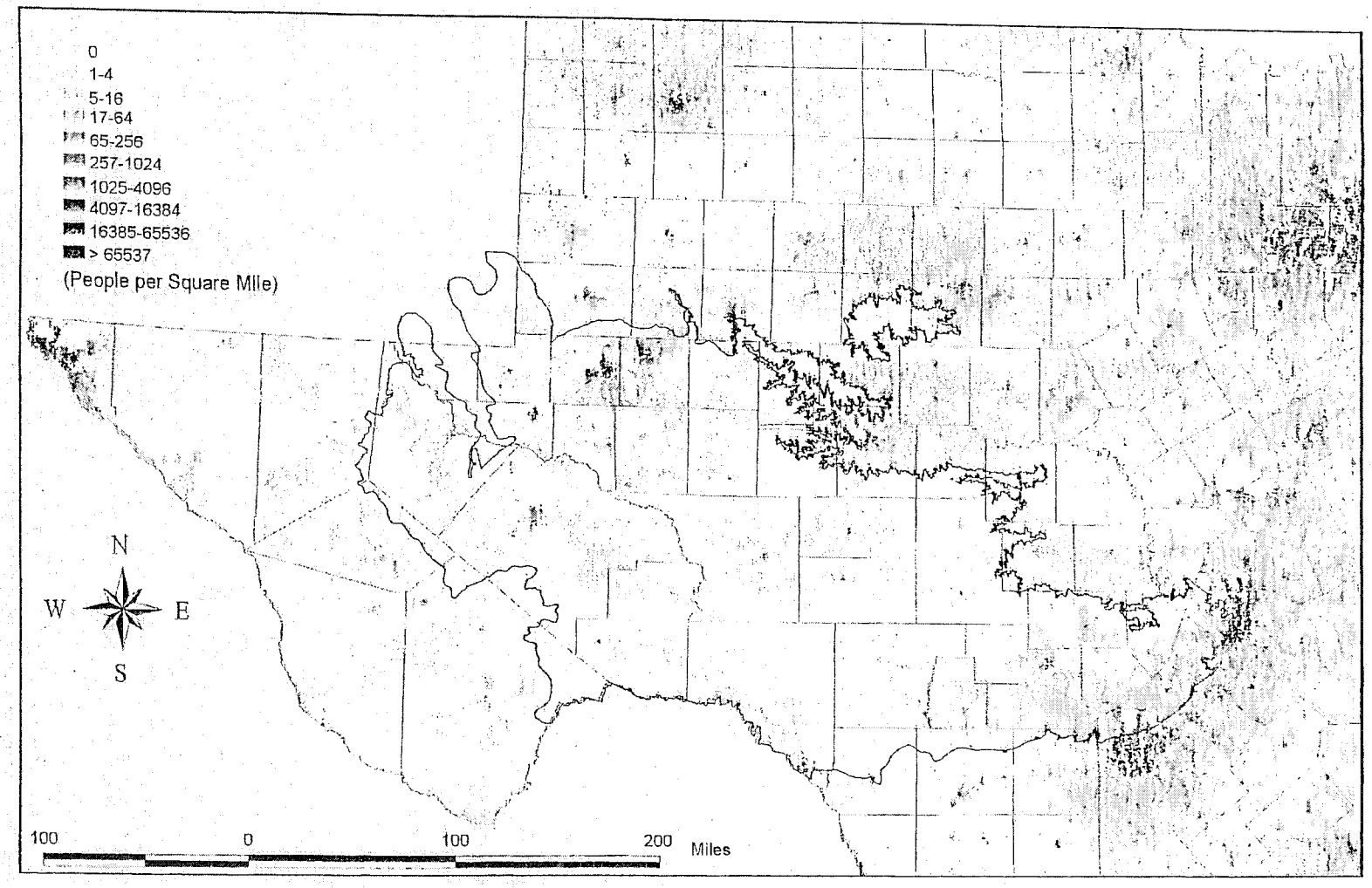

Figure 2-2: Population density from 2000 census.

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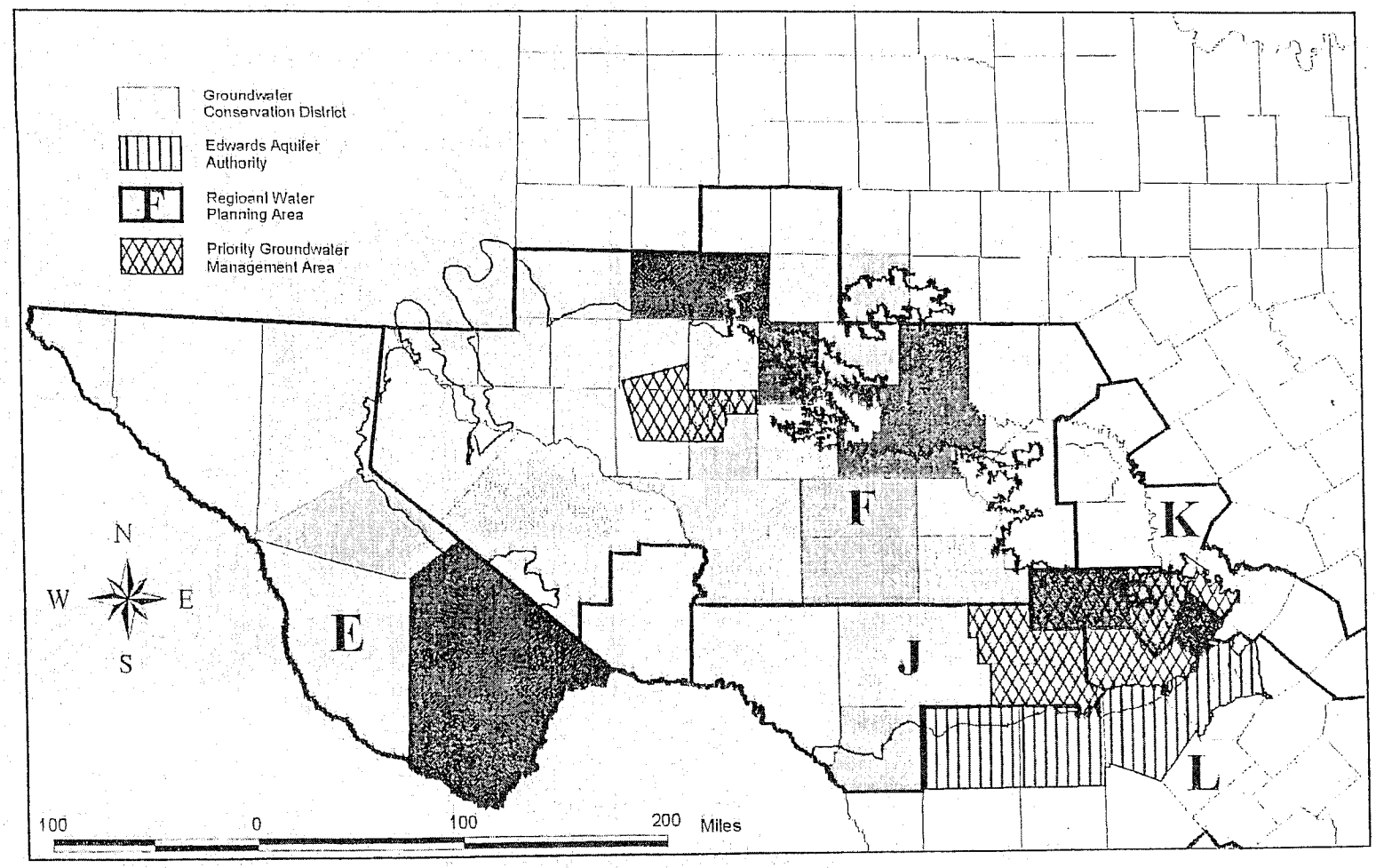

Figure 2-3: Boundaries of Regional Water Planning Areas (E = Far West Texas, F = Region F, J = Plateau, K = Lower Colorado, L = South Central Texas), Groundwater Conservation Districts, and Priority Groundwater Management Areas.

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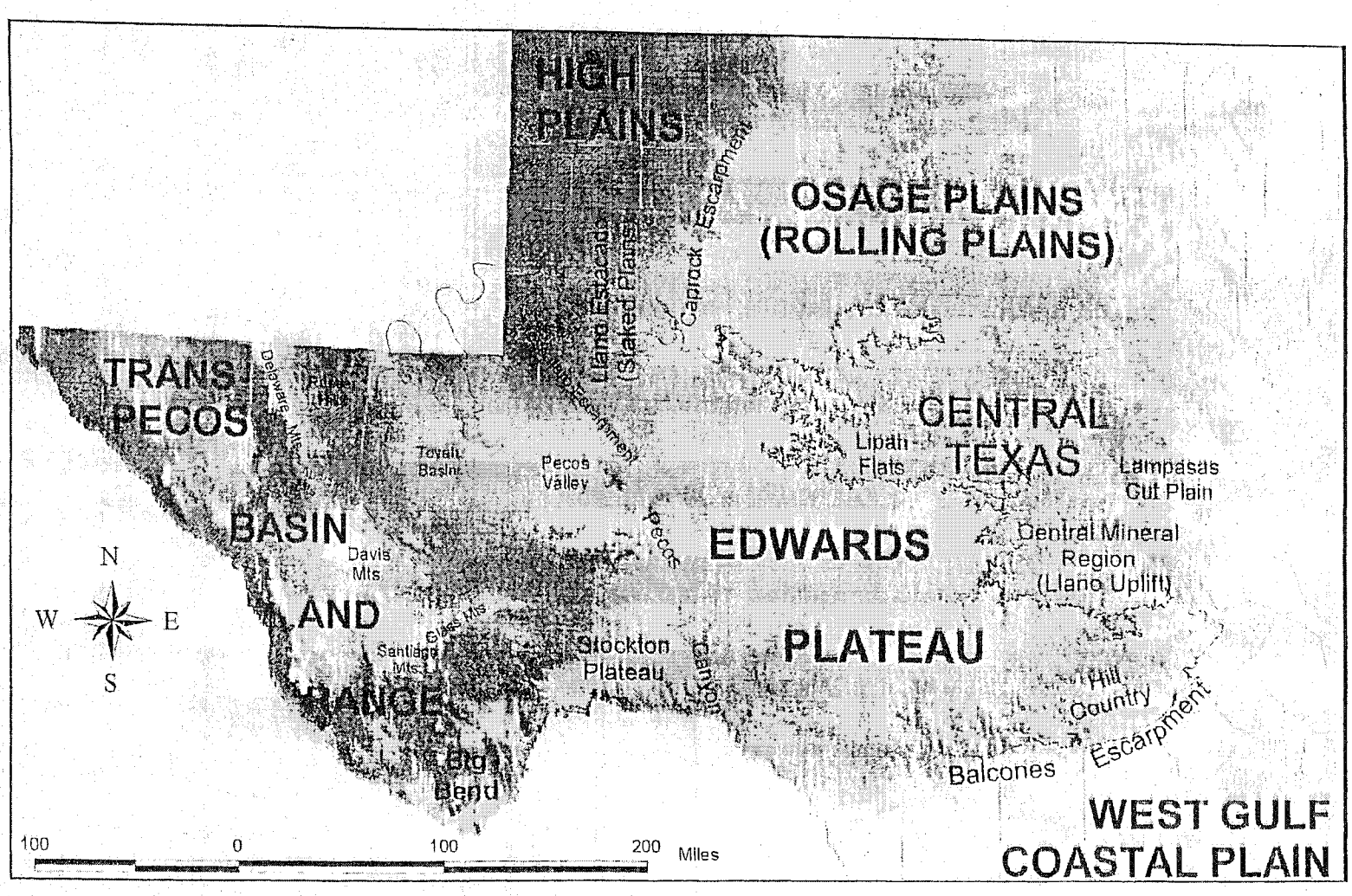

Figure 2-4: Landscape image showing natural landforms and physiographic regions.

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southern and southeastern margins of the plateau are visible from space (Figure 2-5). A pronounced removal of Edwards Group or upper layer of aquifer sediments by the headward erosion of major streams transecting the Balcones Escarpment formed the Balcones Canyonlands, more traditionally known as the Hill Country. The plateau and the aquifer sediments then terminate to the east along a margin of exposed Paleozoic and Pre-Cambrian rocks in the Central Mineral Region, often referred to as the Llano Uplift. Alluvial deposits form the Lipan Flats where the Concho River has cut and filled its way onto the northern plateau. Beyond the Lipan Flats and the northern margin of the Edwards Plateau are the Osage Plains, more commonly called the Rolling Plains, which extend west to the Caprock Escarpment of the High Plains. A thin drape of remnant Quaternary sand sediments, with playa lakes characteristic of the Llano Estacado (Staked Plains) region of the High Plains, extend down to cover a small area of the northeastern Edwards Plateau. These remnant sand sediments and the underlying Edwards–Trinity aquifer sediments terminate to the southwest along the southeast trending Mescalero Escarpment. The eastern flanks of the Rustler Hills (east of the Delaware Mountains), and the Apache, Davis, Glass, and Santiago mountains of the Trans-Pecos Basin and Range form the western boundary of the Edwards Plateau. Thick alluvial deposits fill the Pecos Valley between the western plateau boundary and the Mescalero Escarpment. A local drainage area between the Davis Mountains and the Pecos River is often referred to as the Toyah Basin. The Edwards–Trinity (Plateau) aquifer sediments extend beneath the Stockton Plateau located east of the Glass and Santiago mountains and west of the Pecos River Canyon and continue south into the western Big Bend region and across the Rio Grande into the northern area of the Mexican Chihuahua Desert.

Topography and Landform

The landform of the Edwards Plateau may be described as a flat tableland gently sloping from the northwest at about 3,000 feet above sea level to the southeast at about 2,000 feet above sea level (Figure 2-6). The Edwards Plateau is also one of the largest contiguous karst regions in the United States (Kastning, 1984). The karst morphology exhibits poorly integrated solution features with a sponge-like pattern on the plateau proper, whereas the southern plateau margin has well defined corridors of connected conduits aligned with faults and fractures of the Balcones Fault Zone (Kastning, 1984). The plateau is capped with thick Edwards Group limestone sediments that protect underlying less resistant Trinity and Paleozoic sediments from erosion. The Edwards Plateau has been in a prevailing state of erosion since the formation of the Balcones Escarpment. As the protective limestone cap is breached along the plateau's margins, streams easily carve deep canyons into the softer underlying sediments along the northern, eastern, and southern edges of the plateau. Topographic relief for the entire study area ranges from about 5,000 feet in the mountains of the Trans-Pecos to about 500 feet along the Lake Austin reach of the Colorado River where it flows across the Balcones Escarpment. The greatest local surface relief occurs in the mountainous Trans-Pecos region and the western Hill Country.

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Figure 2-5: Satellite image view of central-west Texas showing the Edwards Plateau and the Balcones Escarpment (Image source from University of Texas Center for Space Research).

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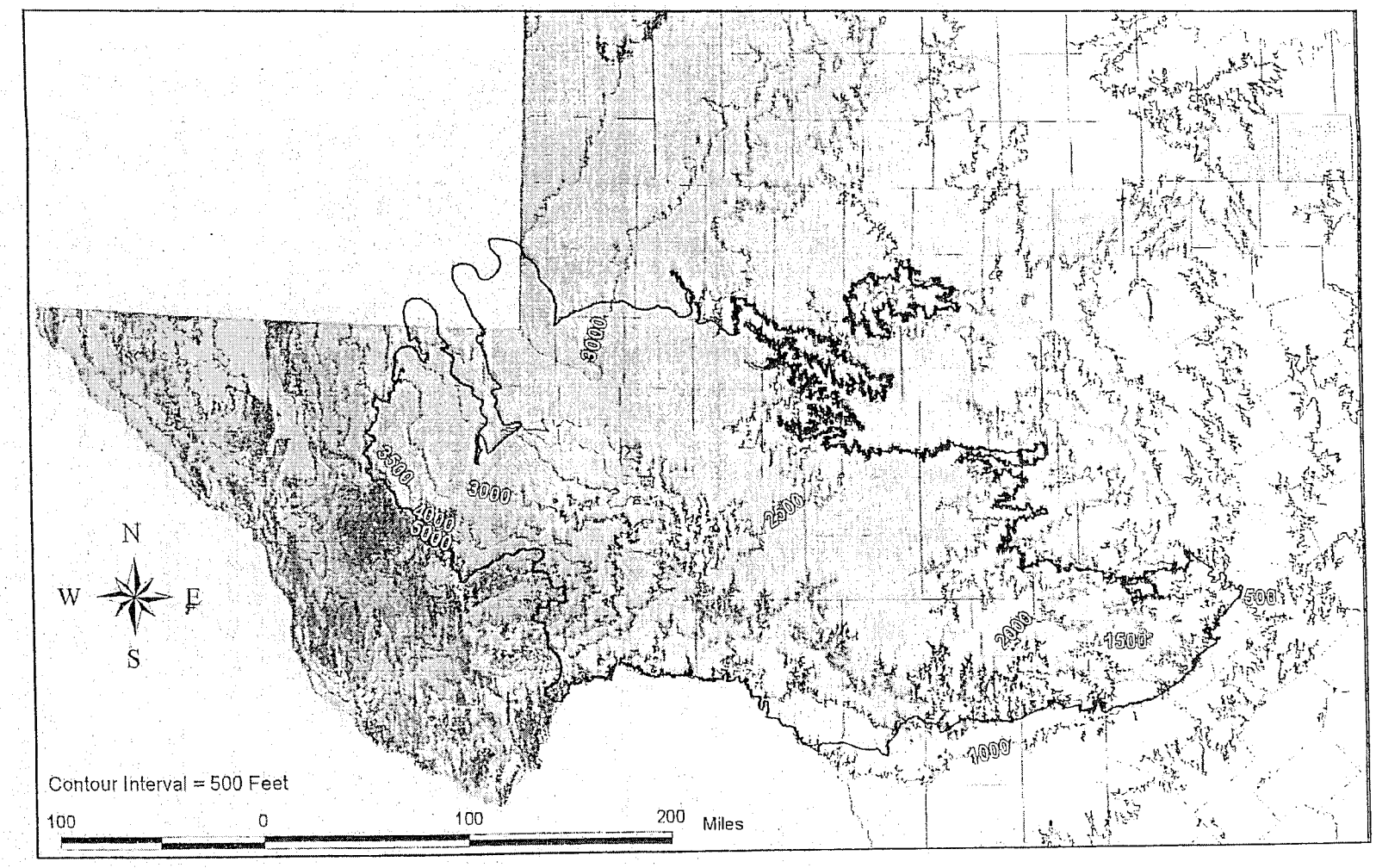

Figure 2-6: Topographic elevations of the Edwards Plateau.

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Surface Drainage

Permanent surface water is sparse to non-existent on the Edwards Plateau and occurs only along the spring-fed tributaries that dissect the northern, eastern, and southern plateau margins. Streams draining the plateau have a very dendritic or branch-like pattern characteristic of drainage patterns for flat-lying geologic strata (Figure 2-7). Stream density (stream channel length per unit area) on the plateau is mostly influenced by local and regional surface-water gradients. Stream density increases with increasing surface water gradients and approaches zero as the topography becomes flat where playa lakes may be the dominant surface-drainage features. However, there is also a distinct increase in stream density towards the east that may be attributed to both the spatial distribution of eastward-increasing mean annual precipitation and the southeastward regional outflow of groundwater draining from springs of the Edwards–Trinity (Plateau) aquifer. Tributary streams of the Colorado River such as the Concho, San Saba, Llano, and Pedernales rivers drain the northeastern portion of the Edwards Plateau into the Lipan Flats and the Llano Uplift. The Blanco, Guadalupe, Medina, Sabinal, Frio, and Nueces rivers drain the southeastern and southern portion of the plateau through the Hill Country and across the Balcones Escarpment. The Pecos River and Devils River, both major tributaries to the Rio Grande, drain the entire southwestern half of the study area. Although there are some small surface-water bodies (less than one square mile) in the central region of the plateau, the only noteworthy water bodies on the plateau are Big Lake (more often a dry lakebed) in Reagan County, Orient Reservoir in Pecos County, and Balmorhea Lake in Reeves County. Other much larger water bodies along the edge of the Edwards Plateau include Amistad Reservoir in Val Verde County, Twin Buttes and San Angelo Reservoirs in Tom Green County, and E. V. Spence Reservoir in Coke County.

Soil Development

The predominant soils for most of the Edwards Plateau are classified as Ustolls, a sub-order of Mollisols that drain easily and develop under grass or savanna type vegetation in subhumid to semiarid climates (USDA, 1999). In the northwestern-most portion of the plateau, remnant soils thicken into more sandy, loamy soils characteristic of the Staked Plains. These soils are classified as Aridisols and are based on the limited availability of soil moisture to sustain plant growth (USDA, 1999). The Aridisols also extend westward across the Pecos Valley into the Trans-Pecos Basin and Range, cover the southern portion of the Stockton Plateau, and continue south into the Big Bend region. In the eastern most portion of the plateau where the Edwards Group sediments have been removed, the soils have minimal soil horizon development and form on steep slopes of young geomorphic surfaces in a humid to subhumid climate (USDA, 1999; University of Idaho, undated). These soils of the eastern Hill Country are classified as Inceptisols. Another soil order found on the plateau includes the Vertisols, which are clay-rich and have high shrink and swell potential (USDA, 1999; University of Idaho, undated). These Vertisols are located in a small central portion of the plateau along the northwest to southeast trending flat topographic divide of the Colorado River and Rio Grande and in another small area of southern Reeves and western Pecos counties (Figure 2-8). Pleistocene paleo-soils that

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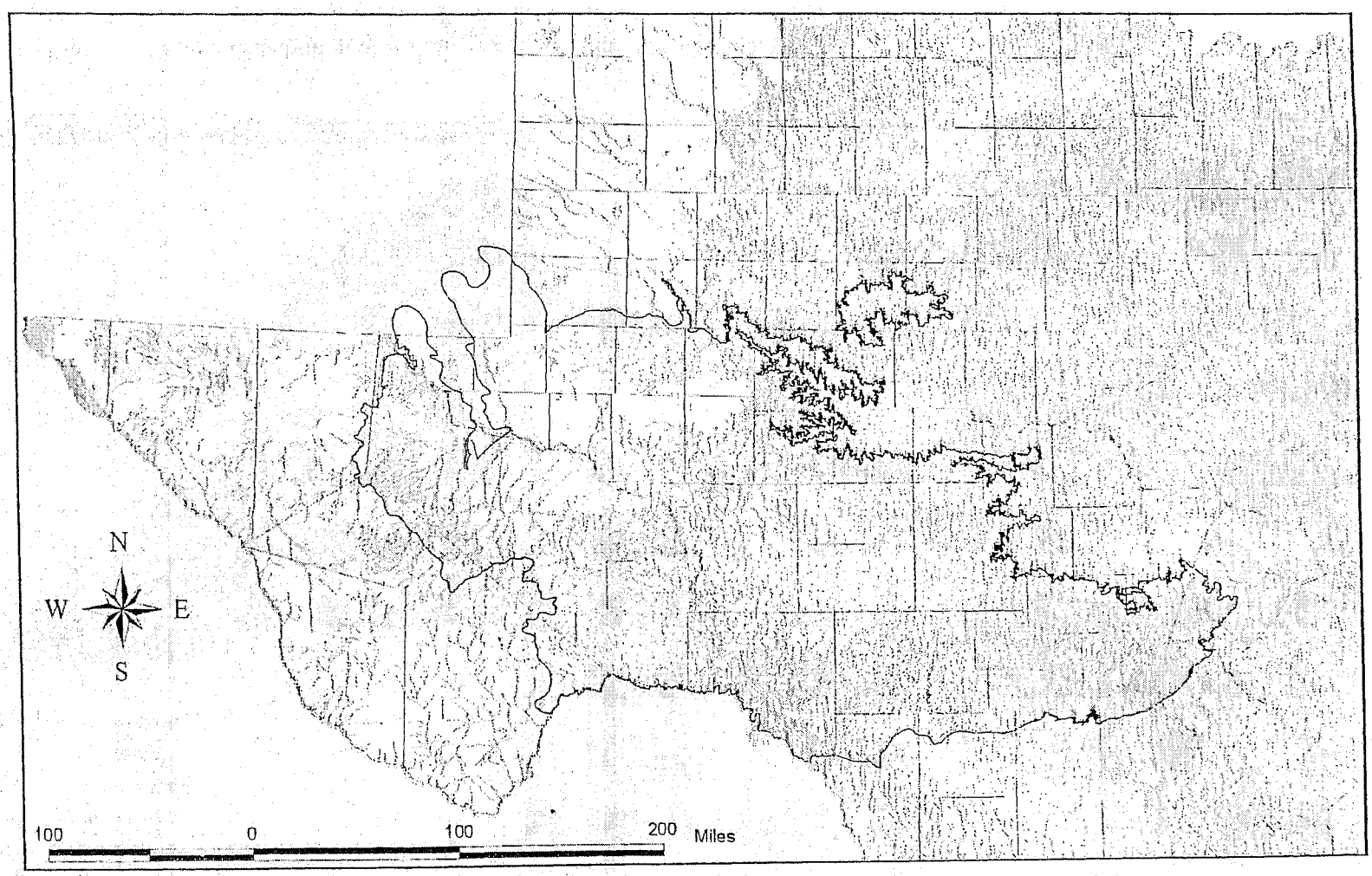

Figure 2-7: Drainage density and dendritic pattern of surface water drainage on the Edwards Plateau.

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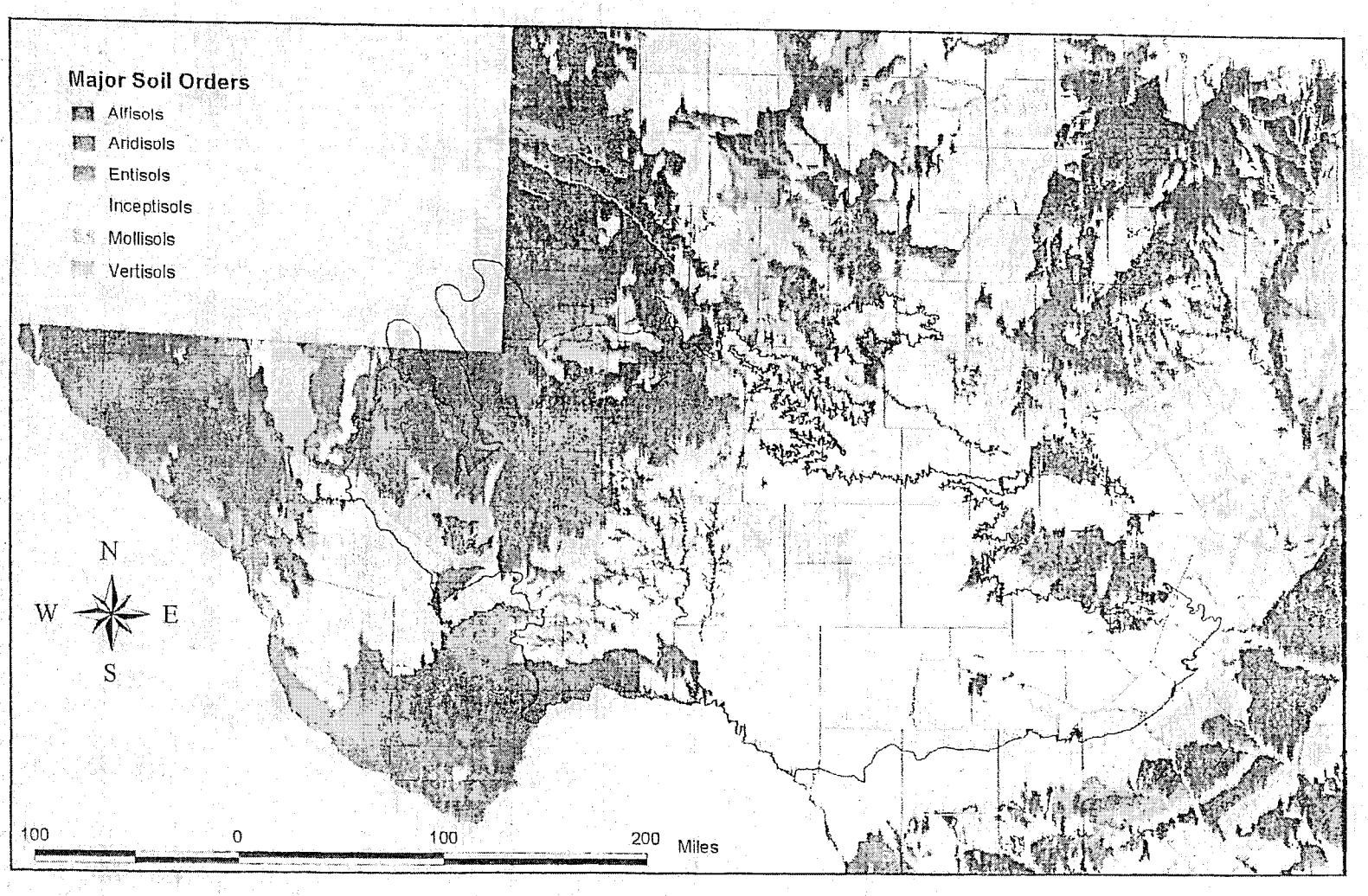

Figure 2-8: Spatial distribution of soil order types on the Edwards Plateau.

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formed about 0.73 to 2.0 million years before present and often called "terra rossas" may be found scattered throughout the plateau, usually within caves and sinkholes where they have been protected from erosion (Young, 1986). Following the last glacial maximum of the Late Pleistocene, the rate of soil erosion on the plateau is thought to have increased due to an increase in aridity and increased variability of seasonal precipitation (Cooke and others, 2003). However, this climate-driven event produced a rate of soil erosion an order of magnitude less than the more recent human induced erosion of soil from the plateau (Cooke and others, 2003). Heavy grazing and the suppression of natural grass fires during the past 150 years of European settlement have augmented the erosional state of the plateau and allowed the soils to develop thin and stony characteristics (Mecke, 1996). The thin characteristic nature of soils of the Edwards Plateau is shown in Figure 2-9.

Natural Vegetation

Early Spanish explorers described the vegetation on most of the Edwards Plateau as being dominated by a diversity of mid to tall grasses with short grasses covering the more arid western regions (Mecke, 1996). The grasslands have since been transformed by unsustainable landuse into a stunted scrubby savanna of oak, juniper, and grass in the north and east and desert shrub and woody mesquite brush in the southwest. The combined landuse effects of overgrazing and inhibiting the natural rejuvenation of grasses by fire allows invasive woody species such as mesquite or *ashe juniper*, often referred to as cedar, to change the landscape. The loss of grasslands reduce the amount of effective rainfall available for groundwater recharge and increase soil erosion while the woody vegetation consume more of the effective rainfall drying up natural springs. Salt cedar has invaded some stream valleys contributing to significant amounts of evapotranspiration. On the steeper canyon slopes, oak forests and oak–juniper woodlands are common. Some recent range management and brush control projects such as the Bamberger Ranch in Blanco County have shown that restoring the native grasslands is not only possible, but also beneficial in recovering springs dehydrated by the loss of grasslands to invasive and thirsty woody vegetation. Additional discussion of brush management on the plateau is provided in a later chapter.

Landuse

Ranching of cattle, sheep, and goats along with wild game hunting leases are the primary forms of land use except for the northern portion of the plateau where irrigated croplands of cotton and grain sorghum are the more dominant land use. Oil and gas production from deep underlying Permian Basin sediments is also common in the northern and western portions of the plateau. Hay, pasture, and small grains are grown in some of the valleys along the southern and eastern margins of the plateau where surface water and rainfall is more readily available. Over a sufficient period of time, mankind is capable of changing the natural vegetation, soils, hydrologic characteristics, and consequently the natural physiographic features of a large region such as the Edwards Plateau through landuse alone.

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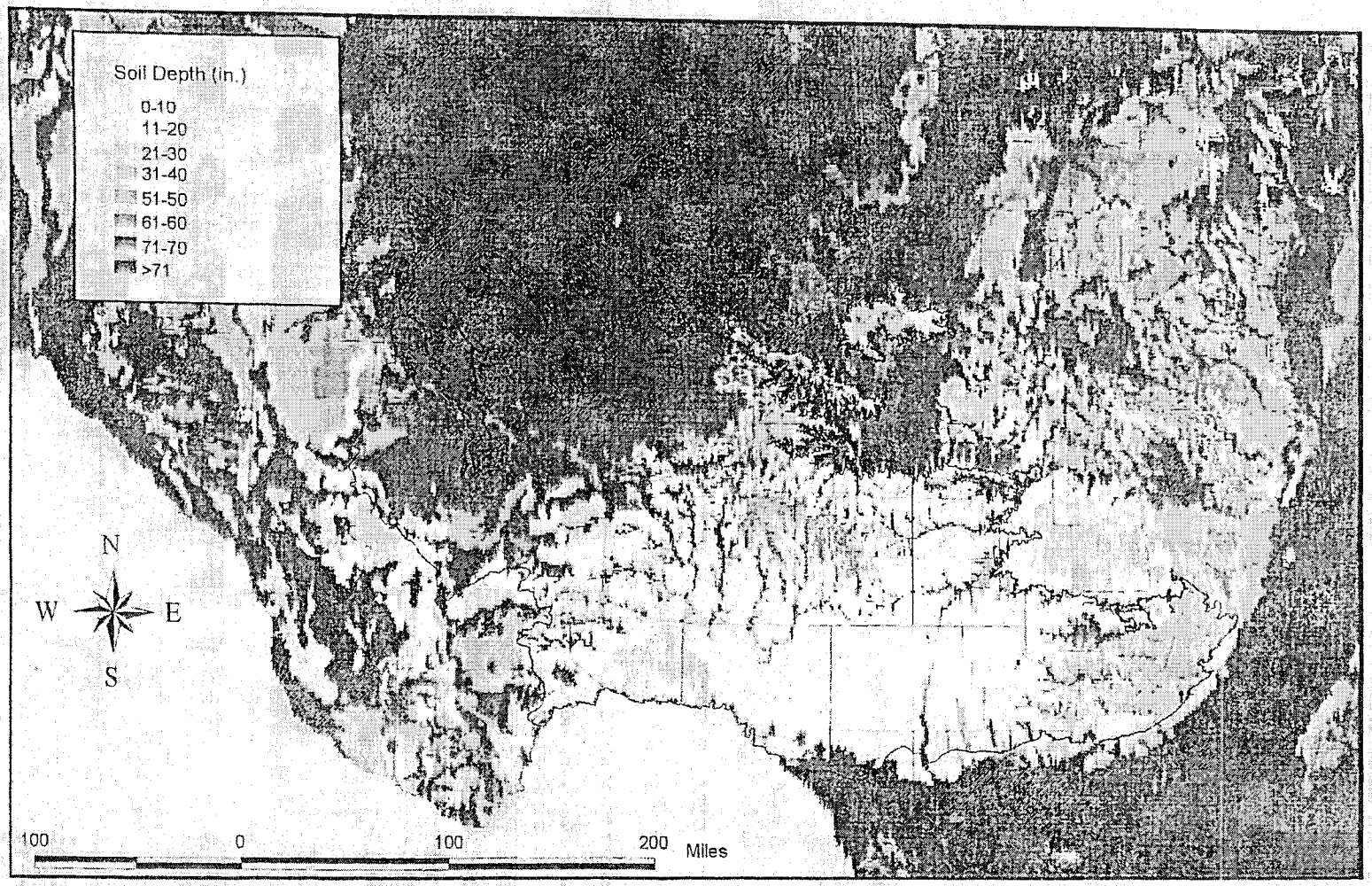

Figure 2-9: Spatial distribution of soil thickness on the Edwards Plateau. Note the thinner soils of the plateau.

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Climatic History

The climate of the Edwards Plateau was twice as wet during the Pleistocene as it is today according to studies of the "terra rossas" found in central Texas (Young, 1986). At some point after the last major ice age, the climate became more arid and variable (Cooke and others, 2003). The more recent climate of the Edwards Plateau ranges from subhumid in the eastern to semiarid in the western plateau (Walker, 1979). The long-term mean annual precipitation for the study area ranges from about 34 inches in the east to about 12 inches in the west (Figure 2-10, for years 1895 through 2000). On the eastern two thirds of the Edwards Plateau, precipitation occurs mostly during late spring and early fall as cool northern frontal air masses collide with warm moist Gulf air masses from the south. On the western third of the plateau, most of the precipitation occurs during July, August, and September. Figure 2-11 shows the significance of orographic precipitation along the Balcones Escarpment that is evident by the westward distortion of the thirty-year mean annual rainfall contours for 1961 to 1990 (Carr, 1967).

Tropical disturbances occasionally find their way onto the plateau from the warm late summer waters of the Gulf of Mexico and contribute to variability in annual precipitation totals. The variability of rainfall generally increases towards the arid west (Bomar, 1983) and the variation of total monthly precipitation is greatest for the month of September throughout the plateau. Other variations in the mean annual precipitation of the plateau may also be attributed to the cyclic interaction between the Pacific Ocean and the atmosphere, known as the El Nino-Southern Oscillation. Precipitation usually increases during the El Nino phase and decreases during the La Nina phase with the greatest variations in rainfall occurring during the fall and winter periods (Slade, 2001). Moreover, the statistical data analysis of stream-flow and precipitation records suggest a slight apparent increasing trend in the general variability of precipitation events over time (Slade, 2001). Rates of evaporation are high throughout the plateau and range between 43 inches in the east (Walker, 1979) to 80 inches in the west (Rees and Buckner, 1980). Droughts are common on the Edwards Plateau with about 10 moderate to severe droughts during the last 100 years. The drought of record occurred during the 1950s, consistent with the rest of the state. Drought on the plateau is discussed in more detail in a later chapter.

Geologic History

The Edwards–Trinity (Plateau) aquifer is composed of Early Cretaceous age sediments of the Trinity, Fredericksburg, and Lower Washita groups (Figure 2-12). The Trinity Group sediments form the underlying Trinity portion of the aquifer while the Fredericksburg and Lower Washita Group sediments form the overlying Edwards portion of the aquifer. The Edwards–Trinity aquifer sediments rest unconformable on top of an uneven erosional surface of Pre-Cretaceous age sediments, mostly folded and faulted Paleozoic age sediments. The following subsections a brief historical account of the evolutionary development of the Edwards–Trinity (Plateau) aquifer system (Figures 2-13 and 2-14).

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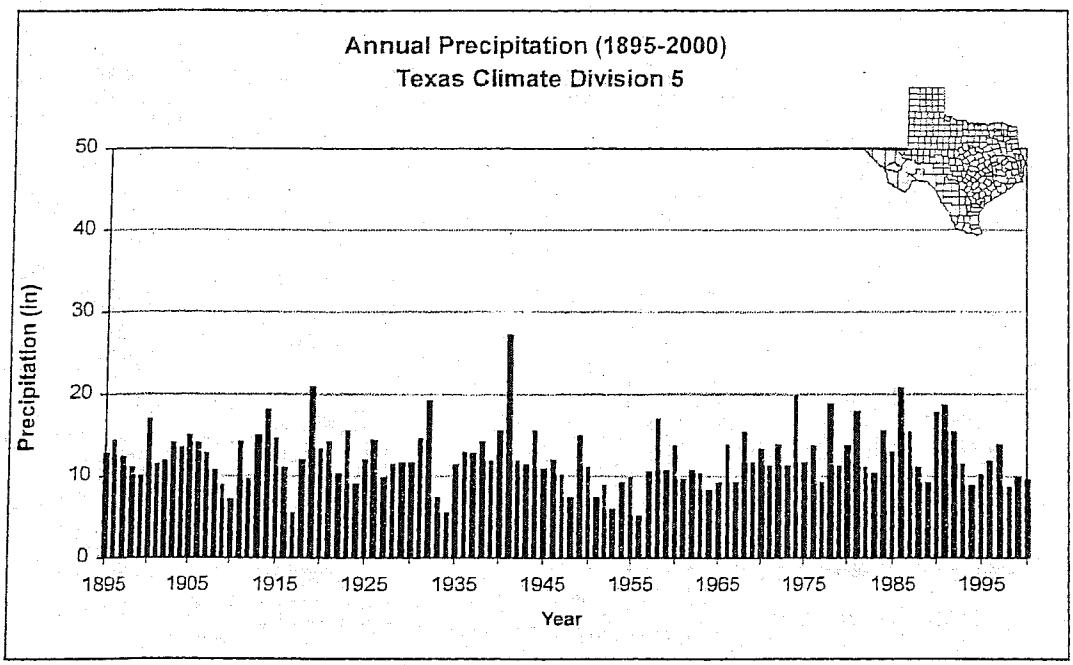

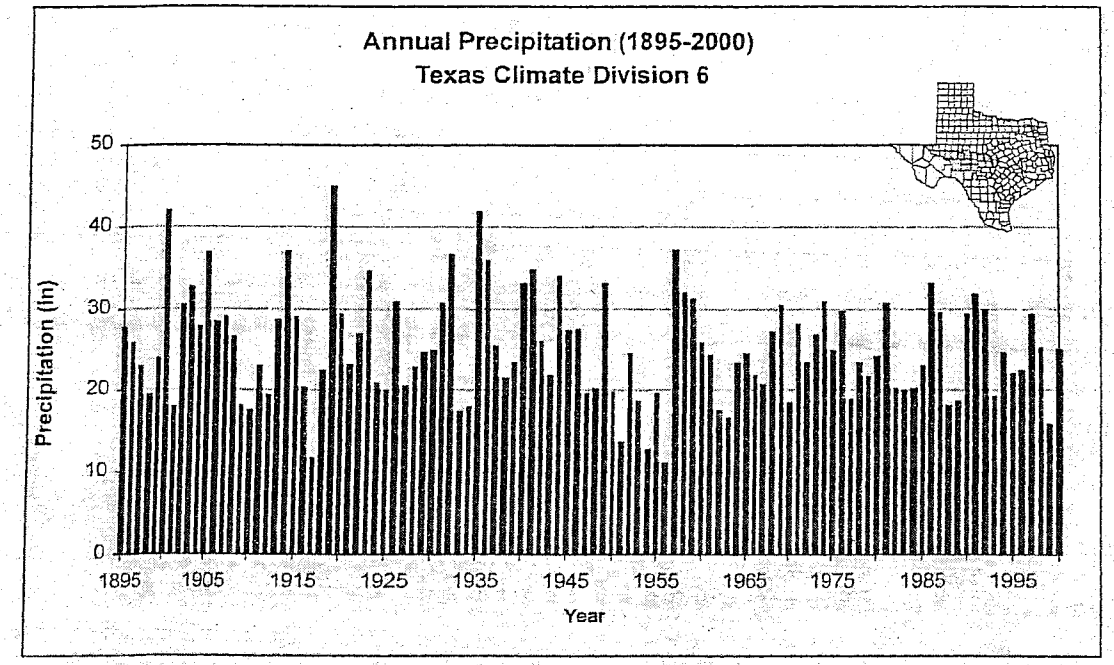

Figure 2-10: Long-term mean annual precipitation for 1895 to 2000.

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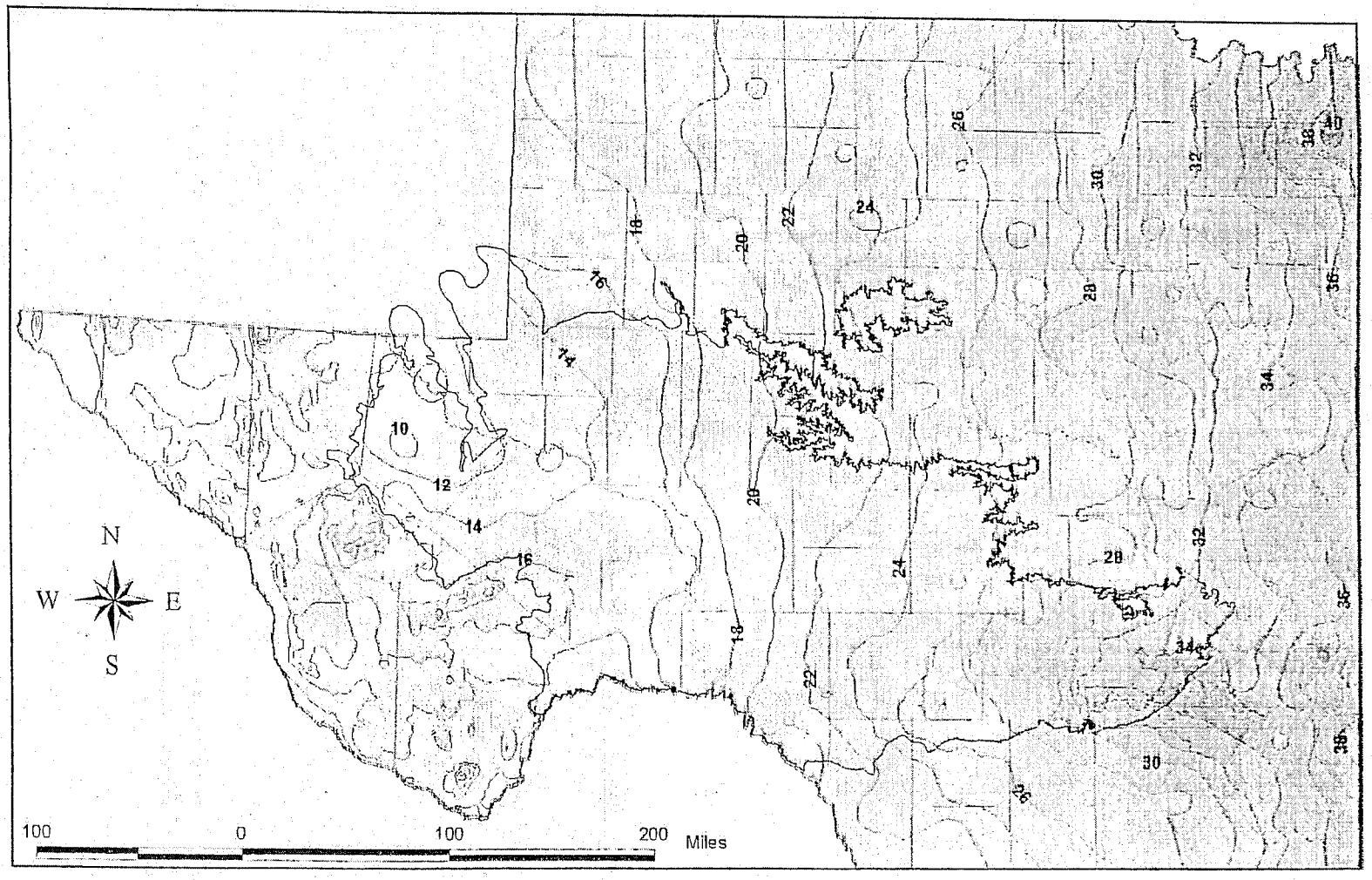

Figure 2-11: Mean annual precipitation for 1961 to 1990 in Texas (in inches).

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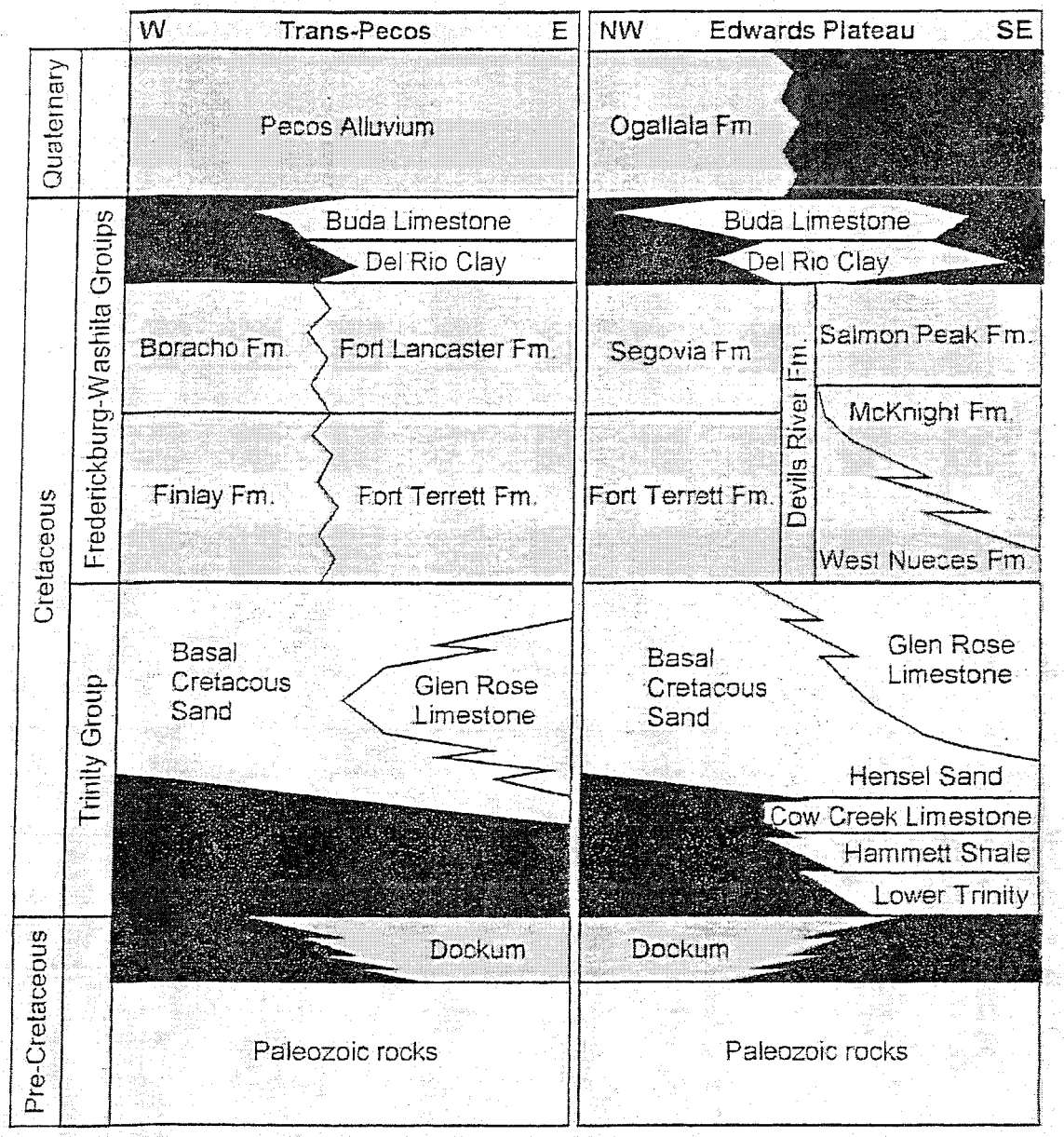

Figure 2-12: Stratigraphic chart of the Edwards–Trinity aquifer sediments (after Barker and Ardis, 1996).

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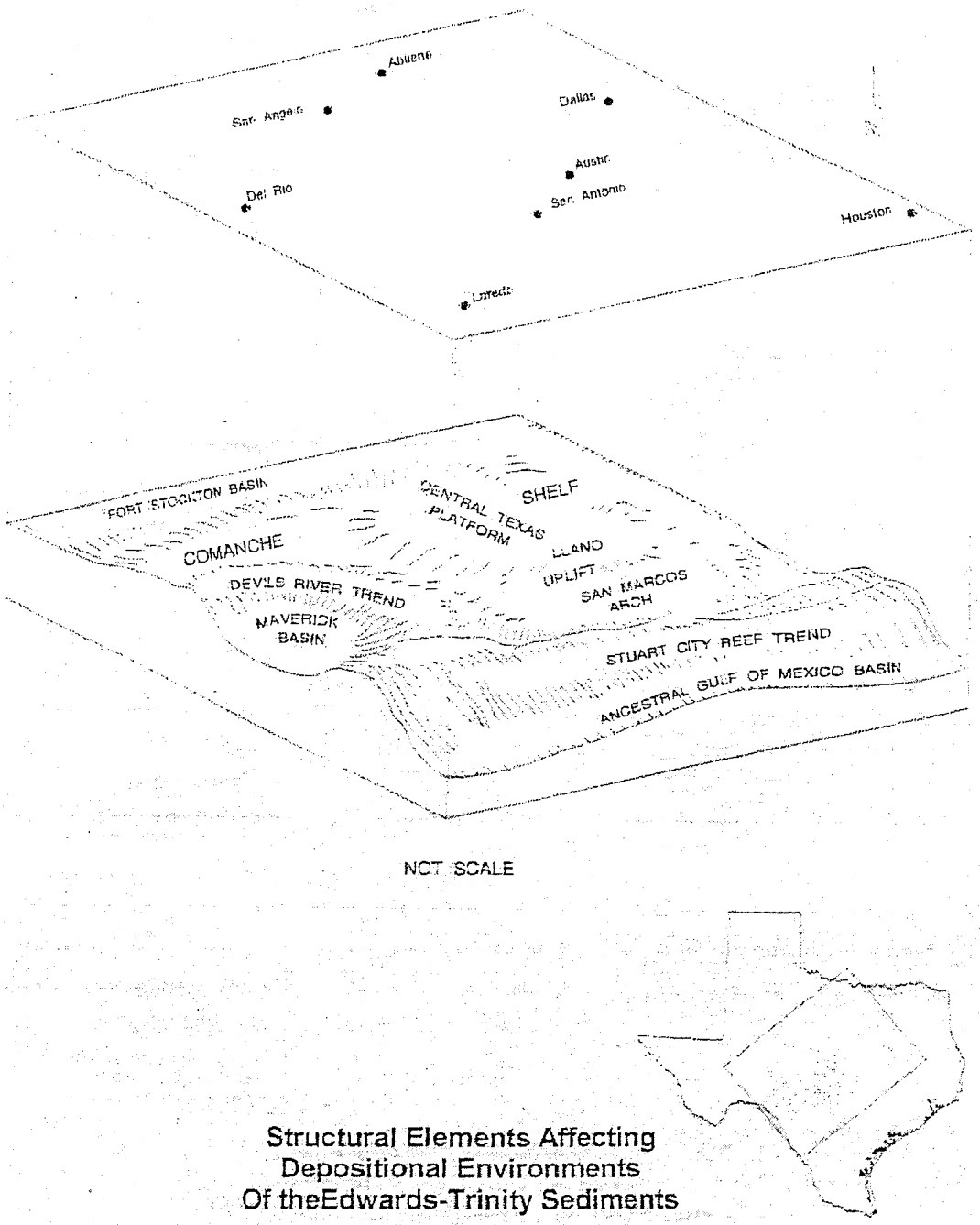

Figure 2-13: Structural elements affecting the depositional environments of the Edwards–Trinity sediments (from Barker and Ardis, 1996).

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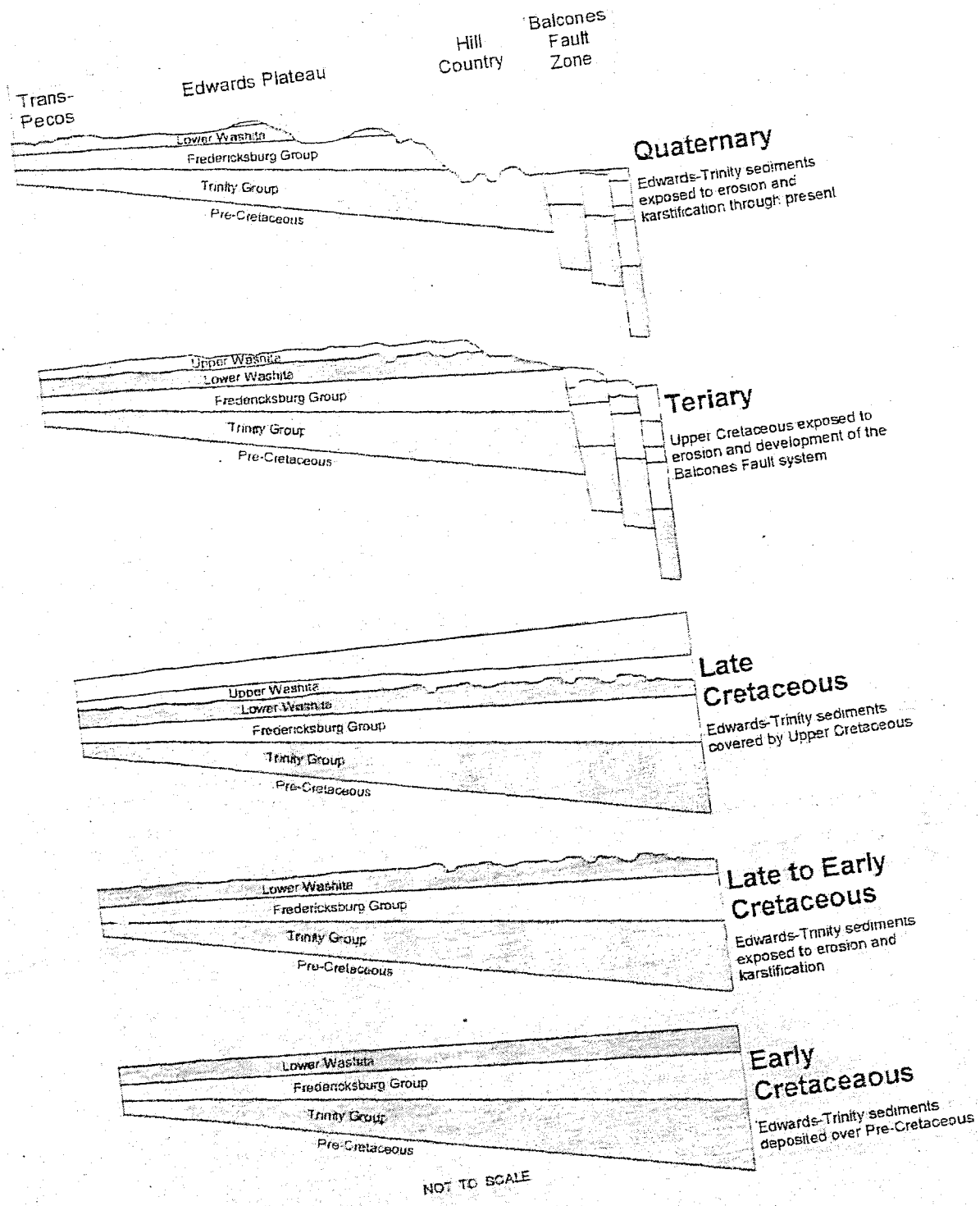

Figure 2-14: Evolutionary development of the Edwards–Trinity aquifer system (after Barker and others, 1994).

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Paleozoic

The Paleozoic Era ended with a tectonic event known as the Quachita orogeny. This orogenic event resulted in the formation of a structural fold belt of sediments deposited during the Ordovician, Silurian, Devonian, and Mississippian periods. The sediments were uplifted, faulted, and folded into a late Paleozoic mountain range that extended from northern Mexico along the present day Balcones Escarpment up into the Quachita Mountains of Oklahoma and Arkansas (Barker and Ardis, 1996). Before a final uplift during the Paleozoic Era, an arid and restricted shallow marine sea deposited Upper Permian sediments and evaporites into the Permian Basin of West Texas.

Triassic

During the Triassic Period, terrigenous clastic red beds were deposited over the Paleozoic rocks as the Dockum Group sediments. The area of the Edwards Plateau was then exposed to erosion during the Jurassic Period to form a rolling peneplain known as the Wichita Paleoplain (Barker and Ardis, 1996). By the end of the Jurassic Period, the Gulf of Mexico had begun to open and tilting of the peneplain towards the southeast provided a structural base for the deposition of the Cretaceous age Edwards–Trinity sediments.

Cretaceous

As the Gulf of Mexico continued to open and the Cretaceous seas advanced from the southeast, a broad continental shelf known as the Comanche Shelf began to form. The Llano Uplift, a tectonically active structural feature since the Pre-Cambrian, became a prominent structural shelf element for the deposition of the Trinity Group sediments (Barker and Ardis, 1996). The Early Cretaceous seas advanced across the Pre-Cretaceous structural base in three cycles of transgressive-regressive stages to deposit the Trinity Group sediments (Barker and others, 1994). The Stuart City Reef Trend began to form parallel to the ancestral Gulf of Mexico about 150 miles inland from the present Gulf Coast enabling the carbonate platform deposits of the Edwards Group sediments to accumulate to the northwest behind the protection of the reef. Other structural shelf elements that formed behind the Stuart City Reef Trend and controlled the depositional environments and lithologic characteristics of the Edwards Group formations include the Central Texas Platform, the San Marcos Arch, the Devils River Reef Trend on the edge of the Maverick Basin, and the Fort Stockton Basin (Figure 2-13). Prior to the deposition of Upper Cretaceous Del Rio, Buda, Boquillas, and Austin Group sediments, much of the Central Texas Platform was sub-aerially exposed allowing for an initial karstification of Lower Cretaceous carbonate sediments (Barker and others, 1994).

Cenozoic

Towards the end of the Cretaceous and beginning of the Tertiary Periods, the Laramide orogenic event and the dissolution of Upper Permian sediments, resulted in the structural collapse and erosion of overlying Triassic and Cretaceous sediments along the Pecos

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River Valley (Barker and others, 1994). These sediments were then redeposited as the Cenozoic Pecos Alluvium throughout the Tertiary and into the Quaternary Periods. During the mid-Tertiary Period, regional uplift and continued deposition of sediments into the Gulf of Mexico provided tensional stresses along the ancient Quachita fold belt. Consequently, the development of the Balcones Fault Zone occurred and displaced Cretaceous and Lower Tertiary sediments by 900 to 1,200 feet (Barker and others, 1994). The Ogallala sediments were deposited over a portion of the Edwards–Trinity sediments from the northern region of the plateau during the late Tertiary Period. The headward erosion of streams has reduced the plateau into its current form throughout the Quaternary.

Previous Investigations

Previous studies on the Edwards–Trinity (Plateau) aquifer began with county-wide studies by the Texas Board of Water Engineers, the Texas Water Commission, the Texas Department of Water Resources, the Texas Water Development Board, and the U.S. Geological Survey. The Texas Department of Water Resources was the first to publish regional study reports on the Trans-Pecos (Rees and Buckner, 1980) and Plateau (Walker, 1979) portions of the Edward-Trinity aquifer. During the late 1980s, the U.S. Geological Survey (USGS) began a Regional Aquifer Systems Analysis (RASA) program for the Edwards–Trinity aquifer system that resulted in the publication of the most recent and comprehensive reports on the aquifer system model (Bush, 1986; Kuniansky, 1989; Kuniansky, 1990; Barker and Ardis, 1992; Ardis and Barker, 1993; Bush and others, 1993; Barker and others, 1994; Bush and others 1994; Barker and Ardis, 1996) as well as a single-layer finite element steady-state numerical groundwater model (Kuniansky and Holligan, 1994). The USGS has also published a groundwater atlas for Oklahoma and Texas that includes a very informative executive summary of the Edwards–Trinity aquifer system (Ryder, 1996). Currently, the Texas Water Development Board is conducting a comprehensive study to develop a state-of-the-art two-layer finite difference numerical groundwater model of the Edwards–Trinity aquifer system with a final report due for publication in 2004. Information on this most recent modeling study is maintained at the following Web address: http://www.twdb.state.tx.us/gam/.

Hydrogeologic Setting

The hydrogeologic setting provides for an understanding of the aquifer system's physical parameters, stress variables, and their interactions. Physical parameters include aquifer characteristics that remain constant over relatively long periods of time such as the hydrostratigraphy, structural geometry, hydraulic properties, steady-state water levels, and regional groundwater flow. Stress variables include aquifer characteristics that fluctuate over time such as recharge, well discharge, and natural interactions between groundwater and surface water such as springs, streams, and lakes.

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Hydrostratigraphy

The hydrostratigraphy represents the vertical and lateral organization of the various hydrogeologic units of the Edwards–Trinity (Plateau) aquifer system and is shown in the stratigraphic chart on Figure 2-12 and discussed below.

Paleozoic

The Hickory, the Ellenburger–San Saba, and the Marble Falls aquifers are hydraulically connected to the Edwards–Trinity aquifer along the eastern margin of the plateau surrounding the Llano uplift. The Permian age Capitan and Rustler sediments are hydraulically connected to the Edwards–Trinity sediments in the Trans-Pecos portion of the aquifer (Bush and others, 1994). In general, most of the underlying Paleozoic rocks provide for a relatively impermeable base for the Edwards–Trinity aquifer sediments (Barker and Ardis, 1992).

Triassic

The Dockum Group consists of the Lower (Tecovas Formation), Middle (Santa Rosa Formation), and Upper (Chinle Formation) members (Walker, 1979). Only where the Chinle Formation is missing, allowing for the Basal Cretaceous sands to be in hydraulic communication with the underlying Santa Rosa Formation, is the Santa Rosa Formation considered to be an aquifer (Walker, 1979).

Cretaceous

The Trinity Group sediments are composed of the Lower, Middle, and Upper Trinity aquifer units in the southeastern portion of the plateau (Ashworth, 1983). The Lower Trinity consists of Hosston Sand (Sycamore Sand in the outcrop), Sligo Formation, and Hammett Shale. The Middle Trinity consists of the Cow Creek Limestone, Hensel Sand, and the lower member of the Glen Rose Limestone. The Upper Trinity consists of the upper member of the Glen Rose Limestone (Mace and others, 2000). In the Trans-Pecos region of the plateau, the Trinity Group sediments are composed of the Yearwood Formation and the Cox Sandstone. Elsewhere on the plateau, the Trinity Group sediments are composed of the Basal Cretaceous Sand, the Glen Rose Limestone, and the Maxon Sand. The Basal Cretaceous Sand and Maxon Sand are sometimes lumped together and referred to as the Antlers Sand or Trinity Sands in the northern plateau area where the Glen Rose Limestone is absent.

The Edwards Group and equivalent sediments consist of the Fredericksburg and Lower Washita Group sediments. The Fredericksburg Group consists of the Finlay Formation within the Fort Stockton Basin; the Fort Terrett Formation within the Central Texas Platform; the Devils River Formation within the Devils River Reef Trend; the West Nueces and McKnight formations within the Maverick Basin; and the Kainer Formation within the San Marcos Arch. The Lower Washita Group sediments are composed of the Boracho Formation within the Fort Stockton Basin; the Segovia Formation within the

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Central Texas Platform; the Devils River Formation within the Devils River Reef Trend; the McKnight and Salmon Peak formations within the Maverick Basin; and the Person Formation within the San Marcos Arch.

The Upper Cretaceous sediments include the upper most section of the Washita Group sediments (the upper confining Del Rio Clay and the Buda Limestone) along with the Eagal Ford Group (Boquillas Formation) and the Austin Group sediments.

Cenozoic

The Cenozoic Pecos Alluvium aquifer is hydraulically connected to the Edwards–Trinity (Plateau) aquifer in the northwestern edge of the aquifer. The Upper Tertiary Ogallala Formation is hydraulically connected only in the northern-most portion of the Edwards–Trinity (Plateau) aquifer.

Structural Geometry

The initial base depositional surface of the Cretaceous sediments is generally flat and tilted towards the Gulf of Mexico. Consequently, the Edwards–Trinity sediments form a wedge that thickens from the north and northwest towards the south and southeast. The exceptions to this structural trend are in the areas near the Llano Uplift and the Trans-Pecos Basin and Range. The Llano Uplift is a tectonic structural high that has persisted throughout the geologic history of the region. Edwards–Trinity sediments were deposited over this structural high and later removed by erosion. The Trans-Pecos Basin and Range is the result of a more recent geologic event, the Laramide Orogeny, which uplifted and block faulted the Edwards–Trinity sediments into mountain ranges and graben basins. The wedge of Cretaceous sediments pinches out beneath the Ogallala sediments in the northern portion of the plateau (Barker and Ardis, 1996). The wedge of Cretaceous sediments is faulted and offset along the south and southeast by the Tertiary Balcones Fault Zone system. Most of the Edwards Group sediments and portions of the Upper Trinity sediments have been removed in the canyonland areas of the Texas Hill Country. A small portion of the Edwards–Trinity (Plateau) aquifer is confined in Val Verde and Kinney counties beneath the Upper Cretaceous Del Rio Clay. The semi-permeable Upper Cretaceous sediments of the Buda Limestone and Boquillas Formation form a thin cap over the Edwards Group in the central and southwestern portions of the aquifer.

Data were collected from several sources and merged within a Geographic Information System (GIS) for analysis. By using geostatistical techniques within the GIS framework, structural surfaces were developed for the tops and bottoms of both the Edwards and Trinity aquifer units (Figures 2-15 and 2-16). The base of the Trinity sediments shows a paleo-valley coincident with the lower Pecos River (Figure 2-15). In addition, a local high exists near the intersection of Schleicher, Menard, Sutton, and Kimble counties. The base of the Edwards sediments also shows the same local high in addition to the Maverick Basin along the southwestern portion of Val Verde County (Figure 2-16). The structural surfaces show a steep gradient along the Balcones Fault Zone that generalizes the fault

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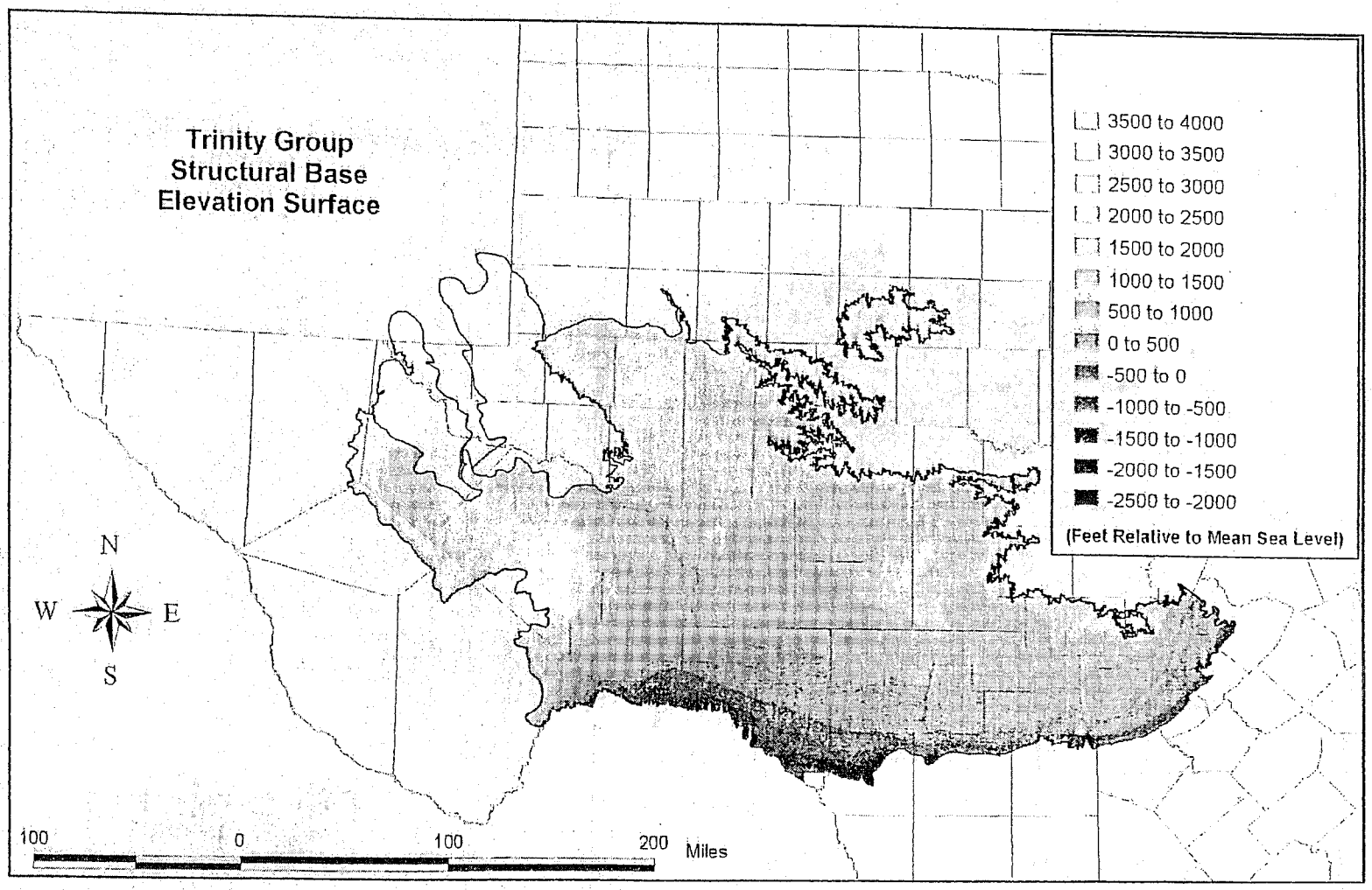

Figure 2-15: Interpolation of the base of the Trinity aquifer unit.

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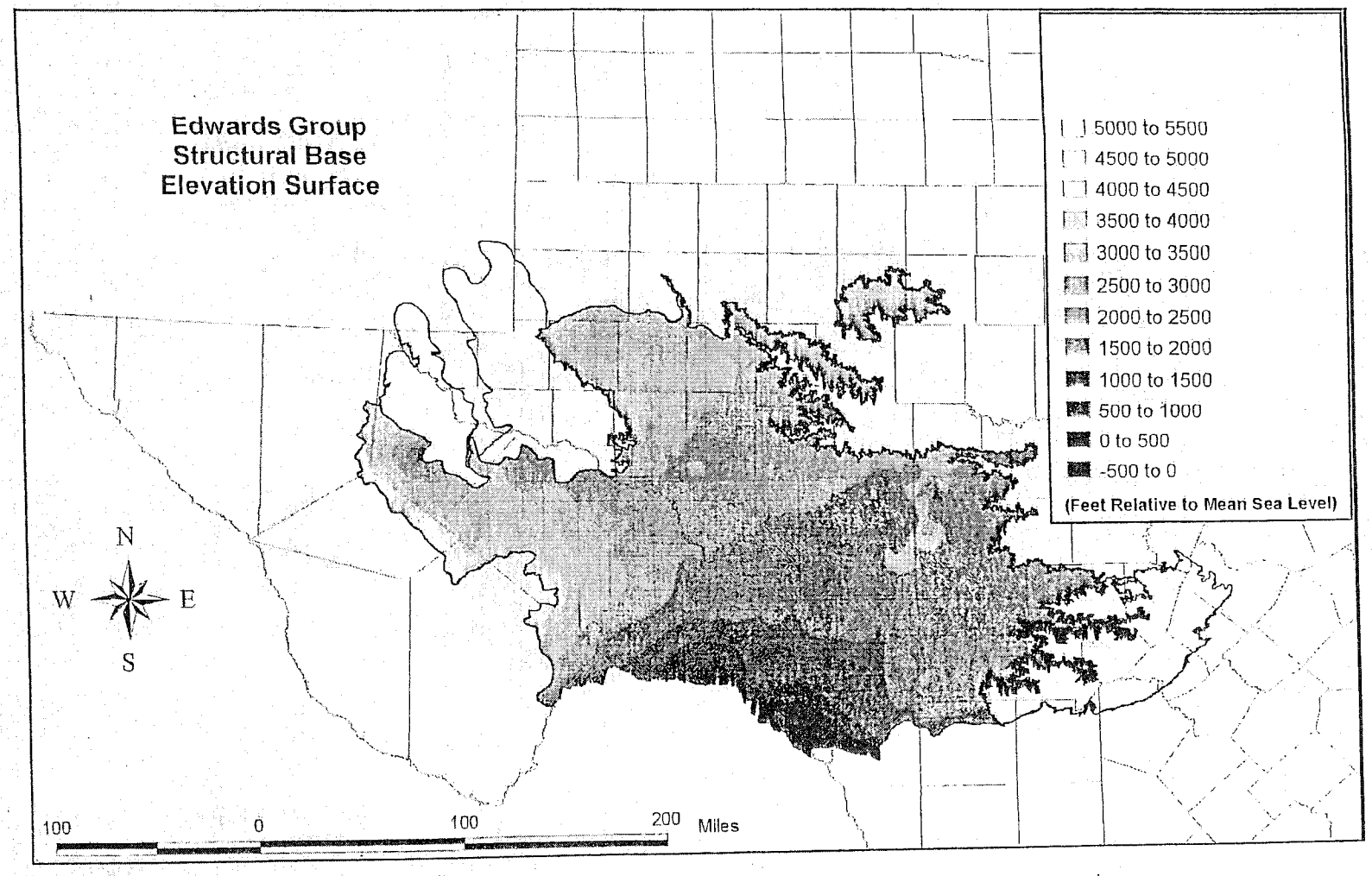

Figure 2-16: Interpolation of the base of the Edwards aquifer unit.

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system rather than actually representing the abrupt stair-stepped offsets of the individual faults.

Hydraulic Properties

The Edwards–Trinity (Plateau) aquifer is hydraulically connected to four major aquifers: (1) the Cenozoic Pecos Alluvium, (2) the Ogallala, (3) the Trinity, and (4) the Edwards (Balcones Fault Zone). The Edwards–Trinity (Plateau) aquifer is also hydraulically connected to several minor aquifers: (1) the Dockum, (2) the Capitan Reef Complex, (3) the Rustler, (4) the Hickory, (5) the Ellenburger-San Saba, (6) the Lipan, and, to a very small degree, (7) the Marble Falls.

The saturated thickness of less than 100 feet to greater than 800 feet for the Edwards–Trinity (Plateau) aquifer system generally increases from north to south and varies the greatest along the western margins of the aquifer. Gentle north-south trending ridges and troughs of the folded Paleozoic base depositional surface combined with the topographic influence on the water table control the variability in saturated thickness (Barker and Ardis, 1996). The aquifer is mostly under water table or unconfined conditions, although the Trinity unit of the aquifer may be semi-confined locally where relatively impermeable sediments of the overlying basal member of the Edwards Group exists (Ashworth and Hopkins, 1995).

Transmissivity is a function of the conductivity of the aquifer sediments and the saturated thickness. The Edwards–Trinity (Plateau) aquifer generally has transmissivity values of less than 5,000 feet squared per day in the north and eastern portions of the aquifer and values between 5,000 and 50,000 feet squared per day in the southern and western portions of the aquifer with an average of less than 10,000 feet squared per day (Barker and Ardis, 1996). Except for areas of significant karst induced permeability, the average hydraulic conductivity of the Edwards–Trinity aquifer sediments is about 10 feet per day based on transmissivity and saturated thickness distributions (Barker and Ardis, 1996).

Specific-capacity test data were collected from the Texas Commission on Environmental Quality (TCEQ) and analyzed to calculate hydraulic conductivity values for both the Edwards and Trinity aquifer units. The spatial locations of these specific capacity data are limited to the area of a standard two and one-half minute quadrangle. An assumption was made to locate the specific-capacity data to the center of their respective quadrangle. Pumping-test data were then collected from the TWDB groundwater database and analyzed to calculate hydraulic conductivity for both Edwards and Trinity aquifer units. In addition, one or more pumping tests were conducted in almost every county of the aquifer system by TWDB staff during 2000. The pumping test data had unique latitude and longitude coordinates assigned to them. The calculated conductivity data were then analyzed and spatially interpolated using geostatistical techniques (Figures 2-17 and 2-18).

The geometric mean of the hydraulic conductivity for the Edwards aquifer unit was calculated at about 6.5 feet per day. The median hydraulic conductivity for the Trinity

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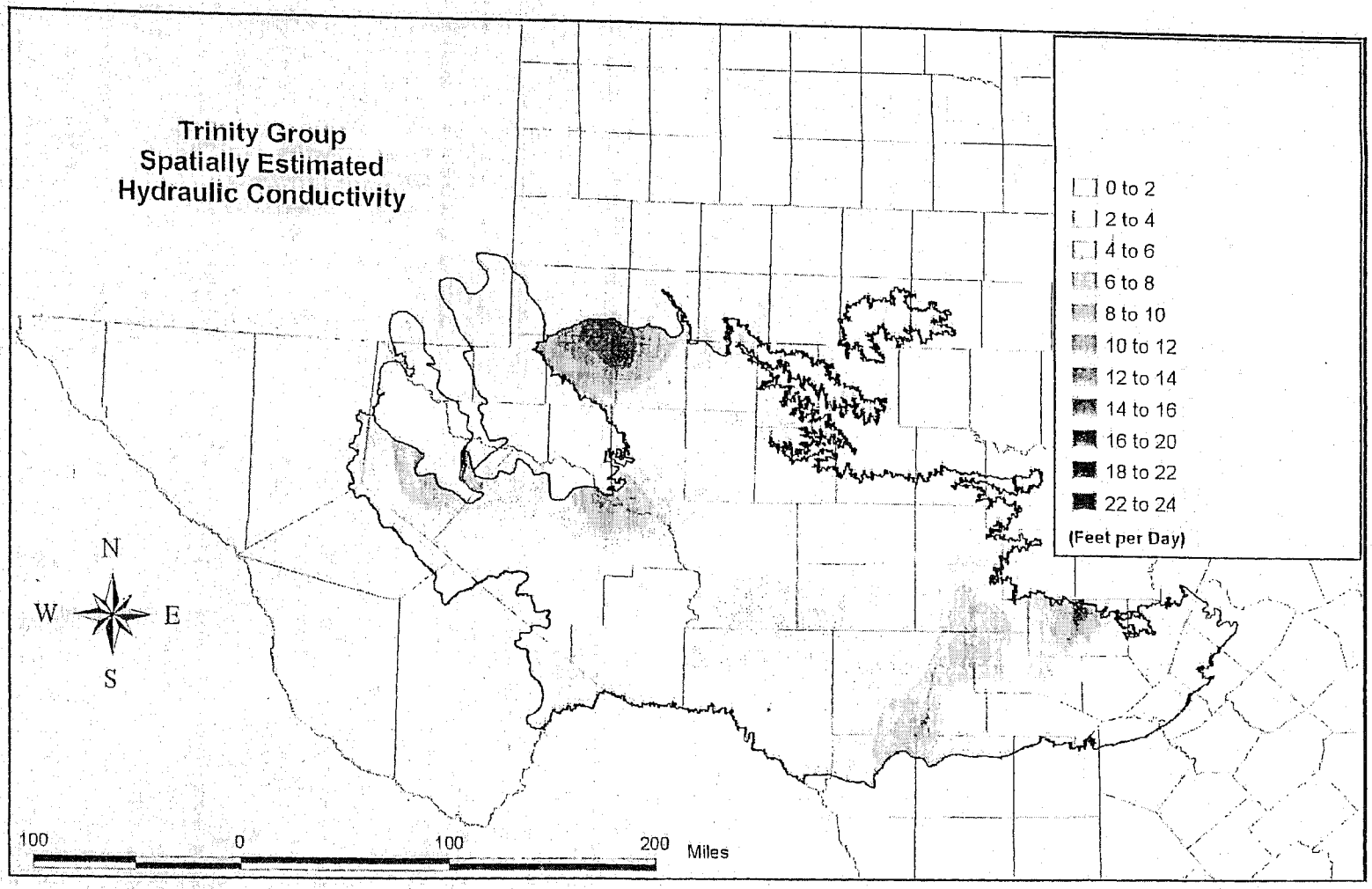

Figure 2-17: Estimated spatial interpolation of hydraulic conductivity for the Trinity aquifer sediments.

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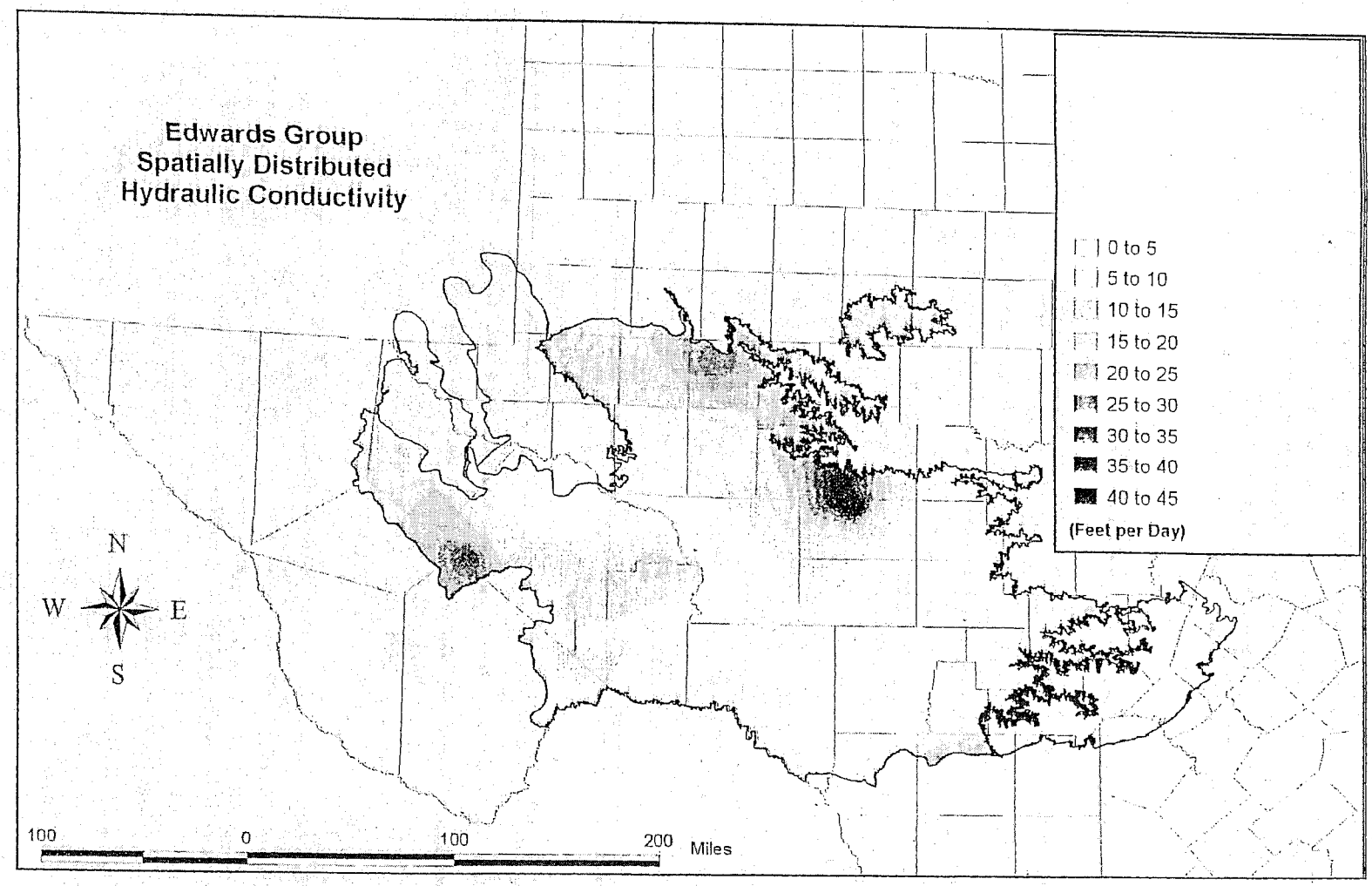

Figure 2-18: Estimated spatial interpolation of hydraulic conductivity for the Edwards aquifer sediments.

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aquifer unit was calculated at about 2 feet per day for the southern part of the aquifer and about 4.5 feet per day for the northern part of the aquifer. Two different median hydraulic conductivity values were calculated for the Trinity aquifer unit because of the difference in sediment composition between the southern and northern parts of the aquifer unit. The southern part of the aquifer is composed of the shale, sand, and limestone transgressive-regressive sequence of the Lower, Middle, and Upper Trinity whereas the northern part is composed of the Trinity Sands.

Water Levels and Regional Groundwater Flow

Although water levels of the Edwards–Trinity aquifer system are influenced by climate, they have remained fairly constant except in areas of the northern and western plateau where a general trend of declining water levels has occurred as a result of increased irrigation pumpage (Ashworth and Hopkins, 1995). Steady-state water levels for the Edwards–Trinity aquifer were analyzed to gain an understanding of the regional groundwater flow within the aquifer system. Water level data from the TWDB groundwater database were queried for the first winter measurements of each well record available for both the Edwards and Trinity aquifer units and excluding measurements taken during the 1930s and 1950s drought years. The water-level data were queried with the assumption that they would have minimal influence from climate and pumpage, thus representing steady-state aquifer conditions. The water-level data were then entered into a GIS for inspection against the structural surfaces of their corresponding aquifer units. The quality controlled water level data were then analyzed and interpolated into potentiometric or water level surfaces for both the Trinity and Edwards aquifer units using geostatistical techniques (Figures 2-19 and 2-20).

The Pecos River has a very significant influence on groundwater flow in the western half of the aquifer system. Some groundwater flow in this part of the aquifer occurs as cross-formational flow from the eastern flanks of the Trans-Pecos mountains into the Cenozoic Pecos Alluvium Aquifer. Regional groundwater flow east of the Pecos River is generally from the northwest towards the southeast. A regional groundwater divide coincident with the surface topography and trending from the northwest in Ector county to the southeast near the common boundary of Real, Kerr, and Edwards counties separates flow towards the Colorado River from flow towards the Pecos River and Rio Grande.

Trinity water levels in the west show a steep gradient towards the Pecos River and towards the Rio Grande. An area of anomalous low water levels appears in the central part of the Reagan-Glasscock county boundary, historically an area of concentrated groundwater irrigation. Anomalous low water levels are also visible within an area of concentrated oil production in central west Midland County. To the north and east of the Pecos River, the Trinity water levels have a more gentle and subdued surface with only the lower Devils River in southern Val Verde County having an apparent effect on the water level surface. Trinity water levels continue with the gentle surface gradient south towards the Balcones Fault Zone and southeast into the Hill Country.

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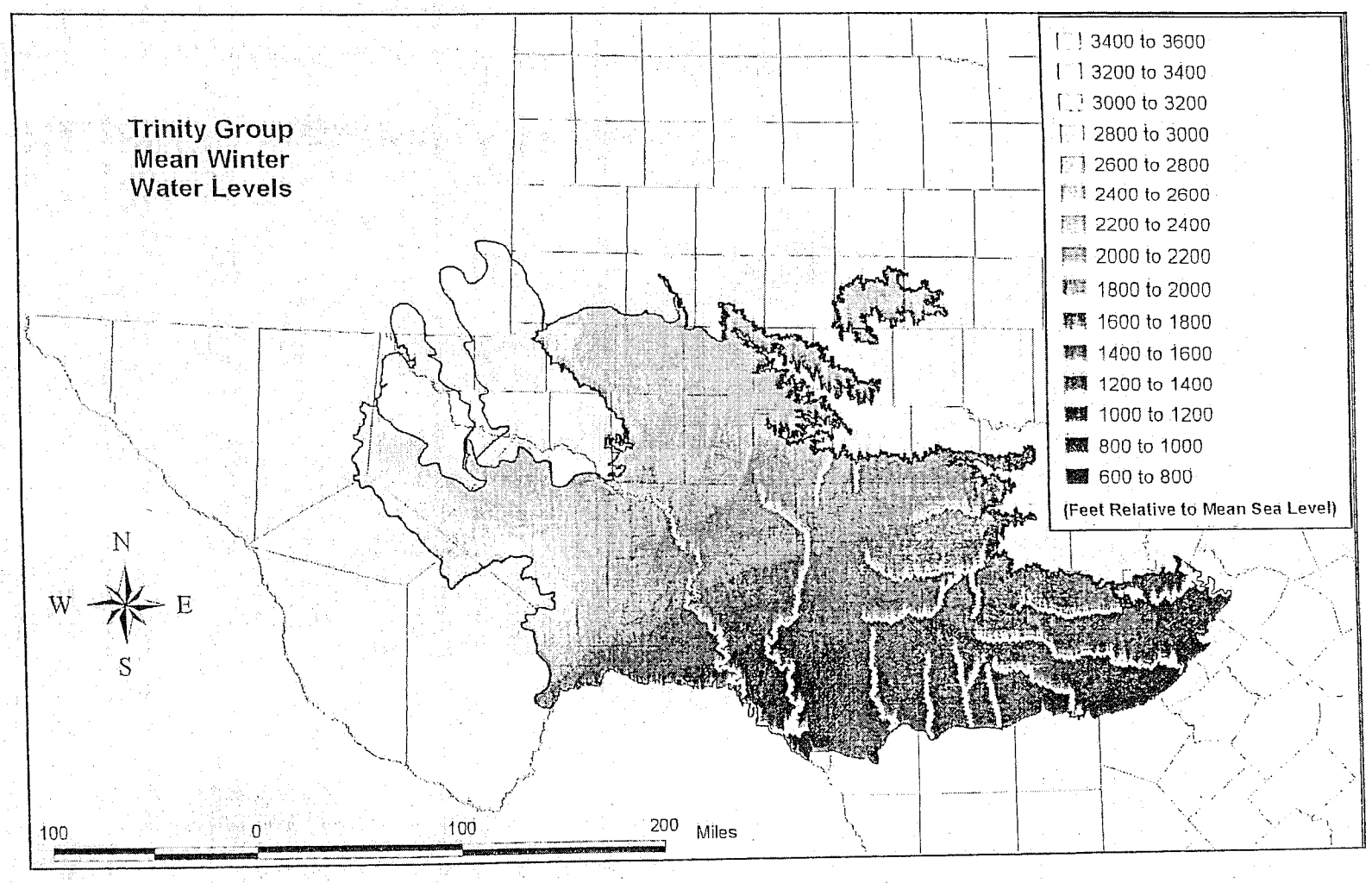

Figure 2-19: Historical mean winter water levels for the Trinity aquifer unit.

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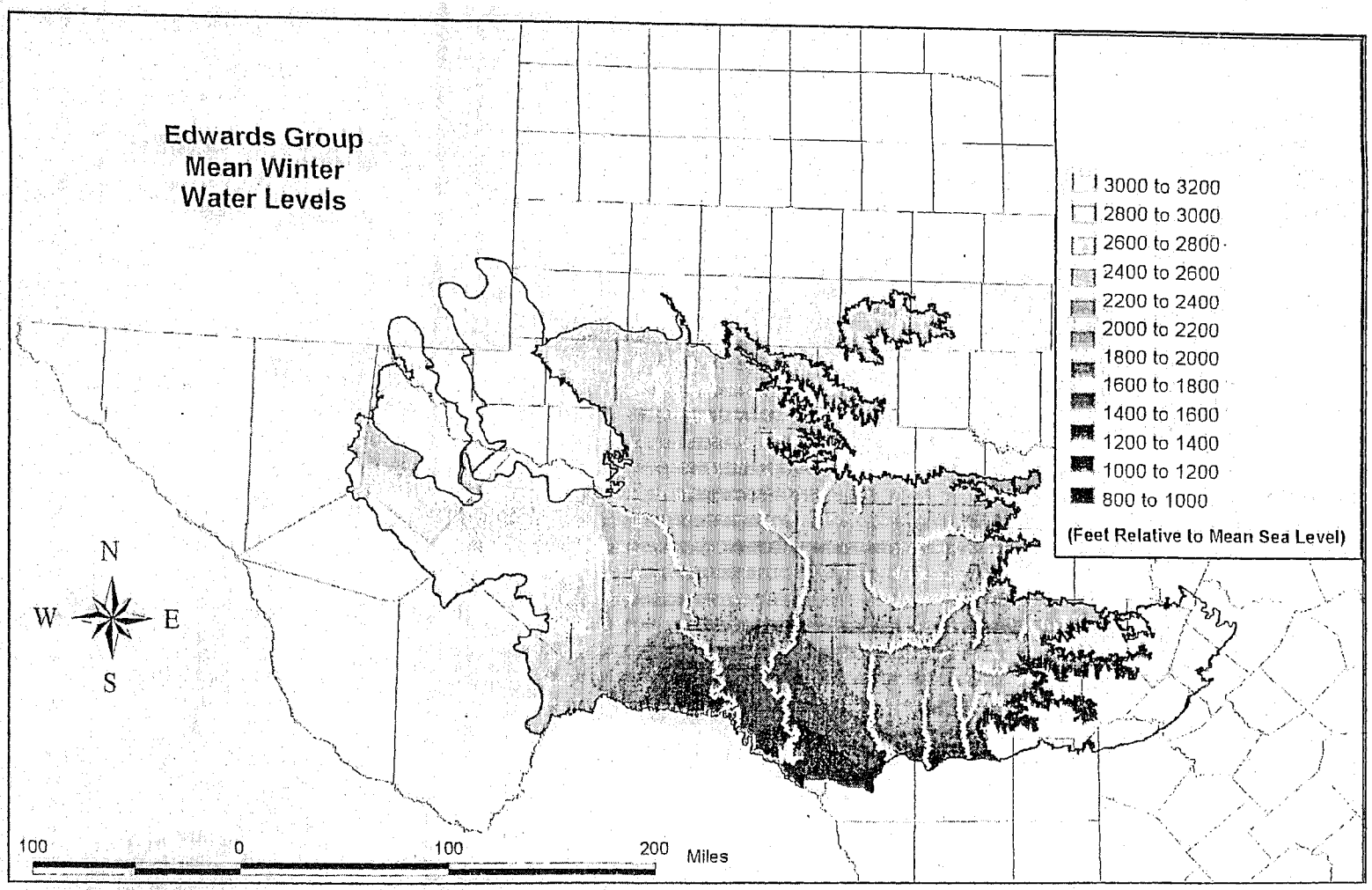

Figure 2-20: Historical mean winter water levels for the Edwards aquifer unit.

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Edwards water levels show a steep gradient towards the Rio Grande in Terrell County as well as the southern part of the aquifer just to the north of the Blacones Fault Zone in Kinney and Uvalde counties. Anomalous low water levels appear in southern Reagan County near Big Lake. The central reach of the Devils River affects Edwards water levels in the southeastern corner of Crockett County. A mounding of the water-level surface is visible in the area near the common boundary of Real, Kerr, and Edwards counties forming a southwest-northeast trending saddle shaped valley through northern Edwards and southeastern Kimble counties.

Recharge

Recharge rates vary with climate conditions, surface geology, surface topography, soils, vegetation, and landuse. Most recharge occurs from the infiltration of precipitation over outcrops of the Edwards–Trinity aquifer, from surface runoff into sinkholes, and stream losses from intermittent streams. An uncertain amount of cross-formational flow from the Ogallala aquifer also provides recharge to the Edwards–Trinity aquifer system in the northwestern portion of the aquifer. Induced recharge occurs in Pecos and Reeves counties as a result of water-level declines due to irrigation pumpage from the Cenozoic Pecos Alluvium aquifer (Barker and Ardis, 1996).

Rees and Buckner (1980) estimated recharge over the Trans-Pecos region of the plateau to be between about 0.3 and 0.4 inches per year. Kuniansky (1989) estimated recharge over the eastern portion of the plateau to range between 0.12 and 2.24 inches per year. The simple strategy of using four percent of the mean annual precipitation will be used as an initial estimate for recharge for the main approach of calibrating recharge within the numerical groundwater flow model. The range in estimated recharge values by other investigators in conjunction with reasonable values in aquifer conductivity estimates will be used as limits in the calibration process.

Interactions of Groundwater and Surface Water

Natural discharge from the Edwards–Trinity aquifer occurs mostly along the margins of the aquifer from springs where the water table intersects canyons or surface topography to provide baseflow to streams. Springs also discharge groundwater along the eastern flanks of the Trans-Pecos mountains and the lower Pecos River canyons. As water levels decline in the western portion of the aquifer due to increased irrigation pumpage, spring flows within those areas have also declined. In addition, many small springs that once flowed throughout the plateau have ceased flowing as a consequence of native grasslands being replaced by woody vegetation that consume high amounts of potential recharge and allow other excess rainfall to runoff before it is able to recharge the aquifers.

Most of the intermittent streams high on the plateau lose their flow to the underlying aquifer. The lower reaches of major streams along the northern, eastern, and southern margins of the plateau become gaining, usually when their stream channel elevation falls below the base of the Edwards aquifer unit. Phreatophytes, mostly along major stream valleys, discharge groundwater naturally as evapotranspiration where the water table is

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shallow enough for the root networks. The Pecos River has perhaps the most prime example of extreme evapotranspiration by invasive salt cedar.

The Edwards–Trinity aquifer interacts with reservoirs or lakes only along the southern margin of the aquifer system. These water bodies initially lost water to the aquifers and raised water levels in their vicinity but have all reached a fairly steady-state condition since the late 1970s. The largest of them is Amistad Reservoir just below the confluence of the Devils River with the Rio Grande in Val Verde County. The remaining lakes are located in the Hill Country just north of the Balcones Escarpment and include Medina Lake on the Medina River in northern Medina County, Canyon Lake on the Guadalupe River in Northern Comal County, and Lake Austin on the Colorado River in Travis County.

Pumping

The Edwards Group sediments provide most of the water in the central, southern, and eastern portions of the plateau while the Trinity Group sediments provide much of the water for the northern and western areas of the plateau in addition to the Hill Country region (Barker and Ardis, 1996). Over three fourths of the total groundwater pumpage from the Edwards–Trinity aquifer is used for irrigation, primarily in the northern and western portions of the aquifer (Figure 2-21). Municipal water suppliers account for the second most common groundwater use followed by minimal use for industrial, mining, livestock, and rural domestic uses. Climate has a significant effect on the amount of groundwater pumpage from the Edwards–Trinity aquifer within areas of irrigation.

Water Quality

Although water quality is typically hard, it is generally fresh except for areas in the Trans-Pecos where groundwater from Permian evaporite sediments and/or oil field brines are able to mix with groundwater from the Edwards–Trinity aquifer (Rees and Buckner, 1980). Water quality is also affected by induced recharge from Pecos River stream losses (Barker and Ardis, 1996). East of the Pecos River, oil field brines and agricultural runoff have a significant effect on the groundwater quality of the northern portion of the Edwards–Trinity aquifer (Walker, 1979). Water quality aspects of the Edwards–Trinity (Plateau) aquifer system are discussed in more detail in later chapters.

Conceptual Model

The conceptual model is a simplified interpretation that provides our best understanding of the aquifer system and defines the hydrostratigraphic units, describes the water budget, and illustrates flow system (Anderson and Woessner, 1992). The conceptual model for the Edwards-Trinity (Plateau) aquifer defines two basic hydrostratigraphic units (Figure 2-22). The lower unit represents the partially confined Trinity aquifer while the upper unit represents the unconfined Edwards aquifer. In addition, the lower Trinity unit is contiguously extended to the southeast to include the Trinity (Hill Country) aquifer.

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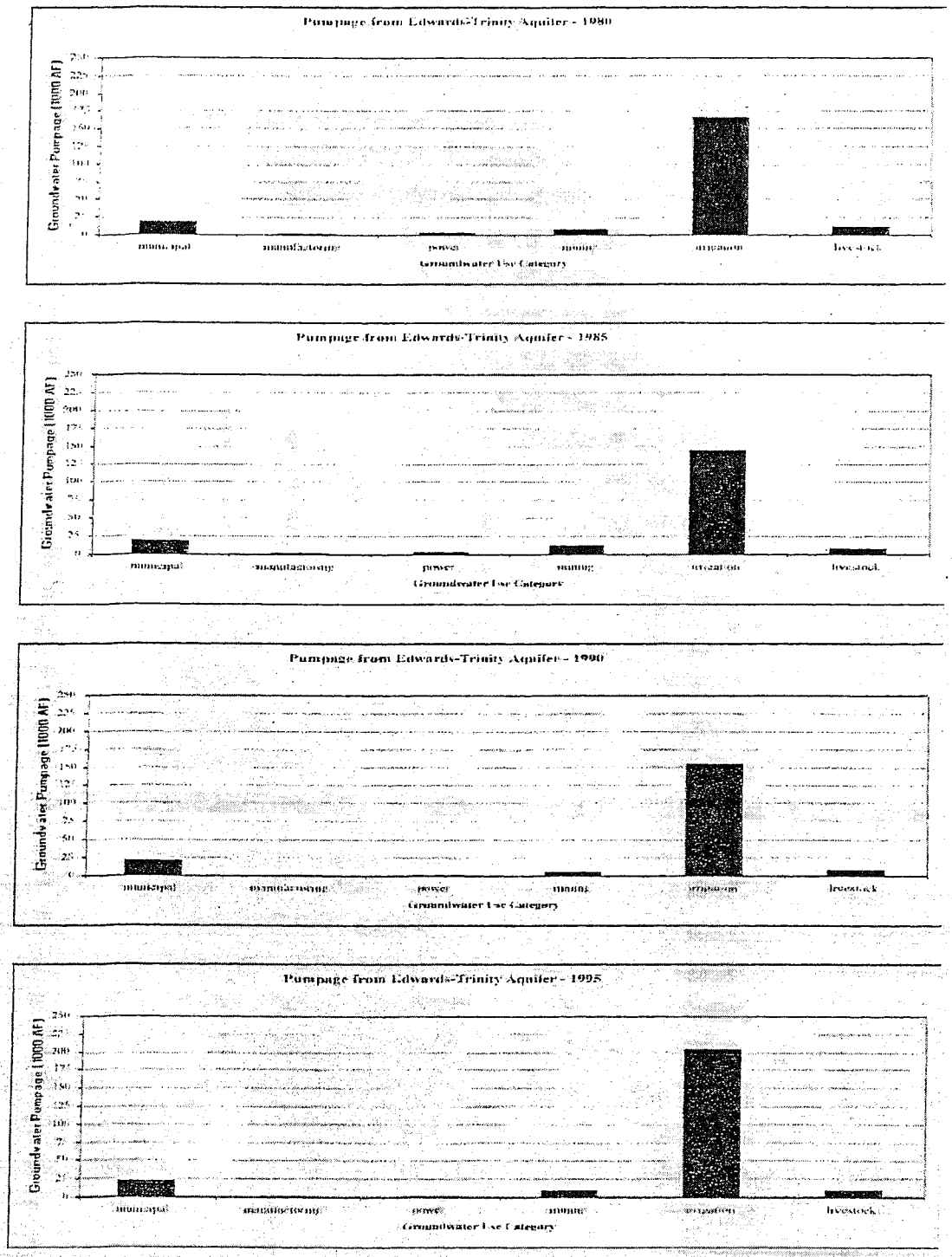

Figure 2-21: Pumpage from the Edwards–Trinity aquifer for 1980, 1985, 1990, and 1995.

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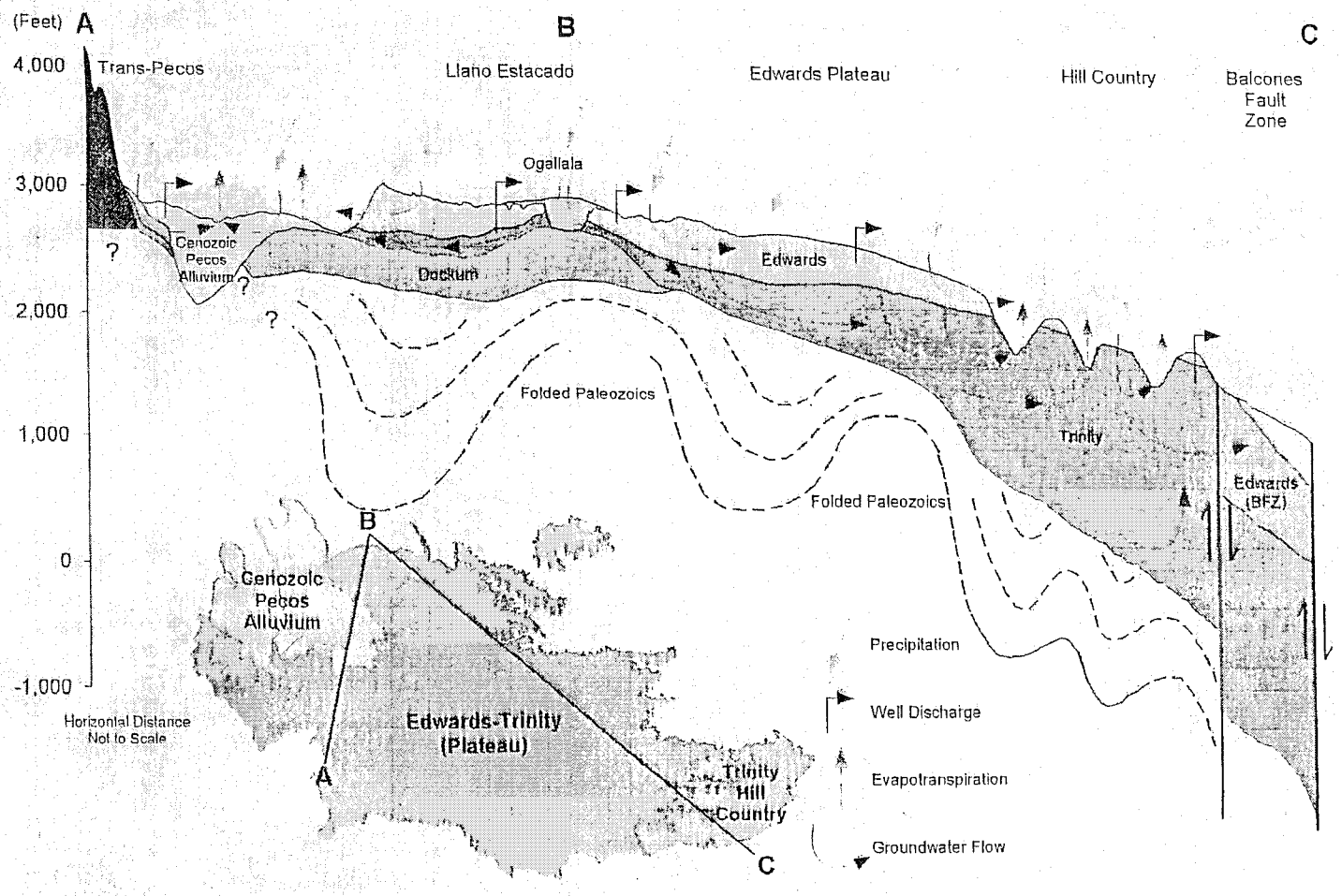

Figure 2-22: Conceptual model diagram of the Edwards–Trinity (Plateau) aquifer system (modified from Kuniansky, 1994).

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The Cenozoic Pecos Alluvium aquifer is included in the conceptual model in the Trans-Pecos region.

The water budget incorporates recharge from precipitation as the primary input into the Edwards aquifer unit. However, most of the precipitation returns to the atmosphere as evapotranspiration or exits from the study area as runoff before it can become recharge. Up to four percent of the annual rainfall enters the aquifer system as diffuse recharge over aquifer outcrops or as direct recharge from losing streams on the aquifer outcrops. Some of the recharge that occurs over the Edwards aquifer outcrop flows downward into the underlying Trinity aquifer unit. Yet, most of the recharge that enters into the Edwards aquifer eventually exits the aquifer unit as (1) seeps and springs along the plateau margins to become the headwaters for tributaries of major streams; (2) baseflow to the lower gaining reaches of major perennial streams; (3) evapotranspiration where vegetation is able to tap into the water table; or (4) pumping from wells.

The Trinity aquifer has few outcrops exposed for recharge and consequently receives much of its water from the overlying Edwards aquifer except in the Hill Country where the Edwards Group sediments have been removed by erosion. In the Hill Country area, recharge over the Trinity aquifer outcrops is about four to six percent of annual rainfall. The Trinity aquifer may also receive some water from the adjacent Ogallala aquifer in the northwest as cross-formational flow. The Trinity aquifer loses its water to pumping wells mostly in the Llano Estacado and Hill Country areas. In the Hill Country, water also flows out of the Trinity aquifer as springs and baseflow to gaining streams and as cross-formational flow to the Edwards (Balcones Fault Zone) aquifer. In the Trans-Pecos area, water exits both the Edwards and Trinity aquifers into the Cenozoic Pecos Alluvium aquifer. After the water levels in the reservoirs and lakes reached their capacity, groundwater generally flows from the aquifer units into the reservoirs and lakes.

Lithologic characteristics are the principal control on the permeability of the aquifer units. The Edwards aquifer unit has relatively high vertical and horizontal permeability because of the mostly massive limestone composition of the Edwards Group. The Trinity aquifer unit has a much more variable lithologic composition. The northern half of the Trinity aquifer is thinner and composed of sands. The southern portion of the aquifer is composed of a thick sequence of sand, shale, and limestone. Consequently, the northern part of the Trinity aquifer unit has higher vertical and horizontal permeability than the southern part. Moreover, the southern part has significantly lower vertical permeability than horizontal permeability because of the stratified sequence of lithologic sub-units.

Conclusions

The Edwards-Trinity (Plateau) aquifer is located beneath the Edwards Plateau of central-west Texas, a region characterized as a tableland with thin soils, subhumid to subarid climate and vegetation, and a sparse population. The aquifer system is composed of Early Cretaceous age sediments of the Trinity Group and the overlying Edwards Group.

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The TWDB is developing a GAM for the Edwards-Trinity (Plateau) aquifer. A conceptual model was developed as an initial task in the design of a numerical groundwater flow model of the Edwards-Trinity (Plateau) aquifer system. The conceptual model is based on characteristics of the hydrogeologic setting such as the hydrostratigraphy, structural geometry, hydraulic properties, water levels, and regional groundwater flow. The conceptual model defines two hydrostratigraphic units for the aquifer system in which the lower unit represents the Trinity aquifer and the upper unit represents the Edwards aquifer. In addition, the conceptual model incorporates the Edwards-Trinity (Plateau) aquifer with the Trinity aquifer in the Hill Country and Cenozoic Pecos Alluvium aquifer systems because of their unique hydraulic connection. Interactions with vertically and laterally adjacent aquifer systems as well as aquifer stresses such as recharge, well discharge, and natural interactions between groundwater and surface-water features such as springs, streams, and lakes are also represented in the conceptual model.

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Chapter 5

Hydrologic Relationships and Numerical Simulations of the Exchange of Water Between the Southern Ogallala and Edwards–Trinity Aquifers in Southwest Texas

T. Neil Blandford[1] and Derek J. Blazer[1]

Introduction

The Edwards–Trinity aquifer is the most significant source of water on the Edwards Plateau, which covers approximately 23,000 square miles in southwest Texas. The aquifer is bounded to the northwest by the physical limit of the Cretaceous rocks, which occurs in the southern portions of Andrews, Martin, and Howard counties (Figure 5-1). The primary aquifer in these counties occurs in saturated sediments of the Ogallala Formation, but the Ogallala Formation sediments thin to the south and often occur above the water table in Ector, Midland, and Glasscock counties where saturated Cretaceous sediments form the predominant (Edwards–Trinity) aquifer. Where significant saturated thickness occurs in Cretaceous sediments, the Trinity Group Antlers sand is the dominant aquifer material. Within the study area, it is often difficult to differentiate between the two aquifers.

This paper provides an overview of the hydrogeology of the far southern portion of the Southern High Plains and the northwestern margin of the Edwards Plateau where the transition occurs between the Southern Ogallala and Edwards–Trinity aquifers. The boundary between the two aquifers is transitional and is not well defined within much of this area. The approaches used in previously published modeling studies to simulate the flow of water across this boundary are reviewed, and modifications made to the recently developed Southern Ogallala Groundwater Availability Model (GAM) to evaluate alternative conceptual models of inter-aquifer flow are presented.

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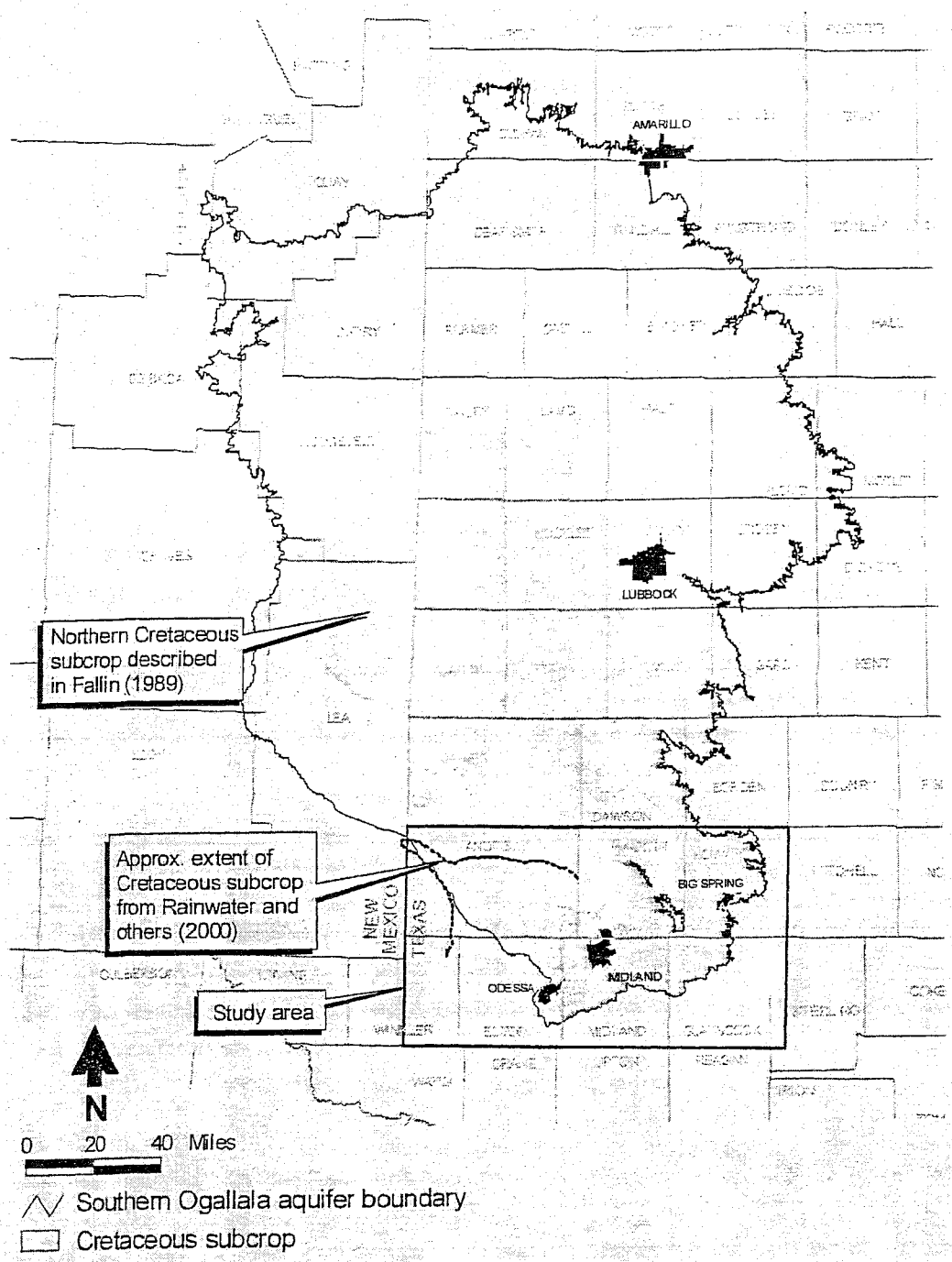

Figure 5-1: Extent of Cretaceous subcrop beneath Southern High Plains and location of study area (after Fallin 1989; Knowles and others 1984).

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Geology

The geologic units within and adjacent to the study area are summarized in Figure 5-2. Where the Cretaceous subcrop beneath the Southern High Plains (Figure 5-1) is absent, Triassic sediments (Chinle Formation "red beds") generally occur immediately beneath the Ogallala Formation. Within the study area, many of the mapped Cretaceous outcrops consist of the Trinity Group Antlers Formation (Bureau of Economic Geology, 1976, 1994), which is equivalent to the Paluxy sand of central Texas (Knowles and others, 1984). The contacts between the different systems are unconformable.

Aquifer Terminology

Prior to proceeding with a discussion of the hydrogeology of the study area, it is important to understand the distinctions in terminology used in various reports to describe the aquifers of this region. The term Ogallala (or Southern Ogallala) aquifer is the standard Texas Water Development Board (TWDB) term for the major aquifer that exists primarily within sediments of the Ogallala Formation. However, the term High Plains aquifer is commonly applied to the same aquifer system (Gutentag and others, 1984; Knowles and others, 1984), implicitly recognizing that in some areas saturated Ogallala Formation sediments are hydraulically connected to underlying permeable Cretaceous rocks. In this paper, the term Southern Ogallala aquifer is used for consistency with TWDB terminology, although portions of the aquifer (substantial portions within the study area discussed here) actually exist within Cretaceous sediments rather than within the Ogallala Formation. To avoid confusion, where a clear distinction between groundwater in each geologic unit is necessary, the terms "saturated Ogallala sediments" and "saturated Cretaceous sediments" are used.

Hydrogeology

Relatively little has been published about the hydrogeology of the Edwards–Trinity aquifer beneath the Southern High Plains. Fallin (1989) provides what is probably the most detailed description of the hydrogeology of the lower Cretaceous rocks that lie below the Ogallala Formation over an area of approximately 10,000 square miles stretching from New Mexico to the eastern caprock escarpment (Figure 5-1) (north of the area of interest for this paper). Rettman and Leggat (1966) and Cooper (1960) provide detailed discussions of the Cretaceous hydrogeology in subregions of the larger northern area. Nativ (1988) and Nativ and Gutierrez (1988) also provide detailed analyses of the hydrogeology and hydrochemistry of the Cretaceous aquifers that exist beneath the Southern High Plains. A comparison of the base of the Southern Ogallala aquifer maps from Knowles and others (1984) and McReynolds (1996) with the elevation of the top of the Cretaceous section provided by Fallin (1989) indicates that, in general, large (more than several tens of feet) thicknesses of Cretaceous rocks are not included within the aquifer as defined by these maps.

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System	Series	Group	Formation	Description of Rocks	Hydrogeologic Units
Quaternary	Pleistocene to Recent		Alluvium, eolian and lacustrine deposits	Sand, clay, silt, caliche, and gravel.	Generally yields small amounts of water to wells; may yield large amounts of water along stream valleys of Edwards Plateau.
Tertiary	Late Miocene to Pliocene		Ogallala	Tan, yellow, and reddish brown silt, clay, sand, and gravel. Caliche layers common near the surface.	Yields moderate to large amounts of water to wells across Southern High Plains. Yields small to moderate amounts of water in Andrews, Martin, Howard, Ector, Midland and Glasscock Counties.
Cretaceous	Comanche	Washita	Duck Creek	Yellow, sandy shale and thin gray to yellowish brown argillaceous limestone beds.	Yields small amounts of water locally to wells.
		Fredericksburg	Kiamichi	Gray to yellowish brown shale with thin interbeds of gray argillaceous limestone and yellow sandstone.	Yields small amounts of water locally to wells.
			Edwards	Light gray to yellowish gray, thick to massive bedded, fine- to coarse-grained limestone.	Generally yields fairly small amounts of water to wells beneath Southern High Plains, but may yield large amounts of water locally due to fractures and solution cavities.
			Comanche Peak	Light gray to yellowish brown, irregularly bedded argillaceous limestone with thin interbeds of light gray shale.	
			Walnut	Light gray to yellowish brown argillaceous sandstone; thin-bedded gray shale; light gray to grayish yellow argillaceous limestone.	Not known to yield water to wells.
		Trinity	Antlers	White, gray, yellowish brown to purple, argillaceous, loosely cemented sand, sandstone, and conglomerate with interbeds of siltstone and clay.	Yields small to moderate amounts of water to wells. Primary aquifer of Cretaceous system within the study area.
Triassic		Dockum	Chinle	Red, maroon to purple shale. Thin, discontinuous beds of sand and silt.	May yield small amounts of water to wells. Commonly known as the "red beds" that form the base of the High Plains aquifer.
			Santa Rosa	Multi-colored fine- to coarse-grained micaceous sandstone with some claystone and shale interbeds.	Yields moderate amounts of water to wells.
			Tecovas	Red to red-brown shale with fine-grained micaceous sand.	Not known to yield water to wells.

Figure 5-2: Summary of geologic and hydrogeologic units (after Walker, 1979; Knowles and others, 1984; Fallin, 1989).

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Within the study area, the Trinity Group Antlers Formation (commonly called the Antlers or Trinity sand) forms the predominant water-bearing unit of the Cretaceous rocks (Knowles, 1952; Walker, 1979; Knowles and others, 1984; Ashworth, 1986; Bureau of Economic Geology, 1976, 1994). For the most part, therefore, the Edwards–Trinity aquifer within the southernmost counties of the Southern High Plains can be considered to be coincident with the saturated portion of the Antlers Formation. Although the Antlers Formation lies below the Ogallala Formation stratigraphically (Figure 5-2), the Antlers sand is similar in appearance to Ogallala sediments, and the two are often not easily distinguishable (Mount and others, 1967, p. 45, *in* Barker and others, 1994). Knowles and others (1984) state that although the Antlers sand is the primary water-bearing formation in Ector, Midland, and part of Glasscock counties, only moderate quantities of water can be obtained from individual wells due to relatively thin saturated thickness and low hydraulic conductivity.

Groundwater flow within the saturated portions of the Ogallala and Cretaceous sediments is generally to the east or southeast (Figures 5-3 and 5-4). Contours of regional water levels within the study area are smooth and continuous and apparently indicate a smooth transition between portions of the aquifer composed primarily of Ogallala sediments and portions composed primarily of Cretaceous sediments. Groundwater from Ogallala sediments discharges at springs along the caprock escarpment, at the margins of salt lakes, along draws, and at wells under post-development conditions.

Water in saturated Cretaceous sediments flows east or southeast toward the Edwards Plateau, unless it is intercepted by wells or discharges at springs. In the past, many of the springs within the study area, particularly in the southern and eastern portions, have discharged groundwater from Cretaceous sediments. For example, Big Spring, at the caprock escarpment in Howard County, reportedly emitted from "lower Cretaceous limestones and sands in a collapse or sink area" before it ceased flowing due to nearby pumping (Brune, 2002, p. 238). Mulkey Springs in southeastern Martin County "poured from Ogallala sand on Antlers sandstone" until the 1950s (Brune, 2002, p. 304).

Recharge to the saturated Ogallala and Cretaceous sediments within the study area occurs primarily from precipitation and lateral inflow. Recharge applied in the Southern Ogallala GAM is about 0.03 inch per year (in/yr) for predevelopment conditions but was increased to a maximum of 0.5 in/yr for agricultural areas (Blandford and others, 2003). Because regional groundwater flow is generally to the southeast, mimicking the slope of the land surface, groundwater flows into the study area from portions of the aquifer to the north (Figure 5-3). As the Ogallala sediments thin and/or occur above the water table, groundwater flows directly into the Edwards–Trinity aquifer (Cretaceous sediments).

Portions of hydrogeologic cross section F-F' from Knowles and others (1984) and geologic cross section B-B' from Barker and Ardis (1996) are reproduced in Figure 5-5. The Knowles and others' (1984) cross section (F-F') indicates that the saturated sediments in Ector and southern Andrews counties are Cretaceous, with a relatively abrupt transition to saturated Ogallala sediments to the north. The transition from the predominance of saturated Ogallala sediments to saturated Cretaceous sediments is not reflected by observable changes in water-table elevations, at least at the regional scale. This is consistent

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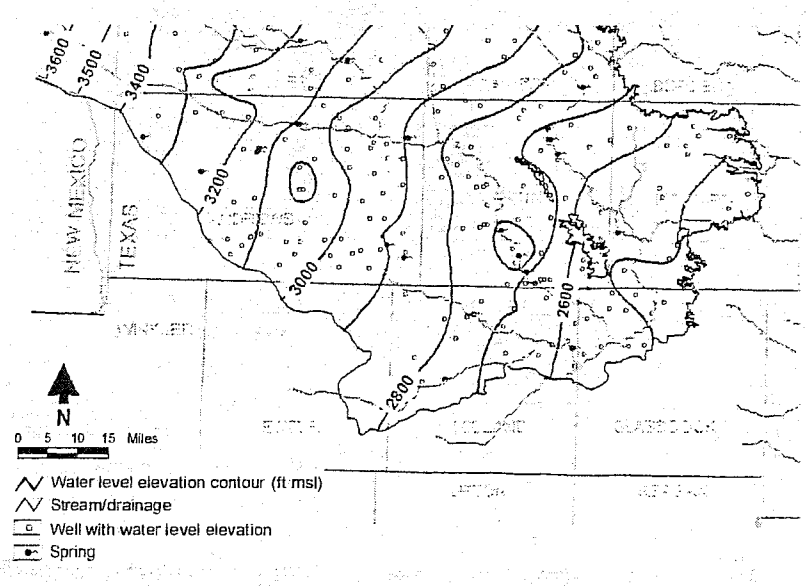

Figure 5-3: Observed water levels for Southern Ogallala aquifer for winter of 1989 and 1990, major drainages and historical spring locations (after Blandford and others, 2003).

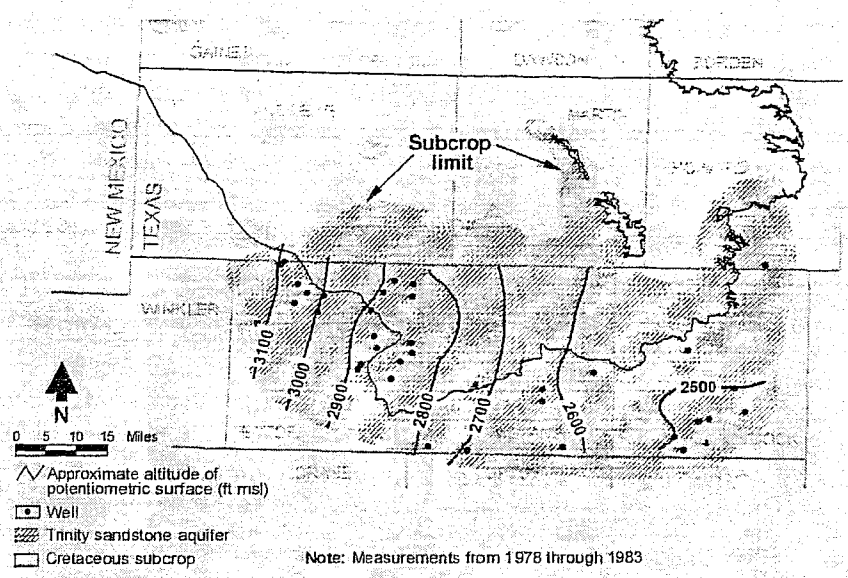

Figure 5-4: Observed water level in the Cretaceous sediments (Edwards–Trinity aquifer) in southern portion of the study area for 1978 through 1983 (after Nativ and Gutierrez, 1988).

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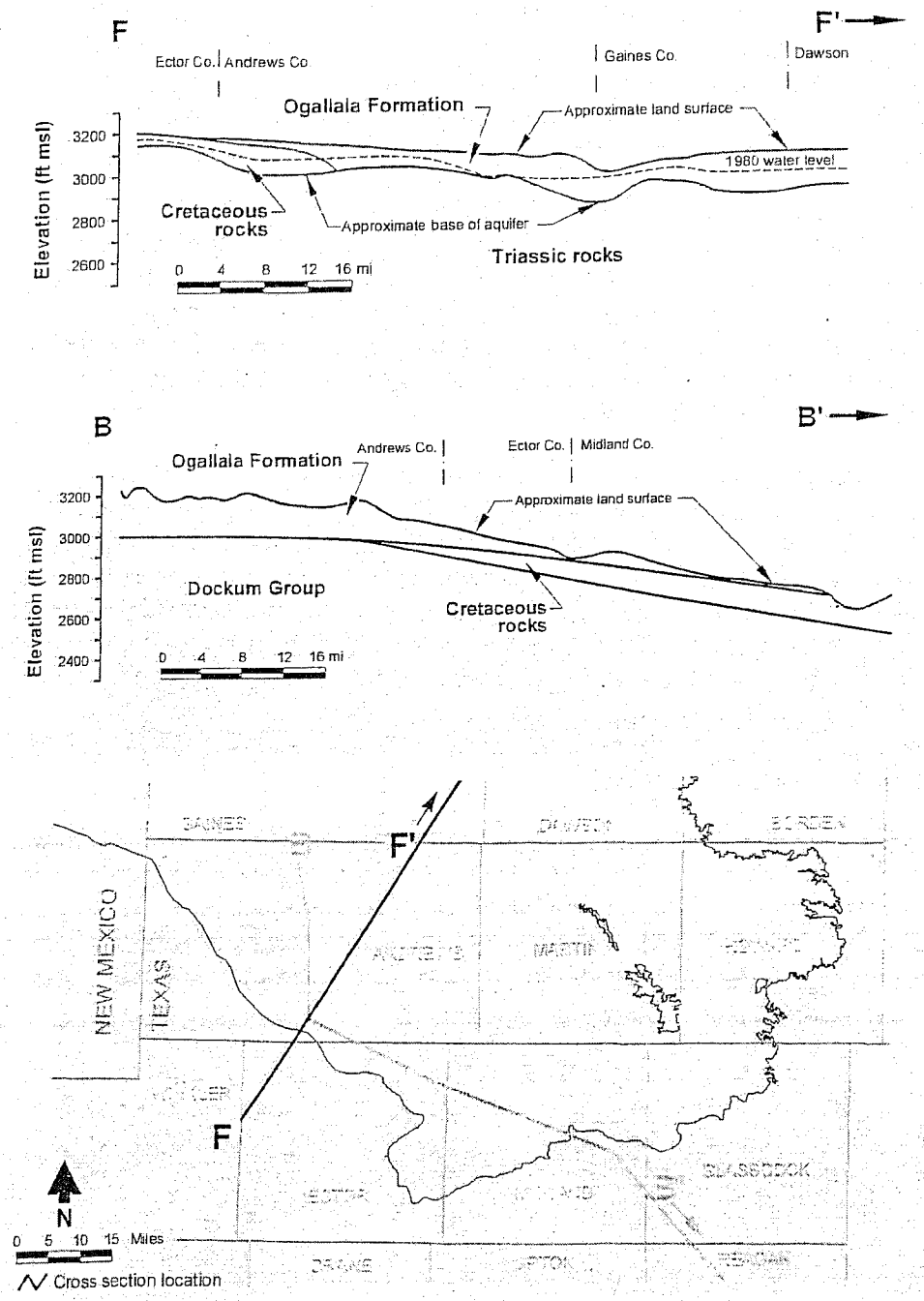

Figure 5-5: Portions of hydrogeologic cross sections (after Knowles and others, 1984; Barker and Ardis 1996).

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with the observations that no apparent significant changes in aquifer thickness or hydraulic conductivity attributable to changes in saturated formation lithology occur within the study area (Blandford and others, 2003). The Barker and Ardis (1996) cross section (B-B') indicates a significant thickness of Ogallala Formation in Andrews and Ector counties, with a thin underlying wedge of Cretaceous sediments beginning in southern Andrews County and thickening to the southeast in Ector and Midland counties.

The base of aquifer map for the study area from Blandford and others (2003), assembled from maps presented by Knowles and others (1984), is provided in Figure 5-6. The map illustrates that the base of the High Plains (Southern Ogallala) aquifer is complex with numerous paleochannels evident throughout the study area. Note that the mapped paleochannels represent the base of the High Plains aquifer and therefore include the saturated thickness of the permeable Cretaceous units (primarily Antlers sand) where they form an important part of the aquifer.

Nativ (1988) presents a map of the difference in hydraulic head between the Ogallala aquifer and the underlying Edwards–Trinity aquifer within the six counties of interest (Figure 5-7). Although details of the construction of Figure 5-7 are not provided by Nativ (1988) or Nativ and Gutierrez (1988), observed water levels from wells completed in the Edwards–Trinity aquifer in Ector, southern Midland, and Glasscock counties for the time period 1978 through 1983 were apparently used by Nativ and Gutierrez (1988) to determine a potentiometric surface (Figure 5-4) that was extrapolated beneath the remainder of the study area. This surface could then be compared to Ogallala aquifer water levels from the same general time period provided by Gutentag and Weeks (1980) (Nativ, 1988; Nativ and Gutierrez, 1988).

Nativ's (1988) conceptual model is clearly one in which saturated Ogallala sediments and saturated Cretaceous sediments form distinct aquifer units with observable differences in hydraulic head between them. Although applicable to the northern section of Cretaceous subcrop beneath the Southern High Plains, it is not clear that this conceptual model is accurate within some portions of the study area discussed in this paper.

Assuming that the interpretation of Nativ (1988) and Nativ and Gutierrez (1988) is correct, Figure 5-7 illustrates that the observed difference between hydraulic head in saturated Ogallala and Cretaceous sediments ranges from 0 to 50 feet with downward flow from the Ogallala sediments into Cretaceous sediments prevalent throughout most of the study area. Although zones of upward flow are depicted in Figure 5-7, no direct water-level measurements are available to confirm the largest mapped region of potentially upward flow from the Cretaceous sediments to saturated Ogallala sediments in western Martin and northwestern Glasscock counties. In addition, recently constructed potentiometric surface maps for the study area (Blandford and others, 2003) differ markedly in some places from that presented by Gutentag and Weeks (1980), the map presumably used by Nativ (1988) to construct the hydraulic-head difference map that is reproduced here as Figure 5-7. Inherent uncertainty in the regional potentiometric surface maps leaves some question regarding the interpreted magnitude and location of vertical hydraulic head gradients between saturated Ogallala and Cretaceous sediments.

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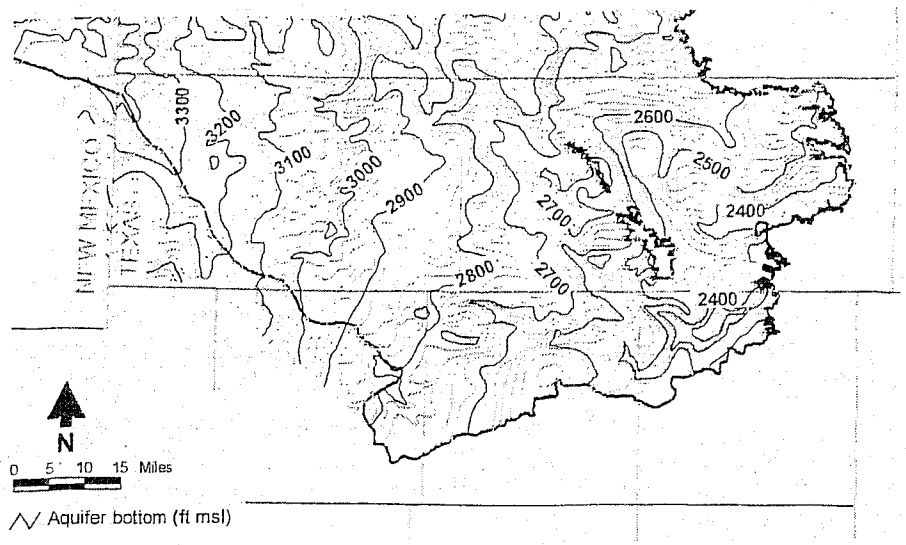

Figure 5-6: Base of High Plains (Southern Ogallala) aquifer within the study area (adapted from Knowles and others, 1984).

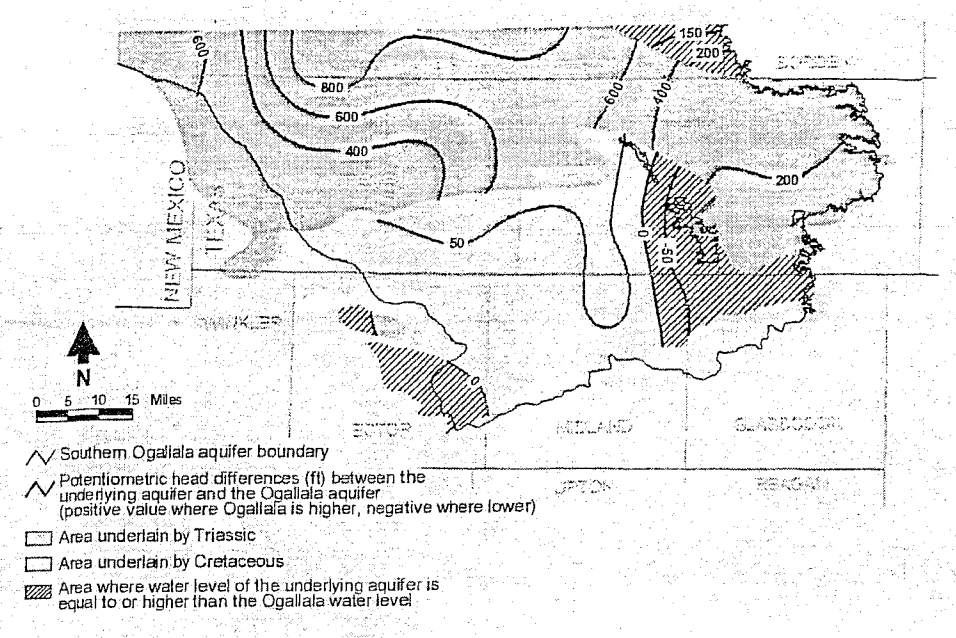

Figure 5-7: Difference in hydraulic head between saturated Ogallala sediments and underlying aquifer units (after Nativ, 1988).

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The difference in hydraulic head between the saturated Ogallala sediments and the underlying Triassic Dockum Group immediately to the north of the Cretaceous subcrop are substantially larger (up to 800 feet), indicating a much higher degree of resistance to groundwater flow in the vertical direction caused by the upper Triassic units (the low-permeability Chinle Formation or "red beds"), as would be expected (Figure 5-7).

Previous Modeling Studies

The U.S. Geological Survey completed a modeling study of the entire Edwards–Trinity aquifer in west-central Texas as part of their Regional Aquifer Systems Analysis (RASA) Program (Kuniansky and Holligan, 1994). In this model, the location of the northwest boundary that adjoins the High Plains aquifer "is somewhat arbitrary," according to the authors, and was simulated as a "head-dependent source or sink boundary placed within the High Plains aquifer" (Kuniansky and Holligan, 1994, p. 23). Other related Edwards–Trinity RASA reports include Kuniansky (1990), Barker and Ardis (1992), Barker and others (1994), and Barker and Ardis (1996).

The TWDB is in the process of developing a GAM for the Edwards–Trinity (Plateau) aquifer. Currently, general-head boundary conditions are used along the northwestern margin of the model to represent downward leakage where saturated Ogallala Formation lies above the Edwards–Trinity aquifer. General-head boundaries are also used to represent lateral inflow from the Southern Ogallala aquifer to the Edwards–Trinity aquifer along the northwestern model boundary (Roberto Anaya, personal communication, October 2003).

Groundwater Flow Simulations

To investigate discrepancies identified during development of the Southern Ogallala GAM (Blandford and others, 2003), the GAM was modified to simulate the exchange of water between the Southern Ogallala and Edwards–Trinity aquifers. It was noted during development of the Southern Ogallala GAM that simulated water levels in the southern portion of the model domain in western Martin County, Howard County, and Glasscock County were significantly higher than observed values. The model calibration was not refined in this area because groundwater uses are small compared to other regions of the model, and it is far removed from areas with the largest observed historical drawdown. However, it was hypothesized during the development of the Southern Ogallala GAM that one reason for the high simulated water levels could be that downward or lateral leakage from the Southern Ogallala aquifer to the adjoining Edwards–Trinity aquifer was not explicitly accounted for in the southernmost portion of the model.

To investigate the discrepancy between observed and simulated water levels, two alternative conceptual models of the hydrogeologic relationship between the Southern Ogallala and Edwards–Trinity aquifers were evaluated using the model.

In the Southern Ogallala GAM, the southern model boundary is assumed to be a no-flow boundary, and all groundwater is assumed to discharge at springs and seeps along the

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draws, the margins of salt lakes, or the eastern escarpment. Lateral groundwater flow out of the model domain to the greater Edwards–Trinity aquifer on the Edwards Plateau is not simulated. The first conceptual model of groundwater flow between the Southern Ogallala and Edwards–Trinity aquifers, called the "laterally continuous" model, assumes that, within the existing Southern Ogallala GAM domain, the full thickness of the Edwards–Trinity aquifer, where it exists, is already incorporated in the model. This approach is consistent with the base of aquifer contours and hydrogeologic cross sections presented by Knowles and others (1984), which indicate that the southernmost portion of the Southern Ogallala (High Plains) aquifer consists entirely of Cretaceous sediments.

The originally developed Southern Ogallala GAM is a single layer model with no leakage components to other aquifer units. The second conceptual model of groundwater flow, called the vertical-leakage model, assumes that, throughout most of the study area, saturated Ogallala sediments overlie the Edwards–Trinity aquifer, and water in the Southern Ogallala aquifer flows vertically downward into the Edwards–Trinity aquifer. This conceptual model is consistent with that applied by Nativ (1988), Nativ and Gutierrez (1988), and the current model under development by the TWDB.

Although not an additional conceptual model per se, some model runs were also conducted where evapotranspiration was implemented in the model. It was hypothesized that evapotranspiration could be an additional physical process neglected in the southern portion of the model that led to simulated hydraulic heads that are greater than observed values.

Modifications to the Southern Ogallala GAM

The laterally continuous conceptual model was implemented by prescribing hydraulic head along the southern boundary of the Southern Ogallala GAM domain (Figure 5-8). In the unmodified model, this boundary was treated as a no-flow boundary because it represents the transition between the Southern Ogallala and Edwards–Trinity aquifers and because the direction of regional groundwater flow is approximately parallel to the boundary (Blandford and others, 2003). Changing the boundary condition from no-flow to prescribed hydraulic head allows groundwater to either exit or enter across the southern boundary, depending on the prescribed boundary head values and the simulated hydraulic head values at interior model cells. This approach is consistent with the conceptual model that the Southern Ogallala aquifer and the Edwards–Trinity aquifer are one and the same along the southern boundary of the model.

The vertical-leakage conceptual model was implemented using a general-head boundary condition (the GHB package of the MODFLOW code), where leakage out of or into the Southern Ogallala model is controlled by a leakage conductance and the difference in the simulated hydraulic head of a given model cell and a prescribed hydraulic head associated with that cell. Conceptually, the prescribed head represents an estimate of the hydraulic head in the Edwards–Trinity aquifer, which is assumed to exist beneath saturated Ogallala sediments. The conductance is equal to the area of the model cell times the average vertical hydraulic conductivity between the two aquifer units, divided by the

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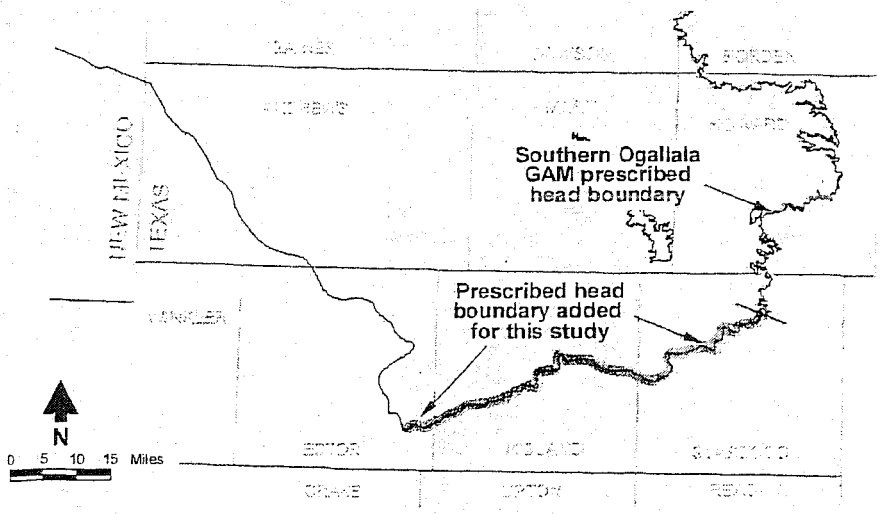

Figure 5-8: Prescribed hydraulic head boundaries used for Southern Ogallala GAM and current model.

average distance in the vertical dimension between the aquifer units. The general-head boundary condition was applied to all model cells that fall within the mapped extent of the southern region of Cretaceous subcrop as illustrated in Figure 5-1.Evapotranspiration was implemented using the ET package of the MODFLOW code. This boundary condition requires that a maximum rate of evapotranspiration and an extinction depth be assigned to a given node. When the simulated water table is at or above land surface, the maximum evapotranspiration rate will be applied. This maximum simulated rate will decline until it is zero (no evapotranspiration) at the prescribed extinction depth. As with the general-head boundary condition cells, evapotranspiration was applied to model cells that fall within the mapped extent of the southern region of Cretaceous subcrop as illustrated in Figure 5-1. However, there is no discharge from these cells unless the simulated water level lies above the assumed extinction depth.

Simulation Results

Simulations were conducted for each of the conceptual models presented above, as well as for various combinations of each approach (for example, prescribed hydraulic head and general-head boundaries). Sensitivity analyses for assumed boundary condition input parameters, such as general-head boundary conductance and evapotranspiration extinction depth, were also completed. As observed historical drawdown has not been extensive over much of the region of interest, most of the revised simulations were conducted using the steady-state Southern Ogallala GAM only, which was assumed to be indicative of average hydrologic conditions during and before 1940 (Blandford and others, 2003). However, hydrographs of simulated water levels for several of the revised

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Table 5-1: Comparison of calibration statistics for Southern Ogallala GAM and modified models.

Model	RMSE (ft)	MAE (ft)	RME (ft)	% Error [1]
Southern Ogallala GAM	34	26	–8	1.5
Run 1: Vertical leakage [2]	32	24	–5	1.4
Run 2: Vertical leakage [3]	34	25	–7	1.5
Run 3: Vertical leakage [3] and evapotranspiration	33	24	–6	1.4
Run 4: Laterally continuous	34	25	–7	1.5
Run 5: Laterally continuous and vertical leakage [3]	33	25	–7	1.4

RMSE = Root-mean-squared error
MAE = Mean-absolute error
RME = Residual mean error

[1] RMSE divided by the maximum difference in observed hydraulic head values
[2] Prescribed head set to 15 feet below observed predevelopment hydraulic head
[3] Prescribed head set to 15 feet below simulated predevelopment hydraulic head from Southern Ogallala GAM

models were checked against those of observed water levels, to confirm that the general fit to water level changes was maintained in the revised models.

The calibration statistics for the Southern Ogallala GAM and the modified versions of the model are presented in Table 5-1. For the laterally continuous model runs, prescribed hydraulic head values along the southern model boundary (Figure 5-8) were obtained from the predevelopment potentiometric surface map in Blandford and others (2003). For the vertical leakage model runs, the prescribed general head boundary was assumed to be 15 feet below the bottom of the saturated Ogallala sediments, and the conductance was assumed to be 92.93 feet per day (ft/d), which corresponds to a vertical hydraulic conductivity of 0.0001 ft/d and a vertical flow distance of 30 feet.

During the sensitivity analyses conducted for both of these parameters, it was observed that the assumed leakance generally had to be increased to allow significant volumes of water to enter or leave the aquifer. The prescribed head for the leakance boundary was applied using two approaches. In the first approach, the prescribed head was assumed to be 15 feet less than the observed hydraulic head. In the second approach, the prescribed head was assumed to be 15 feet less than the simulated head from the Southern Ogallala GAM. The second approach was used to reduce simulated inflows to the model from the bottom that occurred in some regions, partially as an artifact of the simulated predevelopment hydraulic head field.

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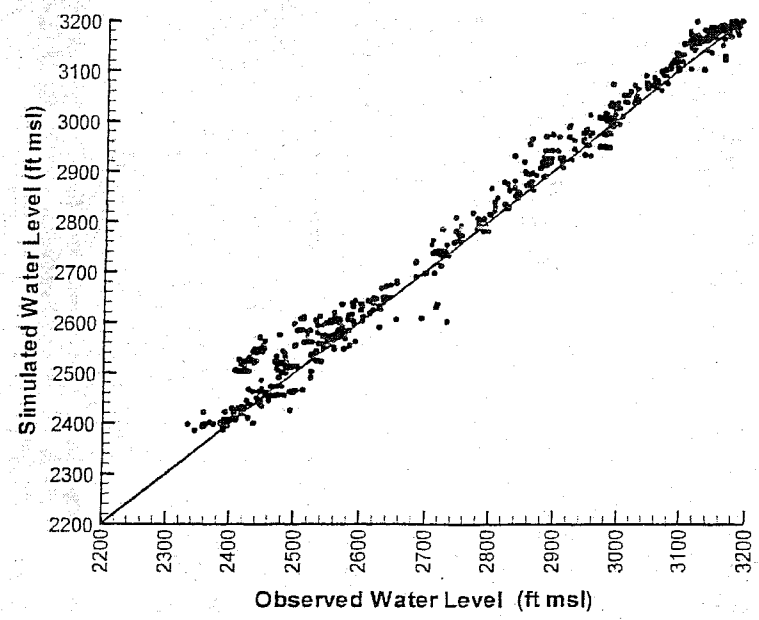

Figure 5-9: Simulated versus observed hydraulic head for Southern Ogallala GAM.

Where evapotranspiration was applied, an extinction depth of 10 feet was used with a maximum evapotranspiration rate of 1 foot per year at the land surface. The assumed rate of evapotranspiration is fairly low so that large volumes of water that could not be verified by field studies would not be removed from the model. Sensitivity runs conducted with higher maximum rates yielded similar results.

The calibration statistics for each of the modified simulations, except Run 4, improved significantly over the original GAM run, especially considering that the adjustments to the model only affect the southernmost points (lowest hydraulic heads) within the overall model domain. Scatter plots of observed versus simulated hydraulic heads for the Southern Ogallala GAM and for the modified model (Run 1) are provided in Figures 5-9 and 5-10, respectively. Comparison of the portion of these plots for the hydraulic heads less than about 2,700 ft-MSL illustrates the improvement in model calibration obtained from implementing the leakage boundary.

The largest improvements in the match between simulated and observed hydraulic heads were obtained through implementation of the vertical leakage model. Implementation of the laterally continuous model through the prescription of hydraulic heads along the southern model boundary did not yield significant improvements in the model calibration (Table 5-1, Run 4). Likewise, the combination of the two boundary approaches also yielded relatively small improvement in the model calibration statistics (compare Runs 2 and 5 in Table 5-1).

Because of data limitations and assumptions used in estimating the boundary condition parameters, it would not be appropriate to use the simulation results as quantitative

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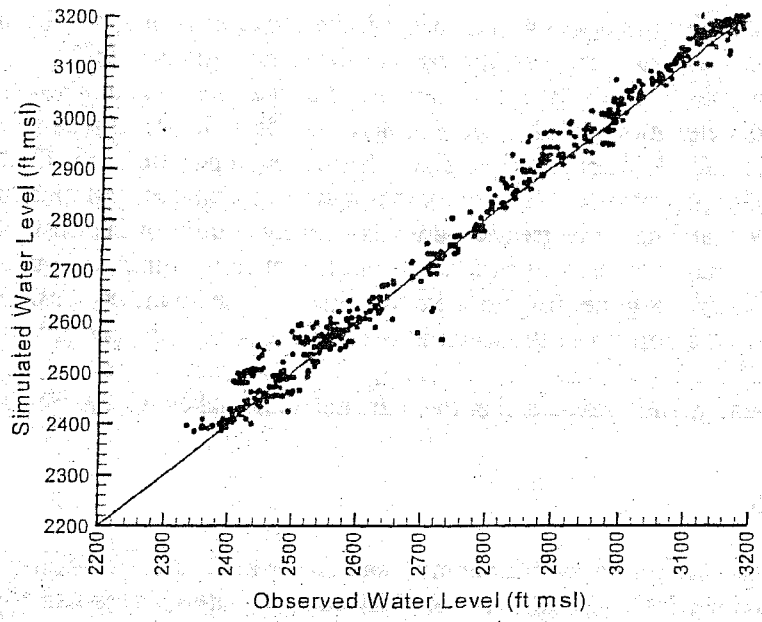

Figure 5-10: Simulated versus observed hydraulic head for modified model that incorporates vertical leakage (Run 1).

estimates of groundwater flow that occurs between the two aquifer systems. In addition, the hydraulic parameters (hydraulic conductivity and aquifer bottom elevation) in the Southern Ogallala GAM are representative of the High Plains aquifer, which includes both the saturated Ogallala sediments and Cretaceous sediments in at least the southernmost portion of the study area.

Conclusion

The Edwards–Trinity aquifer is hydraulically connected to saturated Ogallala Formation sediments within a six-county region of the far Southern High Plains. Within this area it is often difficult to distinguish between aquifer units because (1) the Cretaceous Antlers sand is similar to Ogallala sediments in appearance and (2) a smooth hydrologic transition occurs between aquifers. Some previous studies have considered the saturated Ogallala and Cretaceous sediments as distinct aquifer units, while others have grouped them into one aquifer unit called the High Plains aquifer.

A series of model runs were developed to evaluate alternative conceptual models of the exchange of water between aquifer units. The simulations were conducted using modified versions of the Southern Ogallala GAM. The simulations indicated an improved fit in simulation results when the exchange of water between aquifer units was explicitly accounted for, particularly using a vertical leakage conceptual model, where water flows vertically downward from saturated Ogallala sediments into the Edwards–Trinity aquifer.Although the simulation results best matched observed hydraulic heads when the

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vertical leakage conceptual model was employed, the possibility remains that the laterally continuous conceptual model may be appropriate for some regions within the study area. This opinion is based on review of the documents cited previously and the observation that aquifer bottom elevations used in the Southern Ogallala GAM, derived from Knowles and others (1984), apparently include the saturated portion of the Cretaceous Antlers sand. If this observation is correct, it is hypothesized that the component of groundwater flow that enters the greater Edwards–Trinity aquifer of the Edwards Plateau may be relatively small because (1) regional groundwater flow within saturated Ogallala and Cretaceous sediments generally parallels the approximate boundary between the two aquifer units, and (2) a portion of the water in the Antlers sand is discharged from wells and at springs that occur (or used to occur) along the far southeastern portion of the caprock escarpment, along draws, and at the margins of salt lakes within the study area.

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Chapter 6

Cenozoic Pecos Alluvium Aquifer

Ian C. Jones[1]

Introduction

The Cenozoic Pecos Alluvium aquifer is located in the Pecos River valley of western Texas and southeastern New Mexico (Figure 6-1). This alluvium aquifer underlies parts of Crane, Ector, Loving, Pecos, Reeves, Upton, Ward, and Winkler counties and extends north into Eddy and Lea counties in New Mexico.

The Cenozoic Pecos Alluvium occurs in an arid region characterized by average annual precipitation of 10 to 20 inches and average annual evaporation rates approaching 70 inches (Boghici, 1999). These climatic conditions play an important role in determining the amount of water available for recharge to the aquifer. Climate, together with crop selection, also play a role in determining the water demand for irrigation pumping. In arid areas and especially during drought periods, irrigation pumping is increased to compensate for the absence of precipitation. The Cenozoic Pecos Alluvium aquifer is of primary importance as a source of irrigation water, especially in Reeves and northwestern Pecos counties (Ashworth and Hopkins, 1995; TWDB, 1997). Irrigation pumping accounts for approximately 75 percent of water withdrawal from the aquifer. Some groundwater from this aquifer is also exported to the City of Odessa by the Colorado River Municipal Water District (TWDB, 1997). Groundwater extraction for irrigation and municipal uses has multiple effects on the Cenozoic Pecos Alluvium aquifer including historic water-levels declines and progressive deterioration of groundwater quality. These effects will be discussed in more detail later in this paper.

Geology

The Cenozoic Pecos Alluvium aquifer is composed of Tertiary and Quaternary age alluvium, more than 1,500 feet thick (Figure 6-2). This alluvium unconformably overlies older Permian, Triassic, and Cretaceous age rocks (Figure 6-3; White, 1971). The alluvium is mostly composed of unconsolidated or poorly cemented clay, sand, gravel, and caliche (White, 1971). North of the Pecos River, the alluvium is overlain in places by windblown sand deposited in dunes. This windblown sand was derived from the Pleistocene Blackwater Draw Formation, an older, extensive eolian deposit that crops out east of the study area (White, 1971; Muhs and Holliday, 2001). The sand dunes are

[1] Texas Water Development Board

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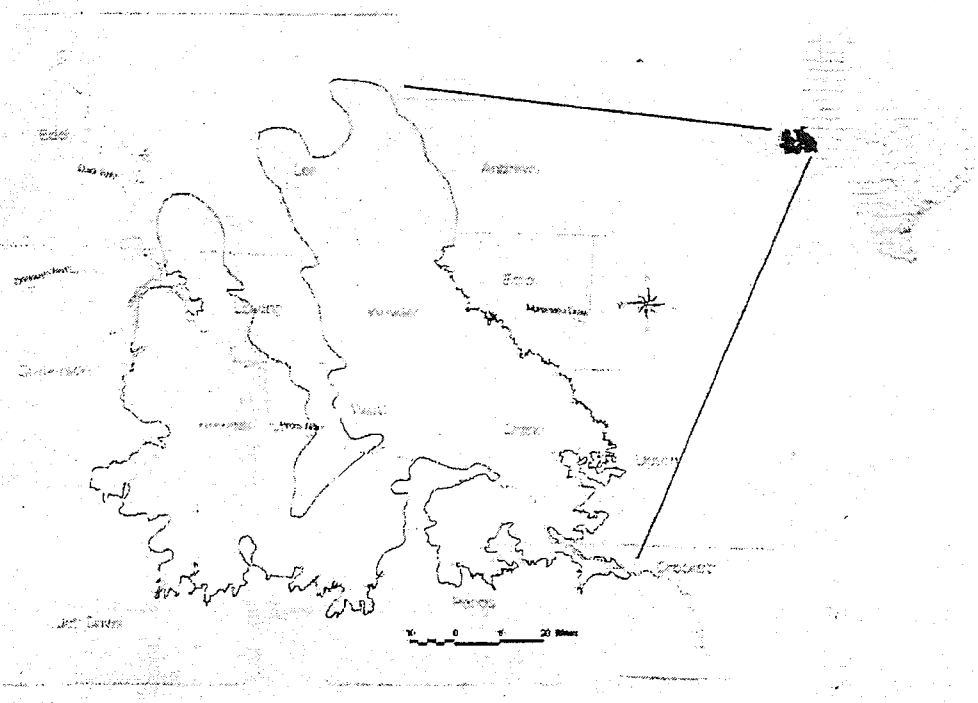

Figure 6-1: The Cenozoic Pecos Alluvium aquifer is located along part of the Pecos River Valley of Texas and New Mexico. This alluvium aquifer underlies parts of Crane, Ector, Loving, Pecos, Reeves, Upton, Ward, and Winkler counties in Texas and Eddy and Lea counties in New Mexico.

composed of fine quartz sand up to 250 feet thick (Garza and Wesselman, 1959; White, 1971). These dunes are potentially important sites for recharge due to relatively high infiltration rates (Figure 6-4). This is indicated by the scarcity of perennial or ephemeral streams north of the Pecos River because rapid infiltration of precipitation into the dune sand produces little runoff.

The Cenozoic Pecos Alluvium aquifer consists of two main north-south oriented basins or troughs: the Pecos Trough and the Monument Draw Trough (Figure 6-5). The aquifer is composed of alluvial sediments deposited in two major depressions during the Cenozoic Era (Ashworth, 1990). These troughs formed due to subsidence that resulted from dissolution of underlying evaporites (rock salt, anhydrite, and gypsum), especially but not exclusively in the Salado and Castile formations (Figure 6-3; Ashworth, 1990).

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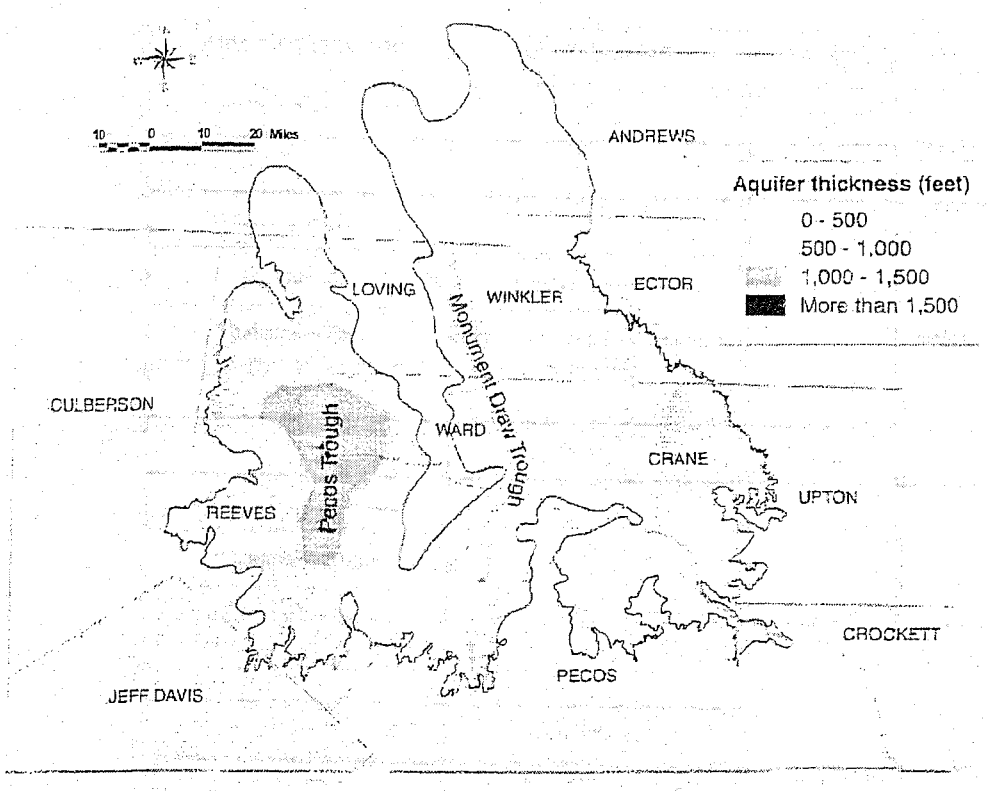

Figure 6-2: The Cenozoic Pecos Alluvium aquifer is composed of two main basins that are more than 1,500 feet deep in places (based on data from USGS, 2002).

Hydrogeology

The Cenozoic Pecos Alluvium aquifer is unconfined, although clay beds may produce local artesian conditions (Ashworth and Hopkins, 1995). In some areas, perched aquifers occur on clay beds located above the main water table (Boghici, 1998; 1999). This alluvium aquifer overlies, and in some places is hydrologically connected to, underlying aquifers. These aquifers are: (1) the Edwards–Trinity (Plateau) aquifer in Pecos and Reeves counties, (2) the Dockum Group in Ward and Winkler counties, (3) the Tertiary volcanics in Reeves County, and (4) the Rustler aquifer (Ashworth and Hopkins, 1995). Well yields in the Cenozoic Pecos Alluvium aquifer are generally moderate to high (Ashworth and Hopkins, 1995). In the Pecos River Valley, depths to groundwater are 10 to 20 feet increasing to about 50 feet away from the river (Boghici, 1998; 1999). Depths to groundwater are much greater in cones of depression.

Recharge to the Cenozoic Pecos Alluvium aquifer takes the form of infiltration of precipitation, seepage from ephemeral streams, cross-formational flow, and irrigation return-flow (Figure 6-6; Ashworth, 1990). Recharge only occurs after soil moisture is

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Era	System	Series/Group		Stratigraphic Unit
Cenozoic	Quaternary			Cenozoic Pecos Alluvium
	Tertiary			Volcanic Rocks
Mesozoic	Cretaceous	Gulf		undifferentiated
		Comanche	Washita	undifferentiated
			Fredericksburg	undifferentiated
			Trinity	undifferentiated
	Triassic	Dockum		undifferentiated
Paleozoic	Permian	Ochoan		Dewey Lake Red Beds
				Rustler Formation
				Salado Formation
				Castile Formation
		Guadalupian		Capitan Reef Complex

Figure 6-3: The stratigraphic units that underlie the study area. The Cenozoic Pecos Alluvium aquifer overlies and potentially interacts with aquifers occurring Tertiary through Paleozoic age stratigraphic units.

high enough to overcome the effects of surface tension that would otherwise adhere the water to sand grains. High soil moisture allows water to infiltrate through to the water table (Ashworth, 1990). Consequently, natural recharge is episodic and associated with heavy rainfall. Recharge is only likely to occur during long-duration rainfall events or periods of frequent smaller rainfall events. Otherwise, the water is lost to the effects of evapotranspiration. The most favorable sites for natural recharge of precipitation are the dune sands that overlie the Monument Draw Trough (Figure 6-4; Richey and others, 1985). These sand dunes are highly permeable and in some places sparsely vegetated (White, 1971). High permeability and sparse vegetation result in rapid infiltration of precipitation because together they minimize losses to evapotranspiration (White, 1971). It is possible that due to the occurrence of these highly permeable sand dunes recharge rates may be higher to the Monument Draw Trough than to the Pecos Trough. Recharge due to infiltration from ephemeral streams is also episodic, requiring sufficient precipitation to generate runoff through these streams. Cross-formational flow primarily enters the Cenozoic Pecos Alluvium aquifer in the south and west where the aquifer is

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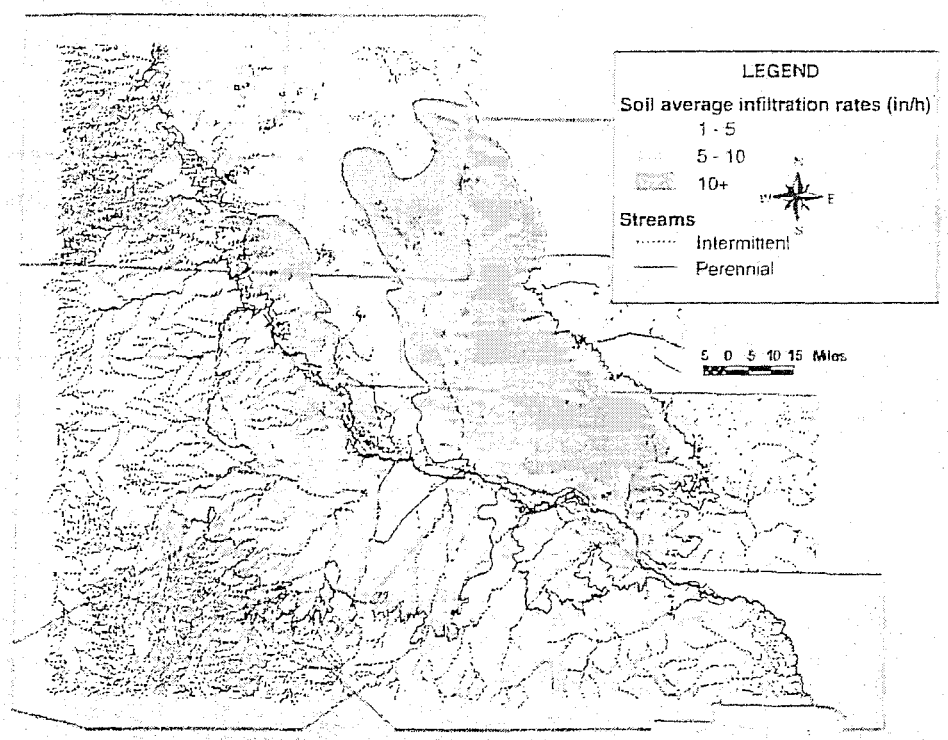

Figure 6-4: The distribution of ephemeral and perennial streams over the Cenozoic Pecos Alluvium indicates that most runoff takes place south of the Pecos River. This distribution can be attributed to the much higher soil infiltration rates north of the Pecos River that would produce higher infiltration at the expense of runoff (based on STATSGO data [USDA, 1994]).

hydrologically connected to Permian (Rustler Formation), Triassic (Dockum Group), Cretaceous (Edwards-Trinity aquifer), and Tertiary volcanics aquifers (Ashworth, 1990). Seepage from irrigation canals and irrigation return-flow also contributes water to the aquifer. Estimates of losses due to seepage from irrigation canals range from 30 percent to 72 percent (Ashworth, 1990). The highest loss rates can be attributed to high permeability sandy soils that overlie parts of the aquifer. Overall, irrigation return-flow is estimated to be 20 percent of applied irrigation water (Ashworth, 1990).

Natural discharge from the Cenozoic Pecos Alluvium aquifer takes the form of evapotranspiration adjacent to Pecos River and discharge into the Pecos River (White, 1971). Evapotranspiration losses are greatest in the lowlands adjacent to the river and other areas where the water table is close to land surface. These losses primarily take the form of uptake by phreatophytes (for example, salt cedar and mesquite) that are abundant in these areas (White, 1971). Water uptake by vegetation can be substantial. For example, estimated transpiration rates for salt cedar, juniper, mesquite, cattail, and shrubs are 2 to 20, about 2, 1 to 2, 4 to 10, and 1 to 2 ac-ft/ac/yr, respectively (McDonald and Hughes,

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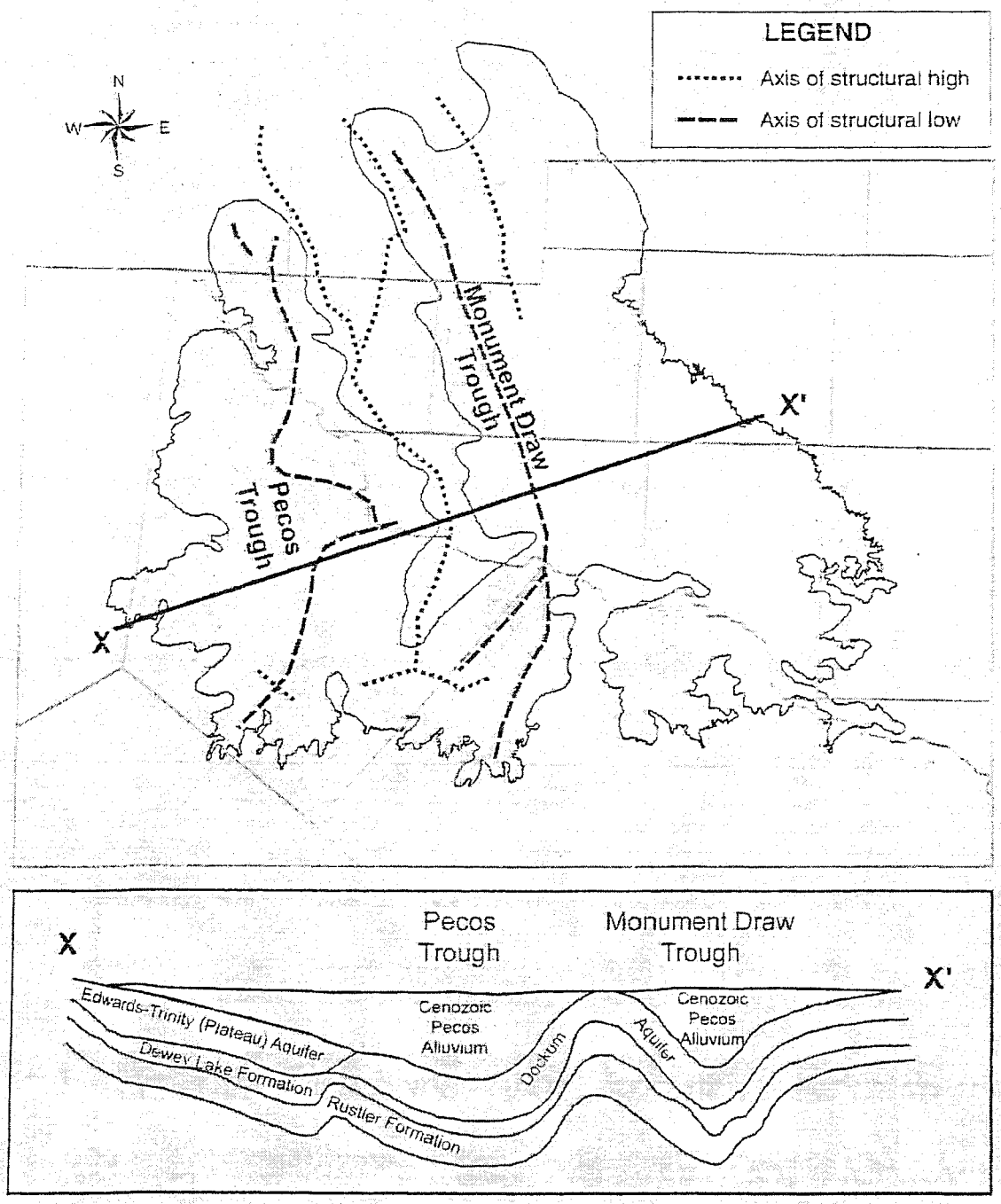

Figure 6-5: The basins of the Cenozoic Pecos Alluvium were formed by subsidence that resulted from dissolution of evaporites in underlying stratigraphic units, such as Permian Salado and Castile formations (modified from Hiss, 1976; Ashworth and Hopkins, 1995).

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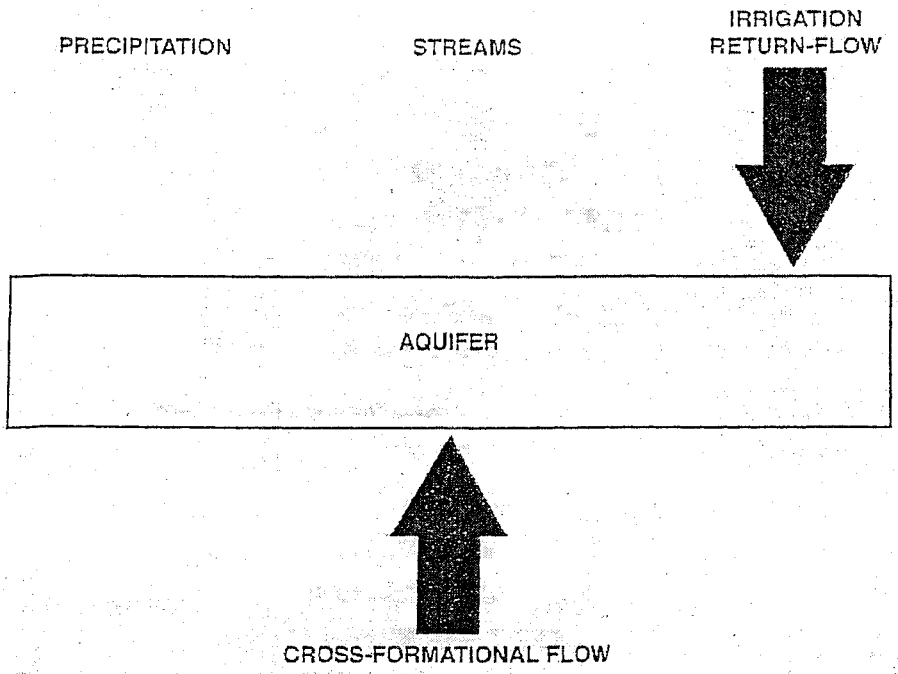

Figure 6-6: Processes that contribute recharge to the Cenozoic Pecos Alluvium aquifer. Precipitation and infiltration from perennial and ephemeral stream contribute fresh water while water from irrigation return-flow and cross-formational flow from adjacent aquifer may be saline.

1968; Ansley and others, 1998; Dugas and Hicks, 1998; Gatewood and others, 1950; Van Hylckama, 1970; Weeks and others, 1987; Devitt and others, 1997).

Water levels

Groundwater flow in the Cenozoic Pecos Alluvium aquifer generally converges on the Pecos River, the main discharge zone, except where pumping forms cones-of-depression (Boghici, 1998; 1999). This suggests that there is no groundwater flow between the Pecos and Monument Draw troughs. Consequently, it can be concluded that the two troughs are separate groundwater flow systems.

The Cenozoic Pecos Alluvium aquifer has experienced historic water-level declines of more than 200 feet in parts of south-central Reeves and northwest Pecos counties (Figure 6-7). One of the results of this water-level decline has been reduced baseflow to the Pecos River. Water-level variations over time in the aquifer have been associated with varying intensity of irrigation pumping (Ashworth and Hopkins, 1995). Irrigation farming developed in Reeves and Pecos counties in the 1940s. Irrigation pumping peaked in the 1960s and has been declining since then (Figure 6-8; TWDB, 1997). In Reeves County, the number of irrigation wells increased ten-fold, from 35 to 355, between 1940 and 1950

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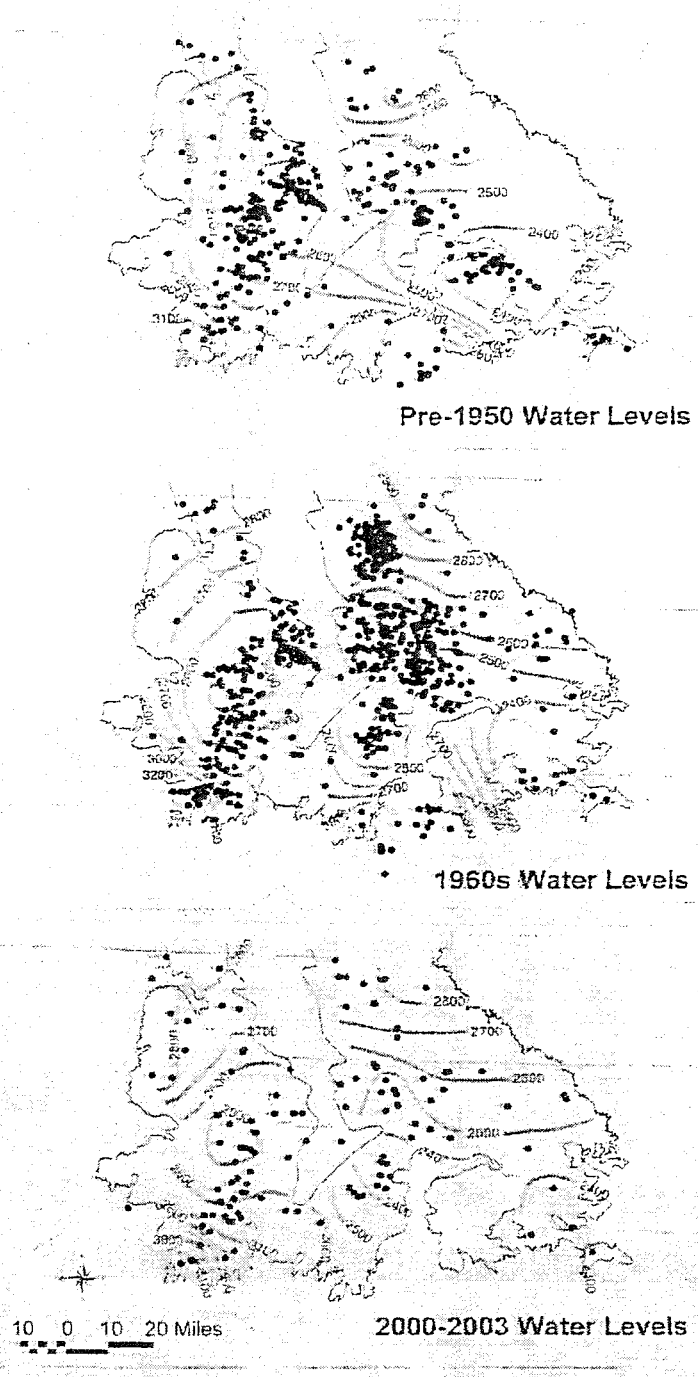

Figure 6-7: Water-level elevations in the Cenozoic Pecos Alluvium aquifer pre-development (pre-1950), in the 1960s, and present-day. These maps show the development of a cone of depression in central Reeves County in the 1960s in response to irrigation pumping. Under present conditions, this cone of depression has recovered slightly, and a smaller cone has developed in central Ward County due to municipal pumping.

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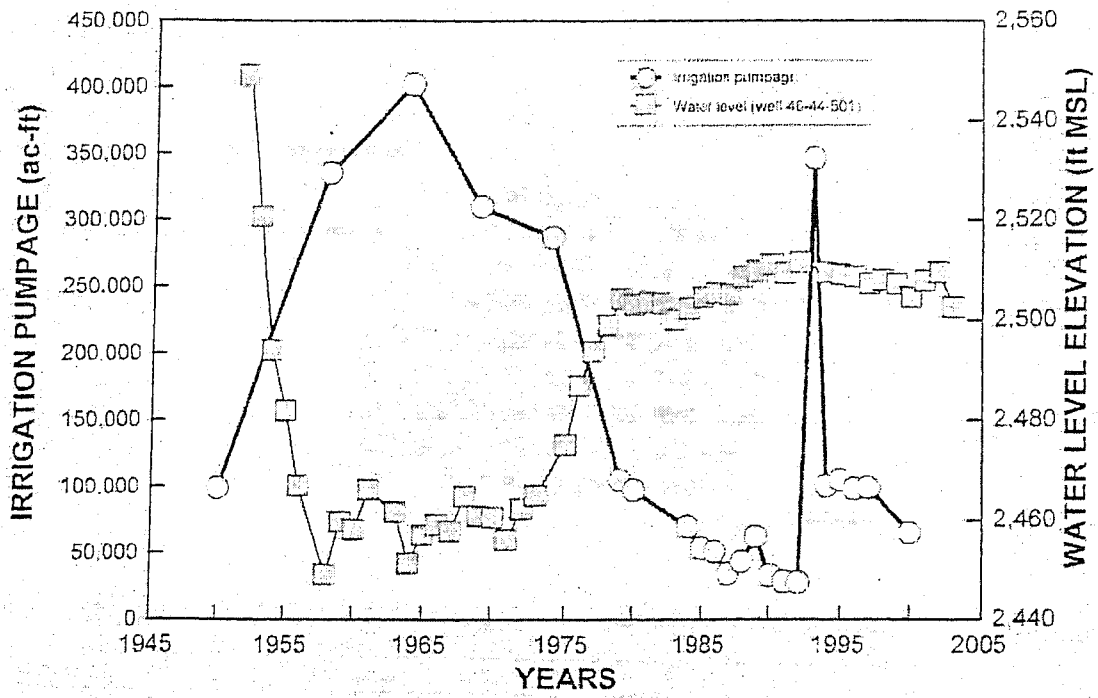

Figure 6- 8: Historic irrigation pumping from the Cenozoic Pecos Alluvium aquifer in Reeves County and associated water-level decline and recovery.

(Hood and Knowles, 1952). Water levels in the aquifer have responded to changes in irrigation pumping rates (Figures 6-7 and 6-8). Water levels declined sharply in late 1940s and early 1950s in response to the development of irrigation farming and leveled off in the 1960s. These water-level declines resulted in the formation of cones of depression in central Reeves and northern Pecos counties associated with large areas of irrigated farming (Figure 6-7). Water levels began to recover in the mid-1970s due to decreased irrigation pumping (Ashworth and Hopkins, 1995). In the main irrigated areas, water levels also exhibit seasonal fluctuations related to seasonal irrigation cycles (Ashworth, 1990). Groundwater levels decline during summer months when irrigation demand is greatest and recover slightly during the winter. Water-level declines have been greatest in the major irrigation areas of Reeves and northern Pecos counties where two major cones of depression have formed in irrigated areas in central Reeves County and the Coyanosa irrigation area of Reeves and Pecos counties (Figure 6-7; Boghici, 1998; 1999). Irrigation pumping has been less intense in the Monument Draw Trough than the Pecos Trough. Therefore, water-level decline impacts have been minor north of the Pecos River (Ashworth, 1990).

Current water levels in the Cenozoic Pecos Alluvium aquifer indicate slight recovery in parts of Reeves County that were previously heavily impacted by irrigation pumping However, continued water-level decline has been observed in other parts of the aquifer (Figure 6-7). Declining water levels are evident in northern Pecos County and central

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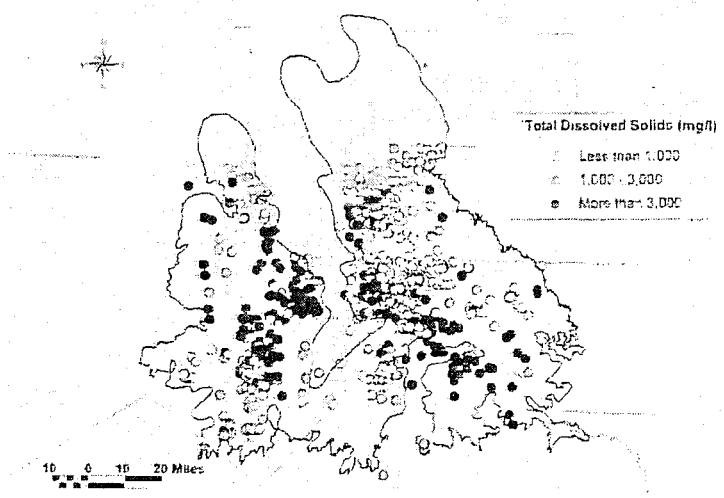

Figure 6-9: Cenozoic Pecos Alluvium aquifer groundwater salinity. Groundwater salinity tends to be greater along and south of the Pecos River. The lowest salinity is associated with the sand dunes in the eastern part of the aquifer.

Ward County (Figure 6-7). Unlike the water-level declines in Reeves and Pecos counties that are attributable to continued irrigation, the water-level declines in Ward County are associated with pumping related to public supply and industrial uses (Boghici, 1998; 1999).

Water Quality

Groundwater quality in the Cenozoic Pecos Alluvium aquifer is variable with groundwater ranging from fresh to very saline water (Figure 6-9). Brine occurs locally in this aquifer. Groundwater quality is generally better in the Monument Draw Trough portion of the aquifer than in the Pecos Trough. Pecos Trough groundwater is generally slightly to moderately saline while Monument Draw Trough groundwater varies from fresh to moderately saline. In the Monument Draw Trough, the fresh water generally occurs in the east, while more saline groundwater tends to occur on the western side of the trough adjacent to the Pecos River. Fresh water (total dissolved solids less than 1000 mg/l) in the aquifer is generally associated with dune sands.

The geochemical composition of groundwater on either side of the Pecos River is generally similar (Figure 6-10). However, the range of groundwater compositions in the Monument Draw Trough is wider, ranging from bicarbonate- to sulfate-chloride-dominated compositions while Pecos Trough groundwater compositions are predominantly sulfate-chloride-dominated. Bicarbonate-dominated groundwater

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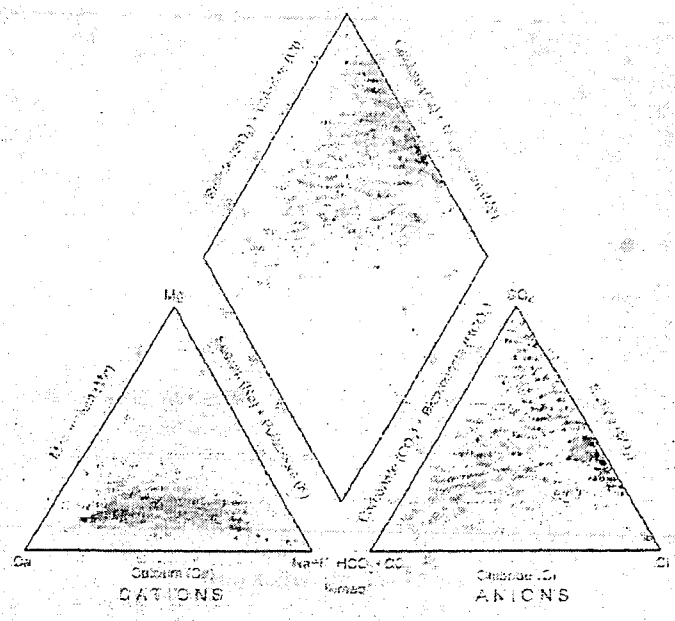

Figure 6-10: Piper diagram showing groundwater geochemical compositions north in the Monument Draw Trough area (open circles) and south in the Pecos Trough area of the Pecos River (closed circles).

compositions are typically fresh water in the eastern Monument Draw Trough. The most saline groundwater in the Cenozoic Pecos Alluvium aquifer occur in shallow wells, less than 300 feet deep (Figure 6-11). At depths greater than 300 feet, groundwater salinity is generally uniform.

Saline groundwater that occurs in this aquifer is mostly the result of natural processes. However, in some areas, poor water quality may result from anthropogenic activity (Ashworth and Hopkins, 1995). Groundwater quality in the Cenozoic Pecos Alluvium is potentially influenced by several factors including: (1) the presence of underlying evaporite beds, (2) evaporation, (3) recharge of irrigation return-flow, (4) pumping, and (5) past oil-field practices.

The range of groundwater compositions in the Cenozoic Pecos Alluvium aquifer suggest varying influences of evaporite dissolution (Figure 6-10). Sulfate- and chloride-dominated groundwater compositions are attributable to gypsum and halite dissolution. Neither gypsum nor halite occurs within the Cenozoic Pecos Alluvium. However, these minerals do occur in underlying Permian stratigraphic units. Consequently, the occurrence of sulfate- and chloride-dominated groundwater in the Cenozoic Pecos Alluvium aquifer can be attributed to cross-formational flow contributing minor amounts of saline groundwater from the underlying Permian aquifers.

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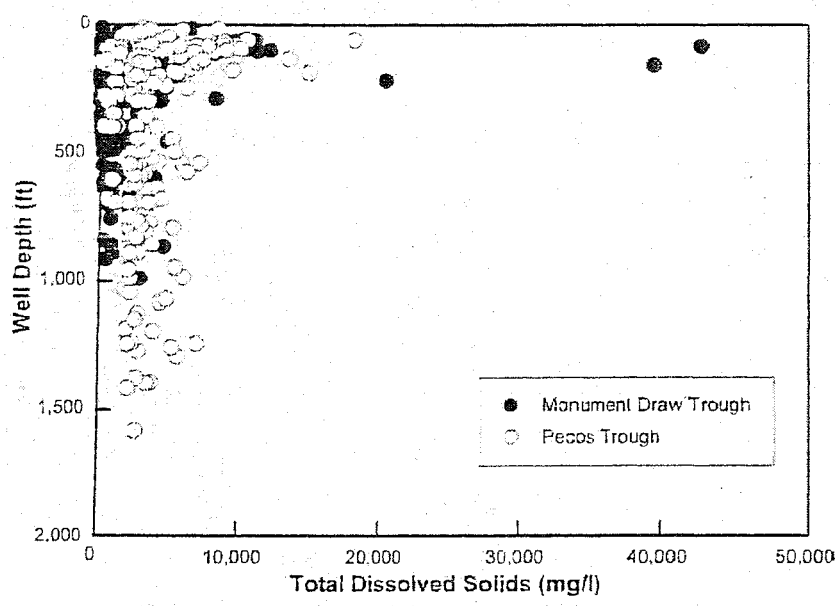

Figure 6-11: Groundwater salinity in the Cenozoic Pecos Alluvium aquifer is highest in shallow wells and relatively uniform at depths greater than 300 feet.

Shallow saline groundwater, especially along the Pecos River, can not necessarily be attributed to cross-formational flow. Decreasing salinity with depth can be attributed partially to evaporation in areas where the water table is shallow (Figure 6-11). Shallow saline groundwater may also result from activities related to agriculture. Salinity may result from recharge of irrigation return-flow, especially in Reeves County (Ashworth, 1990). Irrigation return-flow may explain higher groundwater salinity observed in central Reeves County (Figure 6-9). This zone of higher salinity approximately coincides with a large area of irrigated farmland in Reeves County (Figure 6-12). Irrigation return-flow water becomes saline due to evaporation at land surface, or by dissolution of salts accumulated in the soil. In some areas, nitrate derived from fertilizers may impact groundwater quality (Ashworth, 1990). In these areas, fertilizer nitrogen is leached from the soil by infiltrating precipitation or irrigation return-flow.

Groundwater salinity may increase because heavy pumping draws in more saline groundwater that occurs at depth. This can explain the association of declining water levels and increasing salinity observed in three wells in central Ward County (Figure 6-13). These wells are located in an area that has experienced water-level decline due to municipal pumping. Declining hydraulic heads in the Cenozoic Pecos Alluvium aquifer with respect to hydraulic heads in underlying saline aquifer can produce increased cross-formational flow. This increased cross-formational flow can have detrimental impacts on water quality due to the increased influx of saline groundwater. This process may also be a contributing factor for the elevated salinity in central Reeves County, an area that has also experienced historic water-level decline.

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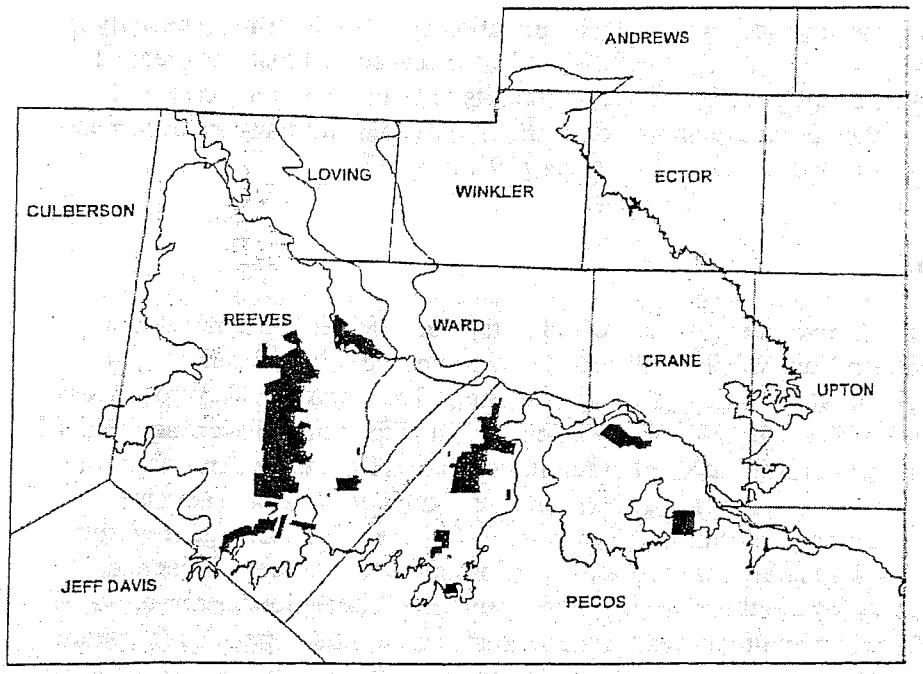

Figure 6-12: The main irrigated farmland areas overlying the Cenozoic Pecos Alluvium aquifer.

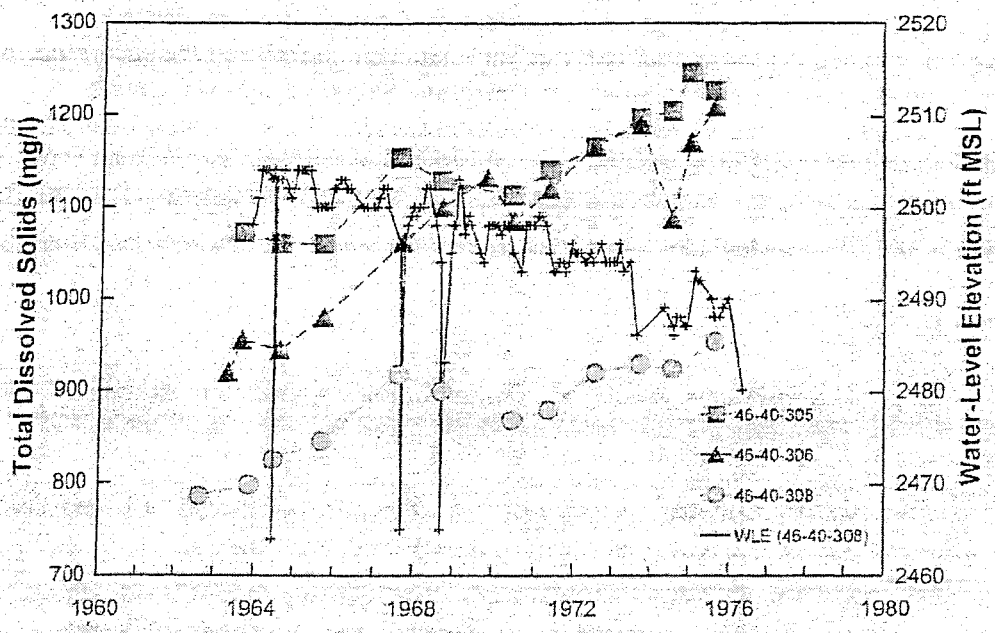

Figure 6-13: Declining water levels are accompanied by increasing groundwater salinity in parts of central Ward County.

08 098

Locally, saline groundwater occurs due to contamination by oil-field brine, especially in Winkler and Loving counties (Ashworth, 1990). Most of this contamination is related to past disposal of large quantities of brine in unlined pits or from improperly cased oil wells (Ashworth, 1990). Brine contamination is the likely explanation for the occurrence of brine in the Monument Draw Trough (Figures 6-9 and 6-11).

Conclusions

The Cenozoic Pecos Alluvium aquifer is located in the Pecos River valley of western Texas and southeastern New Mexico. This aquifer is composed of unconsolidated to poorly cemented alluvium, caliche, and windblown sand. The Cenozoic Pecos Alluvium aquifer is an unconfined aquifer in hydrologic connection with many adjacent aquifers. Recharge takes the form of infiltration of precipitation, water from ephemeral streams, cross-formational flow from adjacent aquifers, and irrigation return flow. There is potential for higher recharge rates in the Monument Draw Trough. Discharge from the Cenozoic Pecos Alluvium aquifer takes the form of baseflow to the Pecos River and evapotranspiration adjacent to the river. Historic water-level fluctuations observed in the Cenozoic Pecos Alluvium aquifer are in response to irrigation, municipal, and industrial pumping. Water quality in the Cenozoic Pecos Alluvium aquifer varies from fresh to very saline with local brine occurrence. Water quality is generally better in the Monument Draw Trough. The most saline groundwater is found in shallow wells. Groundwater salinity in the Cenozoic Pecos Alluvium aquifer results from natural and anthropogenic processes including cross-formational flow, evaporation where the water table approaches land surface, irrigation, pumping, and oil-field brine contamination. The Cenozoic Pecos Alluvium aquifer groundwater displays geochemical evidence of anthropogenic impacts on water quality based on relationships between the occurrence of saline groundwater and land use or water-level decline. Saline groundwater can be attributed to irrigation return-flow and oil-field brine contamination when associated with irrigated farmland and oil fields, respectively. Groundwater salinity due to enhanced cross-formational flow that is the result of pumping is associated with areas of historic water-level decline.

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Report 288

EVALUATING THE GROUND-WATER RESOURCES OF THE HIGH PLAINS OF TEXAS

Volume 1

TEXAS DEPARTMENT OF WATER RESOURCES

May 1984

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TEXAS DEPARTMENT OF WATER RESOURCES

REPORT 288

EVALUATING THE GROUND-WATER RESOURCES OF THE HIGH PLAINS OF TEXAS

VOLUME 1

By

Tommy Knowles, Phillip Nordstrom,
and William B. Klemt

Prepared by the Texas Department of Water Resources in cooperation with the U.S. Geological Survey, High Plains Underground Water Conservation District No. 1, North Plains Ground Water Conservation District No. 2, Panhandle Ground Water Conservation District No. 3, and Texas Tech University

May 1984

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ABSTRACT

A regional ground-water study of the High Plains aquifer was initiated in 1978 by the Texas Department of Water Resources. The study, partially funded by the U.S. Geological Survey, is to be included in that agency's eight-state study of the High Plains aquifer. Two primary purposes of the study were to improve the data base describing the aquifer and to develop a computer model capable of predicting future conditions. The High Plains of Texas covers about 35,000 square miles (91,000 km^2) and includes all or parts of 46 counties. The High Plains aquifer consists primarily of the Ogallala Formation, and includes all water-bearing units, mainly Cretaceous and Triassic sediments, with which it is in hydraulic continuity.

Approximately 14,000 data points were used to construct a detailed altitude to base of High Plains aquifer map. Water levels in over 3,800 wells were measured to provide a detailed 1980 water-level map. The comprehensive nature of these two maps provided a more accurate saturated thickness map than had previously been attained. Maps depicting specific yield and permeability were constructed based on lithologic descriptions and the values derived were used in the digital model. The High Plains aquifer was determined to have an average specific yield of 16 percent and an average permeability of 400 gallons per day per square foot [16,300(l/d)/m^2]. An average annual natural recharge rate of 0.2 inch (0.5 cm), or 371,910 acre-feet (457 hm^3), was applied to the entire aquifer.

A two-part digital model of the aquifer was constructed and calibrated for the period 1960 through 1980. In 1980, the aquifer contained 420.58 million acre-feet (519,000 hm^3) of water, 91.5 percent recoverable. The model was applied to predict the future conditions of the aquifer, with several runs made while varying the degree to which management practices reduce irrigation application rates. The following is a comparison between a model run with the largest reduction in application rates, showing improved management practices in force, and a run without a reduction of application rates.

For the year 2000, results of the model application which used reduced application rates are as follows: 363.46 million acre-feet (448,000 hm^3) of water in storage, 2.348 million acre-feet (2,900 hm^3) of annual net withdrawals, and 4.249 million acres (17,200 km^2) under irrigation. These values represent reductions from 1980 levels of 13.6, 50.4, and 7.4 percent, respectively. The year 2000 results of the model application that did not use reduced irrigation rates are 341.66 million acre-feet (421,000 hm^3) of water in storage, 3.913 million acre-feet (4,820 hm^3) of net withdrawals, and 3.940 million acres (15,900 km^2) under irrigation. The corresponding reductions from 1980 levels are 18.7, 17.4, and 14.1 percent, respectively.

Fcr the year 2030, results of the model application which used reduced application rates are as follows: 310.66 million acre-feet (383,000 hm^3) of water in storage, 2.097 million acre-feet (2,590 hm^3) of annual net withdrawals, and 3.803 million acres (15,400 km^2) under irrigation. These values represent reductions from 1980 levels of 26.1,55.7, and 17.1 percent, respectively. The results for the year 2030 of the model application that did not reduce application rates are 259.89 million acre-feet (320,000 hm^3) of water in storage, 2.385 million acre-feet (2,940 hm^3) of annual net withdrawals, and 2.628 million acres (10,600 km^2) under irrigation. The corresponding reductions from 1980 levels are 38.2, 49.6, and 42.7 percent, respectively.

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EVALUATING THE GROUND-WATER RESOURCES OF THE HIGH PLAINS OF TEXAS

INTRODUCTION

Purpose and Scope

The Texas Department of Water Resources initiated a regional ground-water study of the High Plains aquifer in August 1978. The study was conducted by the Department with assistance from the High Plains water districts and Texas Tech University and was partially funded by the U.S. Geological Survey. The study was in support of the Geological Survey's eight-state study of the High Plains aquifer. The purposes of the Department's study were to improve the data base describing the aquifer; to better describe the occurrence, operation, and use of the aquifer; and to develop a computer model of the aquifer.

The scope of the project included the following activities: (1) research files and published reports to obtain data related to the aquifer; (2) construct detailed maps depicting the elevation of the base of High Plains aquifer; (3) measure depth to water in wells currently in the water-level observation network and in wells which were added to the network to provide adequate coverage; (4) obtain data related to specific yield, permeability, and current ground-water pumpage; (5) construct lithofacies maps of the Ogallala Formation south of the Canadian River; (6) construct 1980 water-level and saturated thickness maps based on the intensive water-level measuring effort and on the detailed base of aquifer maps; and (7) construct and calibrate a computer model with the capability of predicting future water levels and saturated thicknesses based on the physical parameters describing the aquifer and on future levels of pumpage.

This report is prepared in four volumes. Volume 1 contains interpretive information presented as text and related tables and regional figures. Volumes 2 through 4 contain supporting basic data including records of wells and county maps depicting well locations, elevation of base of aquifer, elevation of water levels in 1980, and saturated thicknesses in 1980. The areas covered in Volumes 2 through 4 are shown on Figure 1. They are:

Volume 2. Approximately the northern third of the study area, to include Armstrong, Carson, Dallam, Donley, Gray, Hansford, Hartley, Hemphill, Hutchinson, Lipscomb, Moore, Ochiltree, Potter, Roberts, Sherman, and Wheeler Counties.

Volume 3. Approximately the middle third of the study area, to include Bailey, Briscoe, Castro, Crosby, Deaf Smith, Dickens, Floyd, Hale, Lamb, Motley, Oldham, Parmer, Randall, and Swisher Counties.

Volume 4. Approximately the southern third of the study area, to include Andrews, Borden, Cochran, Dawson, Ector, Gaines, Garza, Glasscock, Hockley, Howard, Lubbock, Lynn, Martin, Midland, Terry, and Yoakum Counties.

Four additional reports were published during the course of this study. The reports discuss results of test hole drilling (Ashworth, 1980), results of surface electrical resistivity surveys (Muller, 1980), results of neutron-probe measurements (Klemt, 1981) and program documentation and user's manual for GWSIM-III computer program (Knowles, 1981).

Description of Project Area

The High Plains of Texas is the southernmost extension of the Great Plains physiographic province of North America which extends from the southern Texas Panhandle northward into South Dakota and includes parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, and Wyoming. The High Plains of Texas covers about 35,000 square miles (91,000 km^2), and includes the Canadian River basin and the upper parts of the Red, Brazos, and Colorado River basins within the state. The study area, which averages about 300 miles (480 km) from north to south, and about 120 miles (190 km) from east to west, includes all or parts of Andrews, Armstrong, Bailey, Borden, Briscoe, Carson, Castro, Cochran, Crosby, Dallam, Dawson, Deaf Smith, Dickens, Donley, Ector, Floyd, Gaines, Garza, Glasscock, Gray, Hale, Hansford, Hartley, Hemphill, Howard, Hutchinson, Lamb, Lipscomb, Lubbock, Lynn, Martin, Midland, Moore, Motley, Ochiltree, Oldham, Parmer, Potter, Randall, Roberts, Sherman, Swisher, Terry, Wheeler, and Yoakum Counties. The extent of the High Plains aquifer study is shown in Figure 1.

The Texas High Plains is essentially a flat plateau. A remarkable characteristic of the region is the great number of shallow depressions, or playas, which dot its surface. During periods of rainfall the playas accumulate drainage from local watershed areas ranging in size **from** less than one square mile to several square miles. Only a very small portion of the rainfall drains into the streams which traverse the plateau.

The Ogallala Formation of late Miocene to Pliocene age unconformably overlies Cretaceous, Jurassic, Triassic, and Permian rocks and consists primarily of sand, silt, clay, and gravel derived from the southern Rocky Mountains to the west. The Ogallala is the major water-bearing unit of the High Plains of Texas. Hydraulic continuity occurs between the Ogallala Formation and both the underlying Cretaceous, Jurassic, and Triassic rocks in many areas of the High Plains, and the Quaternary deposits, where present. Therefore, for the purpose of this study, the High Plains aquifer will be considered to consist of the saturated sediments of the Ogallala Formation and those geologic units which contain potable water and are in hydraulic continuity with the Ogallala.

Pleistocene and recent soils form a thin mantle over the Ogallala Formation. Caliche horizons, at depths ranging from 1 to 6 feet (0.30 to 1.80 m), underlie the top and subsoil zones over most of the Texas High Plains. These caliche zones are generally 1 to 2 feet (0.30 to 0.60 m) thick and grade downward into the lower Pleistocene subsoils or into hard indurated caliche layers (caprock) at the top of the Ogallala. The caprock in many cases separates the Pleistocene sediments from the Ogallala Formation. The topsoils consist of three major textural types: (a)fine sandy and silty loams, (b) clay and clay loams, and (c) fine sandy loams.

The High Plains consists of about 22 million treeless acres (91,000 km^2). A large part of this area is used for irrigation farming; the region is noted for its production of cotton, grain sorghums, and wheat.

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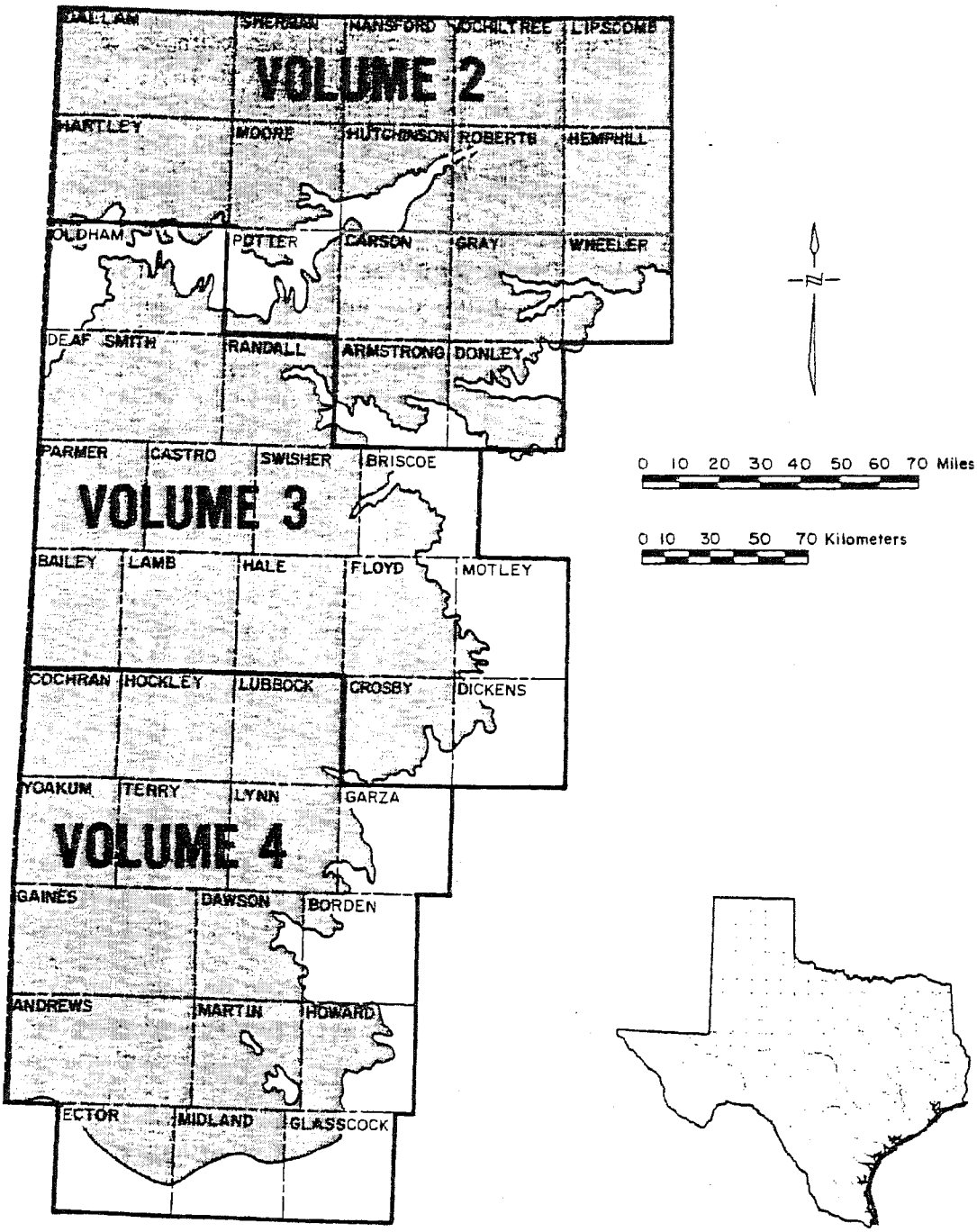

Figure 1
Extent of the High Plains Aquifer in Texas
and Index to Volumes 2, 3, and 4

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About one-half of the High Plains remains in grassland. Buffalo grass and Blue Grama are found on the clay and clay loam soils. On the sandy loam soils Little Bluestem, Western Wheat, Indian, Switch, and Sand Reed grasses are found. In other areas, the deep sands support thick growths of Shinoak and Sand Sagebrush. Mesquite and Yucca are examples of invading brushy plants.

Climate

The climate in the Texas High Plains is semiarid, and the mean annual precipitation over the area ranges from about 14 to 23 inches (36 to 58 cm). Rainfall is usually relatively light during the winter months, increasing during the spring and usually peaking in May. The average May precipitation is about three times the normal precipitation for a winter month. Average monthly precipitation reaches a second peak in September, with slightly less precipitation than the May peak. Snowfall is an important source of moisture in the winter months.

Evaporation is greatest during the summer months. In Lubbock County, the average annual evaporation potential for an open-water surface is about 3½ times the average annual precipitation.

The mean annual temperature for the High Plains is about 59 degrees Fahrenheit (15°C). The average difference between summer and winter temperatures is on the order of 40 degrees Fahrenheit (22°C). The length of the growing season (frost free period) varies from year to year but on the average is about 200 days.

Method of Investigation

The map showing the elevation of the base of the High Plains aquifer was constructed using drillers' logs and geophysical logs of water wells which completely penetrated the aquifer. For most of the study area, one data point per 2 square miles (5 km^2) was used. Where this density could not be attained with existing well logs, other data were utilized in an attempt to provide coverage. This supplemental work included (1) drilling test holes, (2) plotting surface contacts of the formation's outcrop, (3) geophysical logging of wells suspected of penetrating the base but for which drillers' logs were not available, and (4) utilizing geophysical logs of oil and gas test wells. The base map is a State of Texas Highway map and the lines representing the elevation of the base of the aquifer were drawn using a contour interval of 20 feet (6 m). A location map and a tabulation of all wells and data points used in the study were made and included in the study. Approximately 14,000 data points are included in the tabulation; however, thousands of supplemental points were also used in the base construction. The cooperating ground-water conservation districts developed the base of aquifer map, well-location map, and tabulation of all data used within their respective areas.

Water-level elevation maps for the years 1960, 1965, 1970, 1975, and 1980 were constructed utilizing measurements made from water-level observation wells in the High Plains area. The network presently contains over 3,800 wells, representing an average density of one well per 9 square miles (23 km^2). The coverage, however, is not uniform. The water-level measurements are usually taken during the winter months to minimize the effect of pumpage. The regional maps for 1960 through 1980 were prepared by Department personnel. Detailed county maps for 1980

were prepared by Department personnel except for those prepared by district personnel for areas within their respective boundaries. The districts also provided tabulations of data used in the construction of their portions of the maps.

The ability of an aquifer to yield water to wells is dependent on saturated thickness. Saturated thickness equals the interval between the water table and the base of the aquifer. The Department, with the aid of the districts, developed 1980 saturated thickness maps based on detailed base of High Plains aquifer maps and the winter 1979-80 altitude of water-level maps. The maps were used to identify areas containing sufficient amounts of water to support irrigation in the future.

Hydraulic parameters studied were specific yield and permeability. Since the Ogallala in Texas is a water-table aquifer which is being mined, specific yield will govern its useful life. Specific yield varies from one area to the next and also from one vertical interval to the next. The Department employed a varied approach to determine the distributions of specific yield and permeability. A weighted mean specific yield and permeability value was assigned to selected wells by examining the vertical distribution of different lithologic types in the saturated zone as described on drillers' logs and assigning average specific yield and permeability values to each type-layer. Regional maps of specific yield and permeability were then constructed using an average data point density of one per model cell (about 9 square miles or 23 km^2). Values derived from these regional maps were incorporated into a digital model from which computer-generated maps for specific yield and permeability were created (see section on the "Results of Model Operation"). Other approaches used to support the specific yield and permeability map construction included lithofacies mapping, test-hole drilling, laboratory testing, electrical resistivity soundings, geophysical logging, literature research, and computer modeling.

New regional lithofacies maps of the southern portion of the Ogallala Formation were prepared by personnel of Texas Tech University under the supervision of Dr. C. C. Reeves, Jr. The maps indicate distribution of sand, clay, and gravel in the Ogallala Formation. A map describing the distribution of basal Ogallala gravel zones was also produced. All field-determined specific yield and permeability values are representative of only a relatively small area. Since specific yield and permeability are affected by lithology, the lithofacies maps were developed to better estimate regional trends.

Forty-one test holes were drilled to aid in determining the hydraulic characteristics of the aquifer. This was accomplished during drilling operations by collecting undisturbed formation samples from different depths within the aquifer using the Shelby tube or Christensen core barrel. The cores were analyzed to determine porosity, vertical and horizontal permeabilities, specific yield, and grain size distribution. The holes also provided additional data utilized in preparing the base of aquifer map.

Electrical resistivity soundings were conducted to determine any variations in lithology between test holes and to attempt to correlate these soundings to porosity and specific yield values obtained through laboratory analysis of the cores retrieved from nearby test holes. The soundings were also used to determine variations in lithology where neutron soil moisture studies were conducted in an effort to better define the natural recharge and irrigation recirculation to the aquifer.

For the electrical subsurface investigation, the "Barnes Layer Method," which uses the Wenner array, was employed for the selection of electrode spacing to electrically evaluate the water-bearing zones of the aquifer. Following proper site selection, field procedures used in conducting the surface electrical resistivity surveys included selecting the proper electrode spacing, conducting actual soundings, and plotting the field VES (vertical electrical sounding) curve. Field data on apparent resistivity were interpreted by utilization of computer programs. Qualitative variations in hydrologic properties such as permeability and specific yield are shown in terms of the aquifer's apparent formation factor and computer-calculated resistivity.

Neutron soil moisture surveys were conducted in an attempt to determine the amount of natural recharge and irrigation recirculation to the aquifer. Twenty-two widely separated sites were established in carefully selected locations throughout the study area. Considerations for site selection included soil type, method of irrigation, and subsurface structure. At least two boreholes were installed at each site, the first to measure moisture in an irrigated, cultivated field and the second to measure moisture in a nonirrigated field. The boreholes were cased with 2-inch (5-cm) diameter aluminum tubing, sealed at the bottom to exclude moisture. The boreholes were constructed approximately 30 feet (9 m)deep to monitor the movement of moisture below the root zone and zone of evaporation. It was assumed that moisture passing below this depth reaches the water table. Weekly measurements were taken with the neutron moisture tools. These measurements were recorded in the form of a log which registered any moisture build-up. A recording rain gage was also installed at each site to measure precipitation, and the amount of water applied for irrigation was obtained by monitoring the nearby wells being pumped. By monitoring the move-

percolating to the water table. This estimate was compared to the amount of water applied to the surface to determine the proportional amount of irrigation water that becomes recharge and recirculation.

The High Plains Underground Water Conservation District No. 1 and the North Plains Ground Water Conservation District No. 2 serviced 17 of the sites using their equipment while the Department monitored the remaining 5 sites. Site monitoring began in November 1978 and continued for 12 months. This period generally corresponds to crop year 1979.

The construction of the digital model utilized data developed from this study and other investigations. The model used the finite difference technique to simulate water levels. The model was calibrated by reproducing water-level changes during the period 1960 through 1980. The model calculated water-level changes based on predicted pumpage through the year 2030. The pumpage prediction procedure accounts for reduced water availability due to dewatering of the aquifer.

Acknowledgements

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The authors appreciate the cooperation extended by the property owners in the High Plains who supplied information concerning their wells and, in many instances, also allowed access to their property and the use of their wells to monitor water-level changes. Acknowledgement is also

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extended to the water well drillers of the area for the use of their drillers' logs provided to the Department. Special thanks are given to the Texas State Department of Highways and Public Transportation for allowing test holes to be drilled on highway right-of-way.

Personnel

Principal investigators for the High Plains aquifer study were Dr. Tommy R. Knowles, P.E., Chief, Data Collection and Evaluation Section, and geologists Phillip L. Nordstrom and William B. Klemt. Contributing authors include John B. Ashworth, Celeste Zouzalik, Bernard Baker, Howard Taylor, and Daniel A. Muller, geologists with the Texas Department of Water Resources. Mr. Klemt served as co-principal investigator for the first part of the study. Also assisting in the completion of this study were personnel of the High Plains Underground Water Conservation District No. 1 (A. Wayne Wyatt, Manager; Don Smith and Don McReynolds, geologists), the North Plains Ground Water Conservation District No. 2 (J. W. Buchanan, former Manager; Orval Allen, Manager; Mike Crawford, geologist), the Panhandle Ground Water Conservation District No. 3 (Felix Ryals, former Manager; Richard Bowers, Manager), and the Department's Data and Engineering Services Division. The study was conducted under the general supervision of C. R. Baskin, P.E., Director, Data and Engineering Services Division. Lithofacies maps of the Ogallala Formation south of the Canadian River were prepared under the supervision of Dr. C. C. Reeves, Jr., of Texas Tech University. Test hole drilling and laboratory testing of samples were conducted by the Department's Geotechnical Services Unit.

Metric Conversions

For those readers interested in using the International System (SI) of Units, the metric equivalents of English units of measurements are given in parantheses in the text. The English units used in this report may be converted to metric units by the following conversion factors:

From English units	Multiply by	To obtain metric units
inches (in)	2.540	centimeters (cm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
acres	.4047	square hectometers (hm^2)
	.004047	square kilometers (km^2)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons per minute (gal/min)	.06309	liters per second (l/s)
acre-feet	.001233	cubic hectometers (hm^3)

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From English units	Multiply by	To obtain metric units
feet per mile (ft/mi)	0.189	meters per kilometer (m/km)
gallons per day per foot [(gal/d)/ft]	12.418	liters per day per meter [(l/d)/m]
gallons per day per square foot [(gal/d)/ft^2]	40.74	liters per day per square meter [(l/d)/m^2]

To convert degrees Fahrenheit (°F) to degrees Celsius (°C) use the following formula:

$$°C = (°F-32)(0.556)$$

STRATIGRAPHY OF THE OGALLALA AND ASSOCIATED WATER-BEARING FORMATIONS

Pre-Ogallala Rocks

Triassic System

The Dockum Group of Triassic age was named in 1890 by Cummins for the community of Dockum in Dickens County, Texas (Sellards and others, 1932, p. 242). Dockum and underlying Permian strata are red, but are readily differentiated by contrasting depositional environments. In some areas, Permian and Triassic strata are separated by an unconformity. Elsewhere, sedimentation was probably continuous from Permian into Triassic time (McGowen and others, 1979, p. 3), resulting in a gradational contact. Dockum beds are overlain unconformably by strata of Tertiary, Cretaceous, or Jurassic age and are exposed at the surface along the High Plains escarpment, in the "breaks", and in outcrops of small areal extent. Table 1 shows the stratigraphic relationship of these systems. The regional dip of Triassic strata is towards the center of the Southern High Plains. As uplifting occurred to the west, the basin was tilted to the southeast (Fink, 1963, p. 7).

The Triassic strata portrayed on Figure 2, showing the geologic units underlying the Ogallala Formation, represents the limit of preserved Triassic in the High Plains. A substantial outlier of Dockum not shown on Figure 2 exists to the east of this limit in the Northern High Plains (McKee and others, 1959, Pl. 4); it provides up to 135 feet (41 m) of water-bearing strata to irrigation wells in portions of Hansford, Hutchinson, Moore, and Sherman Counties and is included in the High Plains aquifer.

The Dockum Group can be subdivided into two or three formations depending on the location within the High Plains and on the authors of the many publications treating the Triassic rocks in this area. Fink (1963, p. 7) subdivides the Dockum in the northern part of the Southern High Plains into three formations. A basal member, the Tecovas Formation, consists of variegated shales and

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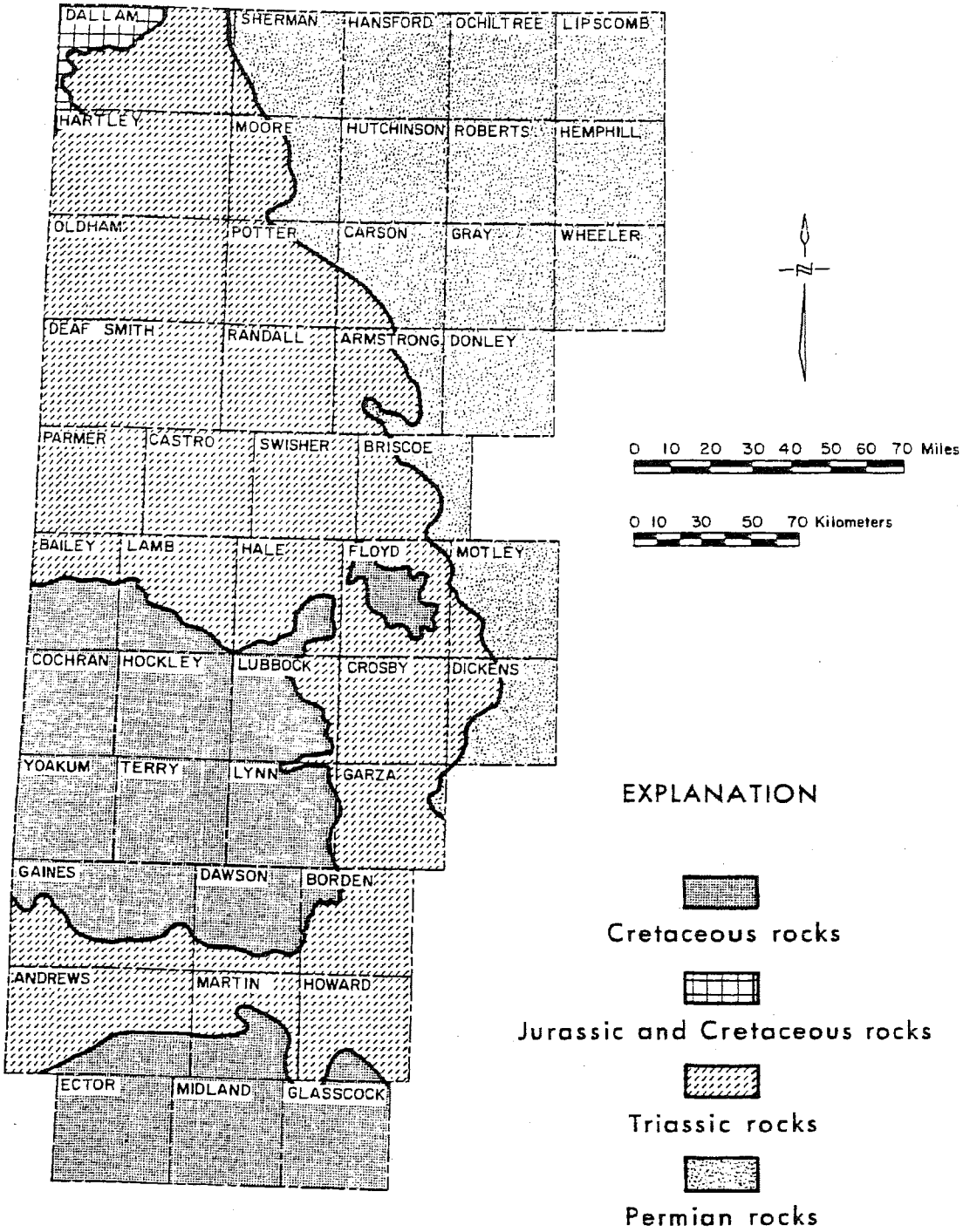

Figure 2

Geologic Units Underlying the Ogallala Formation

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Table 1.—Geologic Units and Their Water-Bearing Characteristics

System	Series	Group	Formation	Approximate maximum thickness (ft)	Physical character of rocks	Water-bearing characteristics
Quaternary	Pleistocene to Recent		Alluvium, eolian and lacustrine deposits	150	Windblown sand and silt, fluvial flood plain deposits, and silt and clay playa lake deposits.	Yields small amounts of water to wells.
Tertiary	Late Miocene to Pliocene		Ogallala	900	Tan, yellow, and reddish-brown, silty to coarse-grained sand mixed or alternating with yellow to red silty clay and variable sized gravel. Caliche layers common near surface.	Yields moderate to large amounts of water to wells. The principal aquifer in the study area with yields of some wells in excess of 1,000 gal/min.
Cretaceous	Gulf	Colorado	Graneros Shale	45	Dark-gray shale.	Not known to yield water to wells.
		Dakota	Dakota Sandstone	190	Tan to yellowish-brown, fine to medium-grained, thin to massive-bedded sandstone with interbedded gray shale.	Yields as much as 150 gal/min to irrigation wells in the northwest part of Dallam County.
	Comanche	Washita	Purgatoire	100	Upper member a dark-gray shale. Lower member a massive, buff to white, fine to coarse-grained, poorly cemented sandstone.	Yields as much as 500 gal/min to irrigation wells in the northwest part of Dallam County.
			Duck Creek	35	Yellow, sandy shale and thin gray to yellowish-brown, argillaceous limestone beds.	Not known to yield water to wells.
		Fredericksburg	Kiamichi	100	Thinly laminated, sometimes sandy, gray to yellowish-brown shale with interbeds of thin, gray, argillaceous limestone and thin, yellow sandstone.	Yields small amounts of water locally to wells.
			Edwards Limestone	40	Light-gray to yellowish-gray, thick bedded to massive, fine to coarse-grained limestone.	Locally yields moderate to large amounts of water to wells from fractures and crevices. Yields small amounts of water to wells.
			Comanche Peak Limestone	55	Light-gray to yellowish-brown, irregularly bedded, argillaceous limestone and thin interbeds of light-gray shale.	Yields small amounts of water to wells.
			Walnut	25	Light-gray to yellowish-brown, fine to medium-grained, argillaceous sandstone; thin bedded, gray to grayish-yellow, calcareous shale; and light-gray to grayish-yellow, argillaceous limestone.	Not known to yield water to wells.
		Trinity	Antlers	125	White, gray, yellowish-brown to purple, fine to coarse-grained, argillaceous, loosely cemented sand, sandstone, and conglomerate with interbeds of siltstone and clay.	Yields small to moderate amounts of water to wells in the southern quarter of the study area.
Jurassic	Upper		Morrison	550	Grayish-green to red shale; white to brown, fine to coarse-grained sandstone; some clay, conglomerate, and limestone; brown-silt member at base.	Yields small amounts of water to livestock wells in north-central Dallam County.
			Exeter Sandstone	50	White to brown, massive, fine to medium-grained sandstone.	Yields as much as 20 gal/min to wells.
Triassic	Upper	Dockum	Undivided	2,000	Upper unit, Trujillo Formation, varicolored siltstone, claystone, conglomerate, fine-grained sandstone, and limestone. Lower unit, Tecovas Formation, varicolored, fine to medium-grained sandstone with some claystone and interbedded shale. Includes units equivalent to Chinle Formation and Santa Rosa Sandstone.	Yields small to moderate amounts of water to wells. Water quality variable with stratigraphic position and depth.
Permian	Upper		Undivided	1,000+	Very fine to fine-grained, red sandstone and shale; white to brown gypsum, anhydrite, and dolomite.	Yields small amounts of water to wells near the outcrop. Water quality generally slightly saline.

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clays, sometimes sandy or silty. Colors and predominately maroon, reddish brown, blue, yellow, and white. In localized areas, the Tecovas also contains fine-grained sandstone and conglomerate lenses. Tecovas beds are up to 200 feet (60 m) thick and are not known to yield water to wells. Occupying the middle unit is the Santa Rosa Sandstone, the major water-bearing unit of the Triassic in this area. Beds may exceed 200 feet (60 m) in thickness and consist of gray, tan, white, and brown, fine- to coarse-grained, crossbedded sandstone and conglomerate with interbedded red, blue, and gray shale and clay. Petrified wood and mica are common with local areas of mudstone and siltstone. The upper unit is the Chinle Formation and consists of up to 600 feet (180 m) of red, blue, and reddish brown clays and shales. Thin beds of micaceous sandstone, conglomerate, and sandy green clays occur locally. Sand zones rarely exceed 30 feet (9 m) and yield small quantities of water to domestic and livestock wells.

Matthews' (1969, p. 24) guidebook on the geologic story of Palo Duro Canyon labels the Triassic deposits as the Trujillo Formation, consisting primarily of fine-grained and massive-bedded sandstones. The basal sandstone is gray to greenish gray and contains channel deposits of coarse sand and an abundance of mica. The middle portion consists of red, maroon, and gray shales overlain by a coarse-grained, cross-bedded sandstone. An upper unit of red and green shale tops the section. The Trujillo is the approximate equivalent to the Santa Rosa as described by Fink (1963).

Hart and others (1976, p. 17) divide the Dockum Group in the Oklahoma Panhandle into an upper and lower sandstone. The lower unit consists mostly of varicolored, fine- to medium-grained sandstone with some clay and interbedded shale. Sufficient quantities of water are available from this unit for irrigation purposes in some areas. Usually the aquifer is used to supplement more productive aquifers that overlie the Dockum. The upper unit of the Dockum is composed mainly of red and green shale with occasional thinly bedded, fine-grained, pink to red shaly sandstone and siltstone. Adequate water for livestock and domestic supplies is usually available from this upper unit.

In wells in the north-central area of Hansford County, the occurrence of red, blue, and yellow clay near the base is common, suggesting the presence of Triassic deposits in the lower section of these wells. Since the base of the High Plains aquifer (Figure 20) was picked solely on generalized drillers' log descriptions, an areal distribution of the Triassic outlier could not be accurately delimited. If the basal material as described in the drillers' logs seemed to contribute to the High Plains aquifer and be hydraulically connected with the Ogallala Formation, then it was included as part of the aquifer.

Logs in the northwestern corner of Hutchinson County indicate a persistant brown clay bed above the traditionally accepted Permian "red bed", sometimes in direct contact with the red bed but more often separated from it by a series of fine, muddy sand and clay layers. The brown clay is often associated with red and blue clay. This lower section seems to be also of Triassic age as seen from color, sand grain size, and areal extent of the clay layer.

Moore County presents the most difficult situation in determining the base of the aquifer. Wells in approximately one-half of the county obtain water from both Tertiary and Triassic(?) rocks. This relationship can be visualized by referring to geologic section B-B' (Figure 23) where the section passes through Moore County. Based on the presence of carbonized wood, mica, pyrite, and the distinctive colors exhibited by both the sands and clays in the lower section, these basal strata are considered to be of Triassic age. Clay colors range from yellow to red and blue.

Sand colors include red, yellow, gray, and a very fine-grained white sand referred to locally as "sugar sand". Similar sections may be seen in outcrops in extreme south-central Moore County where the Canadian River incises the Dockum Group. The developed Triassic sands occur principally in the western, north-central, and northeastern parts of the county. The steep submerged escarpment in the western portion of Moore County, denoted by a line and hatchure symbol on both county and regional base of aquifer maps, represents the western area of the developed Triassic sands. The line begins in the northwest corner of the county and continues south to a point just southwest of Dumas. The lower sand is overlain by a massive red and blue clay layer which abuts the higher red beds to the west. The entire lower section thins rapidly to the east and is not as continuous. The southern area of Moore County was treated separately in view of the low permeability and the development of a separate piezometric surface in the lower sands with the implied lack of permeability. An arbitrary line, based primarily on specific capacity, was extended from the point southwest of Dumas eastward to near the county boundary in order to include erosional remnants not shown on Figure 2. The aquifer base south and east of this line is mapped on top of the highest significant red clay layer. The area north of the line includes the Dockum sands since they do contribute significantly to the water resources of the local area.

The boundary line of Ogallala and Ogallala plus Dockum water-bearing strata ends in the northwest corner of Moore County, where further differentiation was not attempted. Potential for extending the delineation can be seen in Dallam County along the eastern side where closely spaced contour lines occur on both county and regional base of aquifer maps.

In a small area of northeast Randall County, as depicted on the county elevation of base map (Volume 3), wells are completed in both the Ogallala Formation and the Santa Rosa Sandstone of Triassic age, Insufficient water for irrigation is characteristic of the Ogallala in northeastern Randall and northwestern Armstrong Counties. In some parts of this area, even domestic and livestock wells are completed in Triassic sands. In all of Randall County except the above designated area, the base of Ogallala Formation was considered to be the base of High Plains aquifer. Many other counties had areas with water wells completed in Triassic rocks, such as Castro, Deaf Smith, Hale, Oldham, and Swisher Counties, but a lack of hydraulic continuity with the Ogallala or small areal extent excluded these areas from the High Plains aquifer designation.

One other area had dual Ogallala and Triassic water-well completions and was included in the High Plains aquifer. This area parallels the eastern extent of the study and is located in all or parts of Crosby, Dickens, Garza, and Motley Counties. Drillers' logs describe sand, gravel, and broken sandstone below the Ogallala Formation, separated from it by a section of blue clay and "boulders".

In general, the Dockum provides small amounts of water to wells for livestock and domestic use, with isolated areas yielding as much as 500 gal/min (32 l/s) for irrigation. Ground water from the Triassic varies considerably in chemical quality over the High Plains, but generally is more mineralized than water from overlying water-bearing units.

Jurassic System

Exeter Sandstone

Lying unconformably on tilted beds of the Dockum Group of Triassic age, the Exeter Sandstone is the basal unit of the Jurassic System in the study area (Table 1). The Exeter is primarily a

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massive sandstone with a maximum thickness of approximately 50 feet (15 m). It grades up into the brown-silt member of the Morrison Formation.

The Exeter is a massive, white to buff, fine- to medium-grained sandstone which grades into a brown color near the contact with both the Morrison and Dockum beds. Locally, lenses of clay and gravel are present (Hart, Hoffman, and Goemaat, 1976, p. 17).

Yields of as much as 20 gal/min (1.3 l/s) can be obtained from wells in north-central Dallam County. Water quality is better when overlain directly by Tertiary deposits, but quality decreases as the overlying Morrison Formation thickens.

Morrison Formation

Underlying Tertiary or Cretaceous units in Dallam and Hartley Counties, as delineated by the Jurassic limit depicted on Figure 21, is the Morrison Formation of the Upper Jurassic Series. The Morrison overlies the Exeter Sandstone disconformably. Forming the basal unit of the Morrison is the brown-silt member, into which the underlying Exeter may grade (Baldwin and Muehlberger, 1959, p. 46). Sandstone beds occurring in the upper part of the Morrison contribute some water to wells where these beds are in direct contact with the Cretaceous Purgatoire Formation or the Tertiary Ogallala Formation. The relationship of the Ogallala, Cretaceous, and Jurassic strata in Dallam County can be seen on geologic section B-B' (Figure 23).

The Morrison Formation consists of varicolored shale dominated by gray-green and red, interbedded with white to brown, fine- to coarse-grained sandstone beds, locally thick. A persistent bed of brown silt occurs at the base of the Morrison. Strata of clay, marl, and conglomerate also occur at some locales.

Only small quantities of ground water are produced from domestic and livestock wells completed in the Morrison, and locations of most such wells are restricted to the north-central part of Dallam County. Chemical quality of ground water from Jurassic beds generally limits its usefulness. Thicknesses of up to 550 feet (168 m) have been documented in test holes drilled through the Jurassic into Triassic rocks.

Cretaceous System

Antlers Formation

The Trinity Group is represented by the Antlers Formation in the southern part of the High Plains study area. These rocks are considered to be equivalent to the Paluxy Sand of Central Texas, and are generally referred to as the "Trinity Sand" in the High Plains. The north-south limits of the Cretaceous occur where the sequence of Cretaceous rocks thins markedly or is absent in the subsurface due to erosion. In the Southern High Plains, isolated Cretaceous remnants occur north and south of these boundaries (Figure 2). The Antlers is underlain by an eroded surface of Triassic strata and overlain by Tertiary or other Cretaceous formations. Both boundaries exhibit an unconformable relationship.

09 024

Although absent in places, the Antlers forms a basal sand unit in the Cretaceous system in the southeastern and southern portions of the High Plains. It is a white to purple, loosely consolidated, fine- to coarse-grained, quartz sandstone, locally hard, and commonly interbedded with fine-grained yellow sand, green clay, and gray to pink siltstone. Scattered lenses of gravel occur throughout the unit, but a more persistent, basal conglomeratic unit with interbedded coarse sand is present in most sections. Ferruginous and calcareous cementation is common.

Small to moderate amounts of water can be pumped from wells completed in the Antlers Formation. Where a sufficient saturated thickness of Ogallala sediments overlies the Antlers, the well completion interval usually encompasses both formations. In Ector, Midland, and part of Glasscock Counties, the Antlers sand yields more water of acceptable quality than any other water-bearing formation, but because of relatively thin saturated thickness and low permeability, only moderate quantities of water can be obtained from individual wells. Well yields are usually less than 100 gal/min (6.3 l/s). Water from Cretaceous wells is only slightly more mineralized than water pumped from wells completed in the Ogallala. The High Plains aquifer includes the Trinity Group in Ector, Midland, and parts of Gaines, Andrews, Martin, and Glasscock Counties.

the Fredericksburg Group limestones (Table 1) overlying the Antlers, but the dissimilar hydraulic characteristics and localized nature of this water source kept these formations from being included as part of the High Plains aquifer. Such large capacity wells were found in several areas, but were most extensive in Hale and Floyd Counties.

Purgatoire Formation

The Purgatoire Formation of the Washita Group underlies the Dakota Sandstone and unconformably overlies the Morrison Formation of Jurassic age (Table 1). Where the upper shale unit in the Purgatoire is absent, the Dakota and Purgatoire sandstones are contiguous and difficult to differentiate. For the purpose of this study, the Dakota Sandstone and Purgatoire Formation are referred to as Cretaceous rocks. In localized areas, water-bearing sandstone units of Upper Jurassic age in contact with the basal Purgatoire unit contribute sufficient quantities of ground water so as to be included in well completion intervals. The resulting Jurassic and Cretaceous rock combination shown on Figure 2 constitutes part of the High Plains aquifer, and all maps and sections of text referring to the High Plains aquifer make use of geologic and hydrologic data derived from wells completed in the Ogallala, Dakota, Purgatoire, Upper Jurassic, or any combination thereof. The extent of Purgatoire coincides with the extent of Dakota in Dallam County. The approximate thickness of the Purgatoire is 100 feet (30 m). Geologic section B-B' (Figure 23) further shows the subsurface position and net thickness of the Cretaceous and Jurassic rocks which contain the Purgatoire.

The upper unit of the Purgatoire consists of dark gray shale with thin sandstone ledges and is not water bearing. The lower unit is a buff to white, fine- to coarse-grained, poorly cemented, massive sandstone. Conglomerate beds are sometimes present in the basal part of the lower unit. The Purgatoire-Morrison contact is occasionally difficult to pick from geophysical logs in areas where sandstone beds occupy the upper interval of the Jurassic.

The primary source of water for irrigation wells in northwest Dallam County is the Purgatoire, with younger stratigraphic units (Ogallala and Dakota) also being included in well completions.

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Yields of up to 500 gal/min (32 l/s) can be obtained from wells completed in the Purgatoire, and yields exceeding 800 gal/min (50 l/s) are realized when all water-bearing strata are included in the completion interval.

Dakota Sandstone

The Dakota Sandstone lies below the Graneros Shale (Table 1) and rests disconformably on the Purgatoire Formation, both of which are of Cretaceous age. Where the Graneros Shale has been removed by erosion, the Dakota is overlain by Ogallala sediments. The Dakota crops out along several creek beds in the northwest part of Dallam County and the weathered surface exhibits an iron oxide veneer ranging in color from yellow to orange to brown-black. The thickness of the Dakota approaches 190 feet (58 m) and the extent is restricted to a part of northwest Dallam County, falling within the boundary shown on Figures 2 and 20.

Tan to brown, thin to massive-bedded sandstones of the Dakota locally contain a middle interval of lenticular to parallel-bedded gray shale to dark gray mudstone. The upper interval is mainly a shaly sandstone grading into a massive-bedded basal unit. The sandstones are fine- to medium-grained and exhibit intense crossbedding.

Many irrigation wells are completed in the Dakota, usually in conjunction with water-bearing formations above or below which increase well yields. Quantities of ground water up to 150 gal/min (9.5 l/s) can be obtained from the Dakota Sandstone. Where the Graneros or basal Ogallala clays are present, the water in the Dakota is confined under artesian pressure.

Ogallala Formation

Depositional History

The Ogallala Formation in Texas is the southernmost extension of the major water-bearing unit underlying the Great Plains physiographic province of North America. It was named by Darton (1898) for the town of Ogallala, Nebraska, near the type locality.

Following the Laramide revolution in which the southern Rocky Mountains were uplifted and the Cretaceous seas retreated, rivers flowing east and southeastward cut valleys into the pre-Ogallala surface. This erosional pattern continued until late Miocene or early Pliocene (Neogene) time when the climate became progressively more arid (Leonard and Frye, 1974). Sediments transported from the unstable southern Rocky Mountains began to accumulate in the valleys and basins formed on the Permian, Triassic, Jurassic, and Cretaceous surfaces. As the valleys and basins filled, sediments overflowed to form coalescing aprons fed by braided streams that spread across a generally level plain. Throughout the time when Ogallala sediments were being deposited, the southern Rocky Mountains remained tectonically active, providing source material for the Ogallala Formation.

Seni (1980) has described a deltaic system of deposition of the Ogallala Formation in Texas consisting of three overlapping fan lobes of which only the medial and distal fan facies occur in Texas. Each lobe contains distinct lithologic systems identified as channel, inter-channel, and inter-fan lobe.

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At its maximum areal range, the Ogallala Formation in Texas may have extended as far as 175 miles (282 km) east of its present location (Walker, 1978, p. 23). Earlier studies have suggested areal extents as far east as the Dallas area (Byrd, 1971, p. 29; and Menzer and Slaughter, 1971).

Aggradation continued until late Pliocene time when climate change and upwarping of the High Plains area caused alluviation to cease and erosion to begin. Pleistocene time followed with extensive erosion laterally along the eastern escarpment and along major river valleys. Vertical erosion has been limited due to the resistant caliche "caprock" that formed over much of the surface of the Ogallala.

During Pleistocene time the southward flowing Pecos River captured eastward flowing streams thus isolating most of the Texas High Plains from the source from which it was derived.

Stratigraphy

The Ogallala Formation consists primarily of fluvial elastics which unconformably overlie Permian, Triassic, Jurassic, and Cretaceous strata. In the Northern High Plains the formation has been divided into three subdivisions, the Valentine, Ash Hollow, and Kimball, based on fossil vertebrates and flora. The subdivisions, often referred to as floral zones, are less distinguishable in the Southern High Plains although Frye and Leonard (1957, 1959) have identified distinctive fossil seeds which correlate to the three floral zones as far south as Howard County, Texas. Evans and Meade (1948) have suggested subdividing the Ogallala of Texas into the Couch Formation consisting of coarse-grained valley fill material, and the Bridwell Formation consisting of the finer grained material deposited by coalescing streams. For this report, the Ogallala will be treated as a single unit although different depositional facies will be discussed. Lithologic descriptions are based on observations made on the 41 test holes (Ashworth, 1980) and on previous works.

Basal Ogallala sediments consist primarily of fine- to coarse-grained elastics. The sands are generally tan, yellow, or reddish brown, medium- to coarse-grained, moderately to welt sorted, unconsolidated quartz grains, interbedded with thin layers of clay and occasionally sandstone. Gravel commonly occurs in layers in the basal section and ranges in size from boulders to pea size. The gravel is usually associated with sand, silt, and clay and is occasionally cemented. Quartzite is the predominant rock type in the gravel, although a high percentage of limestone boulders and cobbles occur in the southern third of the study area along with weathered Cretaceous invertebrate fossils. The occurrence of limestone gravel and Cretaceous fossils indicate that a local source possibly contributed to the Ogallala sediments in the southern third of the study area.

Basal Ogallala sediments occupy previously eroded drainage valleys and thus are not everywhere present. Grain size and condition of sorting is an indication of the high energy involved-in the depositional process of these sediments. As expected, sand grain and gravel size decreases and sorting improves eastward.

Above the basal segment of initially deposited coarse-grained elastics are fine- to medium-grained, well to poorly sorted sand, silt, clay, marl, and occasional stringers of small gravel. The sand is generally poorly consolidated to unconsolidated, although local cementation by calcium carbonate and silica occurs. These sediments completed filling the valleys and overflowed onto a flat alluvial plain.

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Near the surface of much of the Texas High Plains are layers of resistant caliche known as "caprock". Caliche occurs in both Ogallala and post-Ogallala sediments and is formed by the leaching of carbonate and silica from surface soils and the redeposition of the dissolved minerals in layers below the surface. Although caliche layers occur primarily near the surface, deeper zones of caliche are also present. These deeper layers represent older soil horizons.

Reeves (1970, p. 355) has classified the caliche "calcrete," profiles as young, mature, and old based on age, physical factors, and chemistry. The caliche ranges from crumbly to very hard and is almost impermeable although secondary porosity has been observed in many samples. Figure 3 (by Ries, 1981) shows the number and classification of calcrete horizons, and Figure 4 shows the thickness of calcrete horizons overlying Ogallala calcrete. The effect of caliche layers on infiltration rates will be discussed in another section.

Thickness of the Ogallala Formation is primarily controlled by the morphology of the eroded pre-Ogallala surface. The greatest Ogallala thickness occurs where sediments have filled previously eroded drainage channels. These channels generally trend east or southeast. Other areas of large Ogallala thickness occur in the northeast quadrant of the Texas High Plains where sediments have filled collapsed basins formed by dissolution of Permian evaporites. Positive structures beneath the Ogallala result in a thinning of the formation and exist where Cretaceous remnants occur in Floyd and Hale Counties. These structures are shown on the elevation of the base of aquifer map, Figure 20, and on the generalized geologic sections, Figures 21 through 27. Thickness of the Ogallala Formation, which is generally greater in the northern part of the study area and thins toward the south as it overlaps Cretaceous rocks, ranges from 0 to approximately 900 feet (0 to 274 m).

Sedimentary Zonation of the Ogallala Formation

The hydraulic properties of the Ogallala aquifer are dependent on its lithology. Therefore, to accurately estimate the future potential and limitation of the Ogallala Formation, it is necessary to possess a thorough knowledge of the distribution of sediments of various types. As the principal investigator of sedimentary zonation, Dr. C. C. Reeves of Texas Tech University provided maps showing percentage distribution and thickness of sand, gravel, basal gravel, and clay. In addition, a sand and gravel to clay ratio map was supplied. Paul H. Buika and Randall K. Smelley, research assistants for Dr. Reeves, produced the following discussion and associated maps concerning sedimentary zonation of the Ogallala Formation south of the Canadian River in Texas and New Mexico.

Method of Study

Water well logs, test hole logs, and measured sections from the outcrops of the Ogallala Formation were studied. The total thickness and percentage of sand, clay, and gravel within the Ogallala section was calculated for each log.

The thickness of the gravel at the base of the Ogallala section as well as total gravel through the entire Ogallala section was determined. The positions of ancient (pre-Ogallala) stream channels were established by examining structural maps of the base of the Ogallala section. Wells located in most channels were excluded when calculating the basal gravel map, but were included in calculating total gravel thickness.

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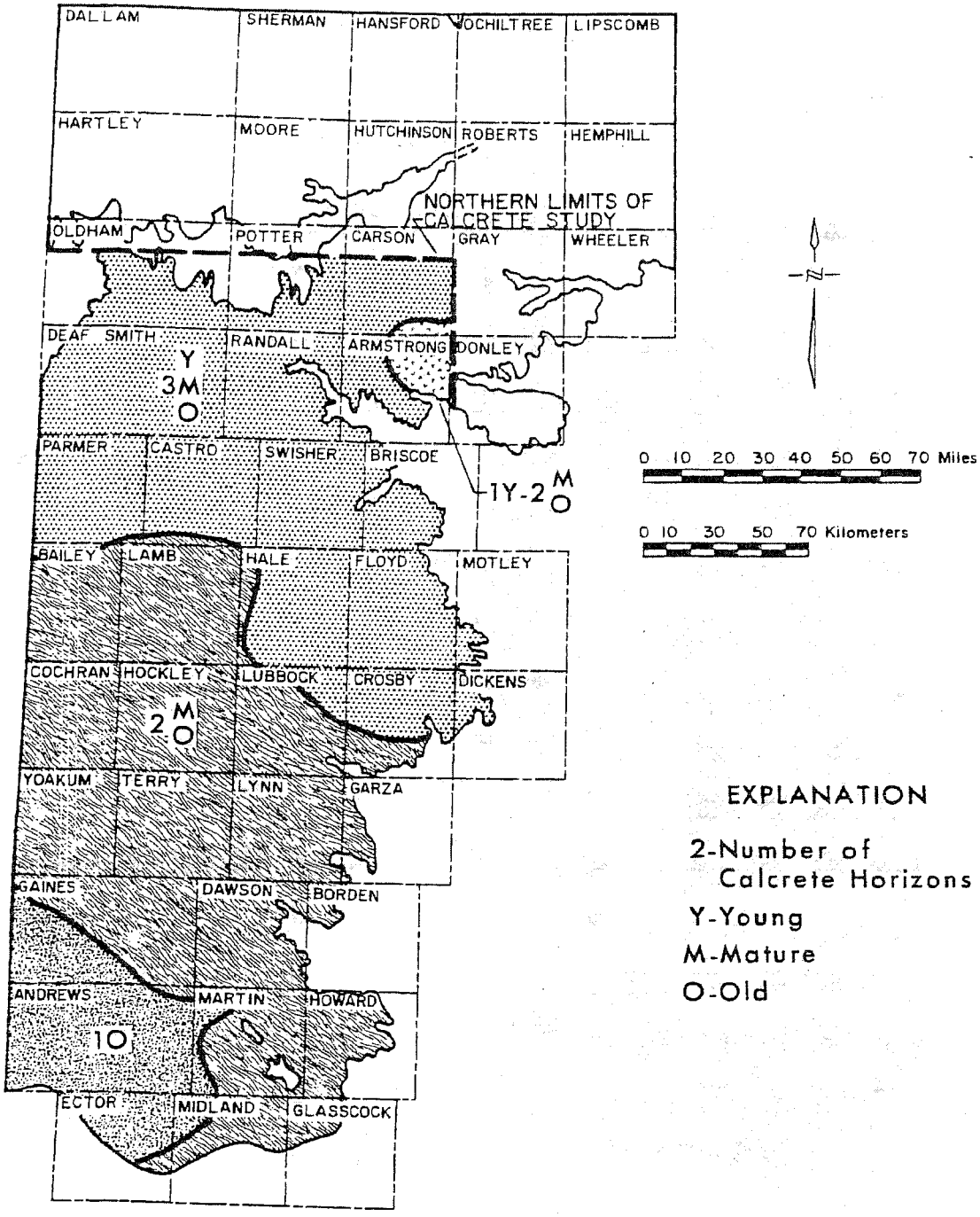

Figure 3

Number and Classification of Calcrete Horizons, Southern High Plains (After Ries, 1981)

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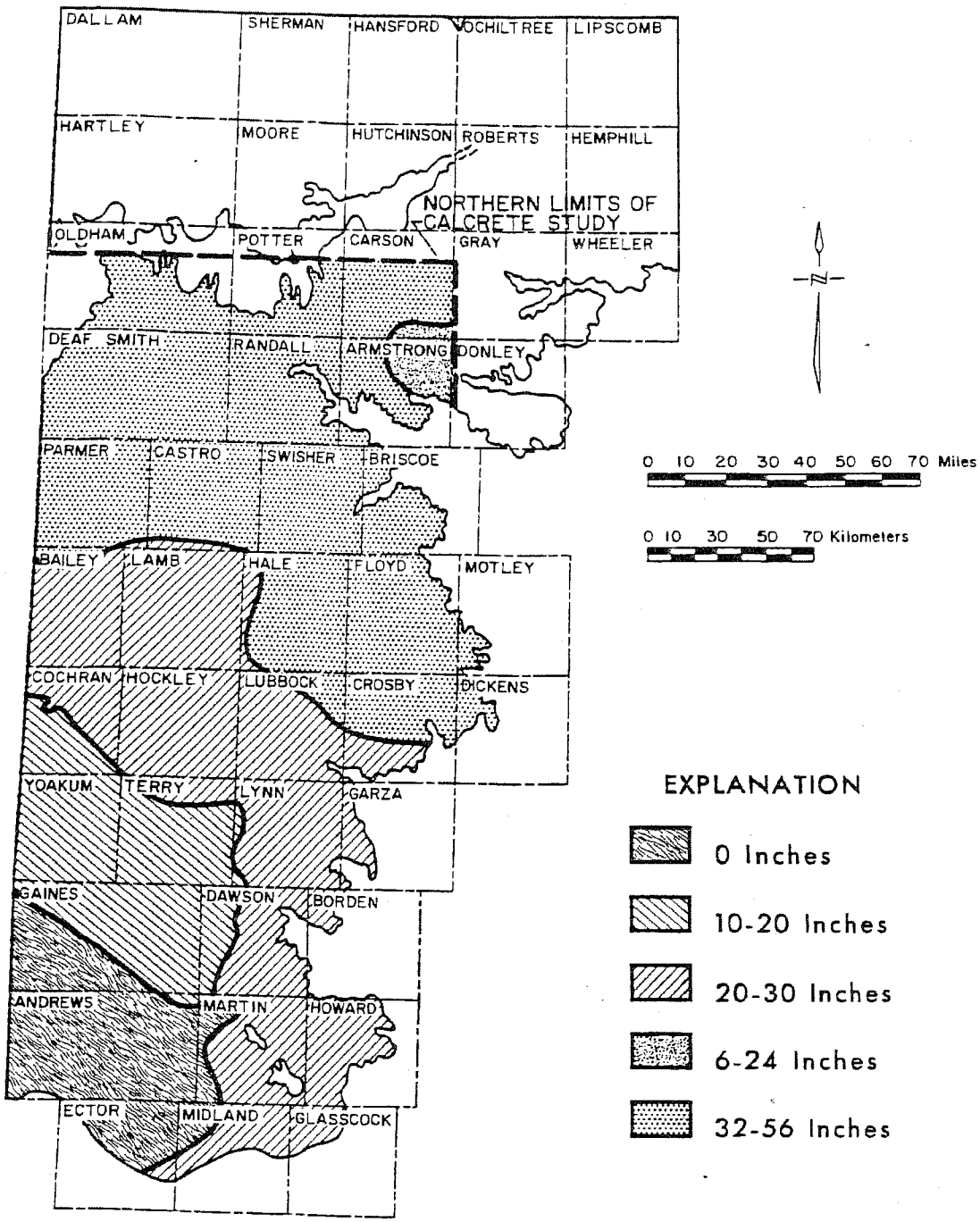

Figure 4
Thickness of Calcrete Horizons
Overlying Ogallala Calcrete
(After Ries, 1981)

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Because of inconsistent and vague lithologic descriptions of well logs written by some drillers, certain guidelines were established. Lithologic sections ambiguously described as "rock" were excluded from individual calculations of sand, clay, or gravel thicknesses. "Caliche" was classified as sand, because sand was the parent material in most cases for calcrete development. Sections described as limestone were classified as sand, because limestones in the Ogallala section are principally calcrete. Sections described as "shale" were classified as clay.

A 10-mile (16-km) square grid was established using the Texas-New Mexico state line as the "base line". Data were gathered for each grid area, with an approximate well density of no more than 1 square mile (2.6 km^2). Only wells which completely penetrated the Ogallala section were used. The selection of each well log was determined by the completeness of the log and comparison of the log to adjacent wells. Unfortunately, in many grids there was not enough available data to insure representative figures. To eliminate skewness, the highest and lowest values within each grid were dropped if they were considerably higher or lower than most of the other values. The remaining figures were then averaged, and the mean value plotted at the center of each grid.

Sand Distribution

Sand accumulations within the Ogallala section of the Southern High Plains exhibit regional thinning to the southeast (Figures 28 and 29), ranging in thickness from 20 to over 360 feet (6 to over 110 m).

[illegible] consistently ranges from 50 to 60 percent. However, due to large amounts of clay in localized areas, sand values (thickness and percent) are low. Sand percentages remain high through the northern part of the Southern High Plains (60 to 90 percent), thinning both to the east and west from Curry County, New Mexico, where sand accumulations comprise over 90 percent of the Ogallala section. Sand percentages increase to the south through Andrews, Dawson, Gaines, and Martin Counties.

Clay Distribution

Clay distribution of the Southern High Plains thickens regionally to the north and northeast. The thickness of the clay ranges from 0 feet in Lea and Roosevelt Counties, New Mexico, to over 300 feet (91 m) in Carson County (Figure 31) where clay exceeds 50 percent of the total section (Figure 30). Excessive accumulations of reddish to reddish-brown clays indicative of lacustrine lakes are found in Castro, Cochran, Crosby, Dawson, Deaf Smith, Floyd, Hale, Hockley, Lamb, Lea (New Mexico), Parmer, Swisher, Terry, and Yoakum Counties.

Gravel Distribution

Figures 32 and 33 show regional trends of thick gravel accumulations indicative of pre-Ogallala drainage channels where initial Ogallala sediments were deposited. Figure 34 exhibits relatively high basal gravel values extending east-southeastward from Parmer to Floyd County, and from southern Roosevelt (New Mexico) eastward to southern Lubbock County. Basal gravel

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values from southern Lea County (New Mexico) eastward through Martin County suggest the presence of a minor pre-Ogallala drainage (from relatively thin, but continuous, gravel accumulations in Lea County, New Mexico). However, thick localized gravel accumulations in Martin County combined with lack of sufficient data in Andrews County (Figure 33) discourage the assumption of a drainage system flowing eastward through the southern region of the study area from the Rocky Mountains.

Low gravel values of 0 to 5 feet (O to 1.5 m) through the southwestern (Andrews, Gaines, Lea, and Yoakum Counties) and northern (Deaf Smith, Oldham, Potter, and Randall Counties) regions of the Southern High Plains represent broad upland areas lying between pre-Ogallala drainage systems. Thin gravel accumulations are also present in Briscoe, Howard, Lynn, and Swisher Counties.

Gravel thickness diminishes to less than 5 feet (1.5 m) in the northwest corner of the Southern High Plains (Quay County, New Mexico). An anomalous high value in southwestern Quay County, New Mexico, indicates the presence of either a pre-Ogallala drainage system or a sink filling. The gravel distribution within Carson County exhibits a wedge which thickens to the northeast (Figure 33). Inconsistent values calculated within Carson County are attributed to numerous logs which show high thicknesses of basal gravel. This anomaly may indicate an ancient drainage channel which flowed eastward from the Rocky Mountains north of the sedimentary zonation study area, a northeast source supplying sediment to the Southern High Plains, or a complex of sink fills. A gravel wedge thickening to the west in southern Roosevelt County, New Mexico, is related to initial Ogallala sediments deposited in a pre-Ogallala drainage channel. Thick gravel accumulations within the Slaton Channel are prominent through southern Lubbock and northern Lynn Counties.

Figure 32 shows gravel comprising from 5 to 10 percent of the Ogallala section in the central Southern High Plains. High percentage values in the western region (Roosevelt and Lea Counties, New Mexico) are evidence of pre-Ogallala drainage.

Ratio of Sand and Gravel to Clay

Attempts to recharge the aquifer will be more favorable in areas which contain high percentages of permeable and porous sediments. The peripheral distance that recharged water will flow through an aquifer from an isolated recharge site is principally dependent on permeability of the rock, while storage capacity of the aquifer is controlled by porosity. Therefore, the average ratio of sand and gravel (high permeability) to clay (low permeability) within the Ogallala section was determined for each grid based on percentage values.

Figure 35 shows that the ratio of sand and gravel to clay is between 1 and 4 for most of the central Southern High Plains. The ratio increases sharply (up to 100) along the western Southern High Plains (Curry, Lea, Quay, and Roosevelt Counties) as a result of thick channel gravels (Figures 32,33, and 34). The ratio remains high (4 to 10) through the northern region (Deaf Smith, Parmer, and Randall Counties), but drops considerably to the east in Carson County where thick accumulations of clay occur (Figures 30, 31, and 35). Moderately high values (4 to 6) are found throughout the southern region of the study area (Andrews, Dawson, Gaines, Martin, and Yoakum Counties).

Conclusions

Conclusions inferred from the percentage distribution, thickness, and ratio maps (Figures 29 through 35) are as follows:

1. Sand accumulations in the Ogallala section of the Southern High Plains range from 20 to over 360 feet (6 to over 110 m), or 20 to 100 percent, regionally thinning to the southeast.

2. Clay thicknesses in the Ogallala section range from 0 to over 300 feet (0 to over 90 m), or 50 percent, regionally thickening to the north and northeast.

3. Local, thick clay accumulations scattered throughout the study area suggest the possibility of several Ogallala-age lake basins.

4. Gravel accumulations in the Ogallala section (excluding basal gravel) are thin and discontinuous—0 to 20 feet (0 to 6 m), or 0 to 10 percent. Gravel accumulations in suspected sinks or channels show higher values of 20 to 100 feet (6 to 30 m), or 15 to 30 percent.

5. Basal interformational gravels in the Ogallala section reveal two major stream systems flowing east-southeastward from the southern Rocky Mountains and entering the High Plains in New Mexico.

6. Gravel accumulations in Carson County, Texas, and in the southern region of the study area (Lea County in New Mexico and Andrews and Martin Counties in Texas) suggest the possibility of additional channels supplying sediment to the Southern High Plains.

7. The majority of sand and gravel to clay ratio values range from 1 to 4 for most of the study area, with higher values (up to 100) in the western (New Mexico counties) and northern regions (Deaf Smith, Randall, and Parmer Counties) of the Southern High Plains.

Post-Ogallala Rocks

Post-Ogallala sediments consist of windblown sand and silt, alluvium, and playa lake deposits. Windblown sands occupy the largest surface area of the High Plains of Texas and are of both Pleistocene and Recent (Holocene) age. They are primarily fine-grained to silty, sometimes calcareous, and are derived from lacustrine, fluvial, and eolian deposits. These sands and silts form sheet or cover sand, dunes, and dune ridges with thicknesses generally ranging from 0 to 10 feet (0 to 3 m).

Alluvium is present as fluvial floodplain and terrace sediments along the more active streams and rivers. The deposits consist of poorly sorted, often cross-bedded, gravel, sand, and silt.

Lacustrine deposits, consisting primarily of clay and silt, line the bottom of the many playa lakes on the High Plains. The sediments are virtually impermeable, thus restricting natural recharge to the underlying formation.

Reference 10

Texas Water Development Board

Report No. 314

Hydrogeology of Lower Cretaceous Strata Under the Southern High Plains of Texas and New Mexico

by
J. A. Tony Fallin

March 1989

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INTRODUCTION

Purpose and Scope

The primary purpose of this report is to describe the hydrogeology of Lower Cretaceous strata under the Southern High Plains. The Lower Cretaceous strata are incorporated in the High Plains aquifer system that provides essentially all of the ground water used for crop irrigation purposes on the Southern High Plains.

Significantly, clay and marl intervals in the Lower Cretaceous section under the Southern High Plains form regional aquicludes in the High Plains aquifer system. The aquicludes separate individual ground-water flow zones in the Lower Cretaceous section, forming boundaries between aquifers that have unique hydraulic characteristics, and that are discussed individually under separate headings in this report.

The report pertains to all areas where Lower Cretaceous strata are know to exist under the Southern High Plains (Figure 1), including parts of southeastern New Mexico as well as Texas. This allows for the presentation of New Mexico data that have a direct bearing on flow dynamics, ground-water chemistry, and other hydrologic properties of Lower Cretaceous aquifers in Texas. The report stems largely from field, lab, and office investigations made by the author and other individuals cited in the text.

Approximately 1,000 well logs from commercial and other drilling sources were analyzed to determine and map subsurface facies characteristics, regional thicknesses, and areal extent of Lower Cretaceous strata shown in the report. Well log information supplied from numerous oil, gas, and ground-water investigations made in the study area was obtained largely from office files located at the New Mexico State Engineer's Office in Roswell, New Mexico, and at the Texas Water Development Board (TWDB) in Austin, Texas. Regional cross-sections presented with the text were also constructed from select information recorded on drillers' logs filed with the New Mexico State Engineer's Office, the Texas Water Commission (TWC), and from descriptions of formation outcrops measured in the field. Water samples collected from wells tapping the Lower Cretaceous strata were analyzed at the Texas Department of Health Laboratories in Austin, Texas, for data used in the report.

As part of the High Plains aquifer system, discrete aquifer intervals in the Lower Cretaceous section under the Southern High Plains are developed locally as a source of fresh to slightly saline ground water. Accordingly, findings in this report have applications to projects addressing ground-water inventory, development, and management on the Southern High Plains.

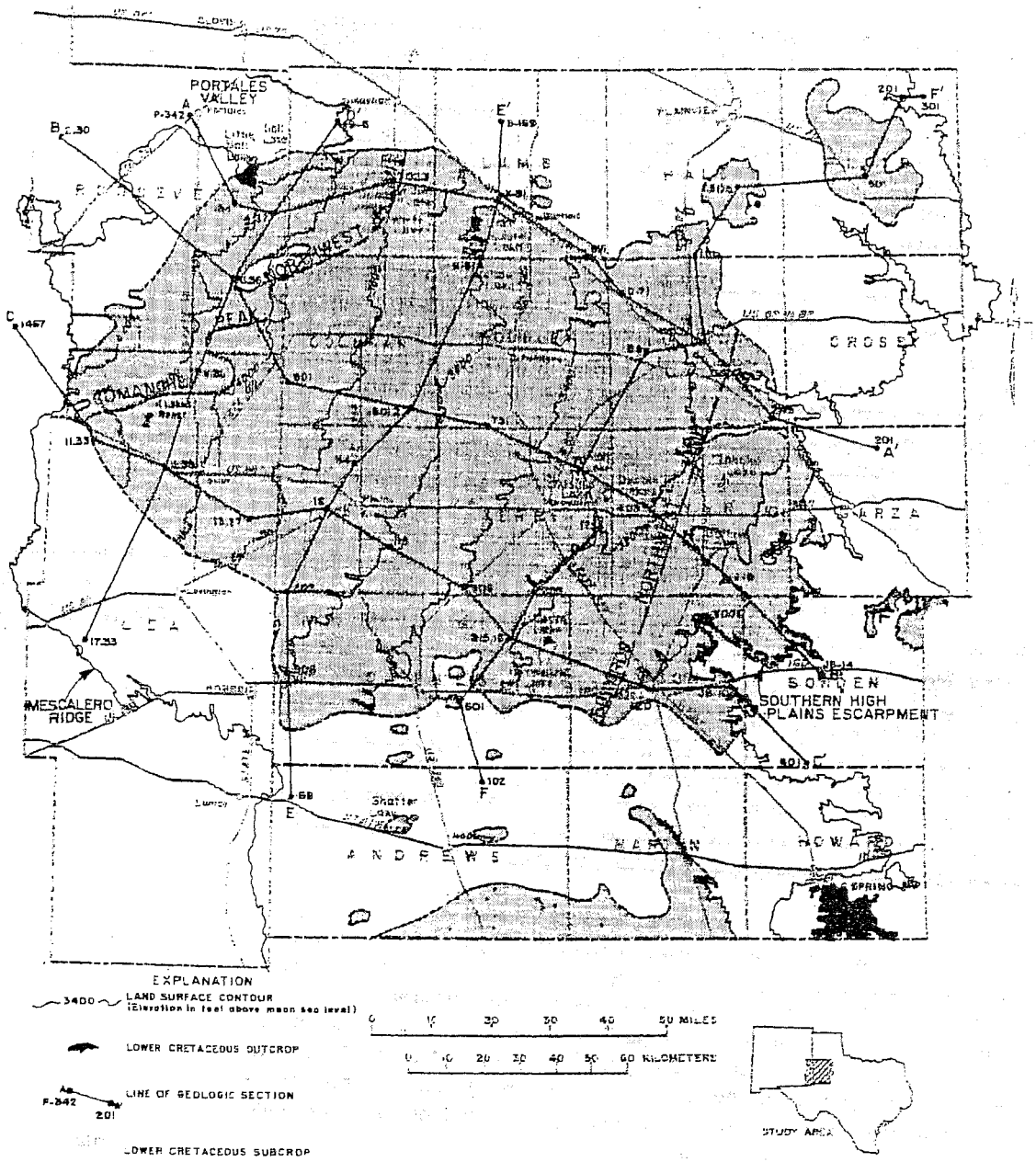

Figure 1

Study Area Location Map

Previous Investigations

Investigative studies describing the geology of Lower Cretaceous strata under the Southern High Plains are limited. Sellards and others (1932) briefly notes that Lower Cretaceous strata are present in the southern Texas Panhandle, with the Edwards Formation extending "...westward to the cap of the Llano Estacado." Brand (1950, 1953) also addresses Cretaceous outcrops on the Llano Estacado of Texas in a University of Texas Ph.D. dissertation and other publications.

Local and regional hydrogeologic surveys that offer short discussions of Lower Cretaceous strata in the study area include reports by Leggat (1952), Cronin and Wells (1960), Mount and others (1967), Knowles and others (1984), and others listed in the Selected References section of this report. Basic ground-water information for the Southern High Plains is also recorded in various State and Federal reports, including annual U.S. Geological Survey publications listing water levels and artesian pressures in the United States.

Location and General Features

Lower Cretaceous strata underlie approximately 10,000 square miles of the Southern High Plains, including areas under all or parts of Bailey, Borden, Cochran, Dawson, Gaines, Garza, Hale, Hockley, Lamb, Lubbock, Lynn, Terry, and Yoakum Counties, Texas, and of Lea and Roosevelt Counties, New Mexico. The strata are covered largely by the Ogallala Formation (Neogene) and other surficial deposits. However, limited outcrops of the Mesozoic rocks are exposed along the margins of isolated playa depressions, and along escarpments demarking eastern and western edges of the Southern High Plains physiographic province.

As an elevated plateau region, the Southern High Plains is characterized by flat, treeless terrain. Shallow playa depressions and sand dunes are also typical features in certain parts of the province. The plains slope imperceptibly to the southeast and are generally devoid of major drainage systems. Native vegetation in the region includes numerous dryland grasses and more localized growths of shinoak, sagebrush, mesquite, and yucca. Farm crops are cultivated over much of the Southern High Plains, primarily during late spring and summer months.

Economic Development

The Southern High Plains economy is based largely on agricultural development and the production of oil and gas. Large-scale irrigation farming began in the region during the 1930's and 1940's, primarily with the development of water-bearing formations within the High Plains aquifer. At about the same time, large oil and gas deposits were discovered in various Permian Basin reservoirs underlying the study area.

Today, the Southern High Plains is one of the most intensively cultivated areas in the North American mid-continent. Crops grown in the study area include cotton, grain sorghums, soybeans, wheat,

barley, oats, corn, and assorted vegetables. Beef cattle are also raised in the region, often being penned and fattened in feedlots that have expanded over the province since the early 1960's.

Oil and gas development is extensive on the Southern High Plains. Collectively, oilfields in the study area contain more than 12 billion barrels of oil in place, making them the single largest oil play in the southern mid-continent area (Galloway, et. al., 1983). The oilfields are particularly well developed in southern parts of the study area where oil reservoirs are defined in carbonate rocks that were deposited on the northern shelf of a Permian-age basin. Many of the fields are in secondary phases of production and some of the world's largest enhanced oil recovery (EOR) projects utilizing injected water and carbon dioxide as hydrocarbon displacement agents are currently operating in the region.

Satellite industries supporting oil, gas, and agricultural development also contribute to the overall economy of the study area. The support industries usually have home or field offices located in local Southern High Plains cities such as Lubbock, Levelland, Brownfield, Plains, Lamesa, Denver City, and Seminole, Texas.

Climate

The Southern High Plains has a semiarid climate, with precipitation generally measuring between 14 and 20 inches a year. Precipitation is usually light during winter months, increasing in the late spring and early fall. Temperatures typically range from the low to mid-90's (degrees F) in the summer and from the low to mid-50's in the winter.

Weather patterns are sometimes extreme over the Southern High Plains. Temperatures can drop as much as 60 F over short periods of time when "blue northers" blow across the region, sometimes depositing light snows in the winter. Low humidity and strong southeasterly breezes commonly accompany higher summer temperatures, resulting in high surface evaporation rates and generating periodic dust storms across the Plains. Thunderstorms crossing the area during rainy periods occasionally produce hail and tornadoes, especially during late spring and summer months.

Acknowledgements

Numerous farmers, ranchers, and other land holders on the Southern High Plains permitted access to their properties and supplied ground-water information integrated in this report. Also, well drillers, pump companies, and municipal officials in the study area provided drillers' logs, pump test information, and municipal well data that were helpful in defining the subsurface character of Lower Cretaceous strata and their contained waters. Private ground-water consultants provided assistance in helping locate drillers' logs and other information used in the report, especially Sherman Galloway of Roswell, New Mexico.

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State and Federal personnel who helped locate well log and quality of ground-water data, or who provided other useful information related to the geology and chemistry of ground water in the study area, included Steve Seni and Ronit Nativ of the Bureau of Economic Geology in Austin, Texas; Arthur Mason of the New Mexico State Engineer's Office in Roswell, New Mexico; and Don Hart of the U.S. Geological Survey Water Resource Division in Albuquerque, New Mexico. Also, earlier researchers who analyzed and published data related to the geology and hydrology of the Southern High Plains are to be credited, with special acknowledgements going to John Brand, Edward Leggat, and James Cronin.

The need for a more comprehensive regional geologic and hydrologic study of Lower Cretaceous strata under the Southern High Plains was brought to the author's attention by Phil Nordstrom of the TWDB. Tommy Knowles, Chief of the Board's Water Availability Data and Studies Section of the TWDB, was subsequently apprised of the need and provided administrative support for the investigation. Manuscript typing and drafting are credited to Yolanda Briones and Steve Gifford respectively of the Board.

GEOLOGY

Regional Setting

A variety of rock types and different sedimentary formations representing all major geologic eras underlie the Southern High Plains. The rocks include deeply buried and structurally complex Precambrian metamorphic and igneous assemblages that generally range from 0.8 to 1.7 million years in age, and occupy a failed rift system that first projected into the southern cratonic area of North America during Proterozoic time. The rocks fringe on the Greenville-Llano tectonic front to the south and are bound by older Canadian Shield provinces to the north.

Early and middle Paleozoic formations under the Southern High Plains are composed largely of shallow marine shelf carbonates that range from 3,000 to 6,000 feet thick. The strata have numerous regional and sub-regional unconformities, suggesting that extensive and frequent epeirogenic crustal movements affected depositional environments during early and middle Paleozoic time.

Late Paleozoic strata in the study area include marine carbonate and evaporite sequences of Permian age that measure over 8,000 feet thick in places. The strata accumulated in and around a shallow structural depression or basin that developed over older Precambrian rift zones in northwest Texas during the Permian.

Mesozoic strata under the Southern High Plains include Late Triassic redbed sequences composed primarily of lacustrine mudstones, and fluvial-deltaic sandstones and shales (Table 1). The continental redbeds are up to 2,000 feet thick in places, and are unconformably overlain by the erosional outliers of Lower Cretaceous marine rocks that are described in more detail in following sections of this report.

Strata capping Mesozoic and older rock units under the Southern High Plains include the Ogallala Formation and younger surficial deposits. The Ogallala Formation is a near-surface deposit of sand, silt, clay, and gravel that accumulated in fluvial, eolian, and alluvial fan depositional environments during Neogene time. Localized fluvial, eolian, and lacustrine deposits forming the Tahoka, Double Lakes, and Blackwater Draw Formations, as well as modern day stream alluvium and dune sand, cover the Ogallala Formation at most locations.

Tectonic History

The tectonic history of the Southern High Plains is varied and complex. During early and middle Paleozoic time, epicontinental seas periodically transgressed over the region in response to epeirogenic downwarping along what is now North America's southern cratonic boundary. Sediments deposited or precipitated in the marine environments included constructional shallow marine carbonates and lesser amounts of clean sandstone and shale (Fallin, 1985; Nicholas and Rozendal, 1975).

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Table 1. - *Physical and Water-Bearing Characteristics of Cenozoic and Mesozoic Strata Under the Southern High Plains.*

System	Series	Group	Formation	Approximate maximum thickness (feet)	Physical character of rocks	Water-bearing characteristics*	
Quaternary	Pleistocene to Recent		Alluvium, eolian and lacustrine deposits	60	Windblown sand and silt, stream alluvium, and silt and clay playa lake deposits.	Yields small amounts of water to wells.	
Tertiary	Late Miocene to Pliocene		Ogallala	600	Composite accumulation of tan, yellow, and reddish-brown silt, clay, sand and gravel that is generally coarser-grained near the base of the formation. Caliche caprock and calcic paleosols occur in fine-grained deposits near the top of the formation.	Yields moderate to large amounts of water to wells. The principal aquifer in the study area with yields of some wells in excess of 1,000 gal/min.	
Cretaceous	Comanche	Washita	Duck Creek	50	Yellow, sandy shale and thin gray to yellowish-brown, argillaceous limestone beds.	Yields small amounts of water locally to wells.	
		Fredericksburg	Kiamichi	110	Thinly laminated, sometimes sandy, gray to yellowish-brown shale with interbeds of thin, gray, argillaceous limestone and thin, yellow sandstone.	Yields small amounts of water locally to wells.	
			Edwards Limestone	35	Light-gray to yellowish-gray, thick bedded to massive, fine to coarse-grained limestone.	Yields moderate to large amounts of water locally to wells from fractures and solution cavities.	Yields small amounts of water to wells.
			Comanche Peak Limestone	85	Light-gray to yellowish-brown, irregularly bedded, argillaceous limestone and thin interbeds of light-gray shale.		Yields small amounts of water to wells.
			Walnut	30	Light-gray to yellowish-brown, fine- to medium-grained, argillaceous sandstone; thin bedded, gray to grayish-yellow, calcareous shale; and light-gray to grayish-yellow, argillaceous limestone.	Not known to yield water to wells.	
		Trinity	Antlers	60	White, gray, yellowish-brown to purple, fine- to coarse-grained, argillaceous, loosely cemented sand, sandstone, and conglomerate with interbeds of siltstone and clay.	Yields small to moderate amounts of water to wells in the study area.	
Triassic	Upper	Dockum	Undivided	2,000	Upper unit, varicolored siltstone, claystone, conglomerate, fine-grained sandstone, and limestone. Lower unit, varicolored, fine to medium-grained sandstone with some claystone and interbedded shale.	Yields small to moderate amounts of water to wells. Water quality variable with stratigraphic position and depth.	

* Yields of wells: small = <50 GPM, moderate = 50-500 GPM, large = >500 GPM.

The convergence and collision of North and South America in the late Paleozoic Era subsequently displaced open marine seas along the southern edge of the North American craton, first into interior sag basins and other depressions bordering the Ouachita tectonic belt, then away from the region entirely. Cut off from open ocean currents, inland seas overlying the Permian Basin in the Southern High Plains region ultimately evaporated, leaving behind large deposits of halite, potash salts, and anhydrite.

In the early Mesozoic Era, fresh water lake basins developed over the mid-continent region, leading to the accumulation of lacustrine and fluvial-deltaic deposits that make up the Dockum Group (Late Triassic). Major source areas contributing sediments to the lake basins included the Ouachita tectonic belt to the south and east, a structural remnant from the collision of North and South America (Granata, 1981).

The separation of North and South America and consequent opening of the Gulf of Mexico followed, with crustal subsidence around the edge of the Gulf tilting and draining mid-continent lake basins to the southeast during the Jurassic Period. At about the same time, compressional orogenic events in western North America, e.g., the Nevadan orogeny, downwarped the entire mid-continent region, permitting oscillating seas to transgress over the study area in the Early Cretaceous Period and to deposit the Lower Cretaceous strata that are the subject of this report.

Laramide uplift and other tectonic events associated with Tertiary doming along the Rio Grande rift system to the west subsequently elevated the Southern High Plains above sea level again, tilting the region to the southeast at the same time. Partial draining and erosion of Cretaceous and older formations accompanied the uplift, exposing the strata to direct fresh-water recharge in some places and depositing younger, fresh water-bearing sediments (i.e., the Ogallala Formation) on top of the units in others. Today, eroded outliers of Lower Cretaceous and younger strata continue to mantle older rock units under uplifted portions of the Southern High Plains.

Cretaceous System

Introduction

A typical Lower Cretaceous section under the Southern High Plains includes a basal sand and sandstone deposit overlain by marine marls, clays, and associated limestones. Deposited on eroded Late Triassic terrain and covered largely by Tertiary-age sediments, the Lower Cretaceous strata form buried mesas with more than 250 feet of subsurface relief at some locations. The buried mesas are erosional outliers of a system of rocks that are much more extensively preserved and exposed in the Edwards Plateau region of South-Central Texas.

The regional unconformities that bound Lower Cretaceous strata under the Southern High Plains are irregular surfaces crosscut with erosional channels at some locations (Figures 2 and 3). The channels trend east-southeast across the study area, with upper

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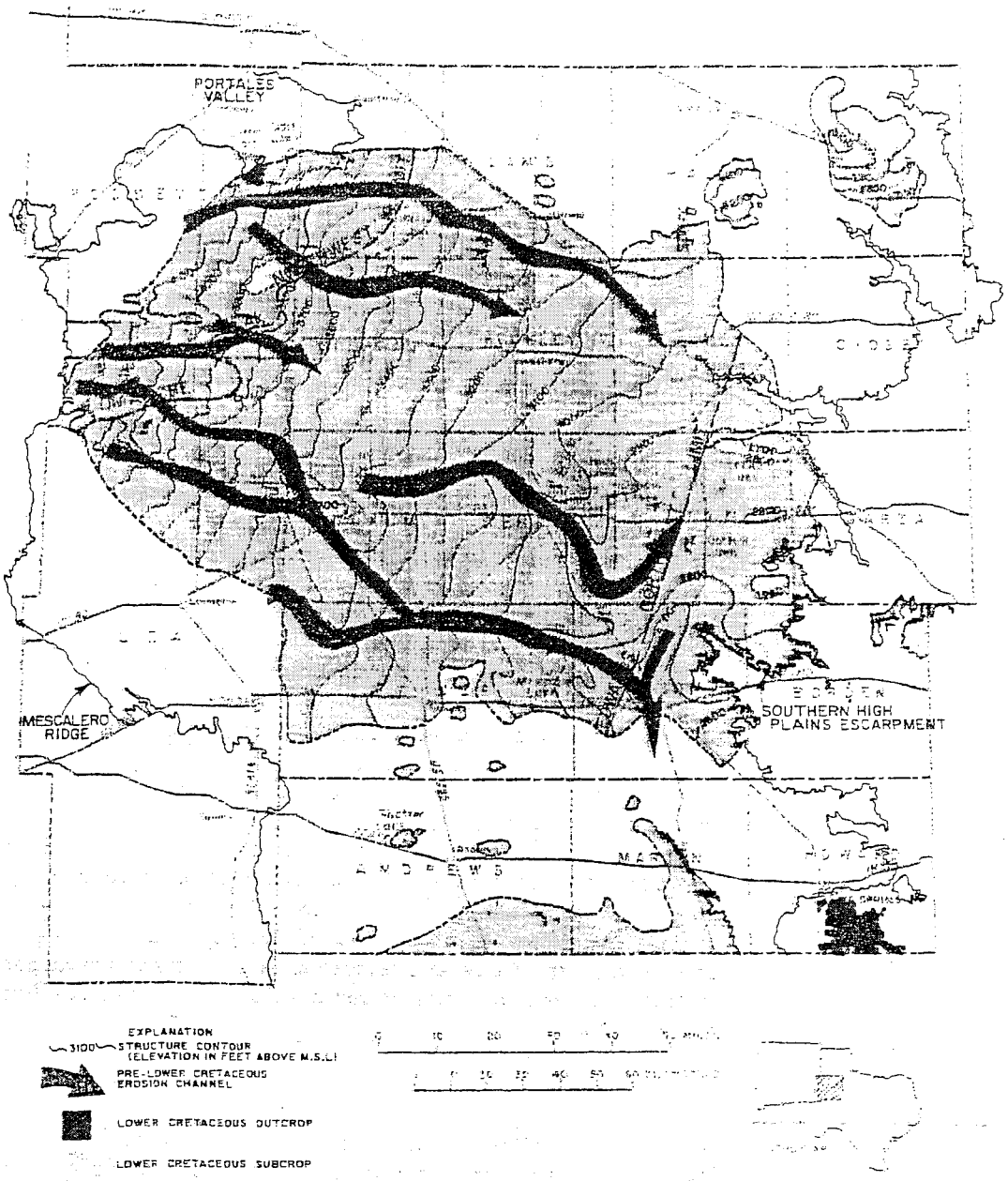

Figure 2

Structure Contour Map Showing
the Altitude of the Base of Lower Cretaceous Strata
Under the Southern High Plains

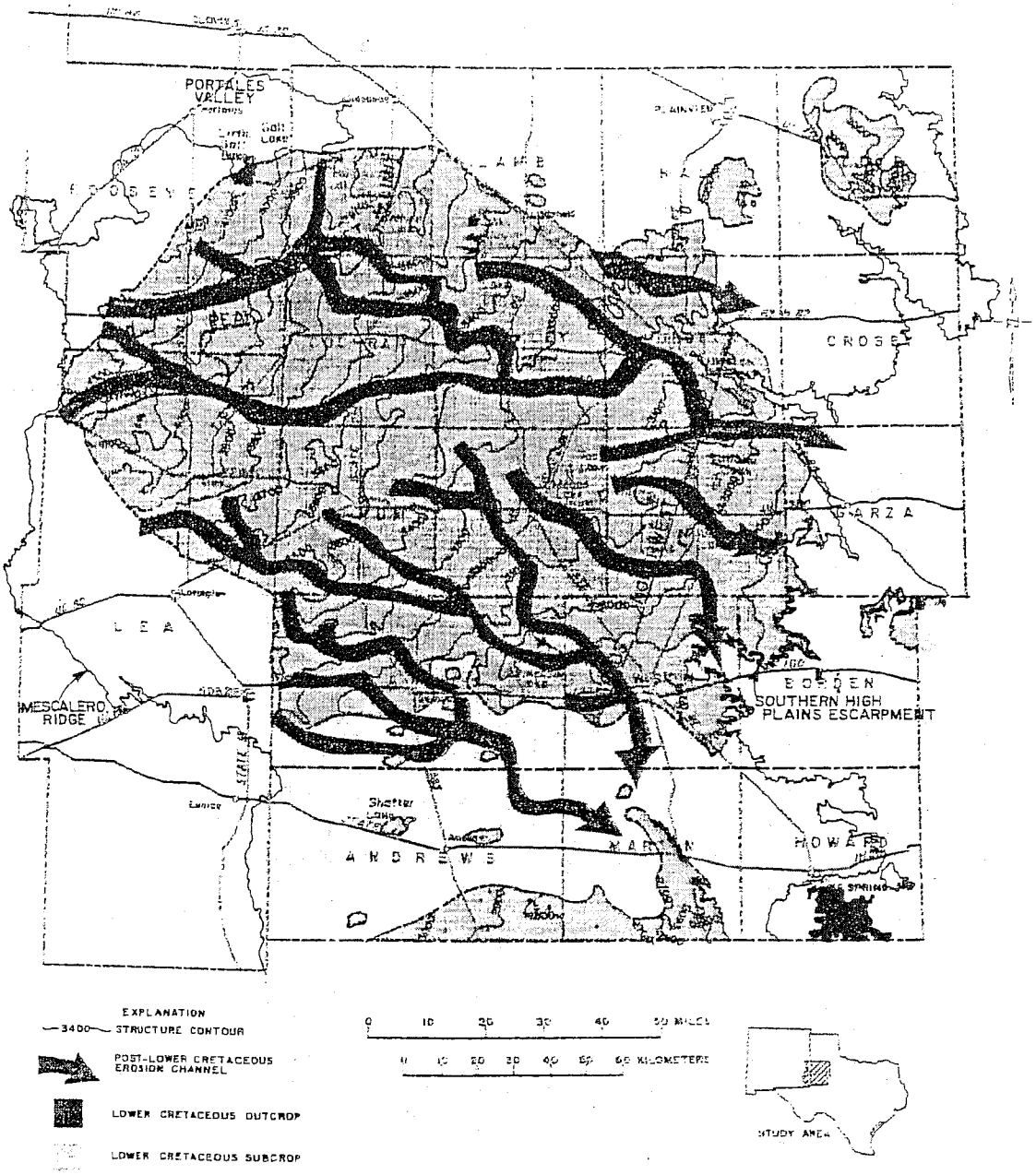

Figure 3

Structure Contour Map Showing
the Altitude of the Top of Lower Cretaceous Strata
Under the Southern High Plains

channel courses sometimes cutting entirely through the Lower Cretaceous section (e.g., Slaton Channel, southeast Lubbock County, Texas).

Strata immediately underlying the regional unconformities are discolored at many locations, reflecting the effects of subaerial weathering during hiatal periods that bounded Lower Cretaceous depositional events. Reddish-brown mudstones are commonly tinted blue-green one to two feet below the Late Triassic-Lower Cretaceous unconformity, and blue-gray limestones and clays in upper parts of the Lower Cretaceous section are often oxidized yellow to a depth of 10 or more feet immediately below the Ogallala Formation.

Stratigraphy

As many as six Lower Cretaceous formations have been described under the Southern High Plains. The formations define parts of the Trinity, Fredericksburg, and Washita Groups of the Gulf Coast Comanchean Series in North America. Biostratigraphic zonation of the sequence is based primarily upon the occurrence of ammonites and other marine fossils in the stratigraphic section (Brand, 1953).

Trinity Group

In the Southern High Plains region, the Trinity Group is represented by the Antlers Formation, a white to purple, unconsolidated to moderately well cemented, fine- to coarse-grained quartz sand and sandstone. In the study area, the Antlers Formation is interbedded locally with green clay and pink siltstone, and has scattered lenses of gravel that include well-rounded quartz pebbles and claystone clasts derived from underlying Late Triassic strata. Quartz grains in the Antlers Formation are typically well rounded and frosted in appearance, both characteristics associated with near-shore marine, beach and dune sand deposits.

As an irregular sheet deposit, the Antlers Formation pinches and swells in thickness while thinning regionally to the northwest (Figures 4 and 5). Measured sections of the unit range from less than one to more than 60 feet thick under the Southern High Plains. In eastern New Mexico and more northern parts of the study area in Texas, the Antlers Formation is locally absent, having been removed by post-depositional erosion at some locations.

Fredericksburg Group

The Fredericksburg Group under the Southern High Plains includes the Walnut, Comanche Peak, Edwards, and Kiamichi Formations. Also, part of the time transgressive Antlers Formation is probably of Fredericksburg age in northwestern parts of the study area.

Lithologically, the Walnut Formation is composed of light gray, calcareous shale, fine- to medium-grained sandstone, and light gray, argillaceous limestones. It grades abruptly upward into thicker, more massive, light gray, argillaceous limestones and interbedded marls of the Comanche Peak Formation.

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Under southeastern parts of the Southern High Plains, the Walnut Formation exceeds 30 feet in thickness, while the Comanche Peak Formation is as much as 85 feet thick. However, like the underlying Antlers Formation, both the Walnut and Comanche Peak Formations thin appreciably to the northwest, disappearing entirely at some locations.

The Edwards Formation overlies the Comanche Peak Formation in the southeast part of the Southern High Plains. It is profiled in steeper parts of the High Plains escarpment, and is a light gray to yellow, thick-bedded "Rudist" limestone that is honeycombed locally with solution cavities.

The Edwards Formation measures as much as 35 feet thick along the High Plains escarpment. However, the formation pinches out abruptly to the northwest, signaling the edge of a platform reef complex that developed over much of the central Texas region during the Early Cretaceous Period.

The Kiamichi Formation is the uppermost stratigraphic unit of the Fredericksburg Group. It is composed primarily of yellow-brown to dark blue-gray shale, but also has thin interbeds of gray, argillaceous limestone and yellow, fine-grained sandstone.

Where completely preserved, the Kiamichi Formation is at least 110 feet thick under the Southern High Plains. However, part or all of the formation is missing in some parts of the study area due to post-depositional erosion.

Washita Group

The Washita Group overlies the Fredericksburg Group and is represented by the Duck Creek Formation under the Southern High Plains. The Duck Creek Formation is composed of yellow-brown shale interbedded with thin lenses of argillaceous limestone and fine-grained sandstone.

Data from isolated wells suggest that the Duck Creek Formation probably exceeds 50 feet in thickness under the Southern High Plains. However, like the underlying Kiamichi Formation, it has been thinned or completely removed by post-depositional erosion at many locations. Undifferentiated sections of the Duck Creek and Kiamichi Formations generally thicken to the north and northwest in marked contrast to other Lower Cretaceous stratigraphic intervals in the study area.

Depositional History

Facies analyses and other geologic criteria indicate that Lower Cretaceous strata in the study area accumulated as epicontinental seas moved over the region from the southeast. The basal Antlers Formation accumulated during Early to Middle Albian time (Figure 9) in near-shore marine, beach, and coastal sand dune environments, sometimes being reworked as seas transgressed, regressed, then transgressed over the study area again. During latter parts of the same depositional period, the Walnut and Comanche Peak

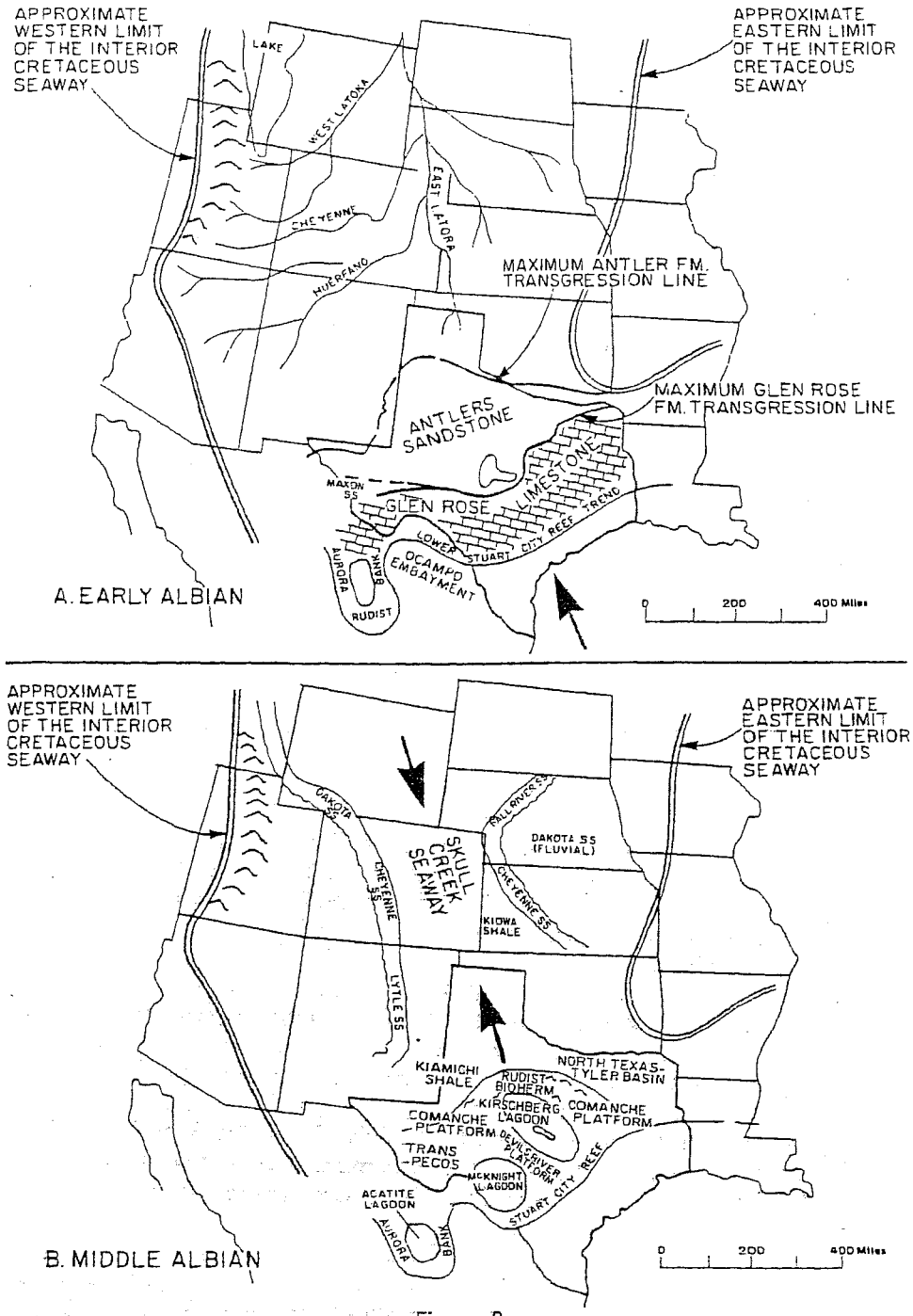

Figure 9

Early and Middle Albian Paleogeographic Maps of the Southern Mid-Continent Region of North America After West Texas Geological Society, 1981; (Mallory, 1972; Fisher and Rodda, 1969)

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Formations accumulated offshore in shallow lagoon and carbonate platform environments. Then, as Mesozoic seas stabilized in early Middle Albian time, a more extensive platform and lagoonal complex developed over much of Central Texas. **Rudist** bioherms grew over and along the edges of the platform, ultimately defining the Edwards Formation that crops out along the southeastern High Plains escarpment and over the Edwards Plateau region of South-Central Texas.

Following Edwards deposition, the Southern High Plains was subaerially exposed in areas where major Edwards bioherms were developed. Then Middle Albian seas transgressed over the region again, eventually covering the entire mid-continent area of North America. The Kiamichi Formation and other lithostratigraphic equivalents (e.g., basal parts of the Tucumcari Shale in New Mexico) accumulated mostly in the expanded shallow marine sea before more stagnant lagoonal environments developed over the study area near the end of Fredericksburg time.

Renewed transgression subsequently opened the mid-continent seaway again, forming a shallow, open marine environment in which the Duck Creek Formation accumulated. Gulfward retreat of Upper Comanchean seas followed, bringing to an end all Lower Cretaceous deposition over the Southern High Plains.

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HYDROLOGY

Introduction

Essentially all Lower Cretaceous strata under the Southern High Plains occur below the regional water table, and are saturated with fresh to moderately saline ground water. Only in limited updip recharge areas of eastern New Mexico, and downdip drain areas along the Southern High Plains escarpment in Texas does the regional water table drop below the upper surface of the Lower Cretaceous subcrop.

The Lower Cretaceous strata are in hydraulic continuity with other water-bearing formations in the region, and are considered to be part of the High Plains aquifer. Basal sandstone beds in the Antlers Formation, and solution cavities, fractures, joints, and bedding planes in limestone portions of the Comanche Peak and Edwards Formations define ground-water aquifers in the Lower Cretaceous section. However, limestone and sandstone stringers in the Kiamichi and Duck Creek Formations also transmit limited amounts of ground water through the system at some locations.

Aquiclude intervals in the Lower Cretaceous section include thick clay and marl beds that form major parts of the Walnut, Kiamichi, and Duck Creek Formations. Yielding little, if any, ground water to wells and springs in the study area, the fine-grained strata serve to confine ground-water aquifers in the High Plains aquifer at some locations, while also diverting regional ground-water flow around and over much of the Lower Cretaceous subcrop.

Ground-water movement and drainage through the Lower Cretaceous strata is generally to the east-southeast in conformance with head distribution and structural dip (Figure 10). Intraformational facies changes, joint patterns, local cementation, and sinuosity of underlying scour channels, however, prompt local deviations in flow patterns.

Ground-water flow rates in the Lower Cretaceous strata are estimated to vary from a few feet per year in lower sandstone sections to more than 100 feet per day sometimes where solution cavities and joint systems are particularly well developed in limestone intervals. Discharge from these aquifers is to well heads in Texas and New Mexico; to streams, springs, and seeps along the Southern High Plains escarpment in Texas; and to surrounding formations. Recharge to the system occurs directly from bounding Ogallala deposits along northern and western parts of the subcrop area, and indirectly by downward percolation or infiltration from the overlying Ogallala at other locations (Figure 11). Precipitation is the principal source of recharge to the bounding and overlying Ogallala Formation, with ground-water renewal rates to the Ogallala generally averaging less than one half inch per year when semiarid climatic conditions prevail over the Southern High Plains.

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Overall well yields from Lower Cretaceous strata under the Southern High Plains range from less than 50 to more than 1,000 gallons per minute. Highest yield rates have thus far come from isolated wells completed in the Antlers Formation in the Causey-Lingo area of Roosevelt County, New Mexico, and from wells completed in the Antlers, Comanche Peak, and Edwards Formations in Hale and Lubbock Counties, Texas. Wells dually completed in Ogallala and Lower Cretaceous rocks are common in many parts of the study area, particularly where the Comanche Peak and Edwards Formations are well developed in the Lower Cretaceous section.

The content of dissolved solids in ground water in Lower Cretaceous rocks is shown in Figure 12. The water is generally characterized by either a mixed-cation-bicarbonate (mixed-HCO_3) or sodium-bicarbonate (Na-HCO_3) hydrochemical signature (Figure 13). However, in areas overlain by saline lakes and the gypsiferous Tahoka and Double Lakes Formations (Pleistocene), either sodium-chloride (Na-Cl) or sodium-sulfate (Na-SO_4) hydrochemical facies usually prevail. Ground water in the Lower Cretaceous section is slightly basic, with pH values ranging between 7.5 and 8.5. The water is moderately to extremely hard, with equivalent concentrations of calcium carbonate typically ranging between 100 and 1,000 milligrams per liter.

As part of the High Plains aquifer, Lower Cretaceous strata have a pronounced effect on regional ground-water movement under the Southern High Plains. More specifically, the baffling effect of Lower Cretaceous clay and marl intervals, and the less extensive development of porous and permeable deposits (i.e., the Ogallala Formation) over the areas of Lower Cretaceous subcrop, serve to restrict regional ground-water flow in the aquifer system. As a consequence, well yields and water quality are somewhat diminished in the study area when compared to most other regions producing from the High Plains aquifer. Ponding of ground water in the Ogallala Formation behind buried Lower Cretaceous subcrop highs is also apparent, particularly in Lea County, New Mexico, where updip Ogallala deposits are buttressed against Lower Cretaceous clay and marl intervals (Figure 6), and in Cochran, Hockley, and Lubbock Counties, Texas, where regional water levels are measurably offset from adjoining areas to the north and south (Figures 7 and 8).

Regional Aquifer Characteristics

Antlers Formation

General Features

As a relatively thin, irregular sheet deposit that decreases in overall thickness to the northwest, the Antlers Formation is limited as an aquifer throughout much of the study area. Only in western and southern subcrop areas where thicker than usual sections

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occur in erosion channels cut into the underlying Triassic section do wells generally produce more than 100 gallons per minute from the basal Lower Cretaceous aquifer.

Stratigraphically, the Antlers Formation is almost everywhere bound by underlying mudstone sequences in the Dockum Group, and by overlying clay or marl beds in the Walnut, Comanche Peak, and Kiamichi Formations. As a consequence, ground water in the formation is usually confined, and artesian pressures are common to the system. Exceptions occur in areas such as eastern New Mexico where numerous uncased seismic holes have been drilled into the Lower Cretaceous strata, allowing confined ground water to leak upward into the overlying Ogallala Formation while decreasing hydraulic pressures in the Antlers Formation below (Ash, 1963).

Regional ground-water flow through the Antlers Formation is generally to the east-southeast in conformance with regional structure dips. Calcite and more limited quartz cementation, however, influences flow patterns through certain parts of the formation, restricting and even preventing water movement at some locations. The cementation is only locally well developed, and loose sand also occurs within the stratigraphic unit. In fact, unconsolidated to only weakly cemented intervals in the basal Lower Cretaceous Formation measure more than 60 feet thick at some locations in southeast Roosevelt County, New Mexico, and in northwest Gaines County, Texas. Another factor that influences regional ground-water movement through the Antlers Formation is eroded channel courses cut into the underlying Late Triassic section. Funneling water in a sinuous east-southeasterly direction, deposits in the paleo-drainage courses are particularly well defined under parts of Lea and Roosevelt Counties, New Mexico, and under parts of Cochran, Dawson, Gaines, Lynn, and Terry Counties, Texas (Figure 2).

The Antlers Formation generally occurs 200 to 350 feet below land surface under the Southern High Plains, and wells tapping it are often dually completed in the overlying Ogallala Formation for additional yield. Actual production from wells completed solely in the Antlers Formation ranges from less than 50 to more than 1,000 gallons of water per minute in the study area, with highest yields thus far coming exclusively from wells completed in thicker-than-average sections filling erosion channels cut into the underlying Dockum Group in Roosevelt County, New Mexico.

Pump Test Data

Pump test data for wells completed in the Antlers Formation varies from location to location. The specific capacity of one well completed in the formation 10 miles south of Whiteface in Cochran County, Texas, was 1.63 gallons per minute per foot of drawdown after it was pumped for 27 hours at a rate of 150 gallons per minute in 1962 (Rayner, 1963). A cone of depression was calculated to extend several miles around the Cochran County well, and it was determined that the aquifer possesses very low

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recoverable artesian storage characteristics at the investigation site. Similarly, another well in Yoakum County, Texas, also indicated limited transmissivity values for the Antlers Formation, having a specific capacity of only 1.1 gallons per minute per foot of drawdown while pumping 65 gallons per minute over a period of time (Mount and others, 1967). Elsewhere, hydraulic conductivity in the formation is clearly better developed, since some wells in Roosevelt County, New Mexico, have produced as much as 1,200 gallons per minute from the Antlers for extended periods of time, then have recovered relatively quickly after pumping has ceased.

Water Quality and Chemistry

Limited analyses suggest that ground-water quality in the Antlers Formation generally ranges from fresh to slightly saline in character, and exhibits either a calcium-bicarbonate or sodium-bicarbonate hydrochemical signature. However, in areas overlain by saline lakes and where the near-surface gypsiferous Tahoka and Double Lakes Formations are present, water quality in the Antlers and in the High Plains aquifer as a whole, is diminished, with dissolved solids exceeding 6,000 mg/l in places, and either sodium-sulfate or sodium-chloride hydrochemical facies prevailing.

Regional Storage

Core, well log, and outcrop data indicate that the Antlers Formation under the Southern High Plains has an average stratigraphic thickness of 15 feet, an average porosity of 15 percent, and an areal extent of about 9,000 square miles, suggesting the formation contains approximately 12 million acre-feet of ground water. Approximately 90 percent of the aquifer underlies Texas, where the storage capacity below specific surface drainage basins is estimated as follows: Colorado River Basin, 7,348,320 acre-feet, and Brazos River Basin, 3,149,280 acre-feet. It is estimated that approximately 25 percent of all ground water stored in the Antlers Formation may be economically recoverable. Finite replenishment rates, overall formation thinness, and low coefficient of storage values will most assuredly limit any sustained, long-term production from the aquifer.

Comanche Peak and Edwards Formations

General Features

Limestone intervals in the Comanche Peak and Edwards Formations combine to form an effective aquifer system under the Southern High Plains, especially where the stratigraphic units are maximally developed along the southern and eastern edges of the study area in Borden, Dawson, Floyd, Hale, Gaines, Lubbock, and Lynn Counties, Texas. Filling solution cavities, fractures, joints, and bedding planes, ground water in the limestone formations generally flows in a southeasterly direction, sometimes issuing at springs and seeps along the eastern edge of the Southern High Plains escarpment.

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Stratigraphically, the Comanche Peak-Edwards aquifer is usually underlain by the Walnut Formation, and overlain by either the Kiamichi or Ogallala Formations. Calcareous shales in the Comanche Peak and Walnut Formations generally form an effective aquiclude that separates the aquifer from artesian ground-water zones in the Antlers Formation below them. In eastern parts of the study area, sand and gravel beds in the Ogallala Formation commonly cover the limestone aquifer, making the system upwardly unconfined. The upward unconfinement permits ground water to occur under water-table conditions throughout most of the area where the aquifer is maximally developed under the Southern High Plains.

Producing intervals in the Comanche Peak-Edwards aquifer range from less than 10 to more than 60 feet thick in the study area, and wells are generally designed to accept water under open-hole or slotted-casing conditions from the entire water-yielding section upon completion. As to be expected, wells completed along zones of major fracture concentrations, or in cavernous parts of the section, yield substantially more water than wells completed in unfractured or uncavernous parts of the limestone aquifer (Figure 14). In the study area, surface lineament studies suggest that major fracture trends in the Comanche Peak-Edwards aquifer are oriented northwest-southeast, and to a lesser extent, northeast-southwest. The fracture trends are especially well developed in Bordon, Dawson, Hale, Hockley, Lubbock, and Terry Counties, Texas (Figure 14). For additional yield purposes, many wells completed in the limestones also draw water from producing intervals in the underlying Antlers Formation and overlying Ogallala Formation.

The Comanche Peak-Edwards aquifer usually occurs between 20 and 250 feet below the land surface along the eastern edge of the study area, with the shallowest parts of the system being located immediately adjacent to the Southern High Plains escarpment in Borden, Dawson, and Lynn Counties, Texas. Well yields from the reservoir range from less than 50 to more than 800 gallons per minute, with highest production having thus far come from well sites in Hale and Lubbock Counties, Texas.

Pump Test Data

Pump tests show that the specific capacity of the Comanche Peak-Edwards aquifer system varies from one locality to the next, reflecting the uneven distribution and development of cavity-prone **Rudist** facies, and other porous and permeable zones in the stratigraphic section over the study area. In Hale County, Texas, where individual well yields regularly exceed 250 gallons per minute, five separate pump tests have indicated the system's specific capacity to be 2.1, 35.3, 62.5, 22.7, and 5.9 gallons of per minute per foot of drawdown, respectively. Another pump test in Lamb County, Texas, showed a specific capacity of 2.2 gallons per minute per foot of drawdown for a well producing 65 gallons per minute from the aquifer. Also, a well completed solely in the Edwards Formation four miles east of O'Donnell on the Lynn-Dawson county line was drawn down only 0.69 foot when pumped at a rate of 810

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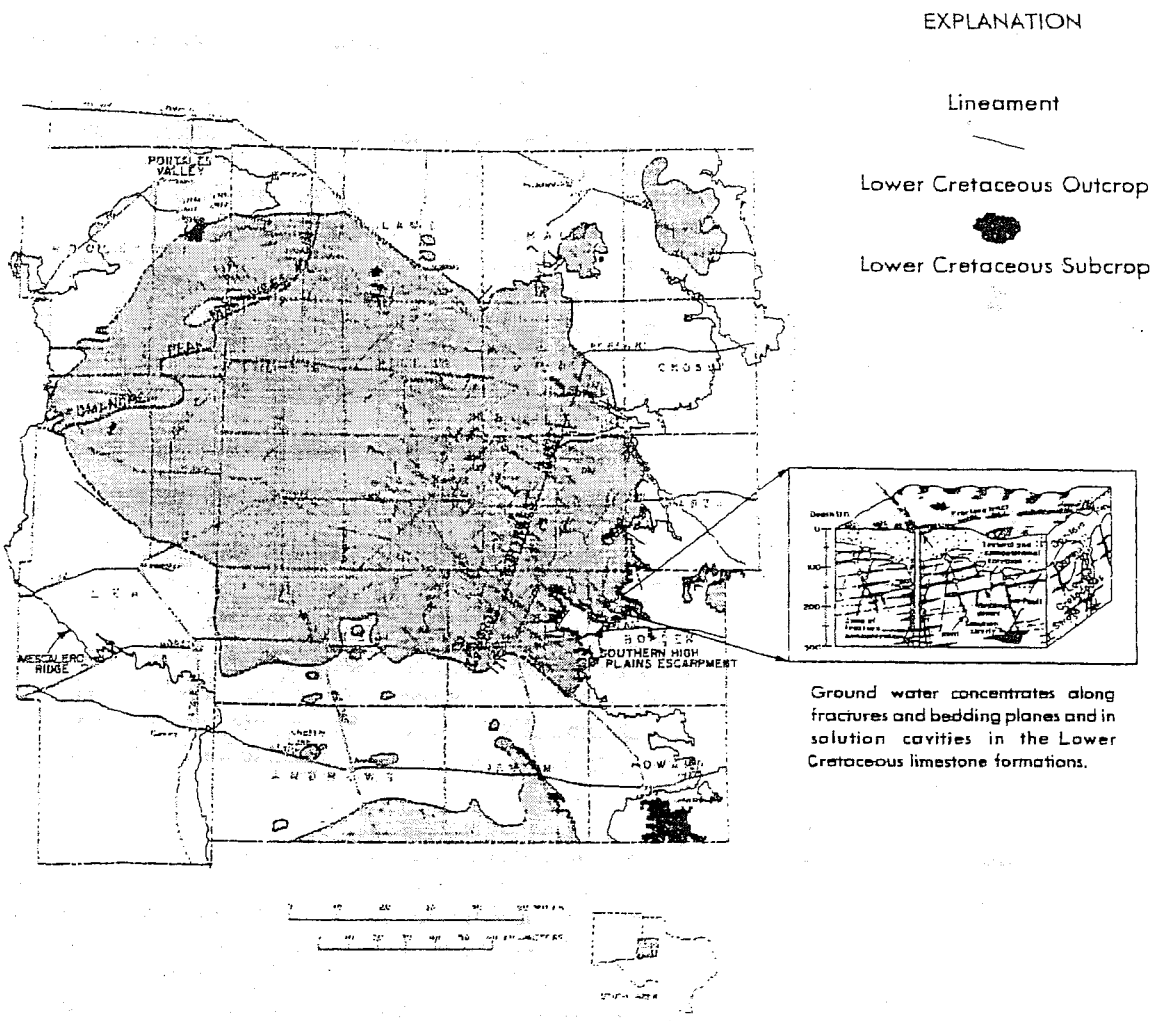

Figure 14
Study Area Surface Lineation Map, and
Block Diagram Inset Showing Ground-Water
Concentrations in Fractured Carbonate Terrain
(After Finley and Gustavson, 1981; Lattman and Parizek, 1964)

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gallons per minute for an hour and twenty minutes in 1950, indicating the aquifer's local specific capacity to be 1,175 gallons per minute per foot of drawdown (Leggat, 1952). Significantly, the latter well is thought to have drawn much of its production from a cavity receiving water from the Ogallala Formation.

Water Quality and Chemistry

Ground water in the Comanche Peak-Edwards system is generally fresh to slightly saline and usually has either a mixed-cation-bicarbonate or sodium-bicarbonate hydrochemical signature. However, as in the underlying Antlers Formation, water quality in the Comanche Peak-Edwards system is diminished in areas overlain by saline lakes, and where the near-surface gypsiferous Tahoka and Double Lakes Formations are present. In northeast Gaines County, and most of Lynn County, Texas, where numerous saline lakes exist and the Tahoka and Double Lakes Formations are widespread, the amount of dissolved solids in ground water from the Comanche Peak-Edwards aquifer regularly exceeds 3,000 mg/l, with either sodium-sulfate or sodium-chloride hydrochemical facies prevailing.

Regional Storage

Core, well log, and outcrop data indicate that the Comanche Peak - Edwards system has an average saturated thickness of 20 feet and average porosity of 1.5 percent, suggesting that the aquifer stores approximately 1.5 million acre-feet of ground water in the 8,000 square mile area where it is maximally developed under the Southern High Plains. Essentially all of the effective storage underlies Texas, 95 percent (1,459,200 acre-feet) being located under the Brazos River Basin. Full aquifer storage capacity under the Colorado River Basin is estimated to be 76,800 acre-feet.

Kiamichi and Duck Creek Formations

In the south-central part of the Southern High Plains, where both the Antlers and Comanche Peak-Edwards systems are poorly developed, ground water is in places transmitted through thin limestone and sandstone beds in the Lower Cretaceous Kiamichi and Duck Creek Formations. The thin, discontinuous strata have limited yield and storage capacities, and are typically separated by thicker shale and clay intervals in the stratigraphic section. Accordingly, wells draw from multiple horizons when producing from the Kiamichi and Duck Creek Formations, with overall yield usually augmenting larger production from the overlying Ogallala Formation.

Regional Recharge and Discharge

The primary source of natural ground-water recharge to Lower Cretaceous strata under the Southern High Plains is inflow from the bounding and overlying Ogallala Formation (Figure 11). The Ogallala Formation, in turn, receives most of its water supply via infiltration of surface precipitation, and runoff that periodically fills playa lakes and other ephemeral drainage systems over the study area, a source of limited and often overdrawn supply in recent years.

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Cross-formational recharge between Tertiary and Lower Cretaceous strata occurs most readily where saturated sand and gravel beds in the Ogallala Formation abut against, or overlie porous and permeable parts of the Antlers, Comanche Peak, and Edwards Formations. Saturated sand and gravel beds in the Ogallala Formation, in turn, occur most frequently in lower parts of the formation along paleovalley courses that were scoured into underlying strata in pre-Ogallala time.

Under the Southern High Plains, pre-Ogallala paleovalley courses are best developed immediately north of the Lower Cretaceous subcrop area, and to a lesser extent, over and around certain parts of the subcrop area itself. Acting as natural ground-water conduits in the High Plains aquifer, Ogallala deposits filling the paleovalley courses distribute ground water in an east-southeasterly direction to, around, and over the Lower Cretaceous subcrop (Figure 3). Subcrop exposures of the basal Lower Cretaceous Antlers Formation thus receive water directly from the Ogallala in Lea and Roosevelt Counties, New Mexico, and in Floyd, Gaines, Hale, and Lamb Counties, Texas, where the Antlers Formation is best developed. The Comanche Peak and Edwards Formations are recharged mostly along subcrop exposures in Dawson, Floyd, Hale, Lubbock, and Lynn Counties, Texas, with joints, fractures, and solution cavities providing infiltration routes through the section.

Tertiary and Lower Cretaceous ground-water aquifers under the Southern High Plains are also recharged directly and indirectly by surface water spreading basins and dual-purpose well systems. Surface water spreading basins are generally limited to areas where high-permeability sediments occur at or near the ground surface, or where major distributary channel trends are best developed in the Ogallala Formation.

Dual-purpose wells, i.e., wells designed for both subsurface injection and ground-water withdrawal purposes, provide an effective means of recharging the High Plains aquifer where low-permeability zones occur between the land surface and the regional water table. The wells are generally constructed in and around playa lake basins in order to take advantage of ponded rain water on a seasonal basis. Life spans of dual-purpose wells rarely exceed 10 years, with sediment clogging usually diminishing system effectiveness over time.

In use since the 1940's, there were as many as 200 dual-purpose recharge wells operating in and around the study area in the early 1970's, 28 being located in Borden County, Texas. Overall use of the dual-purpose well recharge system has declined in the study area since the 1970's, however, and only a few pump systems installed during the 1970's remain operative today.

Discharge from Lower Cretaceous aquifers in the study area is primarily to well heads in Texas and New Mexico, and to streams, springs, and seeps along the Southern High Plains escarpment in

Texas. Annual well pumpage from the Lower Cretaceous ground-water system is estimated to have exceeded 15,000 acre-feet in recent years, although exact figures are difficult to calculate since numerous wells over the Southern High Plains are dually completed in Lower Cretaceous and Ogallala sections, with the component yields from each being undetermined.

Springs and seeps draining from Lower Cretaceous strata in the Southern High Plains are particularly well developed in Borden County, Texas, along the Southern High Plains escarpment. There are also several springs and seeps along the North Fork Double Mountain Fork of the Brazos River that drain from Lower Cretaceous strata in Yellow House Canyon, Lubbock County, Texas. Yields from individual springs in the study area rarely exceed 10 gallons per minute, except when prolonged rainy periods over the plains rejuvenate local systems briefly.

Significantly, Lower Cretaceous strata also discharge some ground water into other, bounding formations. In Floyd County, Texas, the Lower Cretaceous subcrop is completely surrounded by saturated, coarse-grained Ogallala deposits. As ground water flows from the Ogallala deposits into porous updip intervals of the Lower Cretaceous section, it continues to move downdip, ultimately to flow back into the Ogallala system once again. Vertical leakage into the underlying Dockum Group also occurs at isolated locations, particularly in parts of Borden, Cochran, Dawson, Floyd, and Yoakum Counties, Texas, and in Lea and Roosevelt Counties, New Mexico, where coarse-grained fluvial-deltaic deposits occur in upper parts of the Late Triassic section.

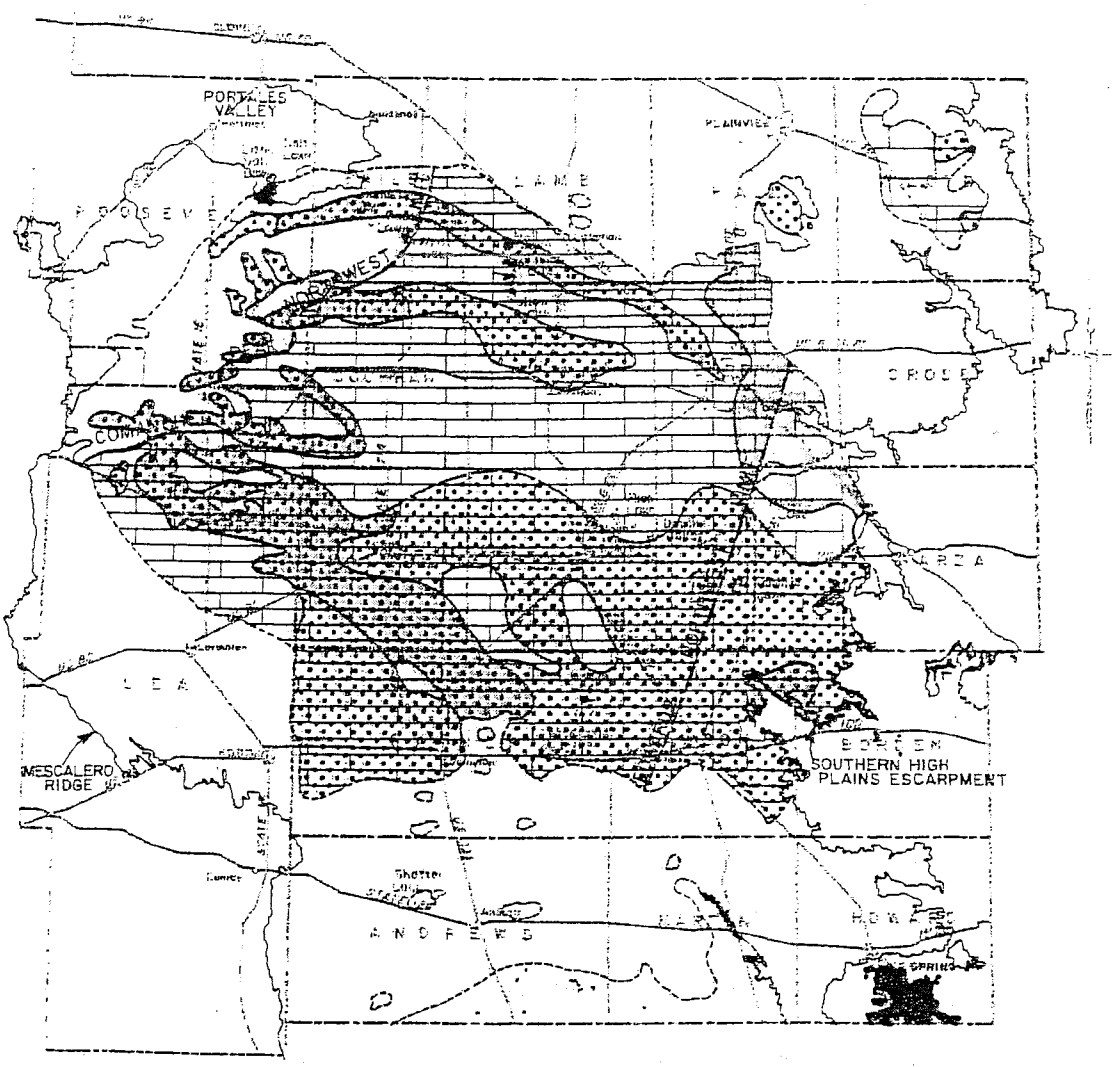
Utilization and Development

Wells completed in the Lower Cretaceous section under the Southern High Plains supply water for a number of different surface uses. Of 250 located wells in the study area, 30 are listed as domestic or stock wells, 35 as industrial wells (used primarily to augment waterflood projects in West Texas oilfields, and to supply glauber and epsom salt mining operations), and 180 as irrigation wells. The communities of Seminole in Gaines County, Wellman in Terry County, Abernathy in Hale County, and O'Donnell in Lynn County, Texas, also draw part of their public water supply from wells completed in the Lower Cretaceous section, as do various residents and public schools in the Causey Lingo area of Roosevelt County, New Mexico.

Spread widely over the study area, wells drawing from Lower Cretaceous strata under the Southern High Plains are mostly concentrated in parts of Floyd, Gaines, Hale, and Lynn Counties, Texas, and in the Causey-Lingo area of Roosevelt County, New Mexico. Undeveloped areas showing potential for further development include parts of Bailey, Cochran, Gaines, and Yoakum Counties, Texas, and northern areas in Lea County, New Mexico, where the basal Lower Cretaceous Antlers Formation fills erosional channels cut into the underlying Dockum Group (Figure 15). Also, the

10 024
~~34 024~~

Comanche Peak-Edwards-Antlers aquifer system appears to have potential for further development in east-central Lubbock and northeast Lynn Counties, Texas, where fresh-water recharge occurs directly by downward percolation from the overlying Ogallala Formation and by lateral infiltration of Ogallala waters along the deeply eroded and buried Slaton channel course (Figure 15).



EXPLANATION

- Antlers Formation present and estimated to be over 20 feet thick
- Comanche Peak Formation present
- Edwards and Comanche Peak Formations present
- Area where Lower Cretaceous aquifer is relatively undeveloped, where Lower Cretaceous water quality is generally fresh, and where Lower Cretaceous well yields will probably exceed 200 gal/min
- Lower Cretaceous Outcrop

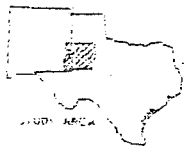


Figure 15

Map Showing the Areal Extent of Lower Cretaceous Aquifers Under the Southern High Plains, With Underdeveloped Areas Having Potential Fresh Ground-Water Reserves Highlighted

~~31 026~~
10 026

Reference 11

Shaw™ Shaw E & I, Inc.

FIELD ACTIVITY DAILY LOG

DAILY LOG			
DATE	2	1	10
NO.			
SHEET 1 OF 3			

PROJECT NAME: WCR-112 | PROJECT NO.:

FIELD ACTIVITY SUBJECT: Drilling MWs

DESCRIPTION OF DAILY ACTIVITIES AND EVENTS:

8:00 - At office and Loading Supplies.

9:00 - On-site. Stand & one-source on-site. JSA & Tailgate Safety Mtn. covered.

9:25 - Mob Equipment over to 1st location. & stop by Metro to buy/Rent warning signs for street.

9:30 - Cambrian Mgmt. Called. Pipeline Clear is all of Second area of 110.

10:00 - Steel Casing Unloaded.

10:20 - Called. J.S. for Variance. Tried 3 hole pattern. Rocks at 1' & 6". (MW-5)

10:30 → Drilling Rig over location (MW-5)

10:40 → Drilling Deep well. (Pilot hole 6 3/4 Bit)

11:02 → Pilot hole at 35'. Red Clay at approx 33'. Called G.I. and forwarded information on to J.S.

11:17 → Started drilling 12 1/4" Diameter hole for isolation Casing.

11:41 → T.D. of 12 1/4" bit reached. Circulating fluid/Clearing hole

VISITORS ON SITE:

CHANGES FROM PLANS AND SPECIFICATIONS, AND OTHER SPECIAL ORDERS AND IMPORTANT DECISIONS:

WEATHER CONDITIONS:
30° Cloudy/Foggy A.M.
P.M.

IMPORTANT TELEPHONE CALLS:
- Called for Variance.

011001

SHAW E & I PERSONNEL ON SITE: T.E./G.I./J.S./

SIGNATURE: [signature] DATE: 2-1-10

327D-6-02

Shaw™ Shaw E & I, Inc.

FIELD ACTIVITY DAILY LOG

DAILY LOG				
	DATE	2	1	10
	NO.			
	SHEET 2 OF 3			

PROJECT NAME: WCR

PROJECT NO.:

FIELD ACTIVITY SUBJECT: MW Drilling

DESCRIPTION OF DAILY ACTIVITIES AND EVENTS:

12:30 - TCEQ on-site.
12:40 - Break for lunch.
13:40 - Back from lunch.
14:09 - Setting Isolation Casing (35' of casing)
14:22 - Welding the two Isolation Casings
14:58 - Running tremmie pipe into well bore. (Annulus of Isolation casing.
16:10 - Outer Annulus cemented. Cutting Isolation casing to ground surface.
16:25 - Cut Casing. Demob off location.
16:36 - Hand Auger 2 locations to 6" & 8" and hit calich Rock. Called. J.S. to issue a variance.
16:40 - Setup on MW-4
16:45 - Started drilling MW-4
17:50 - Reached T. D. of 35'. Plugged back 2' to make new T.D. 33'
17:58 - Installing 20' of 0.020" Screen and 13' of PVC Riser.
18:00 - Plugged back to 31' have to re-enter hole.

VISITORS ON SITE: See Pg. 1

CHANGES FROM PLANS AND SPECIFICATIONS, AND OTHER SPECIAL ORDERS AND IMPORTANT DECISIONS:

WEATHER CONDITIONS:

IMPORTANT TELEPHONE CALLS:

011002

SHAW E & I PERSONNEL ON SITE:

SIGNATURE:

DATE: 2-1-10

327D-6-02

Shaw™ Shaw E & I, Inc.

FIELD ACTIVITY DAILY LOG

DAILY LOG				
	DATE	2	1	10
	NO.			
	SHEET	3 OF	3	

PROJECT NAME: WCR

PROJECT NO.:

FIELD ACTIVITY SUBJECT: Air Drilling

DESCRIPTION OF DAILY ACTIVITIES AND EVENTS:

18:30 - Pulled of of MW-4. Pouring Sand around annulus.
19:00 - Cleaning site and demobing off-site.
19:30 - offsite and back to office.
19:45 - Put samples in office.

VISITORS ON SITE:

See Pg 1

CHANGES FROM PLANS AND SPECIFICATIONS, AND OTHER SPECIAL ORDERS AND IMPORTANT DECISIONS:

WEATHER CONDITIONS:

IMPORTANT TELEPHONE CALLS:

011003

SHAW E & I PERSONNEL ON SITE: T.B.

SIGNATURE:

DATE: 2-1-10

3270-6-02

Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW-4
Sheet 1 of 1

Project Name: WCR-112	Project Number: 137045	Location:	
Drilling Company: Strauss Corp	Driller: T. Elliott	Date / Time Drilling Started: 2-1-10, 16:45	Date / Time Total Depth Reached: /
Drilling Equipment: Star 30K	Sampling Device: Grab-Non	Geologist: T. Elliott	
Drilling Method: Air Rot		Borehole Diameter: 6 3/4 in.	Total Depth Drilled: FT
Well Depth: 33 FT		Water Level (bgs):	
Screen: Dia. 4"	Length: 20 FT	Type/Size: 0.020"	first: FT final: FT
Casing: Dia. 4"	Length: 13 FT	Type/Size: PVC	

Location Description: 8' from W. side of MW-5 (Acme Brick)

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
		0.0'-1.0' Silty Brn Sand			DEPTH = PID READING
		1.0'-5.0' Calich Lt. tan, Some Rock frags			PID =
5		5.0'-7.5' Silty Sand Sl. Damp, Lt tan,			PID =
		7.5'-11.0' Calcarious Siltston Hard, Fractured bits.			
10		11.0'-14.5' Silty Sand Soft with Some Calc. Siltstone/(Sandstone). Damp to moist			PID =
15		14.5'-19.0' S.A.A. Lt tannish Brn, Moist to wet			PID =
20		19.0'-24.0' Silty Sand with clay: Some Gravels, wet. (Clay is Red) (23 wet)			PID =
25	Sand / Sl.	24.0' - S.A.A. More Gravels 24.5' - Sandston Sl. Cemented layer 25.0' Sandston Lt tan and Brn, Some Gravels, No clay, wet.			PID =
30		30.0' - S.A.A. Darker in Color. 32.0' - S.A.A. Some whitish clay.			011004
		33.0' - S.A.A. Sl. Cemented Sandstone Darker in color (Dk. Brn).			
35		35.0' S.A.A. END of Boring			

4

Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW-5

Sheet 1 of ~~4~~ 3

Project Name: WCR 112	Project Number: 137045	Location: Cottonflat & WCR 112	
Drilling Company: Straub	Driller: R. Straub	Date / Time Drilling Started: 2-1-10 / 10:40	Date / Time Total Depth Reached: 2-1-10 /
Drilling Equipment: Star 30K	Sampling Device: None - Grab.	Geologist: t. elliott	
Drilling Method: Air Rotary		Borehole Diameter: 12 1/4 in.	Total Depth Drilled: FT
Well Depth: 80 FT Steel - Isolation Casing to 35'		Water Level (bgs): first: 23 FT	final: FT
Screen: Dia. 4" Length: 40 FT Type/Size: 0.020			
Casing: Dia. 4" Length: 40 FT Type/Size: PVC			

Location Description: Acre Brick Yard (To West of Storage Area outside fence).

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
	conc / conc	0. - 0.5 Silty Brn Sand			DEPTH = PID READING
		0.5 - 6.0 Caliche - Hard, whit/Gray,			
		6.0 - 11.0' - Caliche/Sandy Silt or Siltstone - Hard, Fractured Bits,			PID =
5					
					PID =
10					
	Bent	13.0' - Silty Sand Small Lenses throughout, Hard./Soft, Dry to moist.			PID =
15		15.0' - Hard S.A.A.			
		18.0' - Silty Sand - Brn, Soft, Damp to moist,			PID =
20		20.0' - Silty Sand with clay - Some Gravels, Mostly Red, Damp to Moist			PID =
	▼	23.0' - S.A.A. Moist to wet.			24' Sampled B-1 @ 24' 11:30
25		24.0' - Sandstone layers throughout. Lt. tan, Moist & Dry Sandstone Lenses. Red clay throughout			PID =
		25.0' - (Silty) Sandstone All tan. Some Small Gravels. ~~[illegible]~~ Wet.			
30		30.0' - S.A.A. Some Lt. white clay throughout			

011005

1

Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW-5

Sheet 2 of ~~4~~ 3

Project Name:	Project Number:	Location:	
Drilling Company:	Driller:	Date / Time Drilling Started: /	Date / Time Total Depth Reached /
Drilling Equipment:	Sampling Device: See Pg 1	Geologist:	
Drilling Method:		Borehole Diameter: in.	Total Depth Drilled: FT
Well Depth: FT		Water Level (bgs):	
Screen: Dia. Length: FT Type/Size:		first: FT	final: FT
Casing: Dia. Length: FT Type/Size:			
Location Description:			

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
	Bent. / Bent.	33.0' - Red clay - Dark, Dry, Med. stiffness. (False Reds)			DEPTH = PID READING 35' Sampled PID = B-1 @ 35' 11:50
35		35.0' - Brown Sand - Angular, Som Gravels, wet.			PID =
		38.0' - Sandstone Pink, Sl. cemented 39.0' - Sandstone Tan.			
40		42.0' - Sandstone Tan to dark Brn (Top of Trinity)			PID =
45					PID =
50	Sand / Sand	48.0' Sandstone - very med. Med. Grained Lt Brn to tan			PID =
55		54. S.A. with clay content gravels			PID =
60		55' Shale lense in the Sandstone, Dk Gray, wet Very Prehiplic			

011006

Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW-5

Sheet 3 of 3

Project Name:	Project Number:	Location:	
Drilling Company:	Driller:	Date / Time Drilling Started: /	Date / Time Total Depth Reached /
Drilling Equipment:	Sampling Device:	Geologist:	
Drilling Method:		Borehole Diameter: in.	Total Depth Drilled: FT
Well Depth: FT		Water Level (bgs):	
Screen: Dia. Length: FT Type/Size:		first: FT	final: FT
Casing: Dia. Length: FT Type/Size:			
Location Description:			

See pg 1

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
		61. Sandstone. Lt tan to Brn. Some Gravels very Prolific.			DEPTH = PID READING PID =
65		64. - S.A.A. Less clays & More Gravels (Some Quartz)			
		68. S.A.A. Sandstone; Large to med Grained Some gravels (Some quartz, Lt tan, Prolific.			PID =
70					
		73. Similar to above. Some tannish Gray & Red Clay throughout (Alterating layers of Red & Tan clay with Sandstone as major unit)			PID =
75	Sand / Sand	74.0' S.A.A. No clay content, Tan.			PID =
		75.0' S.A.A. Reddish clay throughout			
80		76.0' S.A.A. Cemented layers of Sandstone			
		77.0' S.A.A. Conglomerate Sandstone - Red clay throughout and white clay.			PID =
85		78. Red clay - Bottom unit. DK Red. Stiff. Dry.			
		79.0 - Shale - Cemented DK Red.			PID =
90		80.0' END of Boring			

011007

7

Shaw™ Shaw E & I, Inc.

FIELD ACTIVITY DAILY LOG

DAILY LOG			
DATE	2	2	10
NO.			
SHEET	1	OF	1

PROJECT NAME: WCR 112

PROJECT NO.:

FIELD ACTIVITY SUBJECT: Drilling Background wells

DESCRIPTION OF DAILY ACTIVITIES AND EVENTS:

8:00 - on-site, Strauss on-site ready to start day, JSA/HASP covered, plan todays activities.

8:45 - Guaged DTW in MW-4 @ 17.7' F.G.S. TD of well is 33'

9:40 - Rig moved back into MW-5. Vac truck moved into location

9:50 - Resumed drilling MW-5.

11:00 - T.D. of MW-5 is 80' into Red clay.

11:10 - Running casing

11:15 - Drive to GPR area and see Next wells.

11:30 - Recall Digless to 2601.

~~11:30~~ 12:20 - off-site for lunch.

13:36 - Back from lunch. Strauss Decon drilling Rig next to MW-4 location.

13:45 - Checking on GPR & EM Area.

14:50 - Cleared MW-3 with Hand Auger to 5' b.g.s.

15:00 - Started Drilling MW-3

16:31 - Finished Drilling MW-3 running Screens & Casing.

17:10 - Starting to Drill MW-6

18:45 - Finished Drilling MW-6

19:30 - off-site.

VISITORS ON SITE: EPA

CHANGES FROM PLANS AND SPECIFICATIONS, AND OTHER SPECIAL ORDERS AND IMPORTANT DECISIONS:

None

WEATHER CONDITIONS:

AM cold drizzly 30°

PM Cold calm 35°

IMPORTANT TELEPHONE CALLS:

None

011008

SHAW E & I PERSONNEL ON SITE: TE, J.S., G.J.

SIGNATURE: [signature]

DATE: 2-2-10

327D-6-02

Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW-3
Sheet 1 of 2

Project Name: WCR 112	**Project Number:**	**Location:**	
Drilling Company: Straub Corp	**Driller:** R. Straub	**Date / Time Drilling Started:** 2-2-10, 15:00	**Date / Time Total Depth Reached:** 2-2-10, 16:30
Drilling Equipment: Star 30 K	**Sampling Device:** Grab	**Geologist:** t. elliott	
Drilling Method: Air Rotary		**Borehole Diameter:** 6 3/4 in.	**Total Depth Drilled:** 45 FT
Well Depth: 45 FT **Screen:** Dia. 4" Length: 35' FT Type/Size: 0.020" **Casing:** Dia. 4" Length: 10 FT Type/Size: PVC		**Water Level (bgs):** first: 26 FT final: FT	

Location Description: Bostwick Property, 10' from Lainge & 200' from WCR 112

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
		0.0-0.5' Sandy Silt - Brown Damp.			DEPTH = PID READING
		0.5-9.0' Caliche - Lt tan & white some Caliche Rock Frags			PID =
5	Bent Conc	9.0'-13.0' S.A.A. Sl. cemented Caliche Rock Frags (Indurated Caliche)			PID =
10					
		13.0'- Sandy Silt w/ caliche Lt tannish white Damp.			PID =
15	Sand				
		18.0'- S.A.A, Damp. Lt tannish white, Less indurated material			PID =
20		20.0'- Sandy silt - Lt tannish Brown, Damp to Moist			
		20.5- Cemented Sandstone Lenses throughout			PID =
		22.0- Sandy Silt - Lt tannish white.			
25		26.0'- S.A.A. More Cementation. V. wet.			PID =
		27.0'- S.A.A. Hard			
30		30.0'- S.A.A. - Trace Clay (whitish tan)			

011009

Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW-3

Sheet 2 of 2

Project Name:	Project Number:	Location:	
Drilling Company:	Driller:	Date / Time Drilling Started: /	Date / Time Total Depth Reached /
Drilling Equipment:	Sampling Device: See Pg 1	Geologist:	
Drilling Method:		Borehole Diameter: in.	Total Depth Drilled: FT
Well Depth: FT Screen: Dia. Length: FT Type/Size: Casing: Dia. Length: FT Type/Size:		Water Level (bgs): first: FT final: FT	
Location Description:			

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
		34.0 - Hard Silicated Sandstone tannish Brwn Some dark grains throughout.			DEPTH = PID READING PID =
35		34.0-34.25 Sand soft, Lt tannish Brwn, Proliplic, Some med grains, mostly Fines.			PID =
40					
		43.0 - S.A.A. Traces of clay throughout. Tannish white.			PID =
45		44.0' - Red clay. Dry, med Stiff, Sl. Plasticity. (upper Red bed)			PID =
50		END of Boring 44'			PID =
55					PID =
60					

011010

10

Shaw™ Shaw E & I, Inc.

FIELD ACTIVITY DAILY LOG

DAILY LOG			
DATE	2	3	10
NO.			
SHEET	1	OF	1

PROJECT NAME: WCK 112 | PROJECT NO.: 137045

FIELD ACTIVITY SUBJECT: MW Drilling

DESCRIPTION OF DAILY ACTIVITIES AND EVENTS:

8:30 - on-site. Drive by drill locations. Very wet and access to road underwater.

8:40 - Met TEEQ discuss options for wet day, waiting for Strauss to show up and chime in.

9:40 - Setup on MW-2 at Stelton's house on 112. Very wet, too wet to log well.

11:30 - Finished Drilling MW-2

12:20 - Break for Lunch

13:20 - Back from lunch. Cleaning up site as much as possible in rain.

14:00 - T.E. off-site to get locks

14:45 - T.E. Back on-site. Strauss off-site & One-Source off-site.

14:50 - Locking well caps with key locks.

15:15 - T.E. off-site.

VISITORS ON SITE: None

CHANGES FROM PLANS AND SPECIFICATIONS, AND OTHER SPECIAL ORDERS AND IMPORTANT DECISIONS: - Change well No. 6

WEATHER CONDITIONS: AM - Very wet Cold. 35-40°F
PM - Very wet Cold 40°F

IMPORTANT TELEPHONE CALLS: None

011011

SHAW E & I PERSONNEL ON SITE: T.E., J.S.,

SIGNATURE: [signature] DATE: 2-3-10

327D-6-02

Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW-2

Sheet 1 of 2

Project Name: WCR 112	**Project Number:** 137024 S	**Location:** WCR 112	
Drilling Company: Straub	**Driller:** K. Straub	**Date / Time Drilling Started:** 2-3-10, 10:10	**Date / Time Total Depth Reached** 2-3-10, 11:30
Drilling Equipment: Ster 30K	**Sampling Device:** None/Grab	**Geologist:** J. Elliott	
Drilling Method:		**Borehole Diameter:** 6 3/4 in.	**Total Depth Drilled:** 56 FT
Well Depth: 55' FT		**Water Level (bgs):**	
Screen: Dia. 4"	Length: 40 FT	Type/Size: 0.020	first: 51.5' FT final: FT
Casing: Dia. 4"	Length: 15 FT	Type/Size: PVC	

Location Description: NE corner of Johson Prop. 2601 WRC 112

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
		0.0'-3.5' - Silty Sa. Dk Brn wet			DEPTH = PID READING
5		3.5'-8.0' - Caliche - Some indurated Caliche throughout, Lt tannish white, Dry.			PID =
10		8.0'-13.0' Sandy Silt - Some Caliche Lt tannish white, Soft, Dry			PID =
		13.0'-15.0' - S.A.A V. Hard Moist to damp			PID =
15		15.0'-17.0' - S.A.A. Very hard Silicious (Some chert) Damp.			PID =
20		17.0'-19.0' - S.A.A. V. hard increasing clay content, Damp.			
		19.75-22.0' Sandstone/siltstone V. Hard, No clay, Damp, tan/white			PID =
25		22.0'-23.5' S.A.A. Softer Less Fines, Dry			
		23.5-27.5 S.A.A. V. Hard, Cemented layers throughout. Damp			PID =
30		27.5-36.0' - Sandy Silt - Lt tannish white Softer, Damp			011022

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Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW 2

Sheet 2 of 2

Project Name:	Project Number:	Location:	
Drilling Company:	Driller:	Date / Time Drilling Started: /	Date / Time Total Depth Reached /
Drilling Equipment:	Sampling Device:	Geologist:	
Drilling Method:		Borehole Diameter: in.	Total Depth Drilled: FT
Well Depth: FT Screen: Dia. Length: FT Type/Size: Casing: Dia. Length: FT Type/Size:		Water Level (bgs): first: FT final: FT	
Location Description:			

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
					DEPTH = PID READING
					PID =
35					
					PID =
40		36.0' - 44.75 S.A.A. Pinkish tan, Less Sand, Sand med grained to Fine grained, Damp			
					PID =
45		44.75 - 50.0' S.A.A Darker Pinkish Red.			
					PID =
50		50.0' - 51.5 Sandy Silt interbedded with Clay lenses, clay Grayish tan, Silt Pinkish Damp			
					PID =
55		51.5 - 56.0' - Sandstone - DK Brn, Rounded med grains, V. wet			
					PID =
60		56.0' Clay - DK Red, Plastic, Med. Stiffness, Dry. END OF BORING 56.0'			011013

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Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW-~~8~~ 1

Sheet 1 of 2

Project Name: WCR-112	**Project Number:**	**Location:**	
Drilling Company: Straub Corp	**Driller:** R. Straub	**Date/ Time Drilling Started:** 2/2/10 1	**Date / Time Total Depth Reached** 1
Drilling Equipment: Star 30K	**Sampling Device:** Grab	**Geologist:** T. Elliott	
Drilling Method: Air Rotary		**Borehole Diameter:** 6¾ in.	**Total Depth Drilled:** FT
Well Depth: 60 FT		**Water Level (bgs):**	
Screen: Dia. 4"	Length: 45 FT	Type/Size: 0.020	first: 24 FT final: FT
Casing: Dia. 4"	Length: 15 FT	Type/Size: PVC	

Location Description: Lainge Property Near back Fence.

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
		0.0 - 3.0' Silty Sand Dk. Brn. Moist. (Top soil).			DEPTH = PID READING
		3.0' - 6.0' Caliche Lt tan to white, Some indurated layers.			PID =
5		6.0' - 11.0' S.A.A. Less indurated layers.			
		11.0' - 13.0' S.A.A. Increasing Sand			PID =
		13.0' - 16.0" Sandstone. Hard, Lt tannish white & Gray, Silisious, v. Hard.			
10		16.0' - 19.0' S.A.A. Soft then hard interbedded layers, Darker Brn in color. Damp			PID =
15		19.0' - 20.5' Sandstone. Hard, Lt tannish white, Silisious. Damp to Moist			PID =
20		20.5 - 26.0' Sandstone & Dk Brn, with Lt Brn Sand lenses. Med. grained. wet			PID =
25		26.0 - S.A.A. Much Harder.			PID =
30.		30.0' S.A.A. V. Hard.			

011024

14

Shaw™ Shaw Environmental, Inc.

MW Boring Log

Borehole ID: MW-X 1

Sheet 2 of 2

Project Name:	Project Number:	Location:	
Drilling Company:	Driller:	Date / Time Drilling Started: /	Date / Time Total Depth Reached /
Drilling Equipment:	Sampling Device:	Geologist:	
Drilling Method:		Borehole Diameter: in.	Total Depth Drilled: FT
Well Depth: FT Screen: Dia. Length: FT Type/Size: Casing: Dia. Length: FT Type/Size:		Water Level (bgs): first: FT final: FT	
Location Description:			

Depth	Well Completion	Description (Include lithology, grain size, sorting, angularity, Munsell color name & notation, mineralogy, bedding, plasticity, density, consistency, etc. as applicable)	Lithology	USCS Symbol	Remarks (Include all sample types & depth, odor, organic vapor measurements, etc.)
					DEPTH = PID READING
					PID =
35		33.5'-34.0' Sandstone soft S.A.A, Lt. tan/Brn 34.0'-31.0' Sandstone/Sand S.A.A. very friable and wet, Lt. Brn/tan			PID =
40					
		43.0'-44.0' Brn clay 44.0'-45.0' Red clay			PID =
45					
					PID =
50		50.0'-51.0' Sandstone with tannish white clay, Some Gravels throughout			PID =
55		56.0'-58.0' S.A.A. increasing Gravels.			PID =
60		58.0' Red clay True Red Bed 60.0' END of Boring			

011025

15

Shaw™ Shaw E & I, Inc.

FIELD ACTIVITY DAILY LOG

DAILY LOG			
DATE	2	4	10
NO.			
SHEET 1	OF	1	

PROJECT NAME: WCR 112 | PROJECT NO.:

FIELD ACTIVITY SUBJECT: MW Installation - Well Development

DESCRIPTION OF DAILY ACTIVITIES AND EVENTS:

- 8:30 - on-site. JSA/Tailgate & HASP covered.
- 9:30 - Straub, TCEQ and Shaw on-site at WCR 112. Working on pads & well development
- 10:23 - Big 2 news on-site
- 11:30 - Setting MW completions and Bob P (TCEQ) being interviewed.

MW-6 @ 21.0'
MW-3 @ 21.32
MW-2 @ 22.79

12:00 - TCEQ off-site. Kevin Suggs on-site
12:40 - Lunch break
13:40 - Back from lunch

MW-5 @ 25.25'
MW 4 @ 17.50

14:00 - T.E. off-site, Straub developing wells and moving drums.

VISITORS ON SITE: News media

CHANGES FROM PLANS AND SPECIFICATIONS, AND OTHER SPECIAL ORDERS AND IMPORTANT DECISIONS: News media

WEATHER CONDITIONS:
AM - Sl. wind & Cold 40°
PM - Calm & Cold 40°

IMPORTANT TELEPHONE CALLS: —

011026

SHAW E & I PERSONNEL ON SITE: T.E., J.S.

SIGNATURE:

DATE: 2-4-10

327D-6-02

Reference 12

WCR112 TCEQ - SSDAP SAMPLING FIELD NOTEBOOK #1

5/12/09

2615 WCR112 7:50 Am GW-43-1, GW43-2, GW-52-1, GW-52-2

~~F~~43-F

	Temp °C	Ph	Cond.	Comments
7:50	20.4	8.97	2.37	Clear
8:05	20.9	8.96	2.34	" "
8:10	21.3	9.05	2.32	" "
8:15	21.3	9.20	2.33	" "

- Resident noted that particulate filter may be plugged
- Picture #2 from inside faucet
- Purging water from faucet inside house for 15 minute for Hex. Chrom.
- Well purged from effluent side.
- Duplicate taken from effluent side.
- Picture taken #1 from store house
- Shaw noted that -1 + -2 will now be A + C Ports.
- Note Shaw changed gloves for ~~every~~ every sample type

Ph +/- 1/2 full ph point value
Cond w/i 10%
Temp +/- 1/2 full point value

CPS

2

9:00 AM 2700 WCR 126 GW-23-1, GW-23-2, GW-23-F

	Temp	PH	Cond	Comments
9:05	24.8	8.68	2.94	Clear
9:20	23.1	8.86	2.90	" "
9:25	22.8	8.86	2.87	" "
9:30	22.6	8.82	2.84	

- Picture #3 well house Picture #5 inside filtration house
- Purging water from effluent
- Kitchen faucet purged for 15 mins (hot water)
- Picture #6 from kitchen sink

9:25 - Collected GW-23-F
9:30 - collected GW-23-1
9:35 - Collected GW-23-2

DPB

elclifton17@yahoo.com

10:20 ~~2505~~ 2502 WCR 112 GW-46-1, GW-46-2, GW-46-F

	TEMP	PH	Cond.	Comments
10:25	23.7	8.62	2.10	Clear
10:40	24.7	8.19	1.96	" "
10:45	24.6	8.35	1.94	" "
10:50	23.8	8.26	1.93	" "
10:55	23.6	8.32	1.95	

Picture #7 well house exterior, Picture #8 Inside well house
Picture #9 Kitchen sink
Purging water from effluent
Kitchen faucet purged for 15 mins (hot water)

GW-46-F taken at 10:35
GW-46-1 collected at 10:55
GW-46-2 collected at 11:00

PPB

4

6

11:20 2601 WCR112 GW-44-1, GW-44-2, GW-44-F

	TEMP	Ph	Cond.	Comment
11:25	24.2	8.28	2.09	Clear
11:40	23.3	8.29	2.01	" "
11:45	23.2	8.34	2.02	" "
11:50	22.6	7.92	2.00	" "
11:55	23.1	8.06	2.00	" "

Water Purged from Effluent

Kitchen water (hot) purged for 15 minutes

Picture #10 Outside of well filtration house, Picture #11 inside house

Picture #12 Kitchen Sink

GW-44-1 collected at ~~11:36~~ 11:55

GW-44-2 collected at 12:00

GW-44-F collected at 11:36

DPB

13:002604 WCR112 GW-47-1, GW-47-2, GW-47-F

	Temp	Ph	Cond.	Comments
1305	26.0	8.38	2.36	Clear
1320	24.3	8.26	2.37	" "
1325	23.1	8.25	2.33	" "
1330	23.0	7.97	2.36	" "

- Picture #13 kitchen sink, Picture 14 Storage shed, Picture 15 filtration system.
- Kitchen sink purged for ~~30~~ 15 minutes
- Well purged ~~for~~ from effluent
- Double valuve off port 1

GW-47-F collected at 11:40
GW-47-1 collected at 13:30
GW-47-2 collected at 13:35

DPS

6

2813 Cotton Flat GW-54, GW-59, GW-54MSD

	Temp	Ph	Cond.	Comments
14:10	25.0	7.87	2.88	Clear
14:25	24.8	7.67	2.95	" "
14:30	—	—	—	—
14:35	—	—	—	—
14:45	25.1	7.60	2.95	" "

- Took samples from a 2,500 gallon tank.
- Pump cycles on and off, may ~~have~~ not get true parameters.

Picture #16 2,500 gallon tank storage, picture #17 pressure tank + pump inside storage shed.

14:18 pump shut off

14:23 pump back on

- Pump cycled on and off throughout the sampling collection period.

DPB

7:40 2811 Cotton Flat Rd. GW-53

	Temp	Ph	Cond.	Comments
7:40	26	7.01	3.73	Clear
7:55	22.2	6.98	3.33	" "
8:00	23.4	6.89	3.73	" "
8:05	22.8	6.83	3.65	" "
8:10	23.0	6.72	3.61	" "

- Photo #18 taken from backyard, has 2,500 gal storage tank & filtration system (Pic. #19.
- draining tank through faucet next to tank
- ~~water~~ water comes from well 40 feet NNE of storage shed.
- picture #20 well box, picture facing ~~S~~ SW.
- Jason fell through the ladder.
- Pump cycled on and off throughout well purge.

8:10 GW-53 collected

DPB

8

2900 South CR 200 GW-60

~~8:55~~	TEMP	Ph	Cond.	Comments
8:55	27.0	6.85	2.50	Clear
9:10	25.0	6.85	2.22	" "
9:15	26.4	6.79	2.31	" "
9:20	26.4	6.90	2.20	" "

- Picture # 21 of pressure tank + well piping
- Property has a total of 4 wells (1 in front, 1 in front of metal building, & 2 in back yard. Only front well has electricity.

9:20 GW-60 collected

DPB

3000 SCR 1200 GW-61

	TEMP	Ph	Cond.	Comments
9.40	23.2	6.83	1972ms	Clear
9:55	23.6	6.79	1931ms	" "
10:00	23.6	6.81	1915 ms	" "
10:05	23.7	6.52	9.91us	" "
10:10	23.5	6.34	10.9	

- well has a R.O. filtration system.
- There is a second well right next to the pumping well that has a cap on it.
- note: parameter readings automatically switched to Micro siemes (ms)
- Picture #22 of well house w/ filtration system, picture #23 location where water was sampled.
- well was purged from existing piping.

GW-61 collected at 10:10

DPB

10

S. County Road 1200 GW-62, GW-63

Temp	Ph	Cond.	Comments
—	—	—	—
—	—	—	—
—	—	—	—
—	—	—	—

-duplicate collected from this location.

* This residence is outside the 1/2 mile radius sample area and will not be sampled at this time

2715 Cotton Flat GW-57, GW-63

	Temp	Ph	Cond.	Comments
10:55	24.6	6.86	2.07	Clear
11:10	24.0	6.96	2.04	" "
11:15	24.0	6.80	2.02	" "
11:20	24.4	6.97	2.03	" "

- A duplicate sample will be taken from this well.
- Well provides water for 3 residences
- Picture #24 is of the outside of the shed housing the well + pressure tank. Pic #25 is the inside of the well house

GW-57 sample collected at 11:20
GW-63 sample collected at 11:35

DPB

12

3004 SCR 207 GW-66

	TEMP	Ph	Cond	Comments
1205	26.0	7.11	1407 ms	Clear
1220	24.7	7.10	1422 ms	" "
1225	24.5	7.11	1420 ms	" "
1230	24.6	7.07	1418 ms	" "

- meter for parameters changed back to (ms).
- Photo #26 ~~to~~ well casing / housing unit.
  Photo #27 inside well storage area.

GW-66 sample collection time 12:30

DPB

2612 SCR 1206 GW-70, GW-84

~~3:10~~

~~3:10~~	TEMP	Ph	Cond	Comments
3:10	31.3	6.74	3.05	Clear
3:25	27.4	6.65	3.05	" "
3:30	26.8	6.67	3.02	" "
3:35	26.5	6.78	3.13	" "

- Photo #28 water well location, photo #29 pressure tank & spigot.
- Duplicate taken here

GW-70 collected at 15:35
GW-84 collected at 15:50

DPB

14

2713 SCR 1206 GW-71

	TEMP	Ph	Cond.	Comment
1600	27.2	6.94	2.10	Clear
1615	26.5	6.86	2.05	" "
1620	26.4	6.87	2.08	" "
1625	26.1	6.98	2.03	" "

-Photo #30 well storage home, Photo #31 sample area.
-Note: Staining on walls, floor.

DRB

GW-74 2715 S. County Rd. 1208 GW-74

	Temp	Ph	Cond.	Comments
8:00	23.1	6.96	1826ms	Clear
8:15	23.4	6.92	1840ms	" "
8:20	22.8	6.92	1776ms	" "
8:25	22.8	6.84	1872ms	" "

- Photo # 32 Sample area Photo # 33 Non-Potable tank + Surface pressure system for load testing electrical equip.
- parameter unit switched to (ms) units.

GW-74 collected at 8:25

DPB

1207 S County Rd 1207 GW-75

	TEMP	Ph	Cond	Comments
8:45	25.0	6.86	3.86	Clear
9:00	23.3	6.77	3.76	" "
9:05	23.1	6.80	3.69	" "
9:10	23.1	6.76	3.85	" "

Photo #34 well location w/pressure tank. Photo #35 tank w/ warehouse at the site.

GW-75 collected at 9:10

DP3

2804 WCR 115 6W-76, 6W-85

	Temp	Ph	Cond.	Comments
9:55	23.2	6.98	2.75	Clear
10:10	25.5	7.07	2.81	" "
10:15	24.8	7.02	2.81	" "
10:20	24.7	7.01	2.82	" "

- Picture #36 well & pressure tank.
- No one home, door tag placed on front door.

6W-76 collected at 10:20
6W-85 collected at 10:35

DPB

2801 SCR 1207 GW-68

	Temp	Ph	Cond.	Comments
10:50	26.4	7.04	2.69	Clear
11:05	25.8	7.03	2.70	" "
11:10	25.3	6.87	2.64	" "
11:15	25.4	6.92	2.75	" "

Picture #37, Well & sample area.

GW-68 collected at 11:15

DJB

2210 W County Rd 111 GW-~~86~~ 90

	TEMP	Ph	Cond. (mS)	Comments
13:10	26.1	6.91	2.19	Clear
13:25				
13:30				
13:35				

- Picture #38 well location w/ plastic bucket over well.
  Picture #39 sample ~~should~~ area.
- Electricity has shut off and the pump has also shut off. 1315

DPB

20

May 19-21 GW
monitoring pictures
are @
I:\State Lead Section\Team 3
(2009-Robert Musick)\
Surgum\0519-2109 GW
Monitoring

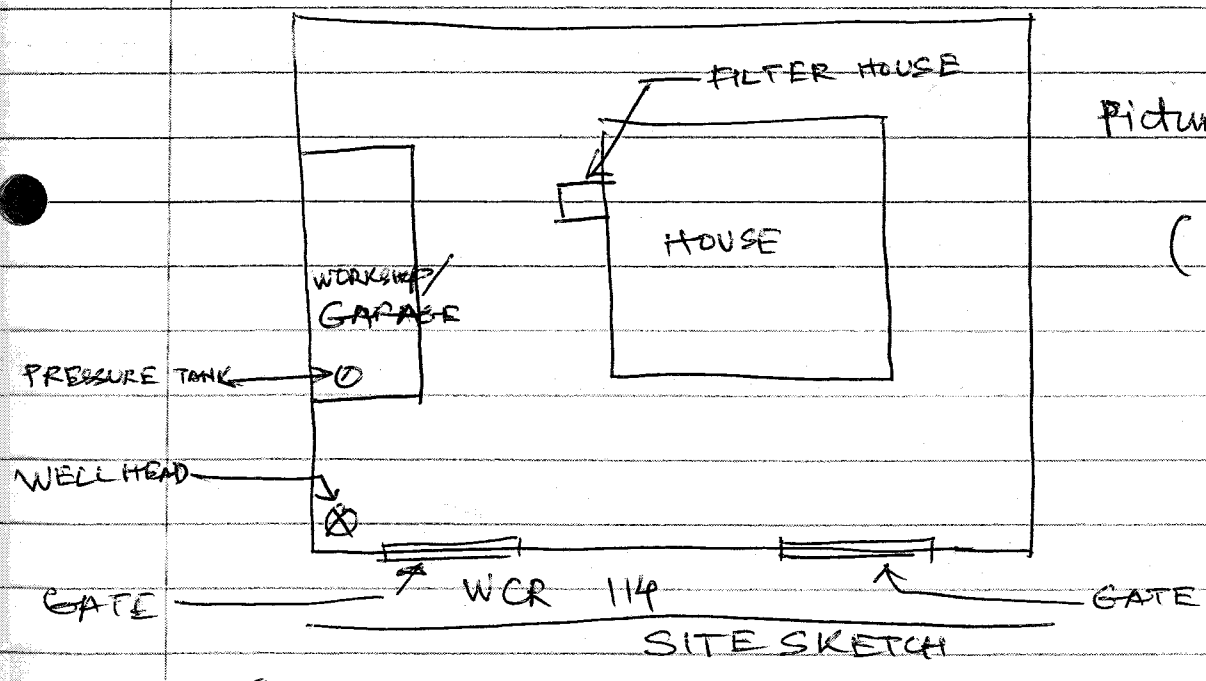
DAY 1 05/19/09

0800 Arrived @ site & met with Shaw sampling team

0805 Clear weather, sunny

0815 Safety meeting conducted

0820 Arrived @ 2700 WCR 114 GW91 A/C



SITE SKETCH

Picture: ~~89-91~~ ~~(30-32)~~ (001-003)

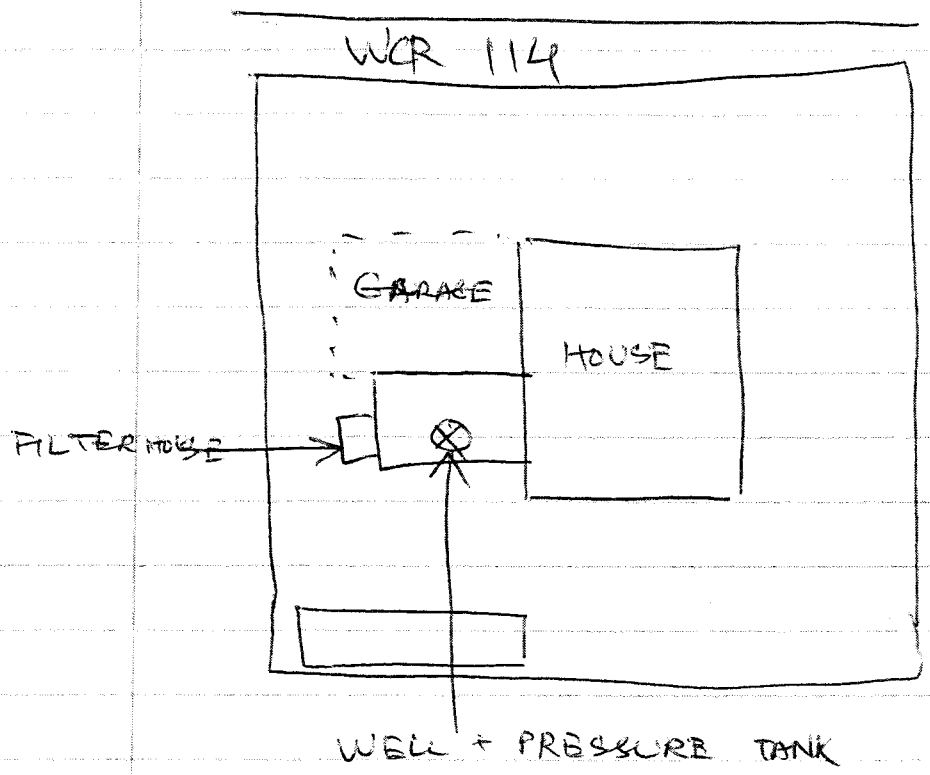
GW PHYSICAL PARAMETERS

TIME	TEMP	PH	COND (mS)	COMMENTS
8:25	20.7	7.15	2.54	
8:40	20.1	6.23	2.51	
8:45	19.9	6.22	2.67	
8:50	19.8	6.23	2.52	

- no ag. wells; 3 adults use bottled water (smells funny); no livestock; some pets

22

0900 reached 2701 W CR 114 GW 95

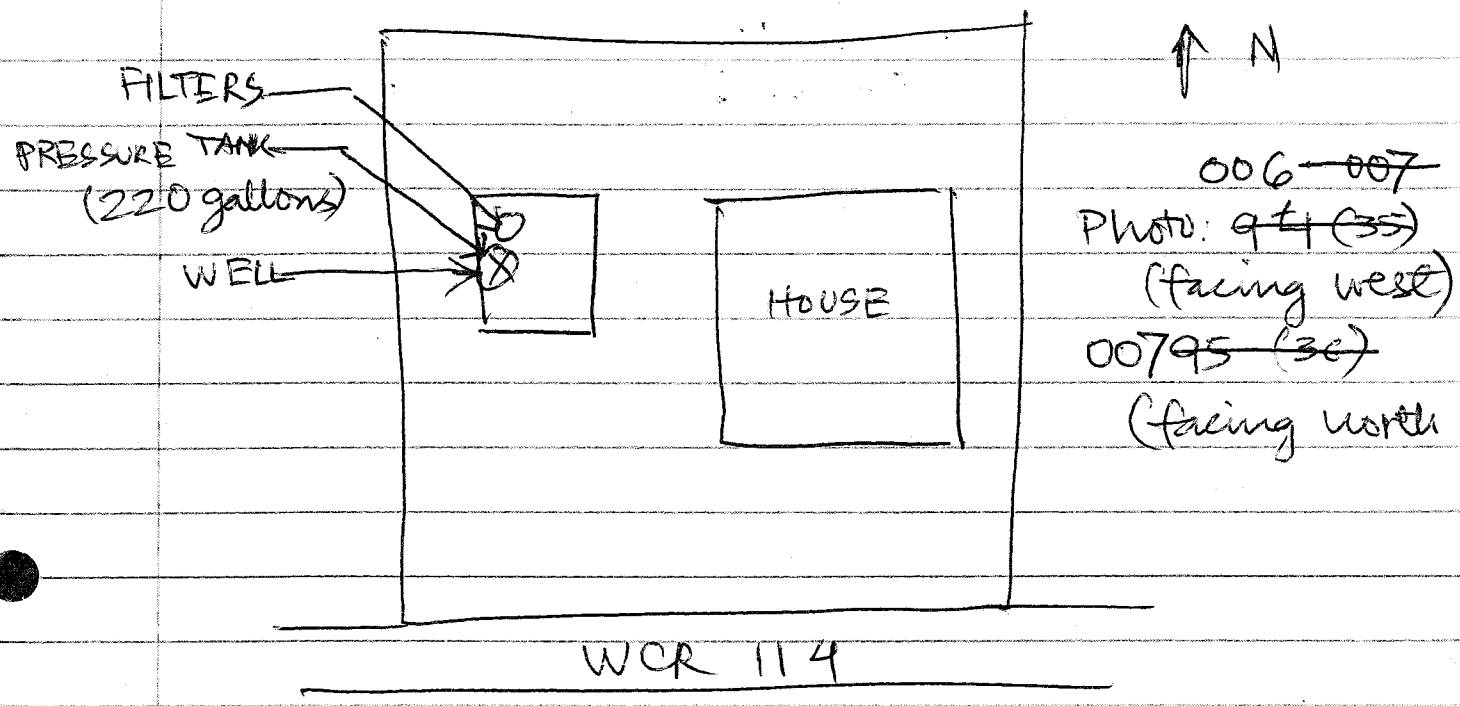


004-005
Photo: ~~12-13 (33, 34)~~
(facing north)

TIME	TEMP	PH	COND ~~µS~~ (mS)
9:13	20.7	6.22	2.44
9:28	20.9	6.19	2.34
9:33	21.0	6.17	2.37
9:38	20.7	6.18	2.36

- no ag. well
- no pets, livestock
- water for himself & his garden
- needs bottled water

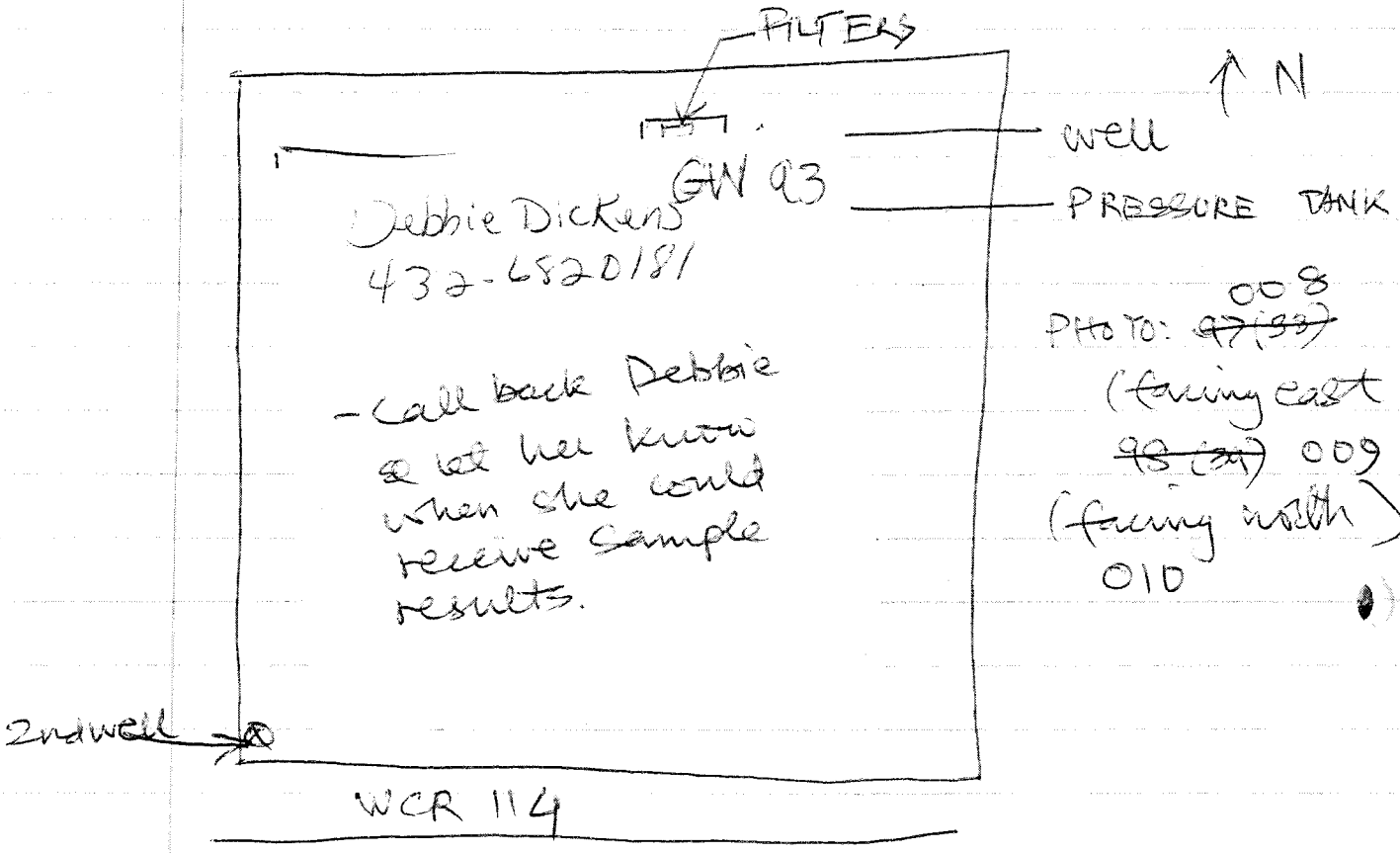
0955 2708 W CR 114 GW 92



TIME	TEMP	PH	COND (ms)
9:58	22.6	6.21	2.84
10:13	24.0	6.14	2.48
10:18	23.2	6.08	2.72
10:23	21.3	6.12	2.69
10:28	21.2	6.12	2.72

24

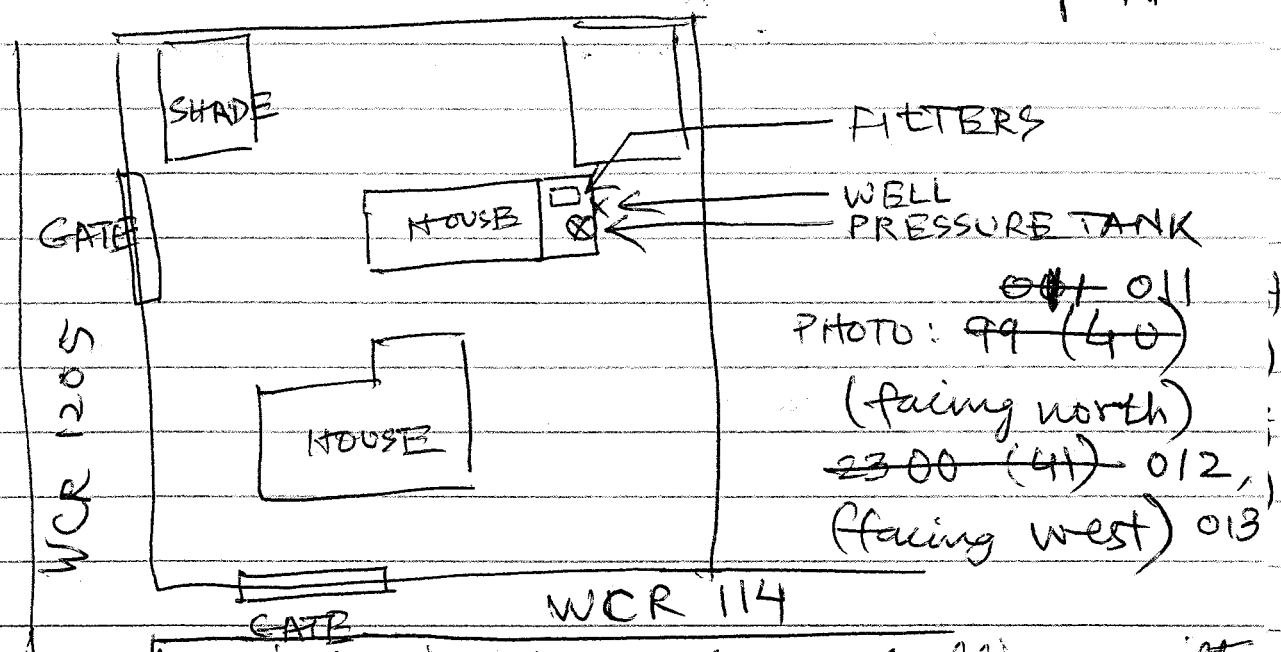
1040 2714 WCR 114 GW 93 + dup GW 120



TIME	TEMP	pH	COND (mS)
10:50	24.6	6.13	2.59
1105	22.0	6.04	2.55
1110	20.7	6.07	2.50
1115	20.7	6.08	2.59
1120	20.9	6.08	2.53

- 2nd well used for gardens
- 1st well used for gardens & inside house
- no ag. well
- used for pet

1155 GW 94 2718 WCR 114

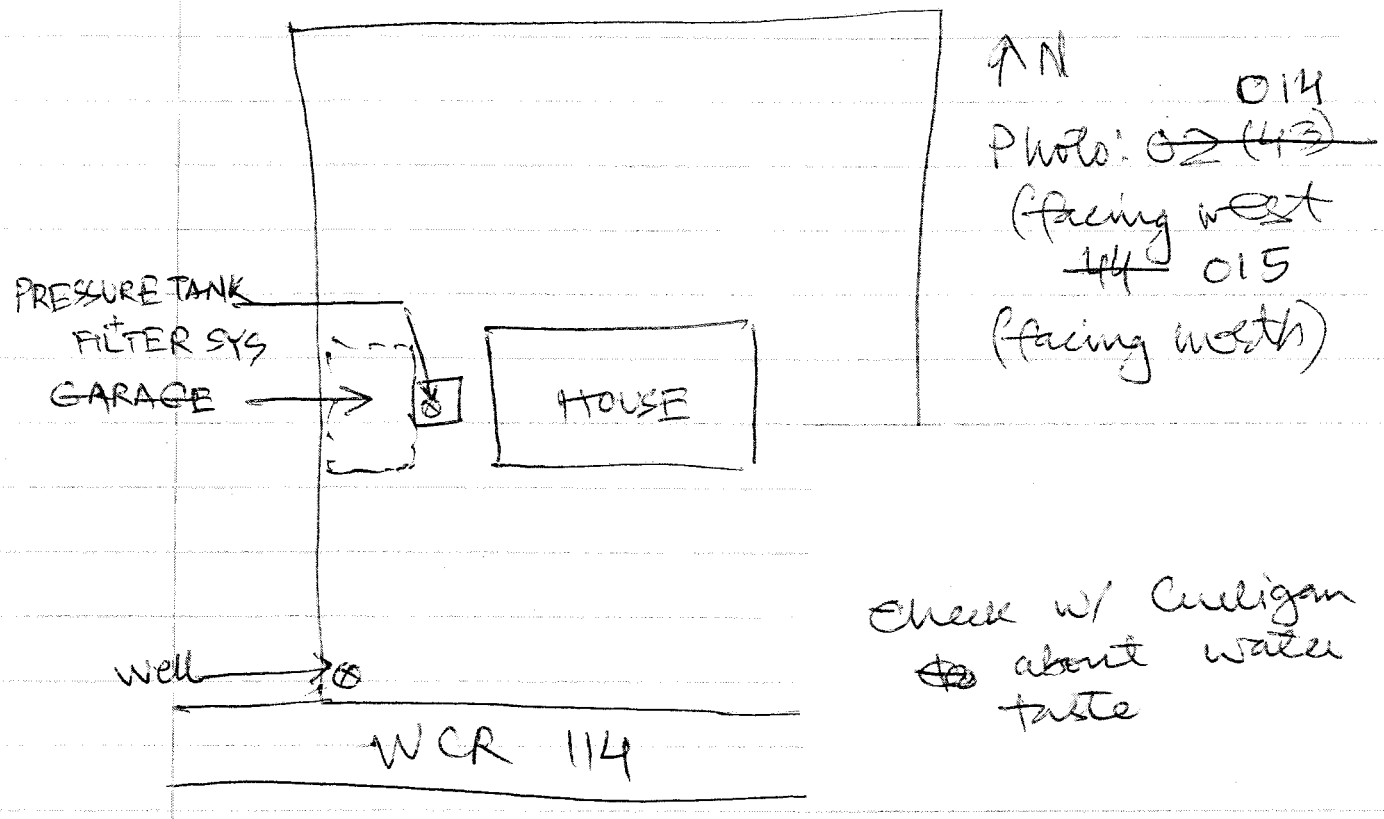


- Port A missing in the system. Culligan will readjust the system to include Port A.
- sample collected from Port C only.

TIME	TEMP	PH	COND (ms)
1200	22.9	6.95	2.45
1215	21.6	6.96	2.54
1220	21.8	6.96	2.44
1225	21.5	6.93	2.51

26

1350 GW 97 2606 WCR 114

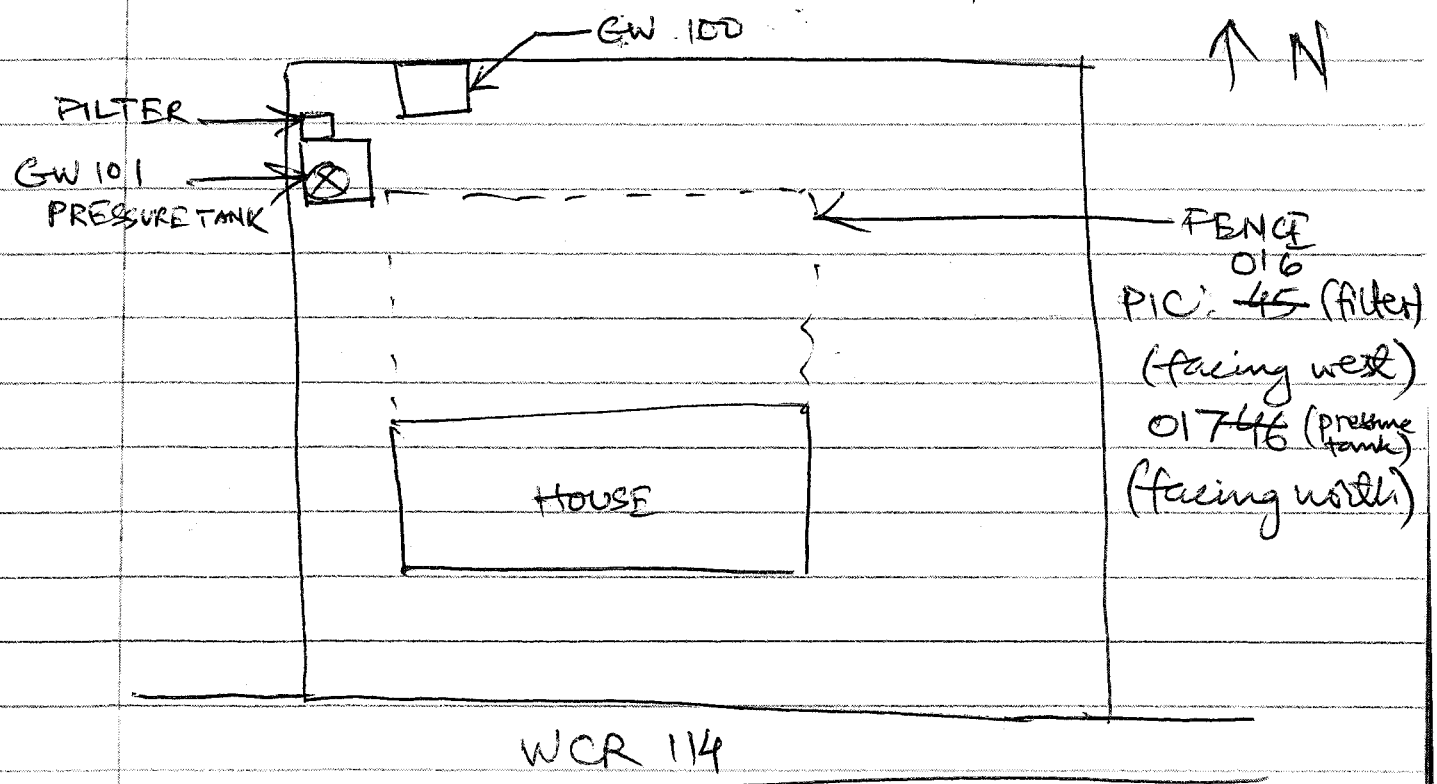


Check w/ Culligan about water taste

- no ag. well
- well water used for self + pets + poultry
- resident said water tastes bad after filter installation

TIME	TEMP	PH	COND (MS)
1355	23.5	7.03	2.37
1410	22.5	7.06	2.40
1415	22.0	7.04	2.32
1420	21.9	7.02	2.43

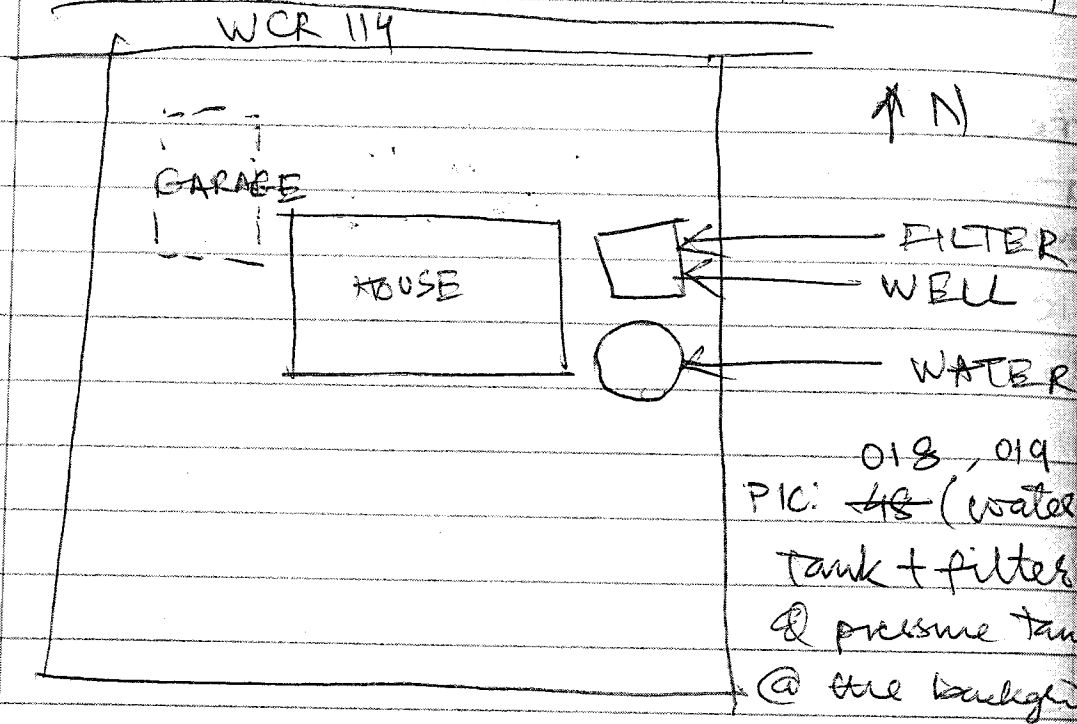
1435 GW 101 2602 WCR 114



- no ag well
- no livestock / pet
- GW 101 & 100 @ the same property

TIME	TEMP	PH	COND (ms)
1440	25.9	6.87	2.19
1455	23.6	7.02	2.20
1500	22.9	7.03	2.11
1505	23.1	7.05	2.12

1530 GW 99 2501 W CR 114 + DUP 1



PIC: ~~018~~ 018, 019 (water tank + filter & pressure tank @ the backgr) (facing north)

- no ag-well
- no livestock
- uses ~~some~~ well water for pets

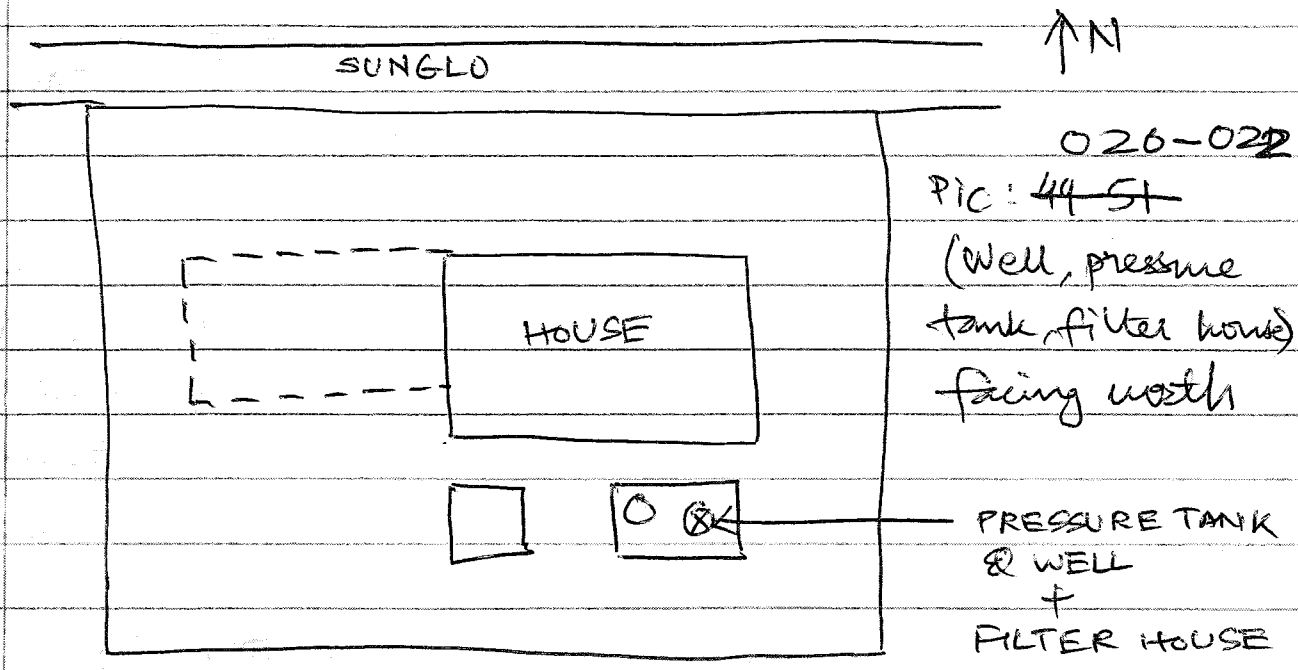
TIME	TEMP	PH	COND (mS)
1532	29.1	7.15	2.13
1537	28.5	7.17	2.05
1542	27.7	7.20	2.28
1547	27.5	7.22	2.23

DAY 2 05/20/09

0800 Arrived @ site Clear weather, sunny

0810 conducted safety meeting

GW 90 2805 W CR 110

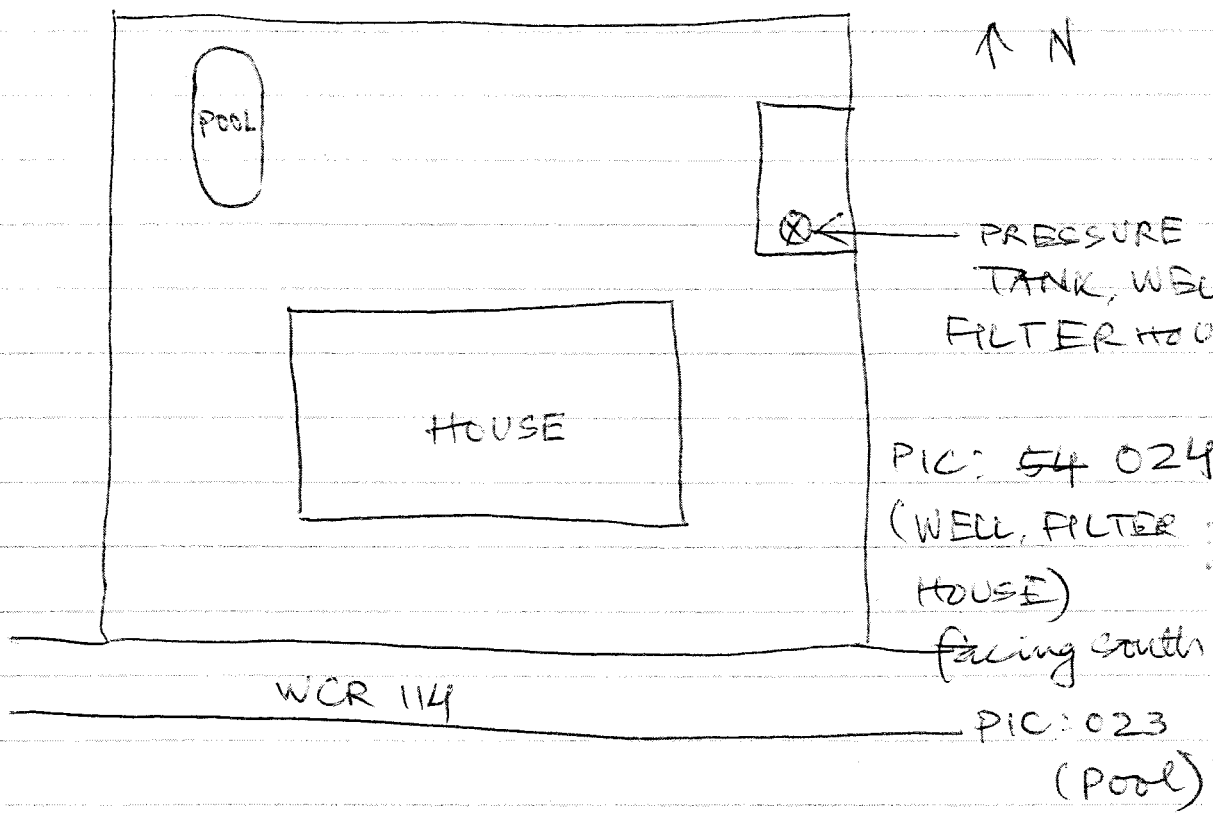


020-022
PIC: ~~44-51~~
(Well, pressure tank, filter house) facing north

TIME	TEMP	PH	COND (mS)
0835	21.8	7.12	2.28
0850	20.5	7.09	2.37
0855	20.1	7.17	2.25
0900	20.2	7.14	2.32

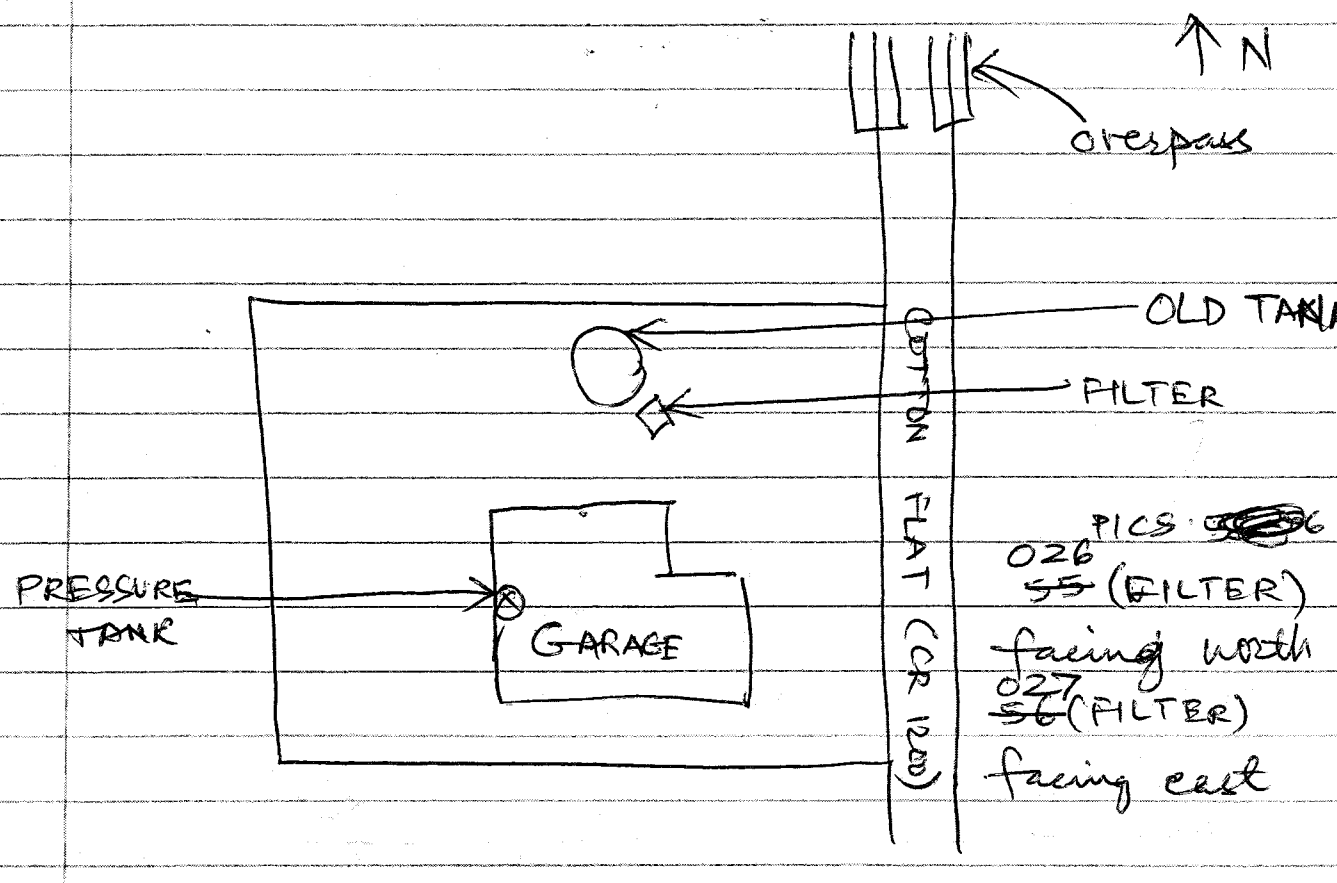
30

0930 GW 103 2414 W CR 114



TIME	TEMP	pH	COND (mS)
0932	20.3	7.14	2.07
0947	21.2	7.14	2.18
0952	21.2	7.19	2.14
0957	21.7	7.18	2.17

1020 GW 105 2524 S CR 1200



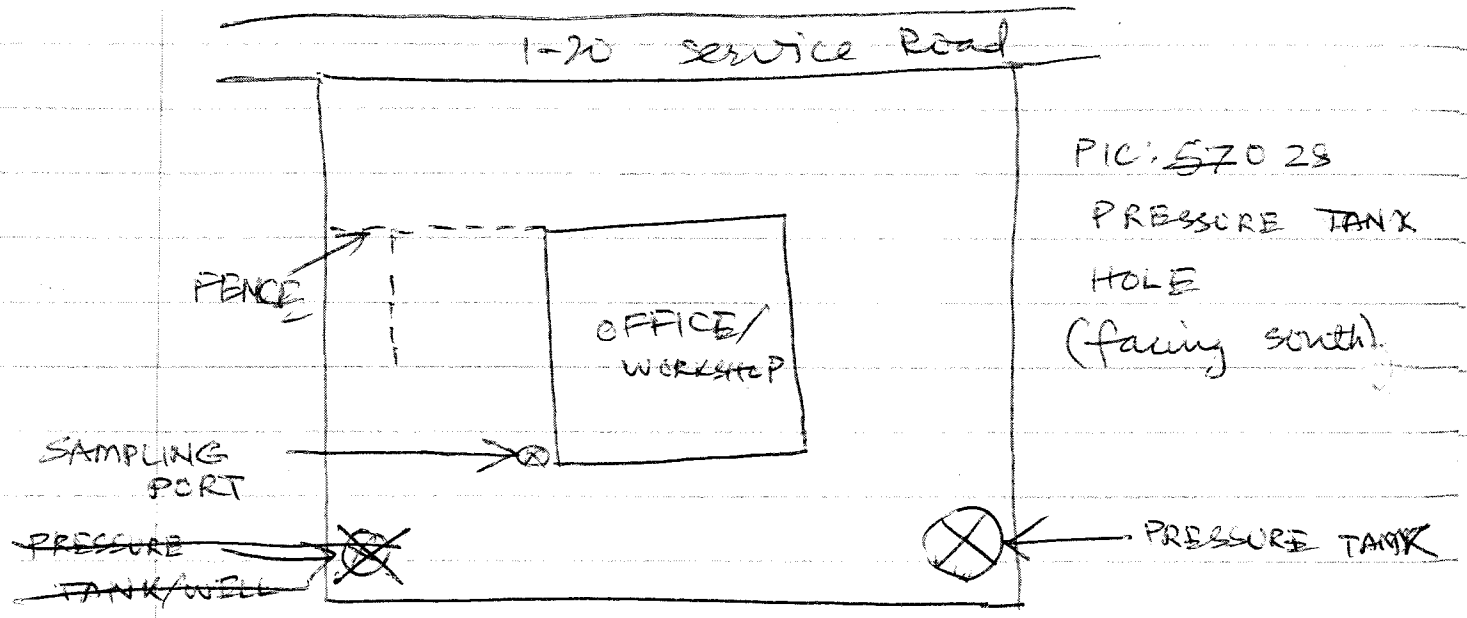
- uses water for poultry & ~~[illegible]~~
- no pets
- doesn't drink gw

TIME	TEMP	pH	COND (mS
1030	22.0	7.25	2.89
1045	21.6	7.26	3.06
1050	21.5	7.22	3.01
1055	21.5	7.21	3.07

32

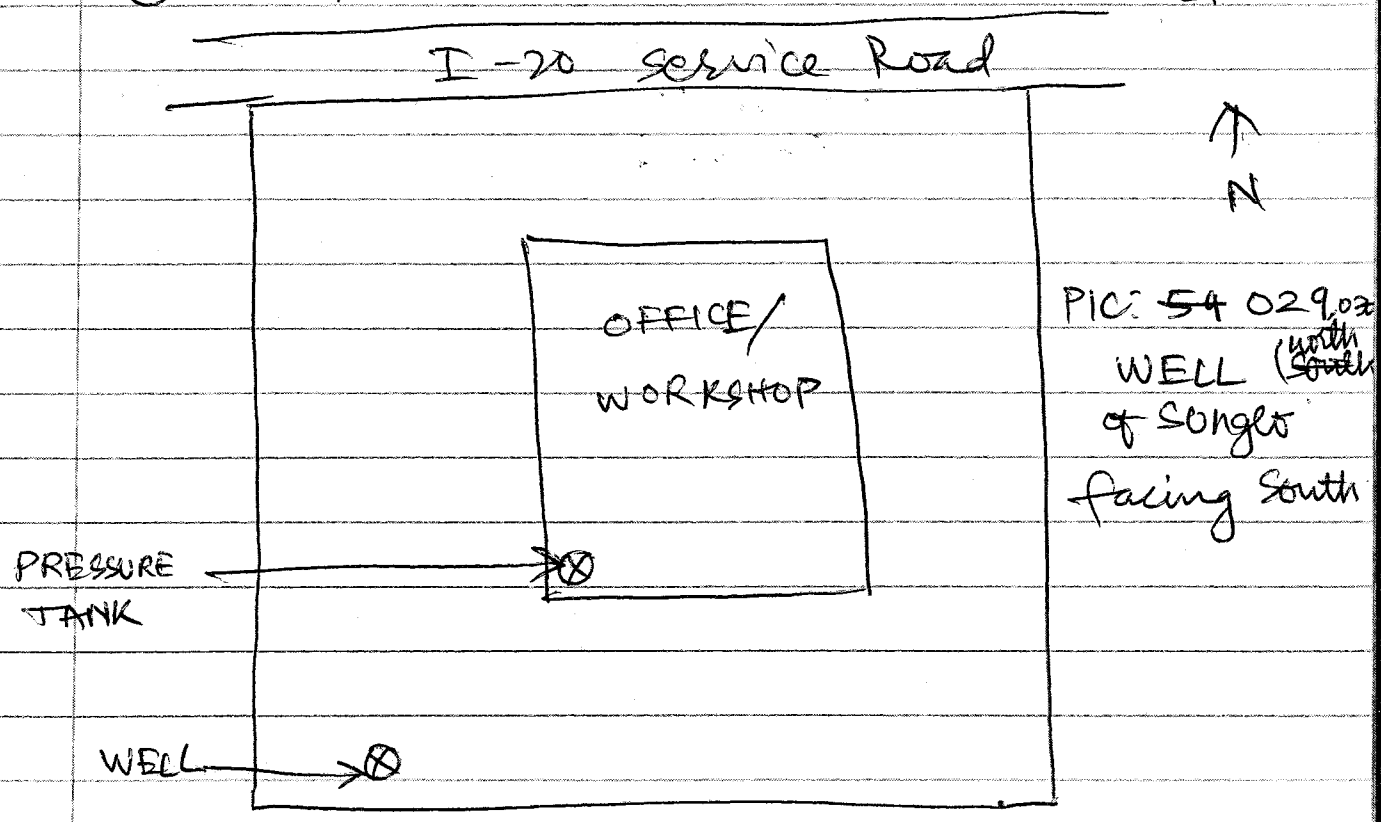
1015 left a copy of survey and access agreement at 2815 W Interstate 20. Said they'd call if they'd like us to sample through.

11 GW-108 2805 W Interstate 20



TIME	TEMP	pH	COND
1155	27.5	7.10	2.35
1210	22.8	7.14	2.29
1215	22.5	7.15	2.33
1220	22.2	7.13	2.38

1400 GW 107 2815 I-20 Service Road

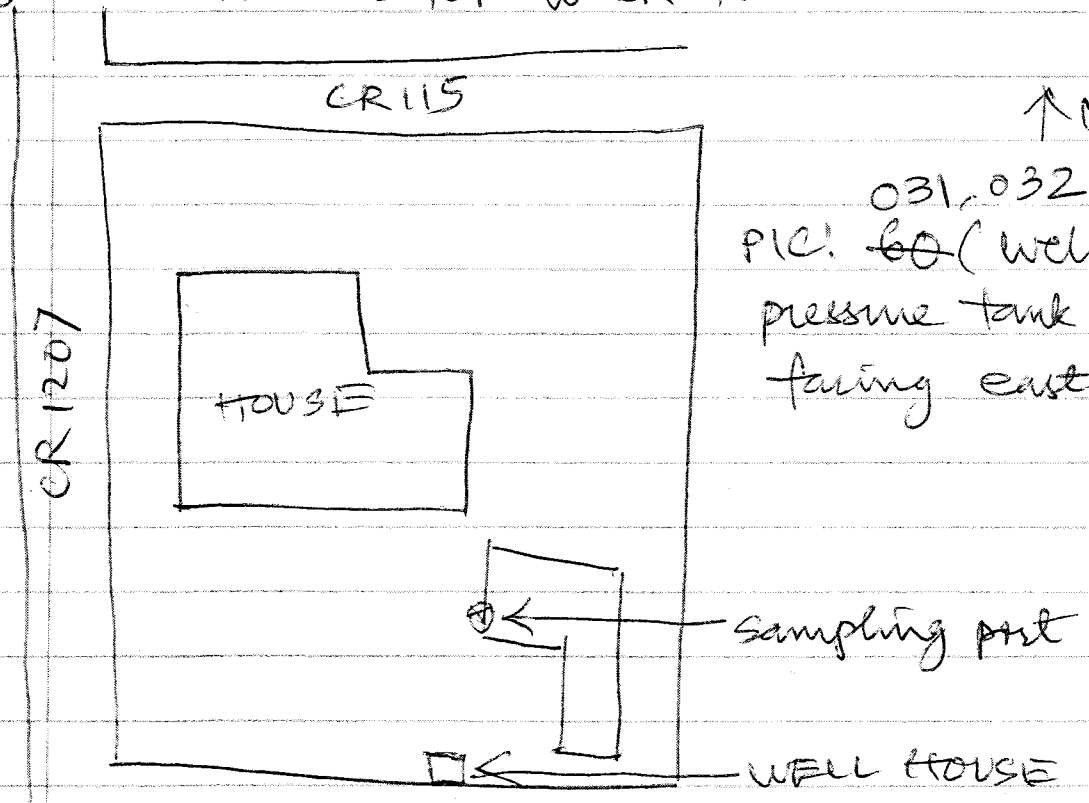


- gw treated with RO system, used by some 20 people;
- gw used for cleaning and restrooms;
- gw not hooked to city water

TIME	TEMP	pH	COND (mS)
1410	24.8	7.19	2.36
1425	23.9	7.22	2.46
1430	23.3	7.18	2.46
1435	22.9	7.19	2.49

34

1505 GW-110 2909 W CR 115



↑N

031, 032, 033
PIC: ~~60~~ (well, pressure tank house) facing east

- uses gw for pets, livestock
- uses ~~bottled~~ water for drinking
- been @ this location since 1980

TIME	TEMP	pH	COND (mS)
1507	22.7	7.12	2.14
1522	22.7	7.12	2.15
1527	22.1	7.14	2.09
1532	21.9	7.15	2.16

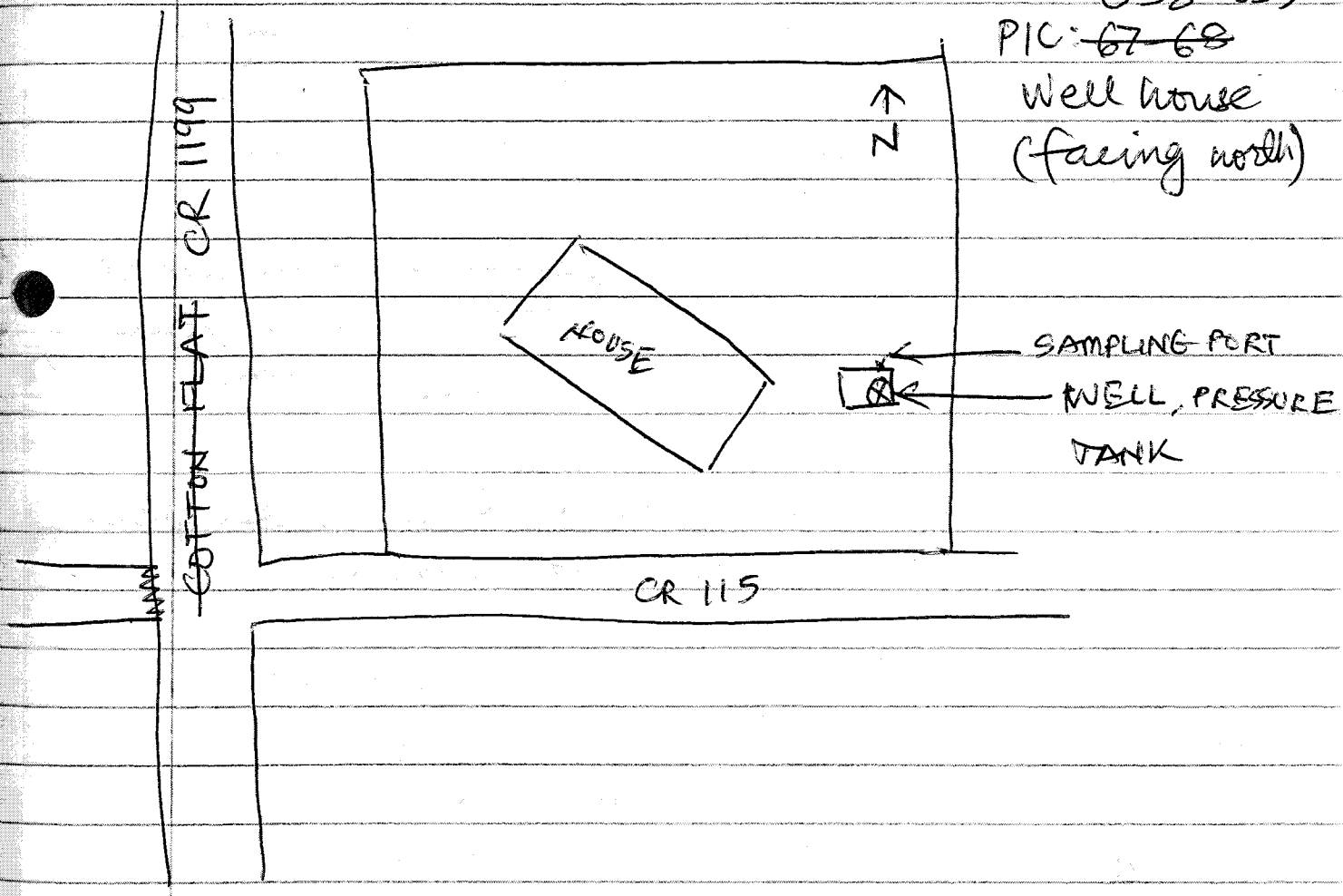
DAY 3 05/21/09

0800 Arrived @ site ; clear weather, cool winds

0810 Conducted safety meeting

0835 GW 112 2108 W CR 115

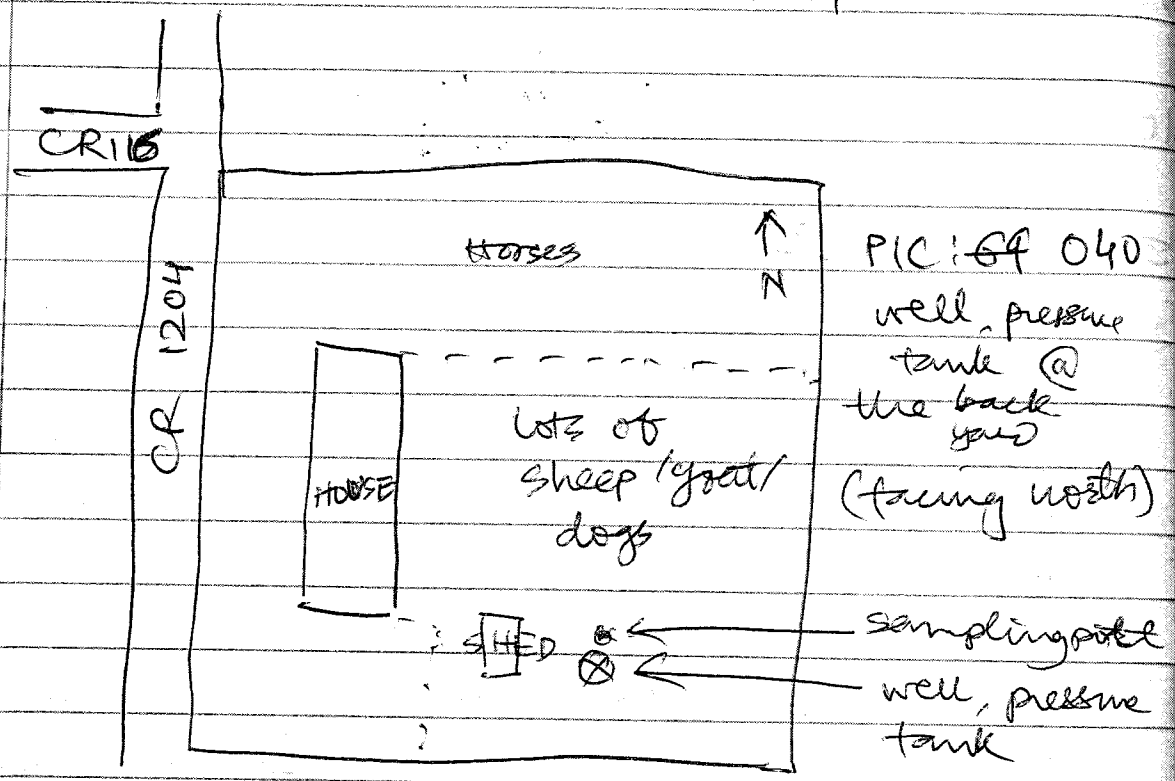
038-039
PIC: ~~67 68~~
Well house
(facing north)



TIME	TEMP	pH	COND (mS)
0835	20.1	7.18	2.79
0850	21.3	7.19	2.86
0855	21.6	7.16	2.73
0900	21.8	7.13	2.83

36

0935 GW 114 3101 S CR 1204



-Spanish speaking resident, so called John Flores to help w/ info dessimination

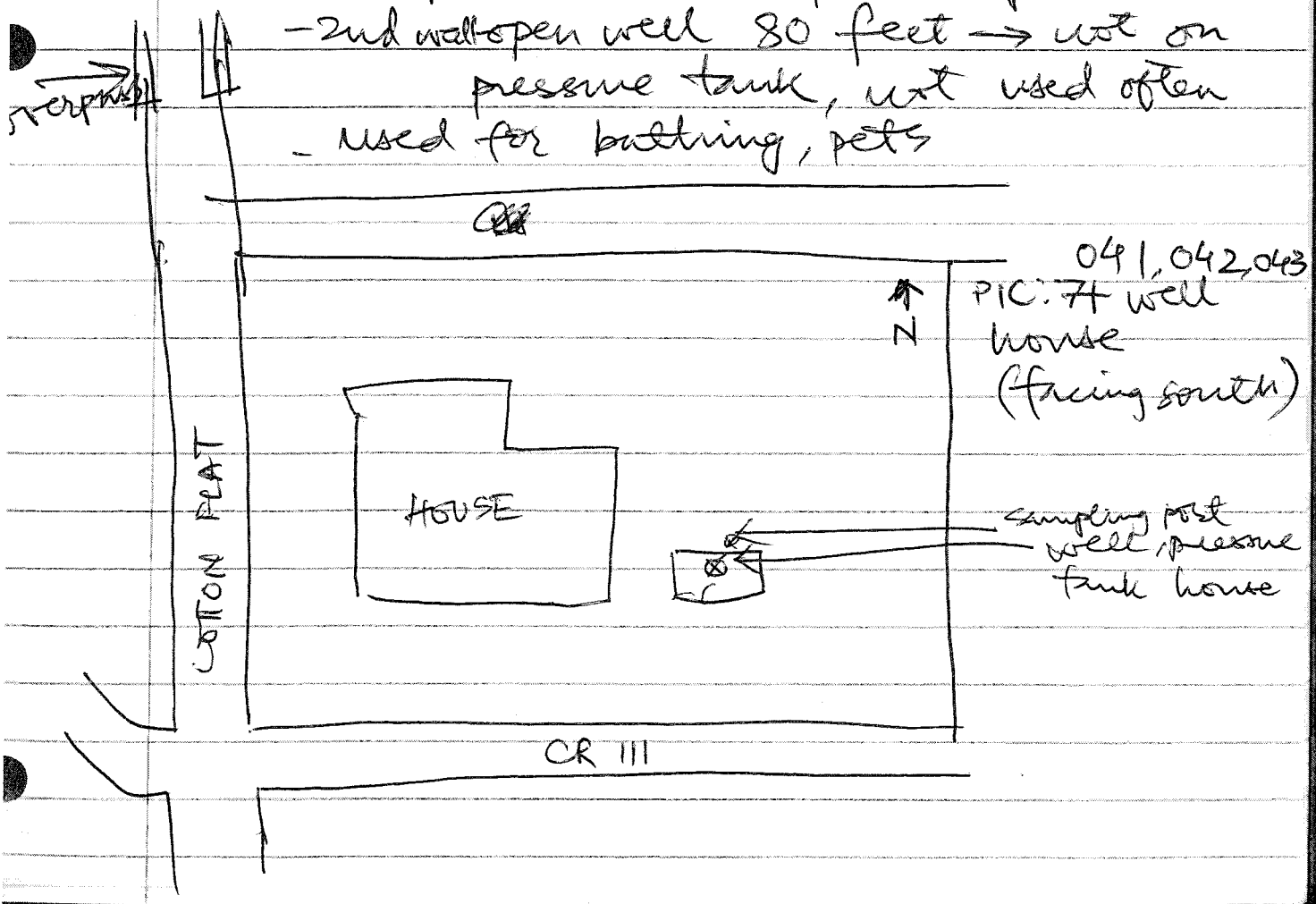
TIME	TEMP	pH	cond (mS)
0940	22.5	6.90	5.90
0955	21.8	6.95	5.95
1000	21.7	6.94	5.93
1005	22.1	6.95	5.91

1015 Reached GW 115 @ 2910 W CR 115, nobody home, called 432-288-4139 but no answer.

1030 ~~Reached~~ GW 116 @ 2902 CR 1199 could not be located, called 432-413-5515 and left a message.

1045 GW 117 @ 2210 CR11

- 1998 well 150 feet deep
- 2nd well open well 80 feet → not on pressure tank, not used often
- used for bathing, pets



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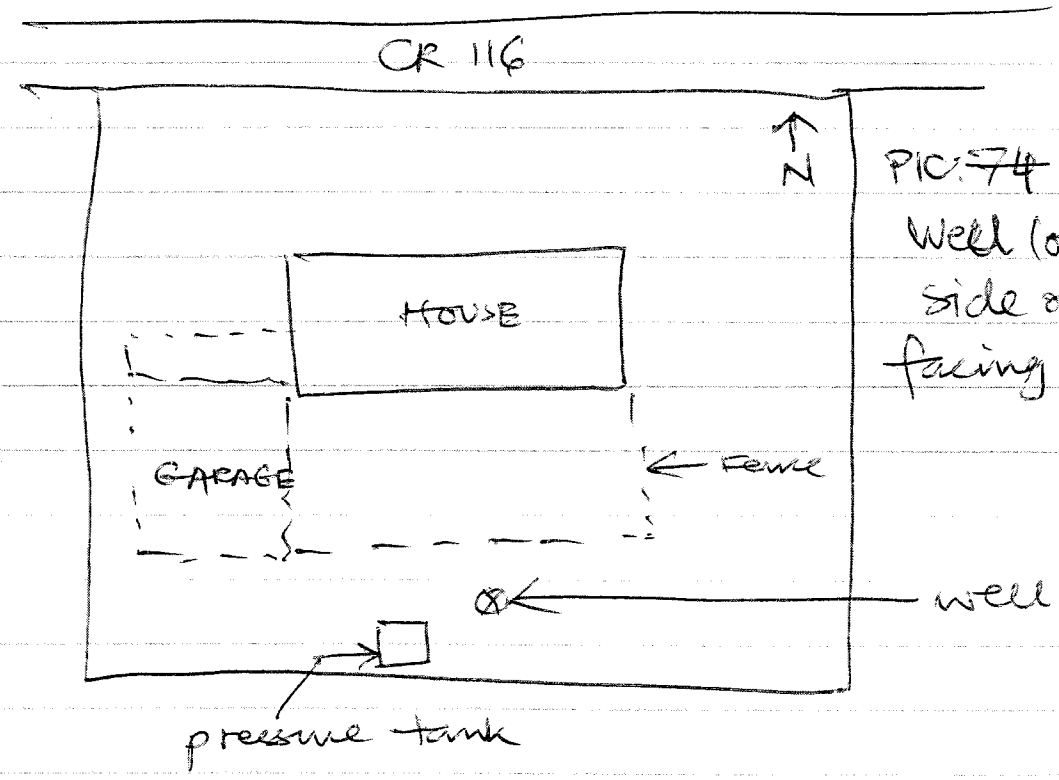
- resident said a lot of wastes (dead animals, hh wastes, liquids from tax) was dumped to east of his residence, which was operated as a landfill and filled it some seven yrs ago.

TIME	TEMP	pH	COND (mS)
1055	22.5	7.11	2.15
1110	22.2	7.13	2.26
1115	21.9	7.11	2.17
1120			

+ dup GW 133

1345 GW 128 2811 WCR 116

- resident been here for 20 yrs
- gw used for garden, bathroom, some cooking

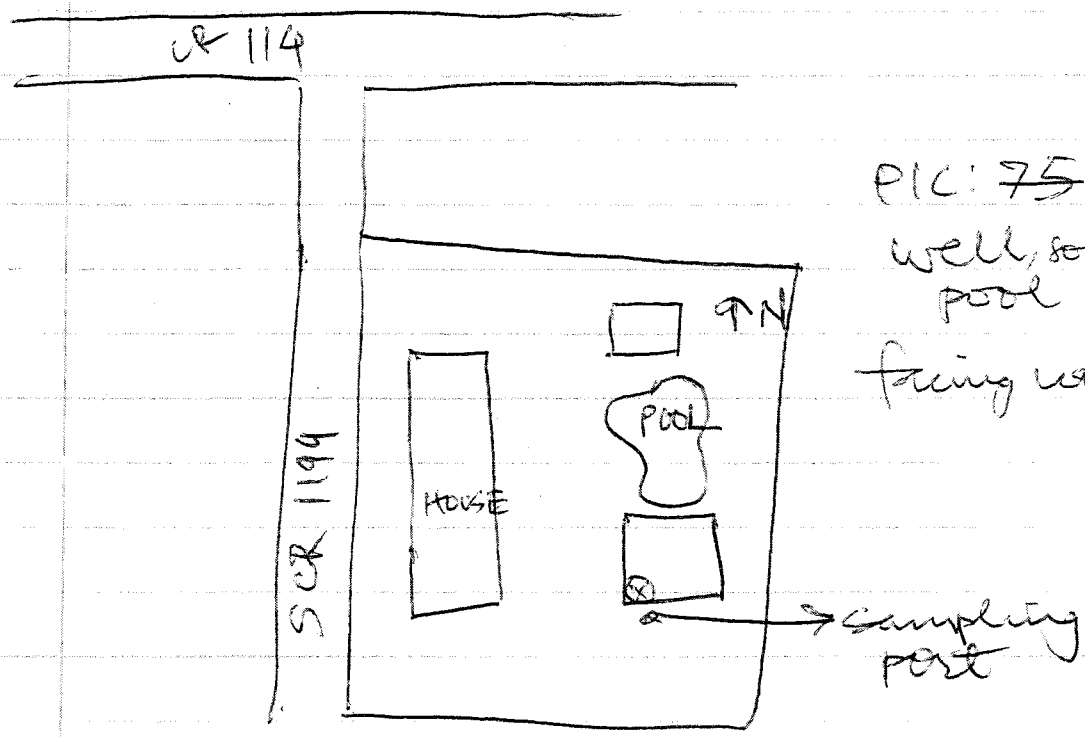


PIC: ~~74~~ 044
Well (on south side of fence facing north

TIME	TEMP	pH	COND (mS)
1350	26.2	6.99	3.45
1405	24.[illegible]	6.99	3.40
1410	23.7	7.01	3.40
1415	23.5	7.02	3.48

4)

1430 GW 116 2909 SCR 1199
- resident called back and said it was okay to sample

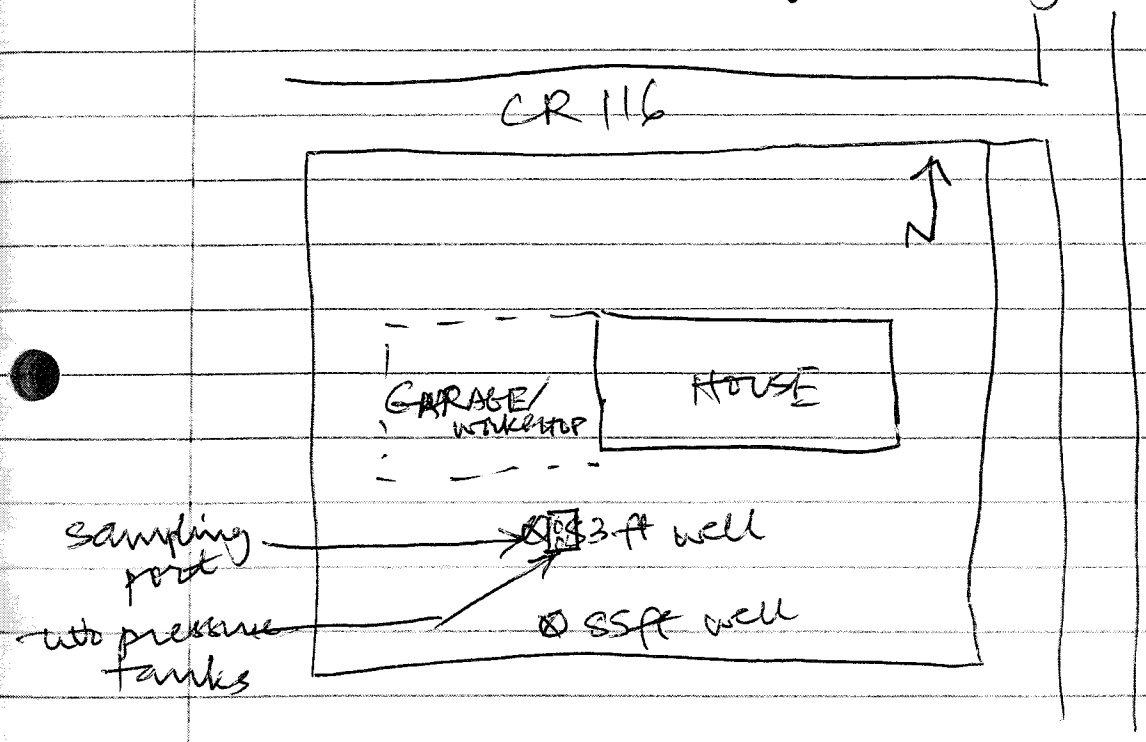


PIC: ~~75~~ 045
well, south of pool
facing north

TIME	TEMP	pH	COND (ms)
1435	25.9	7.14	2.63
1450	23.5	7.10	2.62
1455	22.9	7.12	2.65
1500	22.9	7.18	2.60

1530 GW 131 2715 W CR 116

- uses gw for cooking, bathing, drinking
- has two wells @ 83ft and 85 ft.
- 85 ft well not working
- has been here for 24 yrs



Reference 13

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EXPLANATION

Recent (Holocene)

Qal

Alluvium

Includes low terrace deposits along streams, and sandy silts on pediments locally modified by sheetwash action

Qsd | Qsu
Qs

Windblown sand

Sand and silt in sheets, Qs, locally includes cover sand; dunes and dune ridges, Qsd; and sand sheets, dunes, and dune ridges undivided, Qsu

Recent (Holocene) and Pleistocene

Qgy

Gypsite

Granular gypsum, white to light gray, of several ages

Qau | Qap

Alluvium and other Quaternary deposits

Intimately associated alluvium and Qao deposits undivided, Qau, in dissected areas
Siliceous and igneous pebbles in deposits of uncertain age, Qap, in valleys of Toyah Creek and Barilla Draw

Qt

Fluviatile terrace deposits

Gravel, sand, and silt; gravel, commonly with pebbles and cobbles of chert, quartzite, igneous rock, metamorphic rock, caliche, and at higher levels abraded *Gryphaea*; quartz sand, crossbedded to massive, lenticular, reddish brown, pink, gray to light gray. Contiguous terraces of different ages separated by solid line

Qp

Playa deposits

Clay and silt, sandy, light to dark gray, in shallow depressions; those of Wisconsinan age usually covered by thin deposit of Recent sediment
Note: Water in depressions not shown

Qun

Pond deposits

Gastropod-bearing sandy silt and silty clay, gray to light gray, deposited in ponds and shallow swales, locally may include Tahoka deposits

Qu

Pleistocene surficial deposits undivided

Brown and grayish-brown silty sand and sandy silt deposited as broad, gently sloping sheets

QUATERNARY

Qao | Qgt

Other Quaternary deposits and Toy Limestone

Other Quaternary deposits, Qao, in eastern and central areas, mostly boulders, cobbles, and pebbles of Cretaceous limestone and chert, locally overlain by brown silt, probably equivalent to "Qs3" of Seymour Formation of Abilene, Big Spring, and San Angelo Sheets. In western area includes material from a greater diversity of sedimentary and igneous formations and includes alluvium, colluvium, caliche, and gypsite on surfaces dissected by modern drainage, equivalent to "Old Quaternary deposits, Qao," of Van Horn-El Paso Sheet

Toy Limestone, Qgt, fresh-water limestone near western boundary of area; may be older than Qao; thickness 30 feet

Qta

Tahoka Formation

Lacustrine clay, silt, sand, and gravel, locally calcareous, selenitic. Clay and silt, sandy, indistinctly bedded to massive, weakly coherent, various shades of light gray and bluish gray, reddish brown. Sand, fine- to coarse-grained quartz, indistinctly bedded to massive, friable, gray, grades to gravel at margins of deposits. Molluscan fossils. Thickness up to about 40 feet (Wisconsinan)

Pleistocene

Qc

Caliche

Caliche stripped of covering materials mapped separately; several ages; thickness up to 35 feet

Qcs

Windblown cover sand

Fine- to medium-grained quartz, silty, calcareous, caliche nodules, massive, grayish red; thickness 20 feet, feathers out locally (mostly Illinoian, may include younger deposits)

Qg

Gatuña Formation

Sand, marl, conglomerate, gypsum, silt, shale, and limestone. Sand, fine to coarse, yellow, yellowish to reddish orange, brown, red, pink; locally with worn Cretaceous fossils. Marl, gypsiferous, green, gray, pale olive, pinkish, red. Conglomerate, pebbles of chert, quartz, quartzite, limestone, and igneous rock. Gypsum, laminated to massive, gray and red. Silt and shale, red, dark yellow-orange, green, purplish. Limestone, locally with chalcedony. Thickness 450 feet; included in "Bolson deposits, QTb," on Van Horn-El Paso Sheet

QUATERNARY

Pliocene

To

Ogallala (?) Formation

Basal conglomerate of Triassic and Cretaceous fragments locally overlain by fine pink sandstone; caliche caprock; occurs in Odessa-Midland area mostly in gravel pits; maximum thickness about 20 to 25 feet

Tv

Extrusive igneous rocks

Tuff and basaltic flows

TERTIARY

Upper Cretaceous

Kg

Gulfian rocks undivided

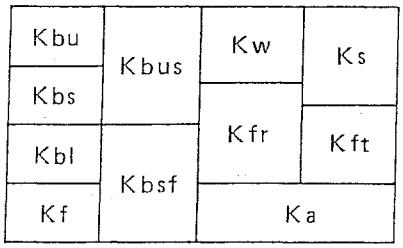
Marl, shale, and argillaceous limestone. Probable correlation with Central Texas units—Taylor, Austin, and upper part of Eagle Ford; thickness 300 feet

Kbo

Boquillas Limestone

Limestone, marl, and shale, flaggy, light gray, light grayish orange, dark grayish orange near base; upper and lower parts only crop out within area of Pecos Sheet

Lower Cretaceous



Washita and Fredericksburg Groups

Buda Formation, Kbu; Boracho Formation represented by San Martine, Kbs, and Levinson, Kbl, Limestone Members; Finlay Formation, Kf; Buda Formation and San Martine Member undivided, Kbus, and San Martine Member and Finlay Formation undivided, Kbsf, in collapsed areas; Washita Group, Kw; Fredericksburg Group, Kfr; Segovia Formation, Ks; Fort Terrett Formation, Kft; and Antlers Sand, Ka

Buda Formation, Kbu, limestone, upper 40 feet, very hard, thin to thick bedded; middle 60 feet, argillaceous, thin to thick bedded; lower 40 feet, bioclastic, coquinoid; thickness 140 feet

San Martine Limestone Member, Kbs, argillaceous, thin to thick bedded, thin interbeds of calcareous shale; prominent 30-foot ledge at base in some localities; marine megafossils throughout; thickness 230 feet

Levinson Limestone Member, Kbl, limestone, marl, shale, and sandstone. Upper two-thirds—limestone, thin to thick bedded, light gray to light olive gray; interbeds of yellowish marl and shale. Lower one-third—shale, light to dark gray; a few thin to thick beds of limestone; sandstone locally near base. Abundant marine megafossils include species found in Kiamichi, Duck Creek, and Fort Worth Formations of North Texas; thickness 150± feet

Finlay Formation, Kf, sandstone, sandy limestone, and massive coarse-grained limestone; thickness 15 to 40 feet, thins northward

Washita Group, Kw, lime tone and marl. Limestone, mostly in upper part, massive, fine to coarse grained, crossbedded calcarenite locally, minor marly limestone, white, gray, yellowish gray; forms ledges; abundant rudistids and other molluscs. Marl, in lower part (locally gypsiferous), thick, dark greenish gray, gray; weathers yellow; abundant molluscs, *Gryphaea navia* at base; grades to limestone along eastern boundary of area. Thickness 230 feet

Fredericksburg Group, Kfr, limestone, dolomite, chert, and minor marl. Limestone, nodular, aphanitic, marly, gray, yellow, white, pink. Dolomite, fine grained, gray. Chert, in thin layers and nodules. Marl, locally gypsiferous, gray, yellowish gray. Abundant *Exogyra texana*, some beds made almost entirely of *Gryphaea* sp. Thickness 135 feet

Segovia Formation, Ks, cherty limestone and dolomite; limestone, miliolid-, shell fragment-, and rudistid-bearing, light gray; dolomite, massive to thin bedded, porous, medium brownish gray; in lower part, miliolid limestone and marl, and marly limestone, light yellowish gray, with *Exogyra texana* and oxytropidocerid ammonites; basal 50 feet crops out within area of Pecos Sheet, thickness nearby on San Angelo Sheet 300 feet

Fort Terrett Formation, Kft, limestone and dolomite. In upper part—cherty limestone and dolomite; limestone in part porcellaneous, aphanitic, in part miliolid-, shell fragment-, and rudistid-bearing, light to dark gray; dolomite, medium brownish gray. In lower part—limestone, argillaceous, thin shale interbeds, nodular and irregularly bedded to thick bedded, light gray, grayish yellow, yellowish brown; marine megafossils. Thickness 120 feet

Antlers Sand, Ka, sandstone, fine to coarse grained, white, gray, tan, purple, soft, friable, commonly crossbedded, upper part calcareous, silty; thickness 90 feet

CRETACEOUS

Lower Cretaceous

CRETACEOUS

Kcx

Cox Sandstone

Mostly sandstone, fine to medium grained, thin to thick bedded, crossbedded in part, pebbly in part; interbeds of silty marl and quartz-pebble conglomerate; outcrop thickness 40 feet, base not exposed

TRIASSIC

T_RD

Dockum Group undivided

Shale, siltstone, sandstone, and gravel; mostly shale and siltstone, micaceous, thin bedded to massive, red, reddish brown, dark yellow-orange; sandstone, fine to coarse, red, brown, gray; gravel, various colored chert pebbles; thickness 275 feet

Ochoa

PERMIAN

Pdl

Dewey Lake Redbeds

Siltstone, sandstone, and clay; siltstone and fine-grained quartz sandstone, reddish orange, reddish brown, brownish yellow; clay, silty, red, grayish green, gypsiferous, numerous thin beds; exposed thickness 40 to 50 feet

Pgrc

Gypsum of Rustler and Castile Formations undivided

Gypsum in collapse structures, white, banded with thin layers of brown calcite; brecciated as much as 30 feet below the surface; mostly from uppermost part of Rustler Formation, may include gypsum and limestone residual from Salado Formation

Pru

Rustler Formation

Limestone, siltstone, sandstone, gypsum, marl, and clay. Upper part—limestone and dolomitic limestone; thickness 50+ feet. Middle part—siltstone and sandstone, yellowish gray; thickness 50 to 70 feet. Lower part—siltstone and fine-grained sandstone, thin to medium bedded, red, interbeds of earthy to sparry red gypsum, a few beds of red and greenish-gray marl and clay. Thickness 50+ feet

VIRGIL E. BARNES, PROJECT DIRECTOR

Geologic mapping mostly by G. K. Eifler, Jr., Bureau of Economic Geology, The University of Texas at Austin, with contributions gratefully acknowledged from Shell Development Company, Cities Service Petroleum Company, and sources shown on Index of Geologic Mapping. Geology compiled on high-altitude aerial photographs by G. K. Eifler, Jr. Map scribed by J. W. Macon. Geologic mapping reviewed by J. B. Brown, West Texas Geological Society, Geologic Atlas Committee.

ANDREWS 24 MI.
17 MI. TO TEXAS 51
780000mE
102°00'
32°00'
30'
15'
GARDEN CITY 32 MI.
MIDLAND
ODESSA
Air terminal
Ector County
Warfield
Pumping station
Fish hatchery
TEXAS AND PACIFIC
Underground pipeline
Monahans Draw
Parks Oil and Gas Field
South Cowden Oil and Gas Field
Johnson-Foster-South Cowden Oil Field
Odessa Meteorite Crater
Pegasus Oil and Gas Field
Sweetie Peck Oil Field
Sinclair Oil Field
Dune Oil and Gas Field
Block 31 Oil and Gas Field
Landreth Draw
Centralia Draw
Oil tanks
Substation
Towers
Tower
Ranch
Plant
Pumping station
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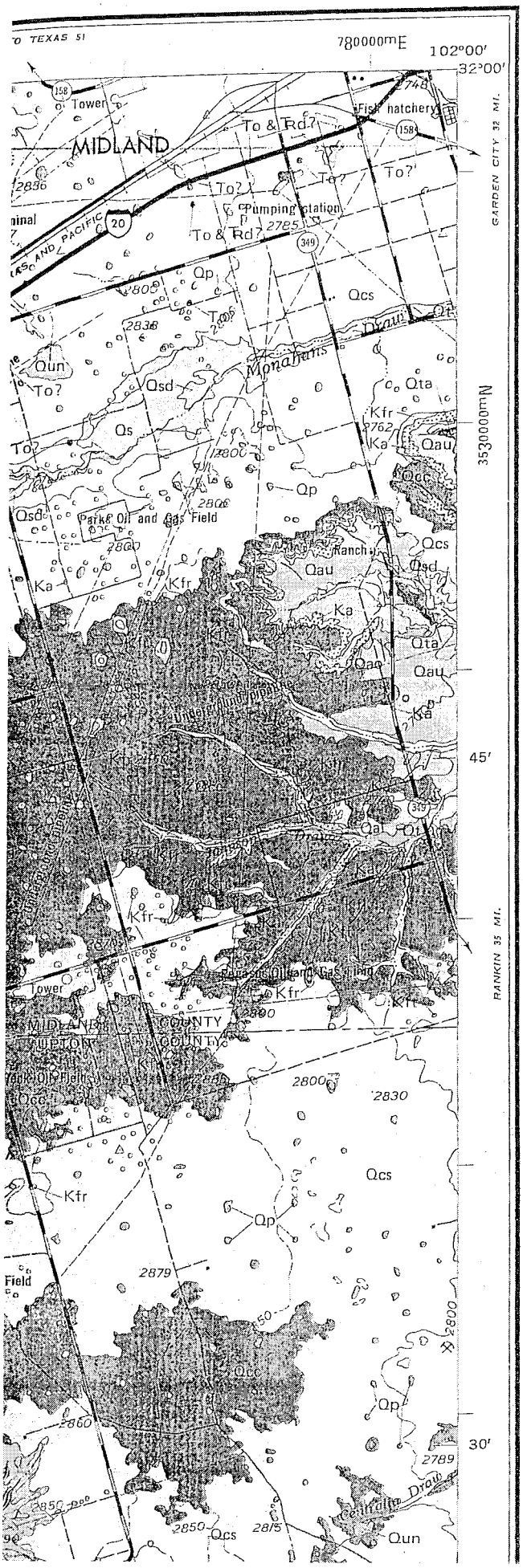

EXPLANATION

Epoch	Symbol	Description	Period
Recent (Holocene)	Qal	Alluvium	QUATERNARY
	Qsd, Qs, Qsu	Windblown sand	
Recent (Holocene) and Pleistocene	Qp	Playa deposits	
	Qac	Caliche	
		Gypsite	
	Qau, Qap	Alluvium and other Quaternary deposits	
	Qt	Fluviatile terrace deposits	
	Qun	Pond deposits	
Pleistocene	Qu	Pleistocene surficial deposits undivided	
	Qao, Qgt	Other Quaternary deposits and Toy Limestone	
	Qg	Gatuña Formation	
	Qth	Tahoka Formation	
	Qcs	Windblown cover sand	TERTIARY
Pliocene	To?	Ogallala (?) Formation	
	Tv	Extrusive igneous rocks	
per Cretaceous	Kg	Buffian rocks undivided	
	Kbo		

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ORGIN, CLASSIFICATION & GEOLOGIC HISTORY OF CALICHE ON THE SOUTHERN HIGH PLAINS, TEXAS AND EASTERN NEW MEXICO

PHOTOS OMITTED

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ORIGIN, CLASSIFICATION, AND GEOLOGIC HISTORY OF CALICHE ON THE SOUTHERN HIGH PLAINS, TEXAS AND EASTERN NEW MEXICO[1,2]

C. C. REEVES, JR.
Department of Geosciences, Texas Tech University, Lubbock, Texas

ABSTRACT

The caliche profiles on the southern High Plains, Texas and eastern New Mexico, are of Pliocene, Pleistocene, and Holocene age. The Pliocene caliche is colloquially known as the "caprock." Differences in age, physical factors, and chemistry allow classification of the caliche into young, mature, and old types. Young caliche is incompetent and powdery except when formed as a laminated zone over an underlying plugged profile. Mature caliche is characteristically nodular, grading downward into old caliche which contains diagenetic quartz. Massive caliches form on semiarid, rapidly aggrading, flat surfaces of desert loess (regional eolian sand ergs), on thick calcareous sands providing local climate fluctuates between humid and semiarid, and on near-surface carbonate rocks. The base and sequential development of the caliche, regardless of parent material, are determined by extent and amount of infiltration of water during humid periods following accumulation of calcareous loess, permeability of the parent material, and rapidity of plugging in the caliche profile. Caliche anticlines, or expansion structures, form *only* in mature caliche or preexisting carbonates due to expansion of the entire zone caused by filling of horizontal and vertical desiccation cracks by vadose silt and calcareous dripstone. The horizontal desiccation cracks are termed "buckle cracks." The most intense expansion structures form on interbedded lacustrine clays and sands; however, isolated structures due to other causes, such as solution and collapse, injection of lacustrine clays, or structures which antedate the caliche, also exist. Induration of the upper part of a thick caliche results mainly from exposure, induration of the lower part of the profile resulting from deposition of diagenetic quartz and carbonate.

INTRODUCTION AND TERMINOLOGY

The southern High Plains, or Llano Estacado, is an isolated, 30,000-sq.-mile remnant of the Rocky Mountain piedmont plain located south of the Canadian River and east of the Pecos River in eastern New Mexico and West Texas. The area, which receives about 16–20 inches of annual precipitation and which has a mean annual temperature around 60° F, is bounded on three sides by a steep escarpment of Pliocene "caprock" caliche (pl. 1*A*), but merges to the south with the Edwards Plateau. Caliche profiles also exist on Pleistocene and Holocene lacustrine and eolian sediments; thus ages of isolated caliche exposures in the area are often difficult to determine.

The Pliocene "caprock" caliche of the southern High Plains has been studied by several investigators, the most notable being Price et al. (1946), Bretz and Horberg (1949*a*, 1949*b*), Brown (1956), van Siclen (1957), and Price (1958), but no studies of the local Pleistocene caliches are known and Holocene caliche has only been briefly discussed in Soil Survey Reports.

The characteristic carbonate horizons of semiarid regions are commonly known as "caliche," whether only a few inches or over 40 feet thick and whether friable or indurated, Lamplugh (1907) suggesting the term "calcrete" for the indurated types. Caliche forms in the C_{ca} soil horizon (Soil Survey Staff 1962); thus normal soil horizon terminology was used in discussing caliche profiles until Gile et al. (1965) proposed K-horizon (from the German *Kalk*) terminology. Division of a caliche profile into K1, K2, and K3 horizons is based on percentage of K-fabric, in which fine-grained, authigenic carbonate occurs as a continuous medium. Because massive caliche profiles such as the caprock are so geographically extensive, massive, and obvious in the semiarid to arid regions of the world, I find terminology dis-

[1] Manuscript received May 19, 1969; revised November 14, 1969.

[2] International Center for Arid and Semi-Arid Land Studies Contribution no. 74.

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tinct from the usual soil-zone terms useful; however, reference to K-horizon definitions proves to be, for the geologist, time consuming and not always correlative with physical and geological attributes of the caliche, particularly because K-terms are horizons with variable morphology (L. H. Gile, written communication, 1969) and cannot be related to relative age of development. K-horizon terminology is also confusing when trying to relate to Butler's (1959) development of "K-cycle" data from study of Australian soils. Because K-horizons are formed by "progressive carbonate accumulation" (Gile et al., 1966), a classification of caliche based on progressive development, physical and chemical features, and utilizing long-standing accepted geological terminology is therefore proposed.

PREVIOUS WORK

Udden (1923) first called attention to the caliche escarpment of the Llano Estacado, and later Sidwell (1943) studied the caprock; however, it was not until the Price et al. study (1946) that origin of the caprock became of general interest.

Caliche (caliche = calix = lime) profiles, though of various thicknesses and types, and though common to all semiarid regions of the world (Glinka 1914; Price 1925, 1933; Woolnough 1928, 1930; Miller 1937; Dutoit 1939; Rutte 1958; Welte 1962; Reeves and Suggs 1964; Reeves 1968), have seldom been classified, mainly because of debatable origins (Theis 1936; Sayre 1937). The most recent studies of the caprock (Bretz and Horberg 1949*a*, 1949*b*; Brown 1956; Price 1958; Aristarain 1962) suggest formation in the C_{ca} soil zone, Gile et al. (1966), Hawley and Gile (1966), and Ruhe (1967) factually illustrating the pedogenic origin for a correlative caliche profile in southern New Mexico. Investigators agree that most thick caliches form under aggrading conditions interrupted by climatic reversals which cause extensive solution and redeposition (Frye and Leonard 1967) by utilizing roots, root holes, desiccation cracks, and solutional channels. However, inorganic and organic deposition in shallow lakes (Elias 1931; Theis 1936; Frye 1945), deposition of carbonate by streams (Trowbridge 1926; Price et al. 1946), deposition by rising artesian ground water (Blake 1902), deposition by capillary rise of ground water (Lee 1905), deposition by a regionally rising water table (Theis 1936), and various combinations of the preceding (Lee 1905; Breazeale and Smith 1930; Price et al. 1946) also have been proposed for the caprock of West Texas and for its extension northward into Kansas and Nebraska.

FORMATION OF CALICHE

Environment.—The ideal environment for caliche formation is neither arid nor humid. Too little water, as in the very arid desert regions, allows only surficial accumulations of carbonate; too much water and relief causes regional leaching of soil solubles. Therefore, the local relation between precipitation, temperature, runoff, and relief is critical. Arkley (written communication, 1969) maintains that "one would expect caliche at even higher rainfalls than 25 inches in hotter climates, and at lower rainfalls, provided the precipitation is concentrated in a cool period, followed by a dry, hot summer as in Mediterranean climates." Thus, caliche formation does not really characterize any particular climatic zone, and the presence of massive caliches in desert areas such as the Chihuahuan or Sahara are themselves indicative of substantial climatic change.

The dissolving of soil carbonate occurs because carbonic acid forms from rainwater and CO_2 in the atmosphere and soil:

$$CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)\,.$$

The very alkaline nature of the solution allows supersaturation by silica (H_4SiO_4) in exchange for carbonate, which explains the absence of chert and opal in the upper caliche zones. The kinetics of silica deposition (i.e., the slow reaction time) also account for absence of amorphous silica in the uppermost, youngest caliche zones, the silica being

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confined mainly to the lower (older) part of the caliche.

The predominant minerals in young caliche are quartz and calcite, transition from young to old caliche involving alteration of perhaps a small percentage of quartz sand grains to the metastable or amorphous types of silica and considerable weathering of the alumino-silicates. Thus, in young caliche the silica/calcite ratio is high due to the high percentage of sand; in mature caliche the ratio is more equated due to the accumulation of calcite and the removal of silica; and in old caliche the ratio is again high due to deposition of amorphous silica.

Variable silica/calcite ratios in sediments are determined mainly by changes in temperature, pressure, partial pressure of CO_2, and pH. Because the solubility and depositional kinetics of silica and calcite are reciprocal, particularly in regard to temperature, there is the possibility that massive caliche formation on the southern High Plains was caused simply by fluctuation of regional temperature during the Pleistocene; however, as Arkley (written communication, 1969) states: "Soil is a very complex organic and mineral material, and the kinetics of pure silica solutions simply do not apply." Rather, there is a critical relationship between the pH of the infiltrating groundwater, the mineralogy of the soil, and regional temperatures. A rise in temperature only would have increased the solubility of silica and decreased the solubility of calcite, providing the partial pressure of CO_2 remained constant. However, as the ground water infiltrated the calcareous soil, the CO_2 would have been depleted by $Ca(HCO_3)_2$ buffering and the pH stabilized around 8.2, a position of very low solubility for silica. Fortunately, the soils of the southern High Plains are rich in illite and montmorillonite (Parry and Reeves 1968); thus higher pH's were probably created by cation exchange which would have also released the silica in the clay-sized fractions.

Under static conditions, soil caliche forms where upper-zone solubles are carried downward and precipitated when soil moisture is removed by evapo-transpiration, some underlying solubles initially rising with capillary water. The caliche remains thin, soft, and incompetent due to depletion of the A-zone solubles, the regional absence of significant moisture or, as suggested by Gile (written communication, 1968), due to insufficient carbonate accumulation. Induration occurs slowly, the speed depending mainly on the amount of available carbonate in the overlying soil, the amount of infiltrating water, the speed of plugging of the profile, and whether the caliche is exposed. If the profile becomes plugged or the top of the caliche is exposed (not necessarily without any soil but with a very thin soil), rapid regional induration and formation of a laminar zone occurs; thus in many areas on the southern High Plains unexposed Pliocene caliche is still chalky and incompetent, but exposed Pleistocene caliche is indurated.

Hawley (personal communication, 1969), from study of the La Mesa caliche in southeastern New Mexico, finds a laminar horizon forming once the caliche becomes plugged, Gile (written communication, 1969) suggesting that "caliche must be within a critical distance of the surface to form a laminar horizon." Blank (written communication, 1968) believes caliche remains soft because of the frequent presence of moisture which contributes to solution rather than to precipitation of the carbonate; however, field evidence suggests that exposure to surficial moisture causes induration. For instance, along the San Pedro River in southeastern Arizona a local incipient laminated caliche has formed, usually beneath only 1–2 feet of soil, only where the greater mass of the overlying surficial debris has been removed by erosion of the river valley (V. Haynes, personal communication, 1969); and in eastern New Mexico soft caliche occurs only where covered by thick eolian and lacustrine deposits. No deeply buried laminated zone has been observed in the studied areas that does not somewhere exhibit evidence of past exposure.

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southern High Plains, the La Mesa of the New Mexico and Chihuahuan Desert, Mexico, or the Reynosa of southeastern Texas, is not possible under static climatic conditions, a fact which is emphasized by definite zonations in the caliches. The only caliche that fails to exhibit evidence of progressive development is incipient.

Desert loess is an important (and probably predominant) source of carbonate for development of most thick caliche profiles, as indicated by the presence of such caliches (or marine carbonate provinces) on the downwind side of the world's major deserts. Studies of carbonate in present eolian dust around Las Cruces, New Mexico, indicate that 16–31 tons of carbonate per surface acre may have fallen during the last 10,000 years, some traps indicating that the amount may actually have been over 3,000 tons per surface acre (Ruhe 1967). However, a thick, permeable, carbonate-rich sand will allow independent formation of a thick caliche if the climatic regimen fluctuates from humid to semiarid and if the sand does not become plugged near the surface.

That thick caliche profiles form under aggrading soil conditions by downward percolation of soil water causing solution, and redeposition is also indicated by presence of carbonate-rich sands under many caliches, radiocarbon dates (Hawley and Gile 1966; Rightmire 1967; Ruhe 1967; Valastro et al. 1968), progressive zonation, increase with age and depth of the thickness of the caliche and the percentage of carbonate (Hawley and Gile 1966; Gile et al. 1966; Ruhe 1967), presence of diagenetic quartz only in the oldest caliche zones and sand lenses separating caliche zones, as well as by computations of possible height of capillary rise related to particle sizes of the soil. Other arguments, in greater detail, are provided by Aristarain (1962).

Classification and process.—Caliche on the southern High Plains, Texas and eastern New Mexico, may be of Pliocene, Pleistocene, or Holocene age, may have formed on eolian, lacustrine, or fluvial sediments of Pliocene, Pleistocene, or Holocene age, and may range in thickness from a few inches to several tens of feet. Studies show that all such profiles have formed as part of a pedogenic process.

Field studies of massive caliche profiles in Mexico, New Mexico, and Texas indicate that all can be classified on the basis of progressive development into young, mature, and old types, the same classification suggested by Price's (1933) study of the Reynosa caliche of southeastern Texas. Considerable overlap may occur, and all types need not be present in any one profile; the parent material, depth and amount of infiltrating surface water, and to some extent chronological age, determine the thickness and zonal development of the profile. Relative age is not necessarily correlative with chronological age, but no old-type caliche of Holocene age was found in the investigated areas.

Formation of caliche begins in thin soils of semiarid regions by evaporation of the intermittent bicarbonate-laden surface and soil moisture, slight dissolution of allogenic quartz, and deposition of carbonate. The resulting caliche is expectantly calcite unless the evaporating solutions are hypersaline (Welte 1962), although Blank and Tynes (1965) "found indications of aragonite in caliche from central Texas under conditions not suggestive of hypersalinity" (H. R. Blank, written communication, 1968).

Young caliche (pl. 1*B*), which more or less resembles the upper part of the Gile et al. (1965) K1 horizon and the Stage I period of formation of Hawley and Gile (1966) and of Gile et al. (1966), is crumbly, may preserve bedding or fissility when invading underlying shales, and exhibits an absence of opal or chert. Color is characteristically white (N9) with enclosed masses of parent material, there being no cementation between the carbonate powder and the residual parent material (pl. 1*B*). Because age influences induration of the top-most caliche by exposure and accumulation of carbonate cement once the underlying zone is plugged, soil caliches which are thin, white, and incompetent are predominantly either caliches

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which have not been exposed or caliches of Holocene age. On the southern High Plains the youngest soils with young caliches are those formed on lacustrine clays less than 4,500 years old.

The youngest caliche in a profile also forms the laminated, "algal," or pisolitic limestone of the southern High Plains (pl. 1*C*), but actual age of formation exceeds 4,500 years in locations studied. This zone is characteristically formed by filling of horizontal and vertical desiccation cracks on top of a nodular plugged profile (pl. 1*C*). Induration results from repeated long exposure coupled with multiple plugging, solution, and redeposition. Thus, caliches that are not plugged and which have not been exposed to surface or infiltrating moisture fail to develop either laminated or pisolitic zones.

Once calcareous powder or young caliche exists, further infiltrating water produces solution and redeposition of carbonate in the form of small nodules separated by incompetent young caliche and blocks or zones of parent material, the whole profile being "honeycombed" if exposed. This (pl. 1*D*), the late youth to early mature stage, corresponds to Stage II of Gile et al. (1966).

The mature caliche profile (Stage III of Hawley and Gile 1966) is characterized by a profusion of nodules, either large or small (pl. 1*D*), cemented by competent carbonate but with sporadic blocks or lenses of parent material. In some areas, horizontal stringers of carbonate (termed "horizontal translocations" by W. Armstrong Price [letter to H. R. Blank 1966]) separate remaining zones of parent material.

Caliche of the late mature stage is characterized by considerable cementation of nodules and an almost complete absence of parent material, the zone corresponding to the plugged horizon of Gile et al. (1966) which forms at the end of Stage III. Any original bedding, structure, or texture is difficult to find, and expansion structures ("pseudoanticlines" or teepee structures) may have formed (pl. 2*A*). Nodules tend to be larger and harder in the upper part of the zone than those in the lower part (pl. 2*B*),

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PLATE 1.—*A*, The Pliocene "caprock" caliche escarpment of central Crosby County, Texas. View to the south. *B*, Young or immature Holocene caliche forming in lacustrine sands in Terry County, Texas. Nodules, where present, are small with most of the caliche being a soft and crumbly calcareous powder. *C*, Plugging of the upper part of the mature zone and exposure of the caliche has produced a young multiple laminated zone. Notice the gradation from loose carbonate nodules at the base of the thin soil (film pack) to the tightly cemented nodules in the underlying laminated horizon. Location Hockley County, Texas. *D*, Exposure of the typical carbonate nodule development characteristic of the lower part of the young and the upper part of the mature caliche zone in sands. Location Hockley County, Texas.

PLATE 2.—*A*, Caliche anticline in the late mature zone of Pliocene caliche, southeastern Lubbock County, Texas. Notice the nodules. This caliche has invaded underlying Ogallala sands. *B*, A young laminated zone formed on the upper part of the nodular mature zone. The pseudobedding is created by formation of horizontal buckle cracks. Notice the increase in nodule size from the lower to the upper part of the mature zone. Location northeastern Hockley County, Texas. *C*, Caliche formed on lacustrine clays of Nebraskan age, Lubbock County, Texas. Notice the pseudobedding inherited from the clays. The caliche is indurated due to exposure.

PLATE 3.—*A*, An injection anticline in early mature caliche formed on interbedded lacustrine clays and sands of Nebraskan age in central Lubbock County, Texas. *B*, Section of young caliche from a surficial multiple laminated zone from Hockley County, Texas. The sequence recorded in this section is: (1) formation of young powdery caliche; (2) solution, redeposition, and formation of nodules; (3) deposition of several thin layers of carbonate around the nodules; (4) exposure causing horizontal and vertical fracturing of the caliche; (5) deposition of vadose silt and carbonate in the fractures and on the undersides of the nodules; and (6) present exposure due to quarrying. *C*, Solution and filling in La Mesa caliche, southern New Mexico. The older void has been filled with sand and caliche fragments, thin caliche lenses developing on top of the fill (pick). A large, younger solution cavity preparing to collapse is to the left. *D*, Section of young caliche from a simple laminated zone formed on top of the complex laminated zone illustrated in 3*B*. Notice evidence of the repeated movement of water along horizontal fractures (buckle cracks).

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cementation starting effectively to plug the profile and allowing formation of the laminated zone at the top of the profile (pl. 2*B*). Lower parts of the profile may exhibit tightly cemented zones of small nodules, the cementing groundmass being either diagenetic quartz or carbonate.

Hawley and Gile (1966) recognized late mature caliche in southeastern New Mexico but did not suggest a separate stage, instead going directly from their Stage III (mature) to Stage IV (old). However, Stage IV caliche was divided into three separate units: an upper laminated, a middle plugged layer, and a lower transitional layer. Field studies indicate that considerable time is needed for development of the three zones; therefore, separate recognition of the late mature period of formation seems justified.

Old caliche, the Stage IV of Hawley and Gile (1966) that is in an advanced stage of development is distinguished by a flinty, siliceous zone at the bottom of the profile. The development of old caliche depends on permeability of the mature zone as well as age. If the mature zone tends to stay permeable, infiltrating waters will finally reach the base of the profile, the downward migration of the water increasing the size of the calcareous nodules in the lower part of the profile (fig. 1*A*). In time, diagenetic quartz in the form of opal or chalcedony will be deposited which plugs the profile, causes the nodules in the upper part of the mature zone to enlarge, and eventually allows formation of the laminated zone at the top of the profile. However, if the mature zone becomes plugged too quickly, no old caliche zone can form at the base of the profile, and there remains a gradational change from large nodules near the surface to the basal transitional zone (fig. 1*B*). Plugging of the upper mature zone allows formation of larger nodules near the surface, the large nodules forming before the laminated zone. Thus, a normal sequential profile of young laminated caliche with underlying mature nodular caliche, which is in turn underlain by old siliceous caliche, results from long, deep infiltration and plugging of the profile from the bottom up (fig. 1*C*).

Although no diagenetic quartz was found

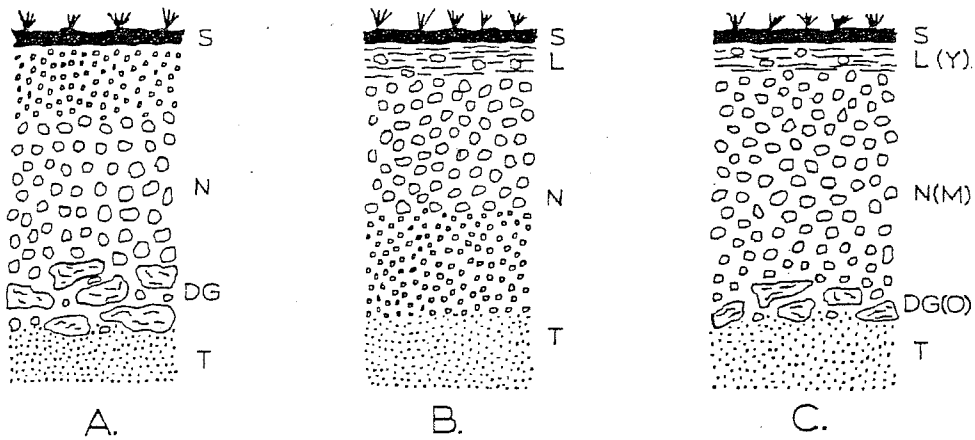

FIG. 1.—Diagramatic cross sections of the three most common massive caliche profiles, southern High Plains, Texas. *A*, The profile developed by plugging of the caliche from the bottom up, but with infiltration still taking place. *B*, The profile developed by plugging in the top of the mature zone, no present infiltration taking place. *C*, The end result of caliche formation in an area where plugging has progressed from the bottom of the profile to the top, no present infiltration taking place. Laminated zone may be simple or complex. *S* = soil, *L* = laminated zone, *N* = nodular zone, *DG* = diagenetic quartz zone, *T* = transition zone, *Y* = young caliche, *M* = mature caliche, *O* = old caliche.

in the upper parts of caliche on the southern High Plains, silica precipitation has occurred in Fresno soil caliches in the San Joaquin valley, California (R. J. Ankley, written communication, 1969). Such occurrences may be due to removal of overlying debris or enrichment by alkaline debris which, at one time, allowed an abnormally high pH in the surficial waters; however, Hawley (written communication, 1969) reports siliceous zones in the southern New Mexico area occurring only in "very complex profiles associated with old geomorphic surfaces."

The lowermost part of a massive caliche profile, the transitional zone, consists mainly of an incompetent to competent mixture of small carbonate nodules or powder and parent material (the K3 horizon of Gile et al. 1965). This zone, which contains the oldest carbonate in the profile, is a remnant of the original C_{ca} soil zone, now deeply buried and preserved from excessive infiltration, resolution, and redeposition by the overlying caliche. Thus, caliche in the transition zone resembles the young type at the top of the profile, although lamination is never present.

Formation of caliche on gravel develops somewhat differently from formation on sands and clays, but this has seldom occurred on the southern High Plains. Investigators interested in this aspect should refer to the excellent discussions by Gile et al. (1966) and Hawley and Gile (1966).

Influence of bedrock.—On the southern High Plains, underlying bedrock associated with caliche formation appreciably affected development of the profile. Fine-bedded lacustrine clays tend to impart bedding to the caliche (pl. 2*C*) and to restrict infiltration; thus bedding, an absence of carbonate nodules, and rapid formation of an upper laminated zone are characteristic of caliche formed on clays or shales (pl. 2*C*). On the other hand, caliche formed on either lacustrine or eolian sands characteristically contains carbonate nodules (pl. 1*D*) after the youthful phase and remains open to infiltration. However, Gile (1961) and Gile et al. (1966) find multiple laminar (K2m) horizons formed in sandy parent material in southern New Mexico.

Formation of caliche on preexisting carbonates has not occurred often on the southern High Plains except in local areas of lacustrine carbonate deposition or where Cretaceous Edwards Limestone is exposed. Other areas where the Edwards is covered by a few feet of soil show evidence of slight carbonate accumulation at the top of the bedrock—the "calichifying" observed by Blank and Tynes (1965) on the Edwards Limestone in central Texas. This process, due to downward leaching or upward movement of carbonate, is also pedogenic.

Structures.—The structures sporadically found in most massive caliche profiles (pl. 2*A*) have been studied by several investigators (Price 1925, 1933; Jennings and Sweeting 1961; Blank and Tynes 1965). Price (1925) thought "pseudoanticlines" formed when "caliche impregnates shale strata and the bedding and joint planes of limestone and sandstone," the anticlines being essentially expansion-contraction phenomena due to "alternate swelling of clays . . . when wet and the contraction when dried in hot sun . . . should produce wavy structures that the flaggy limestones would not resist successfully" (W. Armstrong Price, written communication, 1968). Barnes (1946), working with caliche structures southeast of Junction, Texas, suspected collapse due to removal of the underlying Kirschberg gypsum layer; however, Blank and Tynes (1965), studying the same structures, suggested expansion due to hydration of anhydrite followed by removal of the gypsum, Blank (written communication, 1968) now believing the structures antedate the caliche. Jennings and Sweeting (1961), studying caliche structures in Western Australia, suggested that the structures resulted from arching in limestone due to the caliche formation.

There are undoubtedly several different types of structures found in thick caliche profiles, some formed by expansion or contraction due to various reasons, some formed by solution and settling, some even being

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structures which antedate formation of the caliche. However, large caliche structures are not typical of caliche profiles and represent very local effects, whereas small expansion structures do seem to be typical.

Most small structures I studied formed by expansion of the entire caliche profile due to severe climatic alterations which caused drying, fracturing, buckling, and subsequent filling of resultant voids, much as described for individual boulders by Young (1964). Some of these structures, usually those with the smallest, tightest folds, formed on interbedded lacustrine clay and sand; thus much of the expansion may have been due to a bentonitic content of the clays. A structure caused by injection of underlying, swelling clays (pl. 3*A*) into overlying sands is naturally different from a structure caused by growth of the carbonate zone (pl. 2*A*), the predominant effect of formation and filling of "buckle cracks" being obvious in all expansion structures as a pseudobedding.

The horizontal contraction cracks, or buckle cracks, are caused by the bowing and buckling of beds or lenses of sediment due to water loss. Buckle cracks were first discovered beneath the dry desiccating playas of pluvial Lake Palomas, Chihuahua, Mexico (Reeves 1965), during examination of deep hand-dug water wells but have now been recognized in other playa sediments and in nearly every indurated caliche profile examined. Sizes range from fractions of an inch in height and width in caliche to several inches in height and several feet in length beneath playas; depths range to at least 10 feet beneath the playas. The pseudosheeting commonly found on weathered caliche profiles suggests that the formation of buckle cracks is characteristic of the weathering process on caliche.

The effects of fracturing, infiltration by vadose water, and redeposition in fractures is best illustrated by oriented sawed sections of caliche. Plate 3*B* illustrates the volumetric increase which has occurred in a surficial complex laminated zone. When this occurs on a large scale, the volumetric increase seeks release in expansion structures. However, if this increase occurs along the edges of a canyon, the caliche spalls off by pseudosheeting, and expansion structures may not form.

Other caliche structures may be residual from preexisting rocks, which may be the case for some of those studied by Jennings and Sweeting (1961). Such structures, although not found by me in the investigated area, would probably exhibit continuous, parallel bedding.

Structures due to removal of gypsum (Blank and Tynes 1965) or due to other types of solution and collapse are not numerous in massive caliche profiles. Collapse structures due to solution tend to occur as singular synclines or holes in the caliche lined with dripstone and filled with caliche rubble (pl. 3*C*). In the filled synclines bedding is indistinct within the structure but distinguishable around or over the structure (pl. 3*C*).

Aristarain (1962) suggests that the type of structures that form in caliche is the combined result of the parent sediments, amount of carbonate, the vegetation, the climatic environment, and the time or extent of caliche formation.

GEOLOGIC HISTORY

The Pliocene Ogallala Group of the southern High Plains consists of gravels, silts, and sands, the percentage of silty calcareous sands increasing upward. Studies in New Mexico and West Texas indicate that the end of Pliocene time, and until the first Pleistocene glaciation, was locally marked by semiarid conditions. During this time, interdunal lakes and rivers crossing the Plains dried, and large lakes in the closed valleys of New Mexico experienced desiccation and deflation, the calcareous-rich loess falling across the West Texas area. Penecontemporaneous intermittent moist intervals and normal seasonal variations then formed the first soil caliches on top of the Ogallala.

By the beginning of Nebraskan time the upper part of the Ogallala sands probably contained several feet of young caliche and locally some indurated mature caliche, as

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indicated by caliche gravels in the Nebraskan lacustrine sections. The major pedogenic effect of the first Pleistocene pluvial, and probably of each succeeding pluvial, was the dissolving of carbonate and deep permeation of the bicarbonate-rich water into the Ogallala. On permeation the ground water, by cation exchange with soil clays, experienced a rise in pH which caused deposition of carbonate and solution of silica from the clay fraction. Thus, to generalize, wet periods were times of calcite solution followed at depth by calcite deposition and silica solution. Dry periods were mainly times of loess accumulation and perhaps deposition of silica near the base of the caliche profile.

Originally the base of the caprock caliche was determined by the Nebraskan pluvial, the first extensive period when deep infiltration, solution, and redeposition of carbonate in the upper part of the Ogallala sand occurred; thus the lower parts of the caliche may contain carbonate nodules that have failed to develop past the late youth or early mature stage. In some areas, nodular mature caliche became plugged to infiltrating water after formation of a lower, old flinty caliche zone, but in other areas plugging took place before the old flinty caliche developed. Both occurrences have caused extensive dissolution and redeposition of carbonate by vertically and laterally moving water, resulting in formation of a simple (pl. 3*D*) or multiple (pl. 3*B*) laminated zone over much of the southern High Plains. Simple laminated zones (pl. 3*D*) may form either above the complex laminated zone or above plugged caliche of any age.

Massive caliches in present desert areas, like the well-known dry stream channels and widespread lacustrine features and sediments, are evidence of severe climatic changes even though the present extent of pedocal soils is approximately marked by the 25 inches per year rainfall line. Once a massive caliche forms it is difficult to destroy by only infiltrating ground water because of the protection provided by soil and vegetation, underlying impermeable strata, and plugged horizons, the Reynosa caliche of southeastern Texas being a good case in point. If the caliche also has a laminated horizon and occurs in an area of little relief, permanency is further assured.

CONCLUSIONS

Massive caliches form on thick calcareous-rich sands or on aggrading surfaces of desert loess in geographic areas subjected to geologically short-lived climatic reversals. Because of progressive development with age due to exposure, dissolution, and redeposition of both carbonate and silica, young, mature, and old types of caliche can be recognized.

Radiocarbon dates, calculations of possible capillary rise of ground water, geographic locations, and the thickness and percentage of carbonate increasing with age and depth (at least through the mature zone) illustrate that the formation of thick caliche profiles like the caprock of the southern High Plains is the result of an aggradational, pedogenic process utilizing downward and laterally moving ground water.

Small caliche structures are formed by expansion due to crystal growth and exposure which forms horizontal and vertical desiccation cracks, the horizontal type being termed "buckle cracks." Subsequent filling of the desiccation cracks by vadose silt, clay, and sand prevents collapse and insures the permanent increase in profile volume. Structures produced by this method are true expansion structures and exhibit nonparallel bedding. Structures formed by solution and collapse, or by the injection and swelling of bentonitic lacustrine clays, also occur, the injection-type structures tending to be the largest type. In some areas residual structures in the caliche may exist, particularly where the profile represents preexisting carbonates.

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TEXAS WATER DEVELOPMENT BOARD
AUSTIN, TEXAS

14 013

~~32 016~~

Reference 15

Midland (city), Texas

People QuickFacts	Midland	Texas
Population, 2006 estimate	102,073	23,507,783
Population, percent change, April 1, 2000 to July 1, 2006	6.9%	12.7%
Population, 2000	94,996	20,851,820
Persons under 5 years old, percent, 2000	7.5%	7.8%
Persons under 18 years old, percent, 2000	29.9%	28.2%
Persons 65 years old and over, percent, 2000	12.3%	9.9%
Female persons, percent, 2000	52.0%	50.4%
White persons, percent, 2000 (a)	75.5%	71.0%
Black persons, percent, 2000 (a)	8.4%	11.5%
American Indian and Alaska Native persons, percent, 2000 (a)	0.6%	0.6%
Asian persons, percent, 2000 (a)	1.0%	2.7%
Native Hawaiian and Other Pacific Islander, percent, 2000 (a)	Z	0.1%
Persons reporting two or more races, percent, 2000	2.0%	2.5%
Persons of Hispanic or Latino origin, percent, 2000 (b)	29.0%	32.0%
Living in same house in 1995 and 2000, pct 5 yrs old & over	52.9%	49.6%
Foreign born persons, percent, 2000	7.5%	13.9%
Language other than English spoken at home, pct age 5+, 2000	25.4%	31.2%
High school graduates, percent of persons age 25+, 2000	80.6%	75.7%
Bachelor's degree or higher, pct of persons age 25+, 2000	27.2%	23.2%
Mean travel time to work (minutes), workers age 16+, 2000	17.2	25.4
Housing units, 2000	39,855	8,157,575
Homeownership rate, 2000	66.1%	63.8%
Median value of owner-occupied housing units, 2000	$72,500	$82,500
Households, 2000	35,674	7,393,354
Persons per household, 2000	2.62	2.74
Median household income, 1999	$39,320	$39,927
Per capita money income, 1999	$20,884	$19,617
Persons below poverty, percent, 1999	12.9%	15.4%

Business QuickFacts	Midland	Texas
Wholesale trade sales, 2002 ($1000)	709,393	397,405,111
Retail sales, 2002 ($1000)	1,219,093	228,694,755
Retail sales per capita, 2002	$12,709	$10,528
Accommodation and foodservices sales, 2002 ($1000)	164,121	29,914,774
Total number of firms, 2002	12,851	1,734,509
Black-owned firms, percent, 2002	2.0%	5.1%

American Indian and Alaska Native owned firms, percent, 2002	S	0.9%
Asian-owned firms, percent, 2002	2.2%	4.5%
Hispanic-owned firms, percent, 2002	13.5%	18.4%
Native Hawaiian and Other Pacific Islander owned firms, percent, 2002	F	0.1%
Women-owned firms, percent, 2002	23.5%	27.0%

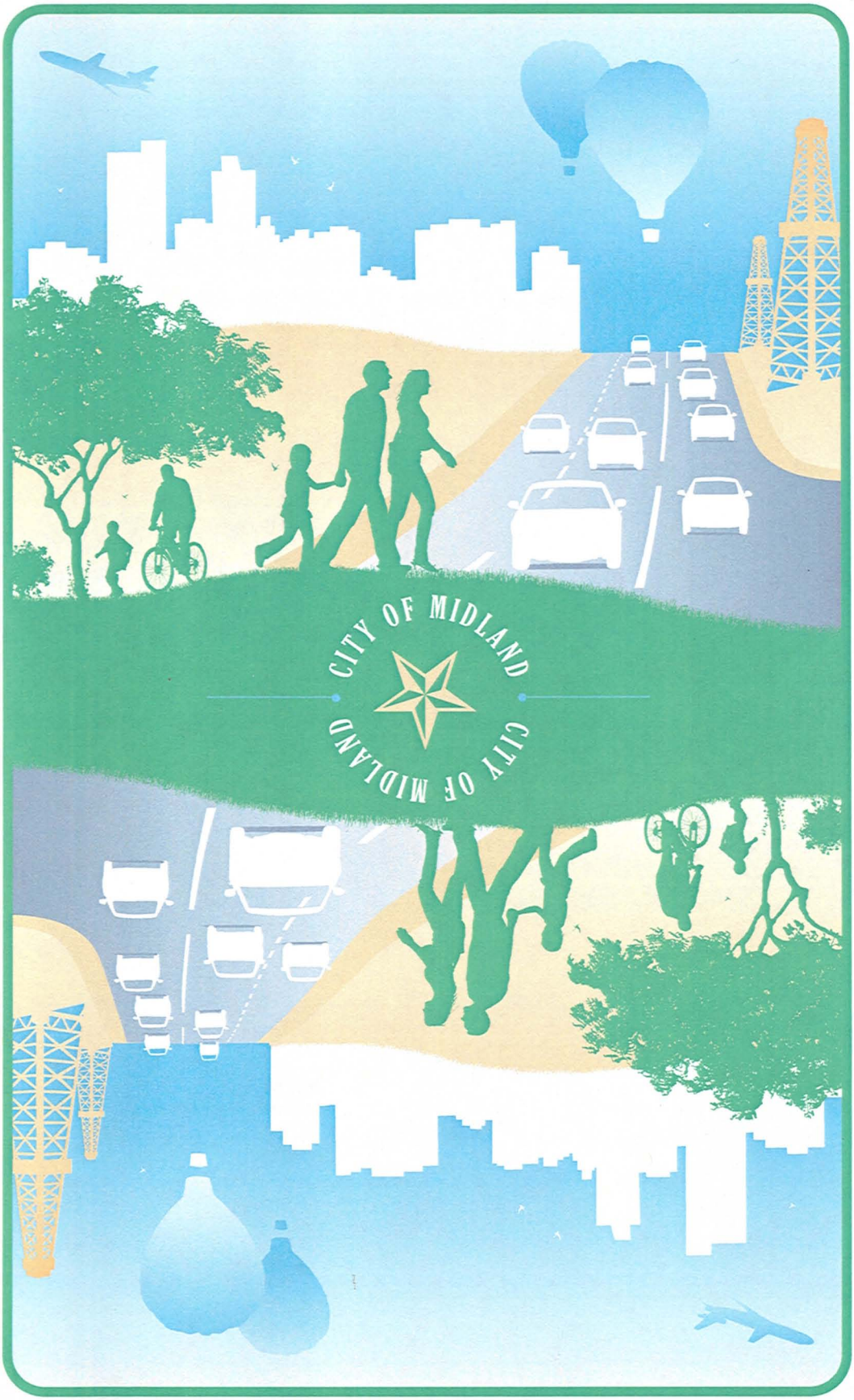
Geography QuickFacts	Midland	Texas
Land area, 2000 (square miles)	66	261,797
Persons per square mile, 2000	1,426.2	79.6
FIPS Code	48072	48
Counties		

(a) Includes persons reporting only one race.
(b) Hispanics may be of any race, so also are included in applicable race categories.

D: Suppressed to avoid disclosure of confidential information
F: Fewer than 100 firms
FN: Footnote on this item for this area in place of data
NA: Not available
S: Suppressed; does not meet publication standards
X: Not applicable
Z: Value greater than zero but less than half unit of measure shown

Source U.S. Census Bureau: State and County QuickFacts. Data derived from Population Estimates, 2000 Census of Population and Housing, 1990 Census of Population and Housing, Small Area Income and Poverty Estimates, County Business Patterns, 2002 Economic Census, Minority- and Women-Owned Business, Building Permits, Consolidated Federal Funds Report, Census of Governments
Last Revised: Tuesday, 05-May-2009 08:36:51 EDT

2008 ANNUAL REPORT MIDLAND



2008 ANNUAL REPORT MIDLAND

150003

Midland: A Winning Hand

A Bright Future is in the Cards...

What a great time to live in Midland! Our city was dealt a winning hand in 2008 and we are moving forward with our good fortune. Midland's economy reached record strength. Sales tax revenues are at all-time highs, and our unemployment remains the lowest in the state, all while new businesses are opening their doors.

Our challenge now is to withstand the highs, as well as the lows, of our oil and gas based economy. The City of Midland is doing its part by reducing the tax rate to its lowest in 20 years and by managing the City's finances with foresight and discipline. The City continues to work in partnership with the Midland Development Corporation to diversify the economy, recruiting and retaining an adequate workforce, and developing Downtown Midland into a vibrant place to not only do business, but to enjoy activities and entertainment after hours.

While Midland's winning streak continues, leaders have not lost sight of providing high-quality basic services in a cost effective manner. Along with Economic Development, the Midland City Council's top priorities also include Infrastructure and Housing. Whether it is developing water and sewer service in newly annexed gateways to the city, reconstructing Midland's arterial roadways, or implementing a plan to pave all neighborhood streets, we are focused on what is important to residents and business owners.

While 2008 was one of the most exciting and robust times for our economy, you can bet Midland is planning a royal flush for the future.

Back Row L to R:
Michael Trost, District Four;
John James, District Three;
Courtney Sharp, City Manager;
Scott Dufford, At-Large;
Jerry Morales, At-Large

Front Row L to R:
LuAnn Morgan, District One;
Wes Perry, Mayor;
Vicky Hailey, District Two

150004

Infrastructure

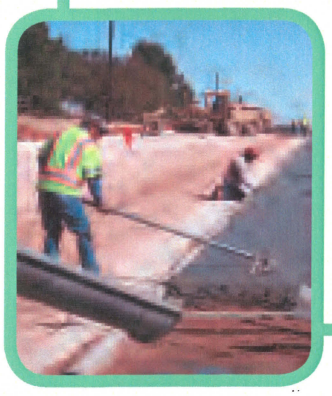
It's in the Cards...

The stakes are raised as the Midland City Council has targeted Infrastructure as a top priority. Managing the community's steady growth and development includes turning an eye toward the essentials of building our future.

In 2008, the green light was given to a plan aimed at paving a total of 66 unpaved streets. The 14-year program will pave one mile of unpaved residential streets each year. In an effort to explain the street paving process, a five-minute video was produced which airs on the City's cable access station and the City's website.

A smoother commute is on the way for Midland motorists. Installation of the City's new Automated Transportation Management System (ATMS) is scheduled for completion in early 2009. The two-way communication system allows for signal lights to be timed for traffic flow and peak hours and workers to modify or make adjustments from a central location.

There are several projects in the works designed to update city facilities. In the heart of downtown, Centennial Plaza is a strategic urban space located in the center of Midland's high-rise downtown community and offers unique outdoor space for urban dwellers. It is located adjacent to the Midland Center. Fueled by an Economic Development Initiative grant, renovations will allow the Plaza to have a more open appearance. The Martin Luther King, Jr. Community Center is approved for upgrades to its gyms and meeting areas and Municipal Court renovations or relocation are being considered.



Focus is also being given to preparing Northwest Midland, and gateways into the city, for future growth by supporting the areas with the necessary infrastructure to spur development.

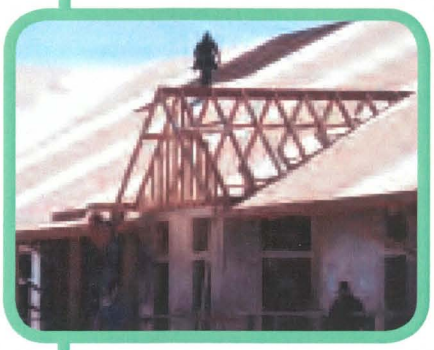
Housing

Winning with a Full House...

Increased property values, more single-family housing communities, coupled with new multi-family developments–Midland continues to win with a full house.

Midland's population, 104,765, is experiencing healthy growth at 2% over last year. At the same time, in 2008, the City of Midland issued 482 residential construction permits. This is an increase of 182% over the past five years.

Good economic times have increased the need for housing in Midland, and not just housing, but affordable housing. The City dealt a hand that developers could not resist by initiating a program offering rebates to builders who are willing to construct quality affordable housing in the $80,000 - $160,000 range. With the help of community partners, the City is also encouraging rehabilitation projects of existing homes to help meet the needs of the community.



In addition, Midland welcomed three new apartment complexes, collectively offering 600 units. One more apartment complex is under construction and will offer another 200 plus units. City leaders are also recognizing the need for condominium style living in downtown as well as the rest of the city.

Midland is now playing with a full deck when it comes to recruiting events and tourists. Three hotels opened their doors in 2008, with four other hotel projects permitted and construction planned for 2009.

Economic Development

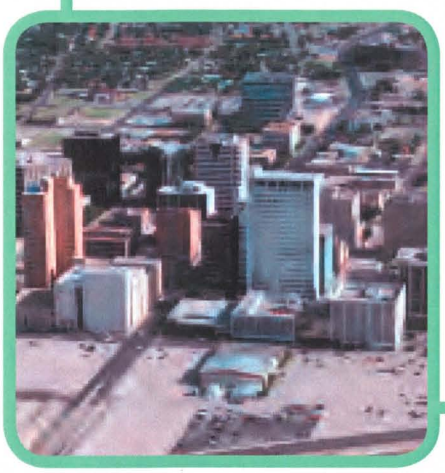
Upping the Ante...

In 2008, Midland saw continued confidence in the oil and gas industry. Crude hit $140 a barrel, sales tax revenues climbed to an all-time-high, and Midland boasted the lowest unemployment rate in the state. As a result, the City of Midland is placing priority on upping the ante for continued economic infrastructure and development.

Today's strong and robust economy has diversification at the heart of Midland's mission. With an economy based in oil and gas, bringing new industry to Midland is the focus.

Downtown is prepared for new industry as revitalization moves forward. In 2008, a number of unoccupied, unusable, office buildings were demolished, including an implosion of the old Midland Savings Building. Hundreds of Midlanders gathered to celebrate as downtown moved into the future. Several other projects are planned for 2009, making way for much needed parking structures, downtown living, green space, and new development. A new website, www.livemidlandtexas.com, was launched representing what is LIVE in downtown Midland, Texas–including a 24-hour live camera.

The City of Midland tops the list of Best Cities to Do Business. Inc.com's 2008 list ranks Midland as #1 in overall cities as well as #1 in the small cities category. The rating takes into consideration recent growth trends, employment data, educational and health services, retail and wholesale trade, transportation, utilities, leisure, hospitality, and government.

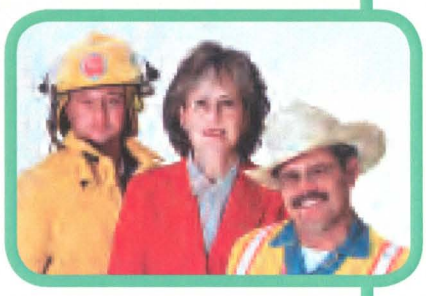


The Milken Institute ranked Midland as number one for best performing small cities in 2008 because of the City's rapid job and salary growth.

Meanwhile, realizing its place at the table, Midland International Airport developed an aggressive plan to retain and recruit air carriers, particularly those traveling to the west.

Funding

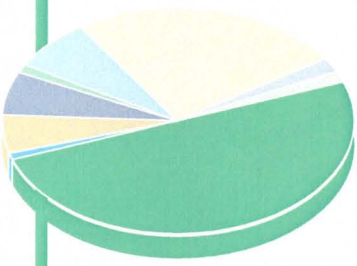
Reaching for the Jackpot...



It was a record breaking year for Midland's economy. During these healthy times, leaders have not lost sight of their dedication to providing efficient, quality services now and into the future. This vision is realized with the implementation of the strategies accomplished through fiscally responsible policies in budgeting revenues and expenditures.

Review of all revenue sources includes conducting a comparative fee schedule to examine all General and Enterprise Fund fees. The review will measure what Midland charges for services as compared to other cities and entities. The study was approved in 2008 with results and recommendations implemented during the 2009-2010 Budget process.

2009 BUDGETED REVENUES - $159,443,585



General
Golf Course
Sanitation
Airport
Sports Complex
Garage
Water & Sewer
Hotel/Motel
Interest & Sinking

2009 BUDGETED EXPENSES - $167,374,477

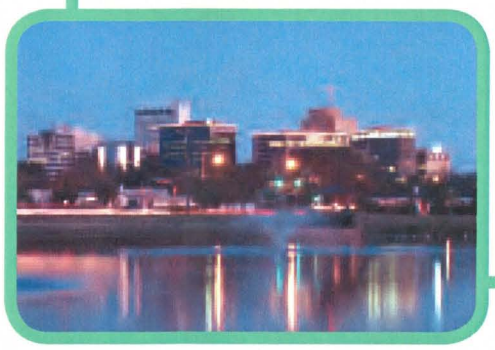
The City's employees are its most important resource. Recognizing this, the City Council approved a salary market adjustment for all employees. The move helps the City remain competitive in tight labor market. Secured state and federal grants are helping to provide needed equipment for both fire and police.

Midland's economic outlook is good. Sales tax revenues for FY2008 increased 13%, or nearly $3,000,000. Midland has reported increased sales tax revenues for more than 60 consecutive months. Property valuations continue to increase, allowing for the actual property tax rate to decrease by 4.51 cents per $100 valuation, an 8.4% reduction in the actual rate. Midland's population has been growing steadily with the number of utility connections and annexations creating revenues to help meet the demands of a growing city.

Quick Facts

Population:	104,765 (est. 2008)
Area:	Square Miles 68.98
Location:	West Texas–Midway between Dallas/Fort Worth and El Paso along Interstate 20
Weather:	March/71°; June/93° September/86°; December/58°
City Property Tax Rate:	48.59/per $100 valuation
Average Price of a Home:	$171,500
Median Age:	Male - 32.6 Female - 36.1
Median Household Income:	$46,976
Ethnicity Percent:*	White - 75.1% Hispanic - 34.2% Black - 6.7% Asian/Pacific Islander - 1.0%
Transportation:	3 Major Airlines Interstate 20 State Highway 349 East/West Rail Line – Union Pacific Mass Transit Bus System
Top Five Employers:	Basic Energy Services (4,915) Midland Independent School District (2,887) Warren Equipment Companies (2,023) Midland Memorial Hospital (1,645) Endeavor (1,500)

*These figures add up to more than 100% on this list because Hispanic and Latino Americans are distributed among all the races and are also listed as an ethnicity category, resulting in a double count.



Reference 16

WCR112 TCEQ-SSDAP SAMPLING FIELD NOTEBOOK #2

5/4/2009

5:30A : left house for Austin Airport

6:10A : arrived at AUS

7:10A : boarded plane to DALLAS

: boarded plane to Midland

11:45A H&S Meeting w/ Kelly Peavler, D. Soule, T. Elliot, and Jason ~~Sullivan~~ Brooks

Dan Soule 5/4/09

5/4 at Noon

2
GW-30 - 2804 S. CR ~~119~~ ~~112~~
1200

- extended E GW sample.
- Ms. Young signed AA onsite

31.962089 N, 102.089024 W

Time	Temp	pH	Cond	Comments
1210	22.4	7.43	2.98	Clear
~~1225~~	~~22.6~~	~~7.08~~	~~2.99~~	~~clear~~
1225	23.2	7.10	3.01	
1230	22.6	7.08	2.99	
	22.5	7.20	3.00	

* W facing photo of well shed

- Ms. Young stated that no one drinks the H_2O, but bathes & cooks w/ the H_2O.

- No children, but one puppy

[signature] 5/4/09

5/4 at 1:00 PM - 2705 W CR115

GW-31 - extended S GW Sampling

- CARMEN MENDEZ Signed AA onsite
- E facing photo of well pump
- 31.958896N, 102.094316 W
- No one drinks, cooks, or bathes w/ H_2O
- Children onsite

TIME	Temp	PH	Cond.	Comments
1305	26	7.29	3.21	Clear
1320	23.6	7.39	3.21	Clear
1325	23.0	7.80	3.22	Clear
1330	22.9	7.62	3.22	Clear
1335	22.6	7.58	3.23	Clear

- no faucet on well, so sampled from ~~closet~~ closes faucet on the front of the trailer
- photo #3 S facing of the faucet where gw sample was collected

Sample collected at 1:35 pm

Samuel Soto 5/4

5/4 (1) 2700 WCR114 (2) 2:03 PM

GW-17 - Spoke w/ Ms. Beauchamp & her daughter.

31.962200°N, 102.09445°W

West facing photo of well pump where GW-1 was collected.

* stated that they noticed that the water turned yellow when the filled their sm. pool last summer

Time	Temp	pH	Cond.	Comments
14.05	24.0	7.58	2.27	Clear
14.20	24.1	7.70	~~2.28~~ 2.22	
14.25	23.8	7.77	2.28	
14.30	23.8	7.72	2.26	

5/4/2009

* GW-26 - 5/4/2009 @ 2:35 pm
31.962415 N, 102.094724 W

* GW-26 was collected ~~x~~ after the tank, since there was no faucet at the pump.

* W ~~E~~ facing shot of the faucet where GW-26 was collected

* ~~n/a~~ made sure we drained tank before we collected - 10 gallons / minute

Time	Temp	pH	Cond.	Comments
14:40	22.6	7.60	2.36	Clear
1465	21.5	7.72	2.42	clear
1500	21.4	7.89	2.45	Clear
1505	21.4	7.85	2.46	

Sample collected at 15:05

Dani Scott 5/4/09

5/4/2009 - 3:32 PM
GW-24

Mentioned NE near Cotton Patch, there use to be an old dump ground where everyone dumped stuff.

31.962211 N , 102.094982 W

North facing photo of the faucet where gw-24 was collected.

No faucet from well pump - GW sample collected from ~~closet~~ nearest faucet, located outside of ~~the~~ well shed

(3) 55-gallon metal drums on back yard one was labeled INC 2708, UN 1933
In addition, (2) plastic 55-gallon drum
~~unlabeled~~ INC-1842

TIME	Temp	pH	Cond.	Observ.
1530	23.6	7.45	2.39	Clear
1554	23.2	7.48	2.39	Clear
1550	22.3	7.31	2.43	Clear
1555	22.5	7.51	2.45	

3:56 PM - Collect Sample

5/4/09

5/4/2009 - W CR 114 (2718)
GW-15
Dup GW-25

Daughter Boat
Cell phone - 661-9468
Trisha (grandd) 425-6543

(2) homes are connected/use the well located Jose Uranga's home at 2718 W CR 114 - Sm. Child (~3-4) lives at the sm. home - Mr. Uranga's Great Grandma/pa.

31.962136°N, 102.095432°W

No faucet in well house, so used the nearest faucet found on the E side of the well house for GW15/25

TIME	Temp	pH	Cond.	Comments
1605	24.2	7.71	2.32	Clear
1620	22.7	7.92	2.30	↓
1625	22.6	7.80	2.31	
1630	22.3	7.71	2.30	

Has a water softener, but no longer in use. 2 equip. still inside ~~the~~ well house. - Sample collected at

Dani Soule 5/4/09

5/4/2009 - 4:41 -
finished sampling
SHAW ~~collect~~ - dropping off
GW samples to lab before
5:30 PM.

LAB aprox. ~20 minutes
from site.

5/4/2009

5/4/2009
5:15 pm –

Meet up w/ the Awbrey's while Culligan was installing their filtration system.

Stated that a chemical spill occur in the late 90's ~~accros~~ N of Interstate 20. They stated that DOW was RP, but now they are called BJ electric (687. 3467).

geneva St. at Williams Paving DAS 5/10/09

Also, a lot of illegal dumping ~~occured~~ occurs at the end of CR 10 – Sees petroplex going by the area

~~Also, pipeline in back~~

Francis and Cotton Flat where settlement ~~occured for chem spill~~

Pipelines – in yard

* States all animals died of cancer

* Mr Ambrey - has skin cancer
* Mrs Ambrey - has breast cancer

* Sewer line was installed in the middle of CR110 that comes from the airport

Sam Ortle
5/4/09

~~7~~ 6pm on 5/4/09

- Spoke w/ Mr. Bowen about his filtration system. Not having any problems

---

~~7pm~~ ~~7~~ 6:05pm on 5/4/2009

- Spoke w/ Ms. Brock & Mrs. Moffit at 2700 WCR 112. Miss Moffit was not having difficulties w/ her filtration systems. Ms. Brock stated that her P in her house was much better since Culligan changed the filter (blue). She did not ~~not~~ mention anything about the amine smell.

6:20 - 5/4/2009

Laing's home at 2604 WCR 112 said their filtration system was doing fine - no problems. However asked about filling pool.

We requested that they wait ~~till~~ to fill the pool till we had offical word. Told we would get back to them ~~on~~ sometime next week.

6:25 PM - 5/4/09
2514 WCR 112 - Mrs. Acosta

Very happy and pleased w/ her filtration system. leaves her skin very soft & smooth.

Belives that her water still is a little yellow. The water looked milky, but not yellow. Also stated that her H2O can leave a little film

Stated 1-2 yrs ago near mustang motors a Rd was closed down b/c of a chemical spill which caught on fire.

Worried about her mom on 3415 SCR 1210 - Hope Barbosa - told her she's outside the 1/4 mile, but if we expand we wond let her know

Finally - wanted us to vont a paint shop on Cotton flat b/c they just dispose of paint in the yard

Dan Sand
5/4/69

54
5/5/2009
8:00AM - Meet SHAW at CR 114
8:06 AM - HSS Meeting
conducted by T. Elliot SHAW
- K. Peavler, D. Soule, B.
8:10AM - Calibrate HANNA Combo

8:28 AM - 5/5/2009 - GW-09
Mr. Howards Well house was locked, but told us that the closest faucet to the well was on the east side of the well house.

31.961814°N, 102.094209°W
E facing photo of the faucet on the side of the well house

- Stated that the well is 75 feet deep.
- Stated that their was too much brine in the water.

- had been running well 1 hour prior to sample collection.

TIME	Temp.	pH	Cond.	Comments
8:30	20.8	6.95	2.22	clear
8:45	21.4	6.86	2.22	" "
8:50	21.4	6.87	2.22	" "
8:55	21.7	6.89	2.18	" "

Collected the sample at 8:56
Dan Soule 5/5/09

9:04 AM - GW-03

- Collected GW sample from nearest faucet located on the N side of the well house.
- Has a small child living in the home.
- 31.962029°N, 102.093587°W
- South facing photo faucet where GW-03 was collected

9:30 A - Collected GW-03

TIME	TEMP.	pH	Cond.	Comments
9:05	21.4	7.04	2.20	Clear
9:20	23.3	7.23	2.26	" "
9:25	23.0	7.3	2.26	" "
9:30	22.9	7.38	2.24	" "

Dan Sonte 5/5/09

Danielle Smith

5/5/09

:40A-GW-18 located at 2606 WCR 114

- Collected GW-18 from W side faucet of the well house closes faucet to the tank. We were not allowed to access the well pump.
- 31.962683° N, 102.093922° W
- W. facing phot of the faucet where gw-18 was collected
- Collected ~~at~~ gw-18 at 10:05

TIME	TEMP	PH	Cond.	Comments
940	23.1	7.42	2.35	Clear
955	22.0	7.67	2.37	↓
1000	22.0	7.70	2.39	
1005	22.3	7.60	2.38	

Danielle Sinclair 5/5/09

10:08 - 5.5.09 - GW-29
~~2606~~ WCR ~~112~~ 114
2609

- Collecting GW-29 sample from east side of well house faucet. The ~~only~~ closes faucet ~~from~~ to the well.

~~31.961288~~ 31.961203°N,
102.093544°W

- ~~E~~ W facing photo of the faucet where GW-29 was collected.

TIME	TEMP	pH	Cond.	Comments
10:10	22.1	7.43	2.19	Clear
10:25	23.4	7.53	2.18	Clear
10:30	23.0	7.62	2.17	Clear
10:35	23.1	7.57	2.18	Clear

Collected the sample at 10:37 AM

Danielle Sonte 5/5/09

~~10:43AM~~
~~5/5/09 — GW-3 -~~ 5/5/09

10:45 - 3001 S CR - 1205 → GW-33

* Got AA from Mrs. Rebbeca Rodrigez
  Also, got ~~an~~ a water well survey.

* 3 people are drinking the H_2O

* Collected GW-33 from faucet off the well pump

* Also stated that she had an old well that was "full of chemicals", so they drilled a new well in the early 80's.

- 31.960190°N, 102.094960°W

- SE photo of well pump & faucet where GW-33 was collected

TIME	TEMP	pH	Cond	Comments
1100	28.2	7.50	2.68	clear
1115	23.3	7.47	2.63	" "
1120	22.9	7.57	2.58	"clear"
1125	22.9	~~6.5~~ 7.54	2.59	clear

Collected gw-33 11:27

Danielle Sonle 5/5/09

20

5/5/2009

11:33 Am - SHAW left site to drop the (5) five gw samples off to the lab.

Danielle Sorle 5/5/0

12:45 PM - 5/5/09 - 2719 W CR 114

- collect GW-32 from E side of the well house

- Really hard to manuver b/c alot of objects throughout the entire property.

- 1954 - deeper than 80 ft

- 31.961439 °N, 102.095175 °W

- East facing photo of the faucet where gw-32 was collected. Can not get much access into well shed.

TIME	TEMP	pH	Cond.	Comments
1305	23.5	7.55	2.32	Clear
1320	24.4	7.45	2.36	" "
1325	23.4	7.54	2.28	" "
1330	23.4	7.60	2.34	" "

1332 - GW-32 was collected

- obtain an AA & WWS from Mrs. Alsup.

[signature] 5/5/09

22
5/5/09
1:50 PM
GW-08/GW-27

14:12 - GW-8 collected
14:27 - GW-27 collected

*GW-08 collecting GW sample after pressure tank using the closes faucet ~~on the~~ to the well.

31.962597°N, 102.091162°W

* South facing photo of the faucet where GW-08/27 ~~was~~ was collected

* GW-27 is the Dup.

TIME	Temp	pH	Cond.	Comments
1350	27.7	7.72	2.00	clear
	26.7	7.20	1.95	clear

I had issues w/ purging the well since the well was set on a timer that would run only every 10 minutes ~~thus~~ and run for 3 three minutes - thus we had the conclusion that the pump had been running thus we only needed to purge the well only 5 minutes prior to parameters. We let well purge for a total of ~15 minutes

1420 - GW-07 - 2500 WCR 114 -

West facing photograph of sample port where GW-07 was collected.

- 31.963048° N, 102.093158° W

- The GW sample was collected at an open end pcv pipe coming from the well head.

TIME	TEMP	pH	Cond	Comments
1420	25.6	7.24	1.86	Slightly yellow
1435	26.7	7.32	1.97	yellow color
1440	25.5	7.36	2.00	" "
1445	25.0	7.44	1.97	" "

Sample collected at 2:48pm

Dan Soule 5/5/09

5.5.09 - GW-06 - 2602 W CR 114
2:50 PM

* GW-06 Sample was collected from a faucet that came after the pressure tank

31.963252 N, 102.093201 W

* North facing photo of the faucet were GW-06 was collected.

TIME	TEMP	PH	Cond.	Comments
1450	27.3	7.74	2.24	Slightly Yellow
1505	25.5	7.76	2.22	" "
1510	24.7	7.78	2.22	" "
1515	24.9	7.86	2.21	" "

GW-06 was collected at 3:17 pm

Kendall Smith 5/5/09

3:28 PM - GW-22 - 2714 W CR 114

- Mr. M was not present. On the phone he stated that he had 2 wells on his property that T together.

When we arrived, we could not find a ~~[illegible]~~ faucet that would allows us to collect a gw sample before it went into a 2,500 gallon holding tank. Thus we ran the water for ten minutes and then collected the sample.

- 31 57 44.8
102 05 25.9

TIME	TEMP	PH	Cond	Comments
1530	28.2	8.31	1.57	Clear
1540	26.7	8.30	1.54	" "

1542 - GW-22 was collected at the top of the 2,500 gallon tank.

[illegible] 5/3/09

-GW-34 -Dup

*
3:50PM-5/5/09-GW-12 -2414 WCR114

*31.963284°N, 102.090870°W

*North facing photograph of Jason collecting gw-12

Mrs. Crouch stated that she had 2 wells that tied together and empty into a 2000 gallon tank. We were unable to find a faucet or entry point for either well, except ~~when~~ after they T together and empty into the container.

Time	Temp	pH	Cond	Comments
16:10	25.6	7.82	1.99	Clear
16:15	25.2	7.88	2.06	" "
16:20	25.2	7.91	2.06	" "
16:25	25.4	7.82	2.05	" "
16:30				
16:35				

~~Samples collected at~~ 16:25 GW-12
~~16:45 GW-34~~

Samples (GW-12 & 34) collected @

5/5/09

4:42 pm - 5/5/2009 - SHAW left site to take samples to XenXo lab

4:48 pm - 5/5/2009
Spoke w Michael Stephens about sampling the water well at Cotton Flat Grocery (2) 8AM.

5:00 pm - 5/5/2009 Mr. Bostwick

* stated filter system was fine - stated that they had a small leak, but Mulligan did fix the problem, yesterday

* stated a pit on Medlin is used as a dumping ground.

5:20 pm - Mr Johnson -
rang doorbell, but no answer

5:33 pm - Spoke w/ Mr. Clinton about his filtration system

* electric company nearby and believes that transductors on the corner on cotton flat and industrial.

* francis St - chemical company
~~millian drive an~~

* Ben Smart Chemicals

* Intergas

5:45 PM - MR ~~[illegible]~~ Rockwell
~~Stated that they sent~~

* Mixed up letters - stated he called Mrs. Christine hamitt - HB30BC

5/6/2009

8:20AM - GW-35 - Supplies water to both CR114 (2409) & 2802 SCR1200

Gerald Stephens
PO Box 2612
Midland TX 79702 → Address for 2802 SCR1200

* Sample collected at the bottom of a 3000 tank at the elbow joint at 837AM.

* 31.962930° N, 102.090218° W

* GW-35 is a combiened gw sample that supplies gw from two wells that together. Water from both wells gose to a 3000 gallon tank. Water enters the tank at the bottom of the tank.

[signature] 5/6/2009

5/6/09 @ 9:05 AM
GW-36 - 2802 S CR 1200

* This property is owned by M. Stephens. It is an paint and body shop called Johnnie's Paint & Body Shop 683-5485

* There was no faucet at the well, thus we took the sample from the ~~closets~~ faucet. Closes

* West facing photo of the faucet where gw-36 was collected.

* 31.962870 N
102.088995 W

TIME	Temp	pH	Cond.	Comments
9:05	21.7	9.11	2.76	Clear
9:20	21.4	9.07	2.95	Clear
9:25	21.2	9.34	2.94	Clear
9:30	21.2	~~2.93~~ 9.53	2.93	Clear

931 collected Sample

Danielle Sonk 5/6/09

9:46 - 5/6/2009
GW-21
2604 S CR 1200

- stop drinking H_2O 1984 or 1985.
- Well is drilled to 82 ft, which is cased all the way down
- collected gw-21 ~~for~~ from faucet on the well head
- stated that he has never had a problem w/ the water. Stated that there was an As scared a long time ago, but South of CR 114 around the old dairy.

TIME	Temp	pH	Cond.	Comments
9:45	21.6	9.86	1.72	clear
10:00	21.6	9.90	1.70	"clear"
10:05	21.6	9.95	1.70	"clear"
10:10	21.5	9.94	1.70	a little sandy

- Had H_2O water in the 90's, but everything was good.
- Collected the sample at 10:08 am.

Danielle Smith 5/6/2009

9:46 - 5/6/2009
GW-21
2604 S CR 1200
- stop drinking H_2O 1984 or 1985.

- Well ... s
cased a...

Dups for CR112

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or...

- stal... ...d a
probl... ...at
there... ...time
ago, ...und
+...

No Pic
OR Coord

TIME	Tem...
9:45	21.6
10:00	21.6
10:05	21.6
10:10	21.5

...ts

...dy

- Had... ...t
ever...

- Collected the ... 3 AM.

Danielle Sinke 5/6/2009

32 5/6/2009

10:22A - GW-14
2524 Cotton Flat Rd.

* 31.965623°N, 102.090240°W
* E. facing photo of the faucet where gw-14 was collected.
* the sample was collected from the closets gw faucet of the well head.
* No one drinks the water
* 2524 - is an auto body/ repair shop.

Time	Temp	pH	Cond.	Comments
10:20	21.4	9.51	2.58	Clear
10:35	21.0	9.65	2.59	" "
10:40	22.0	9.70	2.58	" "
10:45	22.0	9.77	2.56	" "

10:46 - took gw sample from faucet.

Dani Sauls 5/6/09

10:59 – 5/6/2009
GW-19
2716 Cotton Flat ~~Dri~~ Road.
- Well was broken in the front of 2716 Cotton Flat Rd, ~~no w~~ Water was not connected to any faucets or going unto the building b/c well was broken. This is the well they plan on connecting to the building
-

- There is a second well but they removed the pump. It is a shallow well, too. Will need a bailer

- 31.963391°N, 102.089425°W

- We collected the sample from the broken well w/out purging the well! The PVC pipe ~~wt~~ was broken –

11AM – GW-19 was collected.

SW- photo of the well covered.

Danielle Sorel 5/6/09

34 5/6/09 *Thinks that the county tested his well awhile back

11:16A - GW-13 / GW-28 (Dup)
2604 W CR 115

- stated that ~~the~~ he has two wells that are tied together, however, for both wells can not be ~~accessed~~ gw sampled till after the water enters the water tank.

- has not drank the water ~~till~~ since the 1990's

- 31.959851°N, 102.093415°W

- NE photograph of the faucet where gw/13 & 28 were collected.

TIME	Temp	pH	Cond.	Comm.
11:20	25.6	9.73	2.04	clear
11:35	23.0	9.68	2.63	Clear
11:40	23.1	9.67	2.70	clear
11:45	23.2	9.70	2.59	Clear

5/6/09

2pm - 5/6/2009
GW-16
~~2900~~
2901 W CR 114

* GW-16 was collected from a faucet nearest to the well pump. The sample could not be sampled before the well tank, thus we purged the well.

* 31.961128° N, 102.096741° W

* W facing photo. of the faucet where GW-16 was collected.

Time	Temp	PH	Cond.	Comments
1410	46.4	9.68	2.36	Clear
1425	25.0	9.97	2.21	" "
1430	23.7	9.73	2.25	" "
1435	23.0	9.72	2.20	" "

GW-16 was collected at 1437

Samuel Sale

36

2:43p on 5/6/09
GW-37 - 2915 CR 114 W

* The groundwater sample was collected from ~~closets~~ closes faucet near the well pump.

Time	Temp	pH	Cond.	Comments
1445	24.3	9.62	2.04	Clear
1500	23.6	9.58	2.02	" "
1505	22.5	9.64	2.03	" "
1510	22.4	9.45	2.06	" "

* 31.960484 N
102.097363 W

* W facing photo of the faucet closes to the well head where GW-37 was collected.

GW-37 was collected ~~on~~ at 15:11

Dan Sorle

21pm - 5/6/2009
W-01 - 2801 W CR 114

* GW sample was collected at a faucet outside the well house. We could not gain ~~any~~ access inside the well house b/c it ~~was wratchet~~ + bolted shut ~~wt~~ on all directions.

TIME	TEMP	pH	Cond.	Comments
1525	26.9	9.58	2.21	Clear
1540	24.2	9.41	2.24	clear
1545	23.4	9.45	2.26	" "
1550	23.4	9.52	2.22	" "

GW-01 collected at 1551

* 31.961675°N, 102.096355°W

* W shot of faucet

5/6/09

1600: 5/6/2009

GW-38 - 1204 S CR 1205

- The closes faucet to the well was located inside the body/paint shop on the SE side of the shop.

- This business is a body/paint shop owned by the Rolands

Roland's Custom Paint & Auto Body Repair

TIME	TEMP	pH	Cond.	Comment
1600	25.4	9.45	2.22	Clear
1615	24.1	9.25	2.24	Clear
1620	21.8	9.18	2.23	" "
1625	21.6	9.37	2.20	" "

1620 - We collected GW-38 sample

Daniel Smith 5/6/09

4:30 pm
39

5/6/09 GW-40/41 (Dup)

* 31.961900 °N, 102.096505 °W

* S facing photograph of the faucet where GW-40/41 was collected.

* We couldn't get access inside the well shed, b/c it is completely fasten/bolted. We took the sample ~~closet~~ closes to the well on the S. side of the house.

TIME	Temp	pH	Cond.	Comments
1635	~~24.4~~ 24.1	9.62	2.00	Clear
1650	24.4	9.56	1.93	Clear
1655	23.7	9.76	1.94	" "
1700	23.7	9.50	1.94	" "

Sample was collected on 1701 & 1702

Danielle Sinle 5/6/09

Nani Soule 5/6/09

5/6/2009
At 1705 SHAW left w/ samples and brought samples to the lab.

5/6/2009 @ 530 pm – Called Mr. Rockwell to tell him we would be sampling the filtration sys. Stated he would like us to call first befor sampling.

533 pm – called Mr + Mrs Clinton about sampling filtration systems on Monday. (Call before sampling) the filtration systems.

535 pm – called mr. and mrs Jaing about sampling their filtration system
432.
– 528.3182 – Call Mr. George Jaing before ~~sampling~~ we sample.

540 pm – called Jim Baker to confirm we can sample his filtration system. No number on file.

541 pm – called Mr. Mandoza about sampling his filtration system for breakthrough stated he would be out of town, but we could sample his system.

545 pm - ~~spoke~~ called Mr and Mrs. Aubrey about sampling their filtration systems for breakthrough. Early in the morning between 9-10 AM would work best for him.

W

42

800AM - 5/7/2009
GW-10 - 2707 S CR 1206

- sample collected at the closest faucet from the well pump
- The faucet was located ~ 50 ft from the well.

* 31.962962 N, 102.098544 W

* South facing photo of the faucet where GW-10 was collected.

TIME	TEMP	PH	Cond.	Comments
815	22.2	8.05	2.14	clear
830	22.3	8.39	2.15	" "
835	22.3	8.48	2.16	" "
840	22.1	8.37	2.13	some sed.

8:42 the water samples were collected

Danielle Soule 5/7/2009

910AM - 5.7.2009
GW-4 - 2715 S CR 1206
Elite Treating Solutions

The groundwater sample was collected after the pressure tank from a faucet that T-together to a large ~~et~~ tank w/ bleach. We were able to shut the valve that flows to the tank w/ bleach, thus we were able to collect a grab sample before it enters the tank w/ bleach.

TIME	Temp	pH	Cond.	Comments
910	23.4	8.55	2.26	"Clear"
925	~~24.~~ 25.1	7.95	2.08	" "
930	24.8	8:02	2.11	" "
935	24.7	8.29	2.16	" "

Sample was collected at 9:37

Danielle Sante

945AM – 5/7/2009
GW-39 - ~~2614~~ SCR 1206
2611
CAPPELECTRIC

Collected GW-39 sample from a faucet closes to the well head.

TIME	Temp	pH	Cond.	Comments
950A	24.5	8.26	1.80	Clear
1005A	23.6	8.67	1.79	" "
1010A	23.4	8.60	1.84	" "
1015A	24.0	8.66	1.85	" "

Collected sample at 10:16AM

* S. facing photo of the faucet where gw-39 was collected

* 31.963627 N, 102.099123 W

Danielle Spinle 5/7/09

10:40 pm - 5/7/2009

GW-05 - 2414 WCR 114
GW-42 (Duplicate)

* Stated a lot of dumpang occurs in the area.
* Do not drinks the water.
* Stated that the ~~pipe~~ pump company has a pit where they dump waste. Thunks they may be the RP.
* Well is 100 ft deep, but water at 45 ft.

TIME	Temp	pH	Cond.	Comments
10:40	23.2	8.53	2.38	Clear
10:55	23.8	8.68	2.30	Clear
11:00	23.1	8.66	2.29	Clear
11:05	23.0	8.82	2.28	Clear

* S. facing photo of the faucet ø where GW-05/42 was collect.
* 31.965076 N, 102.098951 W
* Samples ~~whe~~ were collected from the closes faucet to the well pump.

Danielle Sonla 5/7/09

1105 AM - 5/7/09
GW-02 - 2805 WCR 110

* N facing photo of of the faucet where gw-02 was collected
* 31.965108 N
  102.097705 W

GW sample was collected at ~~the~~ a faucet on the well in the well shed

Time	Temp	pH	Cond.	Comment
1130	25.2	8.76	2.13	Clear
1145	26.6	7.90	2.11	" "
1150	24.0	~~8~~ 7.96	2.12	" "
1155	22.8	8.22	2.13	" "

[redacted]

Sample collected @ 11:57

Tom Sorle 5/7/09

5/11/2009

840 - HBS meeting w/ SHAW
- Tom Elliot SHAW
- Jason Brooks SHAW
- Dani Soule TCEQ

9AM - 2609 WCR 110
GW-48-A and GW-48-~~A~~ C

We purged the well from the effluant.

Collected water samples for VOC's, Semivolitales, and hex Chrome.

Time	Temp	pH	Cond.	Comments
9:10	21.0	7.95	3.83	"Clear"
9:25	19.1	8.56	3.70	" "
9:30	19.3	8.91	3.69	" "
9:35	18.9	8.86	3.70	" "

Photo #1 - W facing shot of the filtration System. ~~bre~~ 1

Photo #2 - W facing shot of a close up of the filtration system

~~B~~ A-935 ~~3~~ C 940 - Port Collection Time

Danielle Soule 5/11/09

5.11.08 GW-50A & GW-50C

2505 WCR 110

Time	Temp	pH	Cond	Comments ~~Clear~~
10:30	18.2	9.05	2.69	Clear
1045	18.8	9.11	2.65	" "
1050	19.0	9.18	2.64	" "
1055	19.1	9.40	2.64	" "

Mrs Aubrey — not a drinking well just irrigation requested that her second well should be sampled.

Photo #3 E facing photo of the filtration system where gw-50 A&B were collected.

Water was purged from the effluent valve from the filtration system.

Don Johnson collected money and sold ~~to~~ the land for the horseshoe - Francis St. - Midland Tax Ap

Port A Collected @
Port B Collected @

5/11/09 Darrell Sule

11:35 - 5/11/2009 - 2605 W CR 110
GW-49A & GW-49C

We purged the well from the effluant port. Mr Mendoza was not present, but we called and left a door hanger.

- We will be collecting 2-sets of VOAS from port one. One will go to Xenco and the other will go Test Am.
- Photo four: west facing photo of Mr. Mendoza's filtration system connected to his well.

TIME	Temp	pH	Cond	Comment
11:45	21.9	8.06	~~clear~~ 2.88	~~Clear~~ clear
12 NOON	20.6	8.82	2.78	" "
12:05	20.2	8.97	2.80	" "
12:10	20.4	9.10	2.79	" "

[signature] 5/11/09

5/11/09

50

1240 PM- 2710 W CR 112
GW-11A & GW-11C

Purged well from effluent port of the filtration system.

TIME	Temp	pH	Cond.	Comments	
1245	19.7	9.11	2.78	"	"
1200	19.7	9.27	2.81	"	"
1305	19.7	9.37	2.95	"	"
1310	19.8	9.55	3.03	"	"

North facing photo #5 of the filtration System

Port A samples were collected from the influent and port B samples were collected from the effluent.

Danielle Smith 5/11/09

5/11/09 → 14:20

GW-20A and GW-20C / GW-51A & GW-51C
2701 W CR 112

Purged well from water hose, effluent of the filtration Sys

TIME	TEMP	pH	Cond.	Comments
1420	22.2	9.30	2.50	Clear
1435	22.0	9.50	2.47	" "
1445	22.4	9.60	2.45	" "
1450	22.1	9.56	2.46	" "

- Duplicate collected at this location GW 51A & 51C
- MS/MSD collected at this location GW 20C MS MSD

14:45 GW-20A COLLECTED
15:15 END COLLECTING SAMPLES

North facing photo graph of the filtration System.

7:40A - 5/12/2009
GW-43A & GW-43C, 43F
GW-52A & GW-5AC

2615 W CR ~~1~~512

The water was purged from the effluant port of the filtration system.

The duplicate will be collected at port C (effluant).

TIME	Temp	pH	Cond.	Comments
750	20.4	8.97	2.37	
805	20.9	8.96	2.34	
810	21.3	9.05	2.32	
815	21.3	9.20	2.33	

43F- Hex chrome sample collected from Kitchen ~~facet~~ faucet. We left the faucet run hot water for 15 minutes.

Danielle Sonle 5/12/09

5/12/2009

9:06 AM - GW-23A and GW-23C, GW-23f
2700 W CR 112

The water was purged from the effluant port.

TIME	Temp.	pH	Cond.	Comment

micah.beard@shawgrp.com

ellen.clifton@shawgrp.com

905	24.8	8.68	2.94	Clear
920	23.1	8.86	2.90	" "
925	22.8	8.86	2.87	" "
930	22.6	8.86	2.84	" "

9:25 - Collected 23-f - Hex 6
9:30 - Port A - collected - VOA, SV, Hex, TPH
9:35 - Port C - collected - VOA, SV, HEX, TPH

David collected pictures of both sampling locations.

54

5/12/09: GW-46A, ~~[illegible]~~, GW-46C
2502 WCR 112

left the site. David Banda stayed to document sample collection.

[illegible] 5/12/09

10:30A- 5/12/2009
2710 WCR 112
GW-11F

* Collected GW-11F @ 11:45AM—

* North facing photo of the kitchen sink where GW-11F was collected.

GW-11A and GW-11C were collected on 5/11/2009

Danielle Sonte 5/12/09

42

11:04A - 5/12/09 GW-42A and GW-C
2514 W CR 112

The ~~gw~~ water was purged from the effluent end of the filtration system.

* Water is a yellow color from port One

TIME	TEMP	pH	Cond.	Comment
1105	24.3	7.02	2.23	Clear
1120	23.6	6.97	2.12	" "
1125	23.6	7.03	2.22	" "
1130	23.2	7.03	2.14	" "

NW photo ~~down~~ of the filtration system where gw-42A and gw-42C were collected

Mrs. Acosta was no longer home so we were unable to ~~to~~ collect ~~from~~ GW42F1

Jim Sandy

1pm - 5/12/2009
GW-45a and GW-45c ; GW-45f
2401 W CR 112

Mr. Rockwell stated that he was very concern, especially after attending the meeting.

Mr. Rockwell stated that his (winter wheat) wheat that he watered w/ contamnated water the wheat would be more ~~light an~~ than other wheat.

Time	Temp	pH	Cond.	Comments
1320	27.2	7.04	2.43	Clear
1335	24.8	7.10	2.59	Clear
1340	~~23.3~~	~~7.06~~	~~2.5~~ 2.57	23.3, 7.06, 2.49
1345	~~123~~.1	7.09	2.57	
?	22.9	7.00	2.55	

GW-45a and GW-45c were collected from port 1 and 3 respect

Danielle Sule

*5/12/2009
Mr. Cole wanted to know the frequency of the sampling area.

*public meeting

(L) francis, (L) Genuvea — GATE
lots of dumping and spells.

Danielle Soule

5/12/09

* 2900 S CR 1200 that
Trailer Home - stated ^ their are 3 wells on the property. For sure one belongs to the trailer behind 2900 which belongs to his brother. We were given AABWS to sample well at 2900.

Samuel Soule

7:55 Am → 5/13/2009
2805 S. CR 1200

GW-56 - We will be collecting VOA's, SV, and Hex+6.

The well was purged from a faucet closes to the well.

TIME	Temp	pH	Cond	Comments
8:05	21.8	6.97	3.60	Clear
8:20	21.6	6.93	3.96	" "
8:25	21.6	6.92	3.98	" "
8:30	21.6	6.97	3.90	" "

West facing photo of the faucet next to the well shed where GW-56 was collected

Sample was collected at 8:40

Dean Soule

8:59Am - 5/13/2009
2801 S CR 1200

GW-55 - took grab mix from a water softener or RO system.

We were only able to collect a hex +6 sample and not a SV and VOA. We were unable to collect a SV or VOA because the water from well enters a
1,000 - 2,000 gallon tank. Since the tank was full we were unble to to get a push gw sample, thus the water in the poly tank had already volitalize so we did collect VOA's or SV's. If Hex +6 is positive then we will have to drain the poly tank to collect the ~~sample~~ VOA & SV samples

920 - collected Hex +6 sample

Danielle Soute 5/13/2009

62 GW-64
10:05AM - 5/13/2009
3010 S CR 1200

The gw was purged from a faucet located between the well head and pressure tank. GW-64 was collected from the faucet at 10:40AM.

Time	Temp	pH	Cond	Comments
10:07	23.3	6.97	2.46	Clear
10:22	21.8	6.91	2.49	
10:27	21.5	6.96	2.51	
10:32	21.4	6.91	2.53	

NE facing photograph of the well head, faucet, and pressure tank where GW-64 was collect.

31.958896 N
102.088931 W

Danielle Stone 5/13/09

GW-65
11:00AM - 5/13/2009
3011 S CR 1200 / 3007 S CR 1200

- The well sampled provides water to the trailer located at 3011 S CR 1200 and the house located at 3007 S CR 1200.
- The well head and pressure tank are located b/t both ~~x~~ buildings/homes.
- The gw ~~sample~~ was purged from the closest faucet, which was located on the N side of the trailer at 3011 S CR 1200.
- S. facing photo of the faucet where gw-65 was collected
- 31.959733°N
  102.087557°W

Time	Temp	pH	Cond.	Comments
11:07	26.3	7.02	2.29	Clear
11:22	22.6	6.86	2.17	" "
11:27	21.5	6.88	2.27	" "
11:32	21.54	6.87	2.284	" "
11:37	21.5	6.89	2.28	" "

[illegible]

Noon - 5/13/09
GW-67 - 2601 W CR 114

TIME	Temp.	pH	Cond.	Comment
12:05	28.4	7.17	1712	Clear
12:20	23.9	7.14	1696	" "
12:25	22.9	7.17	1727	" "
12:30	22.8	7.14	1693	" "

GW was purged from a east side faucet on the house. This was closes faucet to the well head and pressure tank.

31.962147 N
102.092879 W

NE facing photo of the faucet where GW-67 was collected.

VOA
SVOA
Hex Chrome } Collected

12:40PM - Samples were Collected

303- 5/13/2009
2301 W CR 110
GW-58

* purged and sample from a faucet located on the S of 2301 W CR 110 house. There were no faucets in the well house or head. There was another faucet closer.

31.966771 N
102.091784 W

PO 2026
Midland TX 79702-2026

TIME	Temp	pH	Cond	Comments
1500	25.5	7.04	2.29	Clear
1515	22.4	6.99	2.22	" "
1520	21.9	7.02	2.30	" "
1525	21.7	7.01	2.29	" "

Danielle Smith

66

400 - 5/13/09

2500 Cotton Flat Rd

GW-83 - Extra Volume Sample for VOA & SVOA

TIME	Temp	pH	Cond	Comments
409	24	6.96	2.33	Clear
424	23.1	7.01	2.34	" "
429	22.8	6.98	2.25	" "
434	22.4	7.01	2.37	" "

GW was purged from a faucet located on east side of the well house. This is the closes faucet to the well.

31.966513 N
102.091098 W

W facing photograph of the ~~faue~~ faucet where gw-83

5/13/09

810AM - 5/14/2009

GW-80: 2803 W CR 111 & 2801 W CR 111

Fender property - RingNet (Renters)
- Blazing Safety & Consulting

NE photograph of the well head and pressure tank. The faucet connected to the well head is in the picture, too.

Purged the well from a faucet on the well head. The faucet is located after the presure tank

31.963606'N
102.096892'W

~~SO~~ ~~SO~~ SVOA
VOA
Chrome + 6
} Samples

TIME	Temp	pH	Cond.	Comments
815	21.9	7.04	2.58	Clear
830	21.4	7.02	2.67	Clear
835	21.4	7.00	2.59	Clear
840	21.4	7.02	2.85	Clear

Danielle Sorle 5/14/09

900AM - 5/14/2009
GW-82 - 2809 W CR 111

Byron Fender - Owner
PetroPlex Piping
TR Bridges
2802 W CR 111

The closes faucet to the water well is located in the front yard of the building. We purged the well from this faucet before collecting GW sample.

Time	Temp	pH	Cond.	Comments
1:20	24.1	7.02	2.69	Clear
9:35	23.2	7.04	2.73	" "
9:40	22.5	7.01	2.71	" "
9:45	223	7.04	2.80	" "
9:50	22.2	7.01	2.75	" "

31.963574 N
102.0977921 W

E facing photo of the faucet where gw-82 was collected

955 - GW-82 Collected

Dan Sorn

1020AM- 5/14/2009
GW-81 - 2802 W CR 111

[redacted]
Petroplex Pipe & Construction
TR Bridges
432-697-4540

Purged water from closes faucet located in the front of the building.

North facing phot of the faucet where gw-81 was collected.

31.964003 N
102.096999 W

TIME	Temp	pH	Cond.	Comments
1025	24.6	7.01	3.32	Clear
1040	22.4	6.93	3.11	clear
1045	21.6	7.01	3.26	Clear
1050	21.6	6.98	3.22	

The faucet was so low to the ground we had to use dedicated plastic tubing to fill sample bottles.

Danielle Scull 5/14/09

70

1310 5/14/2009

GW-90 - 2210 W CR 111

TIME	Temp	pH	Cond	Comments
1310	26.1	6.91	2.19	

31.967608° N
102.088373 W

GW was purged from a faucet on the N side of the well shed where GW-90

Power shut off, so we stop sample

5/14/09

Samuel Soule

1345 - May 14, 2009
GW - 86 - 2800 W CR111

- 31.964142 N
- 102.096677 W

West facing photo of the faucet where GW-86 was collected and gw was purged.

- Sample was collected at the closest faucet ~~we~~ to the well head.
- ~~[illegible]~~ Byron Fender owns the property, but Petroplex leases.
- faucet was so low to the ground that we had to use dedicated plastic tubing to ~~collecting~~ collect the gw samples.

TIME	Temp	pH	Cond.	Comments
1345	31.3	6.97	3.19	Clear
1400	25.9	6.88	3.35	" "
1405	24.3	7.01	3.34	
	23.5	6.97	3.36	

Sample time 14:07

Danielle Soule 5/14/09

72 5/14/09 - 2:32pm
GW-87
2800 S CR 1207
Brenderup Bussiness

- The gw sample was collected at a faucet closes to the well on the E side of the well shed.

Time	Temp	pH	Cond	Comments
1430	30.2	6.94	1840	clear
1445	25.3	7.01	1815	Clear
1450	24.7	6.92	1840	
1455	25.1	6.94	1842	

31.960645° N
102.101376° W

W facing photo of the faucet where GW-87 was collected.

[signature]
5/14/09

311pm - 5/14/2009
2716 S CR 1207
GW-88

31.961482 N
102.101033 W

The closes faucet to the well was located E side of the building aprox. 200 feet from the well. The gw was purged and collected from the ~~well~~ faucet

Time	Temp	pH	Cond	Comments
1510	32.9	6.81	2.48	Clear
1525	26.9	6.76	2.43	" "
1530	24.8	6.79	2.51	" "
1535	24.4	6.77	2.58	" "

5/14/09

74

1548-5/14/09

GW-89

A hex chrome sample was collected from the RO ~~sample~~ unit outside the Cotton Flat Grocery Store at [redacted] 2800 SCR 1200.

[illegible]

6/4/01

June 4, 2009
GW-135A and GW-135C
Dup → GW-147 at the effluent end

8:28	23.1	7.21	2.62
8:43	22.0	7.21	2.60
8:48	21.8	7.21	2.59
8:53	21.9	7.20	2.59

Totalizer on pump
initial reading - 0623107
final reading - 0623194

Purged gw from well effluent for aprox. 30 minutes.

Sample collected at 8:54

Danielle Sorli 6/4/09

June ~~6~~ 4, 2009 at 9:22AM
GW-142A and GW-142C
2502 W CR 112

*purged gw from the effluent end of the filtration system

~~Temp~~

Time	Temp	pH	Cond.
9:25	28.8	7.15	2.28
9:40	23.7	7.16	2.29
9:45	22.6	7.16	2.19
9:50	22.0	7.165	2.20
9:55	21.9	7.16	2.20

Totalizer Reading on Pump
initial: 3464991
final: 3465045

Sample Collected at 10AM

Dan Sandl 6/4/09

June ~~6~~ 4, 2009 @ 10:30

GW-146A and GW-146C
2405 W CR 114
Cotton Patch Grocery

Just a grab sample b/c the system ~~requires~~ has a 3,000 gallon tank, thus unable to purge gw w/out causing the pump to go out and empty the tank.

Pump
0054504

Rod Stephenson
PO Box 2612
Midland TX 79702

fax #
432.682.
6771

Danielle Sonle 6/4/09

GW-141A

80

June 4, 2009
Noon

GW-144A & GW-144C
2605 W CR 110

Time	Temp	pH	Cond.
1212	23.1	7.26	2.86
1227	22.8	7.26	2.84
1232	22.3	7.24	2.83
1237	22.2	7.24	2.82

*purge well from the effluent for ~ 30 minutes

Pump Reading

1223769 - Initial Reading
1223824 - final Reading

GW-144A and C were collected at 1240 and 1242, respectively

6/4/2009

Danielle Sule

n

June 4, 2009 - 1245
2505 W CR 110
GW-145A & GW-145C

TIME	Temp	pH	Cond.
1253	26.0	7.12	2.65
1308	22.8	7.09	2.58
1313	21.8	7.07	2.62
1318	21.5	7.11	2.62

purged gw from the effluent for ~ 30 minutes.

pump 0209156/0291 85

* Stated they found (2) two dead birds.
* The Awbrey's have never gave water.
* Stated that the filtration system has doubled her electricity bill.
* Upset that the news only ~~taped~~ showed certain clips.

Danielle Sonte 6/4/09

June 4, 2009 @ 1:30

82

GW-141A and GW-141C
2401 WCR 114

pump 0055750 / 0055860

Time	Temp	pH	Cond.
1345	27.8	7.28	2.70
1400	24.6	7.18	2.70
1405	22.6	7.19	2.69
1410	22.1	7.20	2.66
1415			

*purge the gw from the effluent for aproximate 30 minutes

Danielle Sonle 6/4/09

6/4/2009 - GW-136A & GW-136C

Time	Temp	pH	Cond
745	19.8	7.26	2.40
800	20.2	7.25	2.46
805	20.6	7.25	2.45
810	20.7	7.24	2.40

Danielle Sinle
6/4/09

84 June 4, 2009
GW-138A & GW-138C
2700 WCR 112

Time	Temp	pH	Cond
830	20.9	7.95	2.73
845	21.6	7.80	2.70
850	21.5	7.86	2.70
855	21.3	7.82	2.71

Pump 0371060 / 0371200

Danielle Sole

June 4, 2009
GW-137A & GW-137C - Dup. 147
2710 WCR 112

~~Time Temp pH C~~

I: ~~8~~ 168620
f: 168670 > pump

Time	Temp	pH	Cond
915	23.2	7.77	3.03
930	22.6	7.74	3.15
935	22.4	7.76	3.06
940	22.2	7.75	2.97

Danielle Sante
6/4/09

June 4, 2009
GW-139A & GW-139C
2514 W CR 112

Time	Temp	PH	Con
1022	23.5	7.93	1.98
1037	24.8	7.78	1.94
1042	22.9	7.8	1.96
1047	22.3	7.8	1.96
1052	22.3	7.8	1.95

Vol. Initial - 0136910
Final - 0137010

Danielle Seale 6/4/09

6/4/09
GW-~~139~~ 140A and 140B
2601 W CR 112

Time	Temp	pH	Cond:
1245	25	7.94	1.92
1300	22.8	7.93	1.87
1305	22.5	7.92	1.86
1310	22.3	7.94	1.86

Vol — Initial 0098420
finial 0098570

Danielle Sonle
6/4/09

88 6/4/2009
2604 W CR 112
GW-143A and GW-144C

Initial - 094030
final - 094210

Time	Temp	pH	cond
1207	25.7	7.91	2.23
1222	22.6	7.92	2.24
1227	22.0	7.90	2.24
1232	21.8	7.94	2.23

6/4/09

June 9, 2009
755 Am
GW-150
3109 SCR 1200 - Well # 1

* purged water well from closest* faucet to the well head and pressure pump.

Time	Temp	pH	Cond.
758	27.0	6.85	2.37
813	23.7	7.02	2.30
818	22.1	7.04	2.30
823	21.8	7.05	2.31
828	21.8	7.03	2.31

photo # 48 : E facing photo of the faucet where GW-150 was located

Samuel Sole
June 9, 2009

June 9, 2009 at 8:35AM
GW-151
3109 W CR 1200

Time	Temp	pH	Cond
8:35	23.7	6.95	2.43
8:50	22.8	6.95	2.41
8:55	22.4	6.95	2.39
9:00	22.3	6.94	2.41

photo #44 - N facing photo of faucet where GW-151 was collected

photo # 45 - W ~~facing~~ facing photo of ~~faucet where~~ well house / well where GW-151 was collected from a nearby faucet.

- Trailer Park well #2, which is S of the home located at 3109 W CR 1200

Danielle Sowl 6/9/09

June 9, 2009 at 9:06
GW-152
3109 W CR 1200
Well # 3 - just serves this house.

31.957113°N
102.086429°W

~~W~~ Photo # 46: W facing photo of the ~~phot~~ faucet where gw-152 was collected.

photo # 47: ~~Well house~~ E facing photo of the well and pump.

TIME	Temp	pH	Cond.
907	24.5	6.86	292
922	23.3	6.85	29.7
927	22.9	6.90	2.87
932	22.3	6.86	2.93
937	22.5	6.90	2.90

Well #3 - is located S of well #2 along cotton flat.

Danielle Sorle 6/9/09

Reference 17

WCR 112 TCEQ-SSDAP SAMPLING FIELD NOTEBOOK #3

5/14/09 Field Work

Sissy Sathre 2700 CR 112

Can we install 1 major well.

Mr Howard
2701 CR 112
204 ppb Cr^{-6}

Sonny

2905 - CR 115
at site at 2 30pm Not Home

2901 - CR 115
at site 2:41 pm Not Home

2909 - CR 115
at Site 250 pm

2906 CR 115
at site 250 Return
Lindsey / Kelly

2902 CR 115
at Site 3 pm
Not At Home

2

5

Odess

McGrahe

5/14 Access Agreement

2805 CR 115
at site at 3pm
Did not answer door

3001- CR ~~115~~ 1204
at site at 3:10pm
No Answer

3011 CR ~~115~~ 1204
at site at 3:15pm
No Answer

3101 CR ~~115~~ 1204
at site at 3:20pm
Obtain Site Info and access agreement

CR 1199 Trailer House Near Corner
2801

5/19/08

91

task

task

Task

Last Day of Sampling

5/19/09 CR 112 Re-Sampling

- Arrived at staging area at 8am.

Micah
Jason Brooks

- Safety Mtg (810-830am)

- Schedule of Day

Rd 91 $\boxed{\text{2700 W CR 114}}$

task - Culligan needs to deliver water to resident.
- 2700 W CR 114
- Monthly water
task - What is resin media

Kelly Pearson - Discussed Culligan

- Dostwicks - Red Brick House CR 112
-

Task Need letter for Tax Reduction June 15th deadline
Status

6

2412-W CR114 Day Merchant 402-631-2440
On 112

2601 CR114 Bill Morgan ~~No 6~~ (65)

Rob Mu

5/19/2008 Last Day of Sampling

GW 95

2701 CR114

Franklin Howard
- No Pets
- No Livestock
- Vegetation Only

Need Water
- After Reservoir tank
- Bottled Water

Well located in small shed — Goes through a small pressure tank → flows through the filtration → To house.

Tank Filter Change Out Needs

Road Talk CR112

(432)
682-3018 James Bostwick 2701 W CR 112 Sample Results Last week
685-1979 Bill/Rita Moffitt 2615 W CR 112 Sampled Results Last Wk
770-0351 Debra ~~Angela~~ Brooks 2700 W CR112 Sampled Res Last Wk
☆ < 2½ gallon - Dani asked

2712 - CR 114

Tank Sample Port Only one sample port : New sample port need
Port C only : No Port A

1st Day of Sample

19/2008
:40pm
964
96C

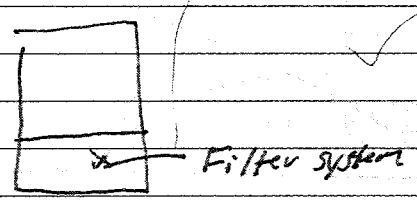
2605 W CR 114

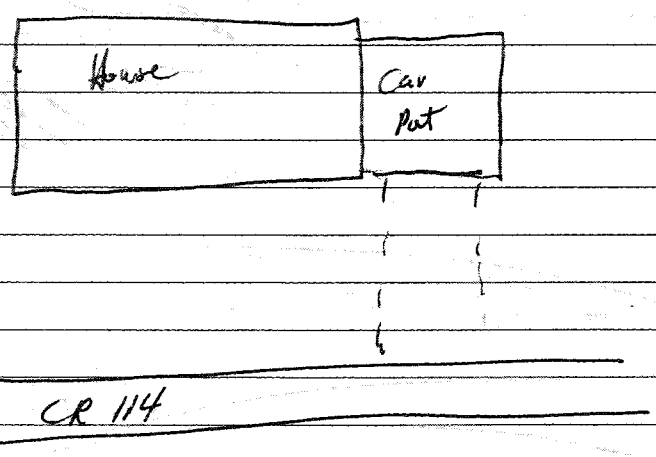
Luis Villanueva

Sampler Jason Brooks

Started Purge at approx 1:50pm

Horses, Dogs,





Photograph 1 Shed with system
Photograph 2 Filter system
Photograph 3 Filter system
photograph 4 House + Decks

5/19/20

initial
1
2
3

GW

1st Day of Sampling

5/19/2009 (continue GW96)

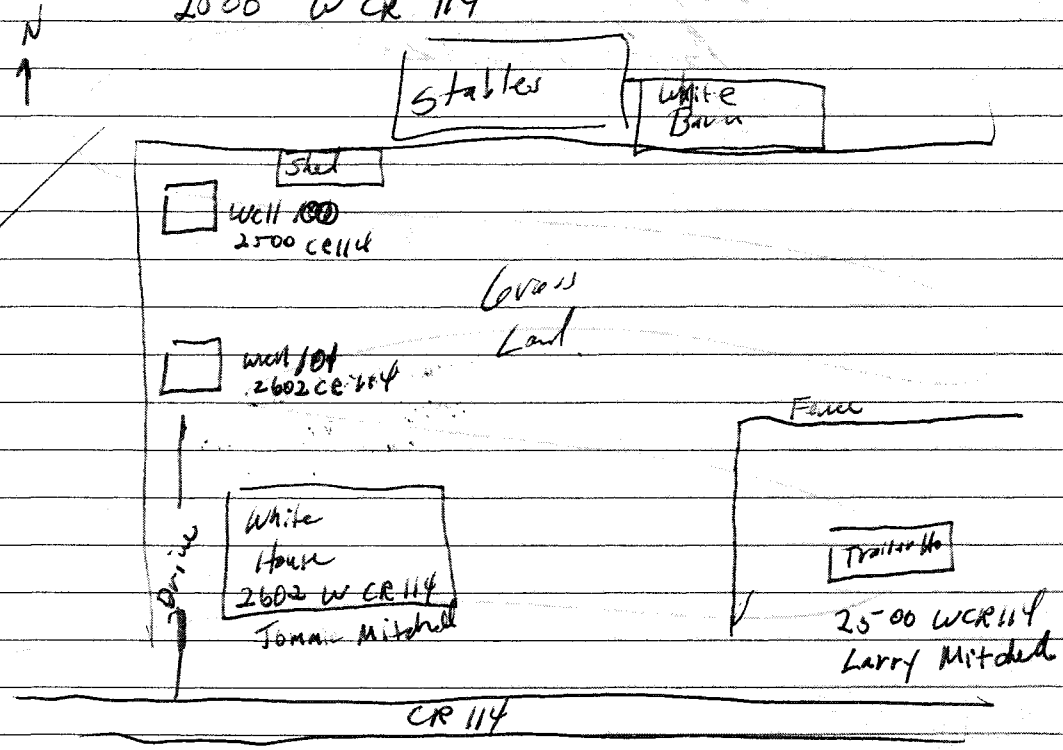
Reading	Time ~~Readings~~	~~Time~~	Temp °C	pH	Cond	
Initial	1350	~~[illegible]~~	23.6	6.17	2.30	Clear
1	1405		24.7	6.16	2.09	
2	1410		23.8	6.11	2.14	
3	1415		23.6	6.11	2.26	

GW-96A 14:17 Sampled TPH/Chrome
GW-96C 14:20 Sampled Chrome

Hex Chrome + TPH
Totalizer 1061820

GW 100 Larry Mitchell
2500 W CR 114

Sketch



5/1

1st Day of Sampling

5/17/2002 GW 100 Continued

Larry Mitchell Owner of Well

Started Purging

Photograph 5 - Inside photo of Well Housing and anion units

Photograph 6 - Outside photo of well head and reservoir tank

Well Head → Reservoir Tank → Filter → House.

Reading	Time	Temp °C	pH	Cond
Initial	1445	27.0	6.00	253
1	1500	24.6	5.92	249
2	15:05	23.8	5.91	2.63
3	15:10	23.4	5.94	250

GW 100 A Port Sampled 15:12 TPH/Chem

GW 100 C Port Sampled 15:15 Chem

Total Reading 0236810

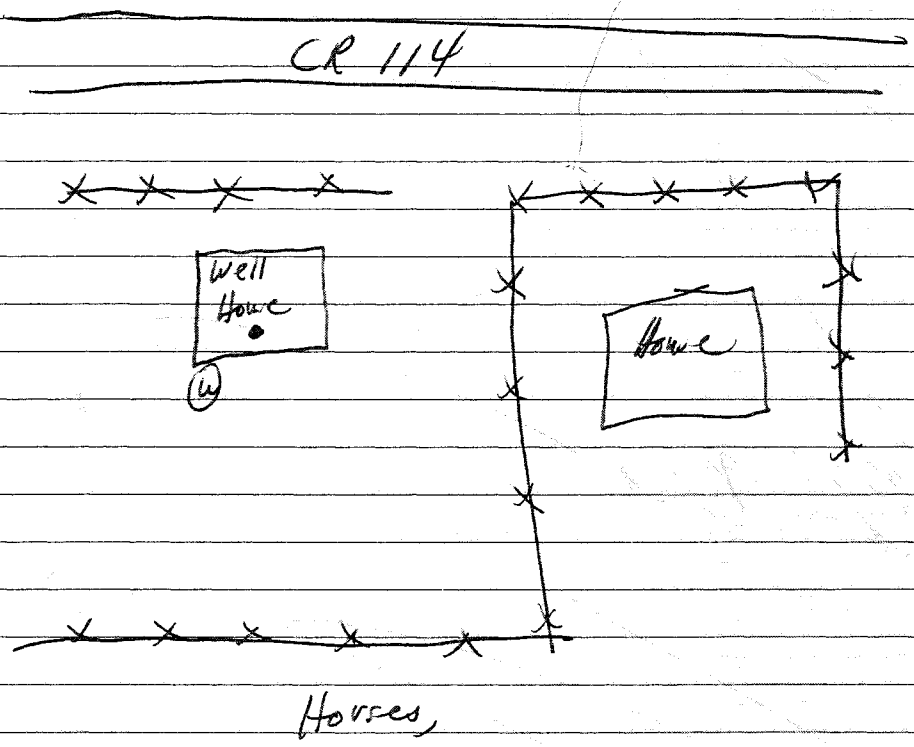
/19/
v 125

5/19/2009 1st Day of Sampling

GW 125

Bill Morgan
2601 WCR 114
Phone 432/813-2580

Sketch



Purging

Time	~~[illegible]~~	Temp	pH	Cond
15:27	~~[illegible]~~	24.3 °C	585	241
1542	~~24.3~~	24.6	581	232
1547		24.3	586	242
1552		24.4	577	239

Port A Sampled 15:55
Port C Sampled 1557

1/20/02

W 102

Tank

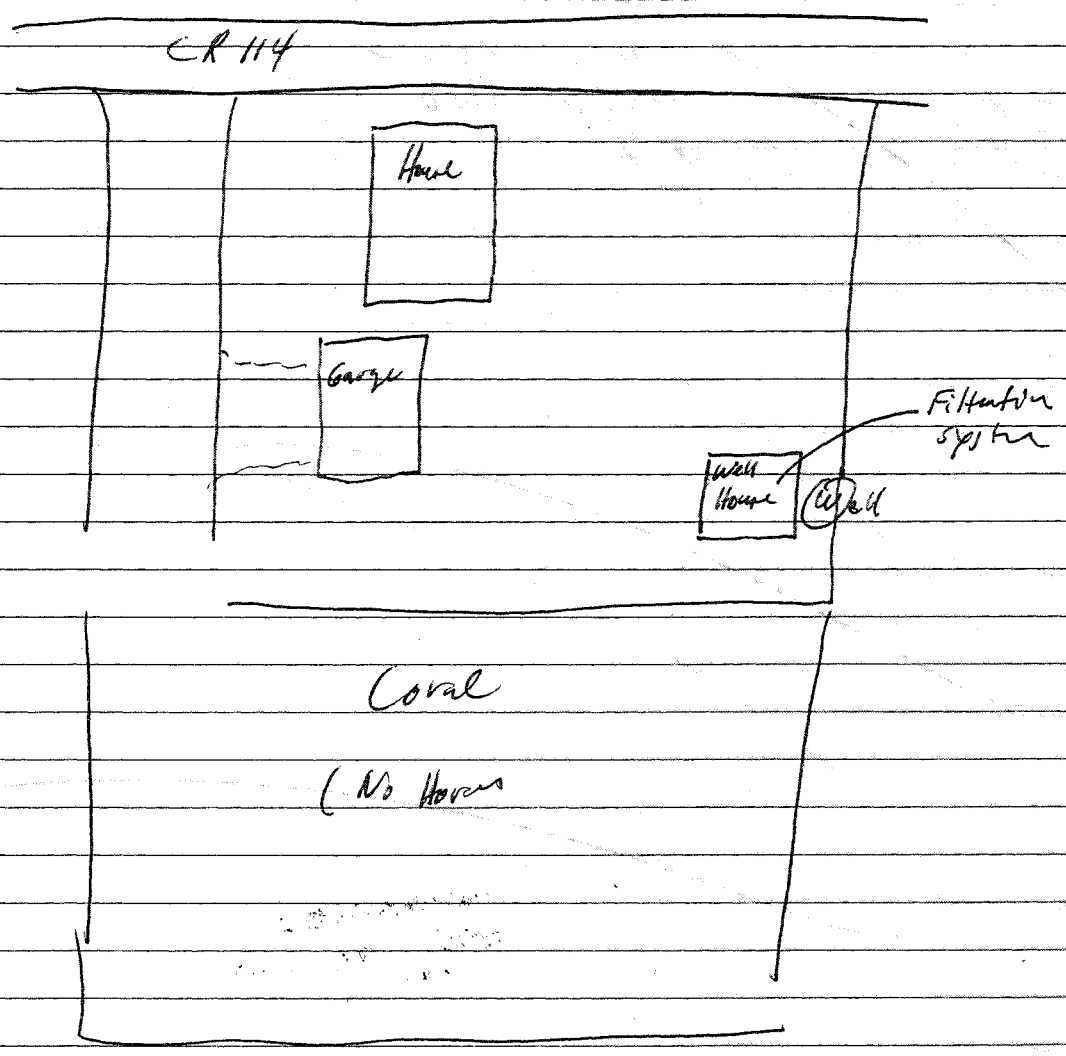
2nd Day of Sampling

5/20/02 GW-102 Danny Marchanti
2413- WCR 114 Phone 432/631-2440

GW 102 413 6110

Talk Bottled Water Needed

Sketch



2nd Day of Sampling

5/20/98

GW 102 Continued

Photograph 8 - Inside look at filter
Photograph 9 Outside look at Well House

Reading	Time	Temp	pH	Cond	
	~~Reading~~	~~Temp~~	~~Temp~~ °C	~~pH~~	Cond
Initial	855	22.5	7.15	7.88	
1	910	23.1	7.06	796	
2	915	23.3	7.02	779	
3	920	23.2	7.00	796	

GW 102 Port A Sampled at 9:21am TPH/Chrom
GW 102 Port C Sampled at 9:24am Chrome

Totalizer 0090140

No Horses, No Livestock

5/20

2nd Day of Sampling

5/20 GW ~~104~~ 127 James Scossin

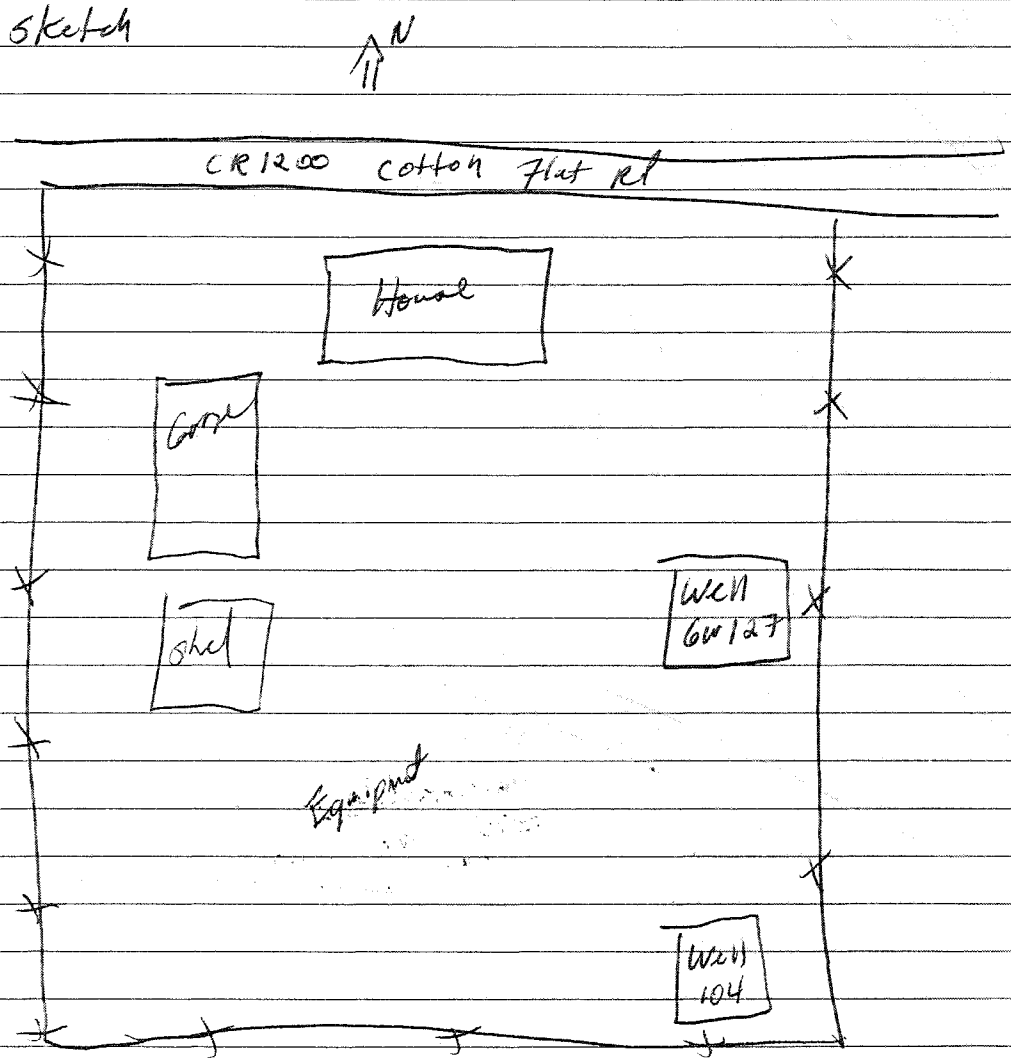
GW 127 (2nd Well located near front of property)

Started purging at approx 9:50am

Photograph 11 – Photo of GW 127 well house.
2nd well on property

~~Photograph~~

Sketch



2nd Day of Sampling

GW 127 (continued)

Reading	Time	Temp	pH	Cond
Initial	949	21.5	6.87	8.40
1st	954	21.3	6.91	8.45

Hex Chrome Only

Second well on property

Livestock- (Use water for Livestock)

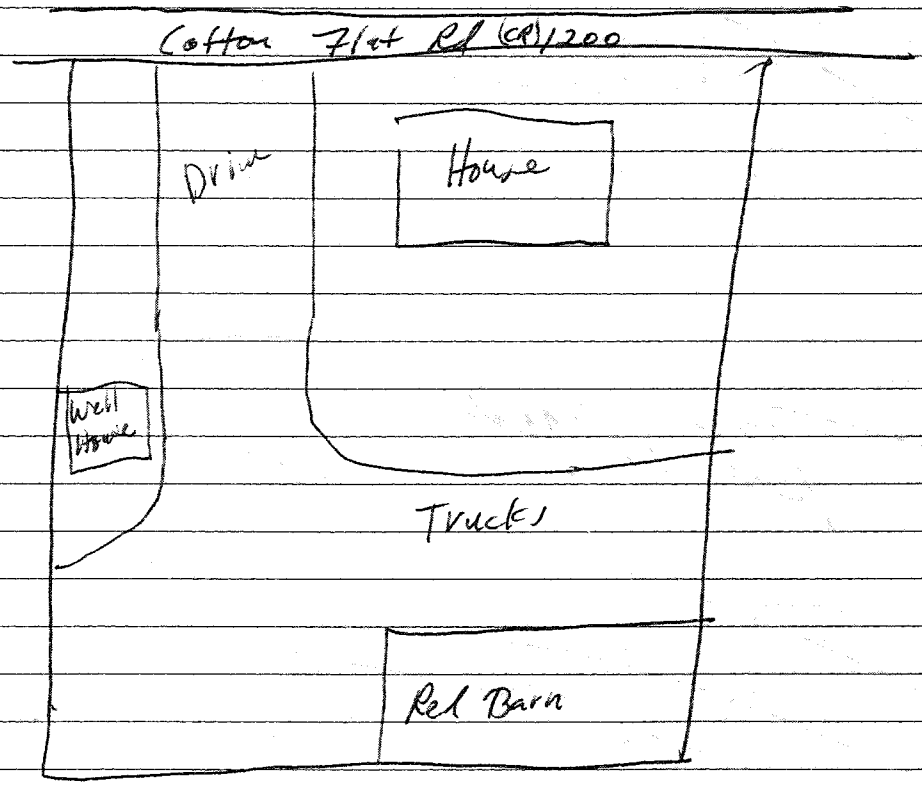
2nd Day of Sampling

5/20 GW126 Ramos
3000 CR 1200 Cotton Flat

Arrival at 10:00 am approx

Met w/ Mr. Ramos.

Sketch



Started Pumping at ≈ 10 am.

Photo 12 - looking West toward Shed where well located

Photo 13 Inside at units

5/2

2nd Day of Sampling

5/20 GW126 Continues

Reading	Time	Temp	pH	Cond
Initial	10:12	22.3	7.07	8.27
1	10:27	20.4	6.98	8.75
2	10:32	20.3	6.92	8.65
3	10:37	20.6	6.91	8.69

GW 126 A 10:38 sampled for 1005/chem
GW 126 C 10:42 sample for Chrome

Totalizer 2256950

5/20

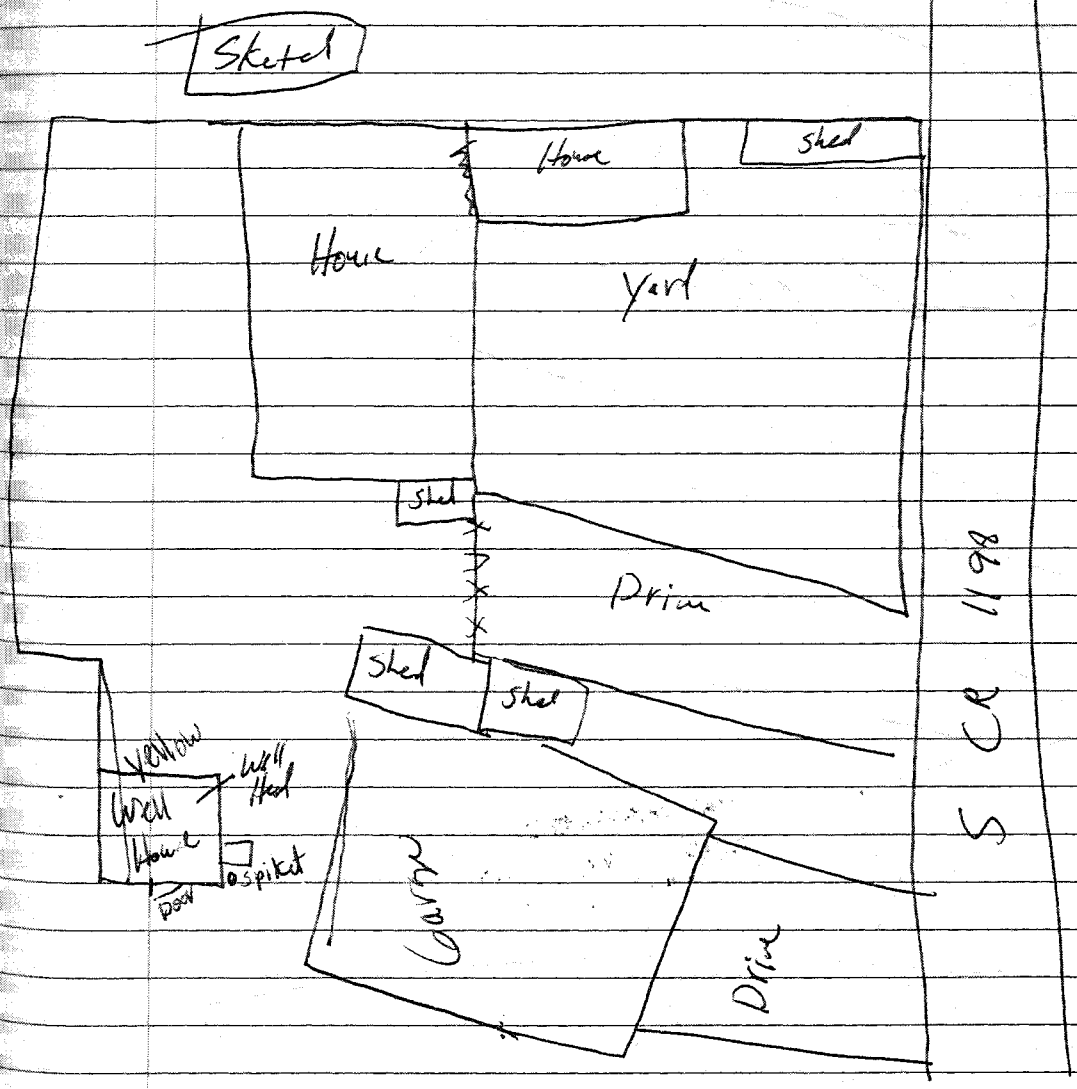
2nd Day of Sampling

5/20 GW106 / GW122 Dup
Johnnie Thomas 432/570-0616
2700 S CR 1199

New Well Sampling
Photograph 13 - Well House at nearest spiket.

Started pursing at = 11:05 am

Sketch



5/20

Rd Misc

2nd Day of Sampling

5/20 6W106/ 6W122 Dup Newhall

TWC Letter March 30, 1990 letter
Summarize results

Reading	Time	Temp	pH	Cond
Initial	11 05	23.1	6.93	209
1	11 20	24.6	6.25	200
2	11 25	23.9	6.30	203
3	11 30	23.8	6.77	203

6W106 11 30 am
6W122 11:45 (Dup)
Hoy
Chrome

R. Moss

5/2

2nd Day of Sampling

5/20/05

SP-01 / Dup-01
2414 CR 114 Beverly Crouch
Swimming Pool
Sample for Cromin

Grab Sample from Swimming Pool for Characterization

Photograph 15 - Truck to install water in pool,
Photograph 16 - Grab Sample

Sample Cromin only
Expedite Sampling

≈ 14,000 gallon of Water $700.00

Sample (12 24 pm) and Dup (12.34 pm)

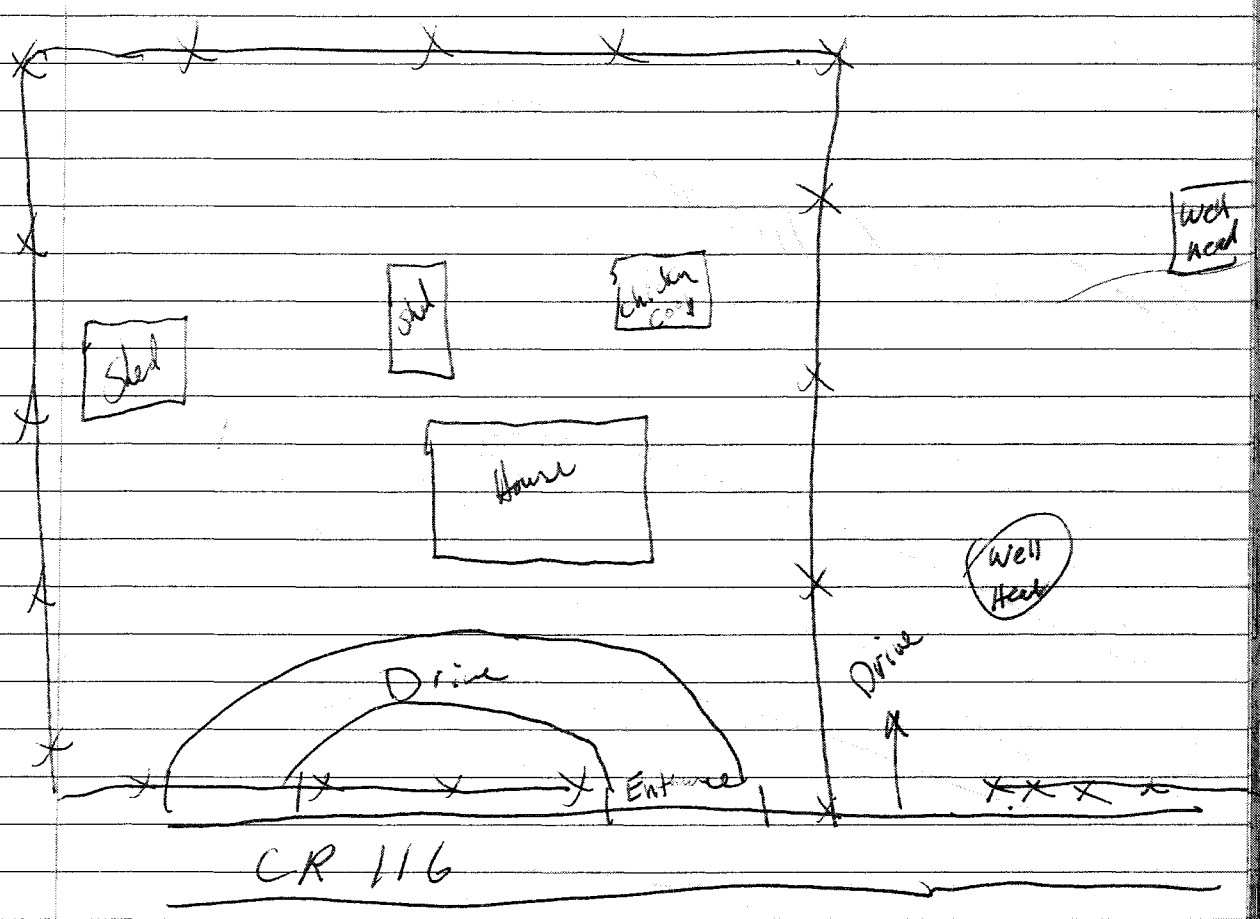
5/20

2nd Day of Sampling

5/20 GW 109 2806 W CR 116
Robert Elliot

Photograph 17 - Well head Photo looks East

Sketch



Purging Well System - Both Wells combined to yield water from House. One sample for both locations. (Combined Water)

5/2

Re Misc

2nd Day of Sampling

5/20 GW 109 (Continued)

Reading	Time	Temp	pH	Cond
Initial	1446	25.5	6.98	3.42
1	1501	25.2	7.07	3.26
2	1506	25.4	7.25	3.40
3	1511	25.3	7.01	3.24

GW-109 Sampled 15:14

5/2

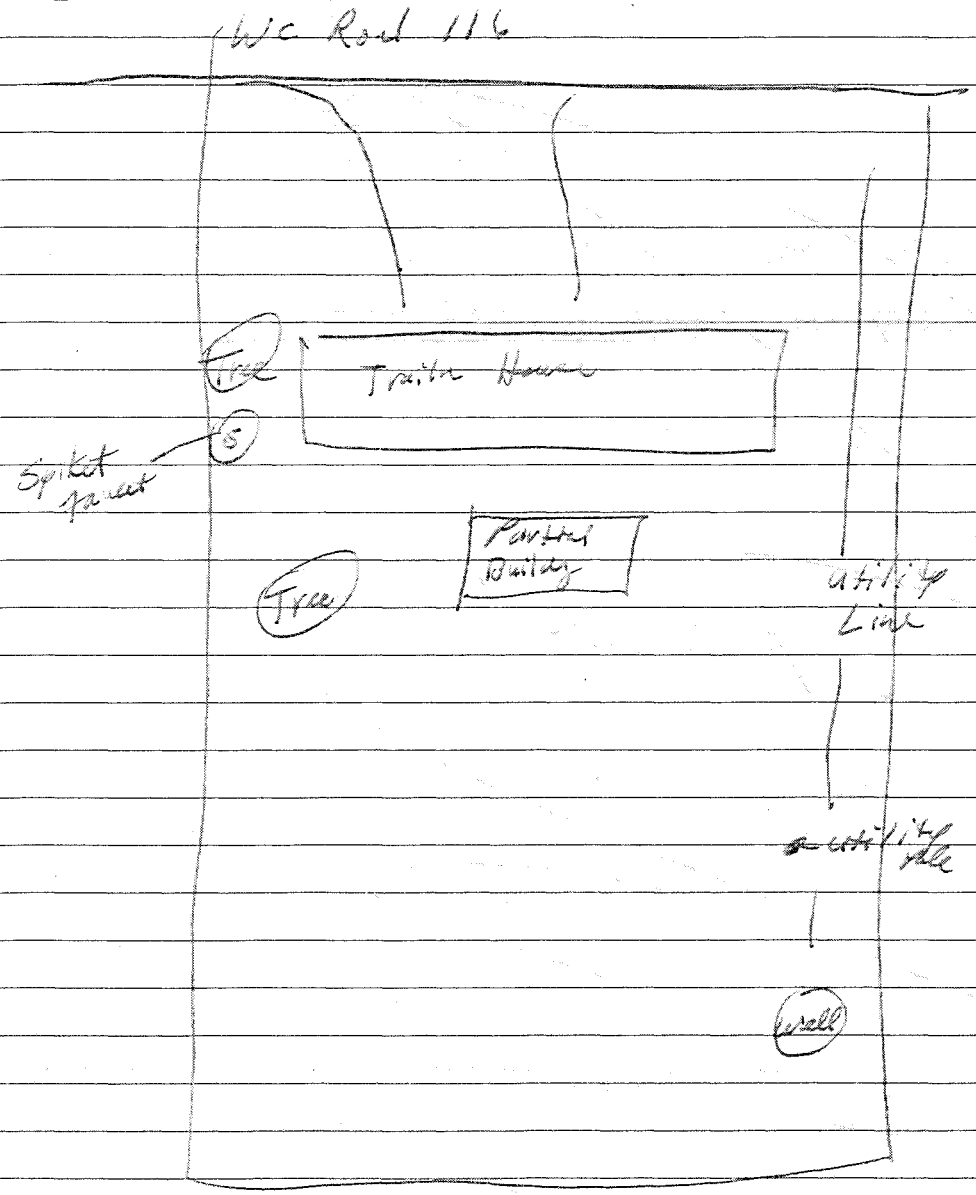
Ro Mrsl

2nd Day of Sampling

6/20 GW 111

Dusty Friday 2801 W CR 116

Sketch



5/20

Rob Mrsd

2nd Day of Sampling

5/20 GW 111 (continued) / GW 124 Dup

Started purging from faucet on west side of house. Faucet is located at least 300 yds from Well Head.

Sampled 1600 Primary
16:15 Dup

Reading	Time	Temp	pH	~~Sal~~	Cond.
Initial	15:33	28.1	7.07	~~Sal~~	3.69
1	15:48	25.5	7.05	3	3.61
2	15:53	25.4	7.11		3.67
3	15:58	25.0	7.11		3.70

R Mark

5/20

4:30pm

Rk Mar

2nd Day of Sampl

5/20 2604 W CR 112 ~ Lang

Mr Large Drum on Front yd
Primer Acid

4:30pm (P.)

Photographs 19 and 20

Photo 19 ~ Label with follower on Blue Drum

Material Doc # 5000001889 2
Material # 2000000591
PO # 9316 Line #10

Empol 1048 Trimer Acid Drum

Photo 20 Blue drum near fence at front yard

Drum located on fence on western portion of property

RJM

5/21

3rd Day of Samples

5/21

Safety Meeting at 8:15am

GW 104 James Scoggins
2604 S CR 1200

Filtration System Port A/C

Photograph 21 - looking easterly at filtration system in back lot of site; Photograph 22 - Looking at filtration units.

Sketch - Look at Page 21 of this book with sketch of wells GW 127 and 104 located at 2604 S CR 1200.

Purging

Reading	Time	Temp	pH	Cond
Initial	8:35	20.2	7.15	2.12
1	8:50	21.7	7.03	2.01
2	8:55	20.6	6.99	2.04
3	9:00	20.7	7.00	2.00

GW 104 A 9:02 Chrome + TY1005
GW 104 C 9:05 Chrome

Totalizer 0307580

5/21

Arrival

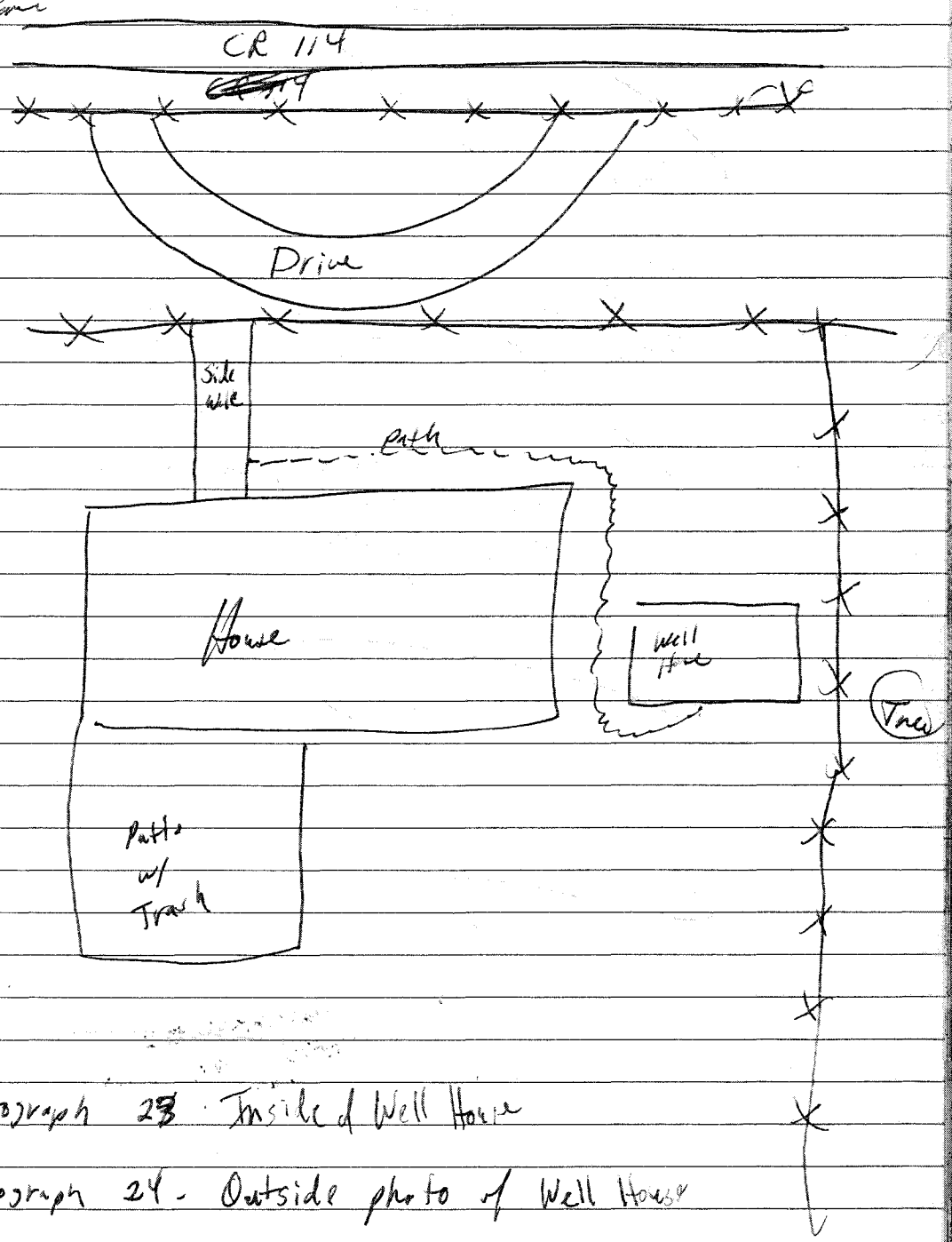
Sket

3rd Day of Sampling

5/21 GW-98 2719 W CR 114
Mrs Alsup

Arrival 9:25 am

Sketch



Photograph 23 · Inside of Well House

Photograph 24 - Outside photo of Well House

51

Rob Mead

3rd Day of Sampling

5/21 6W-98 (continued)

Agriculture - Goats, chicken, cow(1).

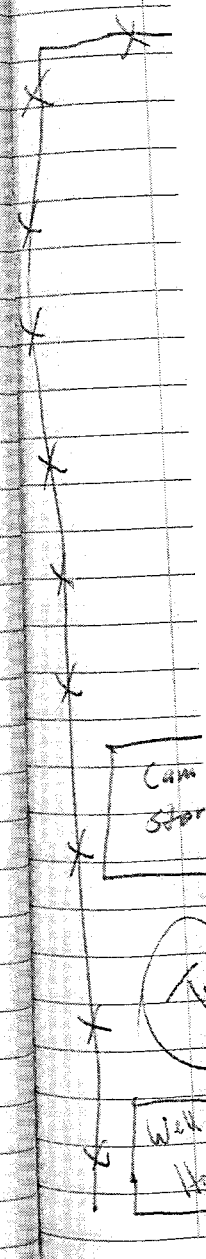
Purgity

Reading	Time	Temp	pH	Cond
Initial	9.26	21.8	7.03	2.75
1	9.41	22.0	7.04	2.62
2	9.46	22.3	6.98	2.72
3	9.51	21.8	7.01	2.68

6W-98 A 953
6W-98 C 955

Totalizer 0757440

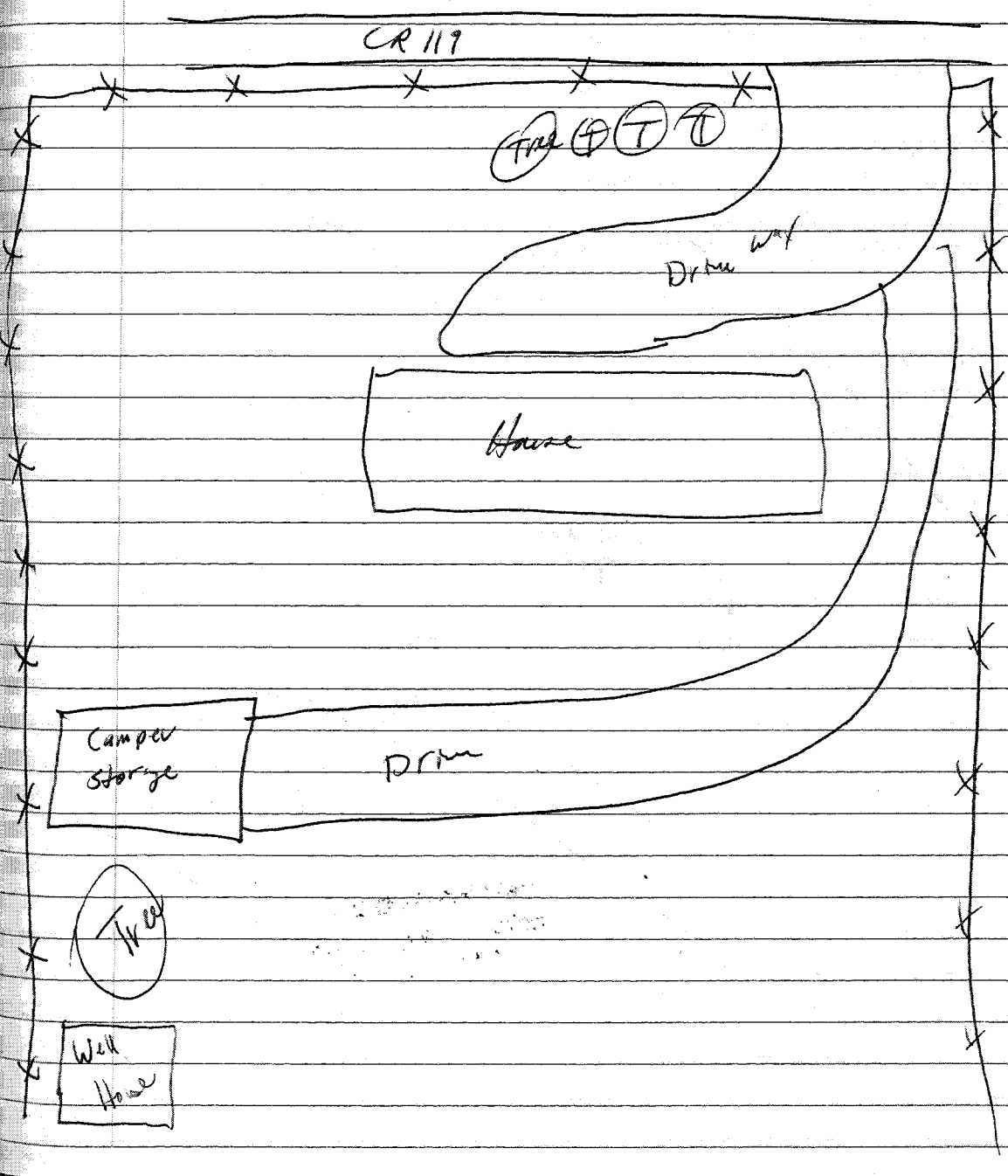
5/21



3rd Day of Sampling

5/21 CR 119
2709 W CR 116
Hector Enriquez

Sketch



Rt Mrs

3rd Day of Sampling

5/21/09

GW-119

Photograph 25 Outside photo of Well House

Photograph 26 - Inside photo of Well head

Reading	Time	Temp	pH	Cond
Initial	10:20	24.2	7.11	4.61
1	10:35	21.6	7.14	4.49
2	10:45	21.2	7.12	4.50
3	10:45	21.2	7.13	4.48

Sample TPH 1005 / Chrome
Sampled 10:47am

Rmuell

5/21

Third Day of Sampling

5/21 2312 - CR 116

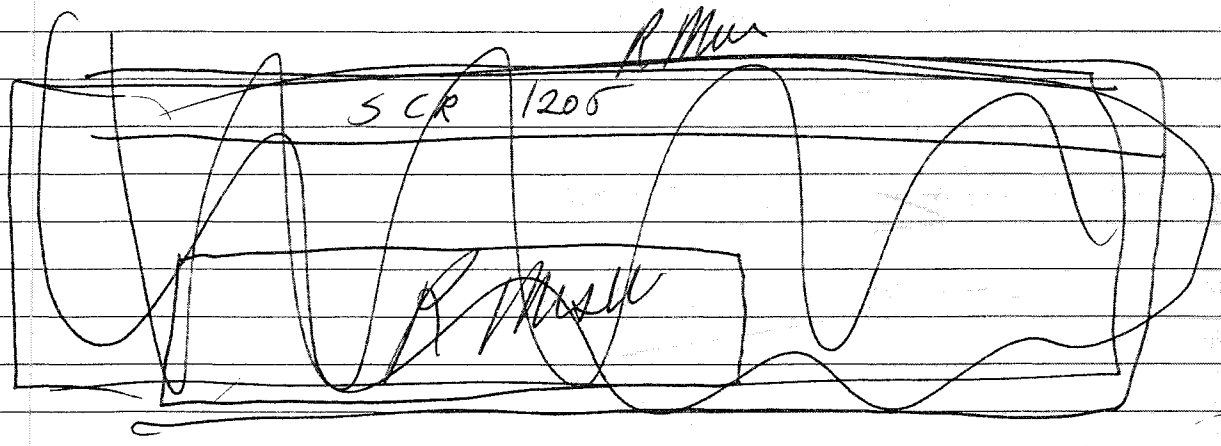
Wit Sample

5/2-1

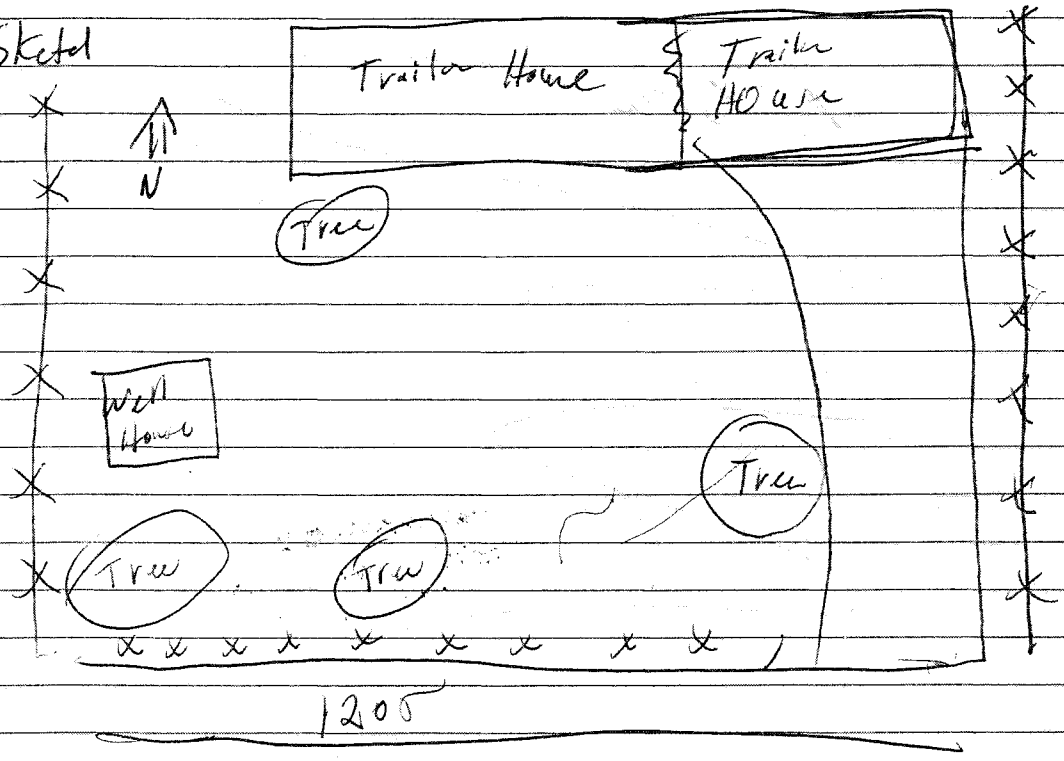
5/21 3005 SCR 1205 GW 129 / Dup 123
Alvarado

Arrived at approx 1 30pm

Sketch



Sketch



5/21

5/21 3005 CR 1205 GW-129 / GW-123 Dup
Alvarado

Started Purging Water at Approx 1:30pm

Reading

Initial	Time	Temp	pH	Cond
1	13:37	40.8	6.89	235
2	24.5	24.5	6.78	2:00
3	24.7	24.7	6.85	1.99
	24.6	24.6	6.77	1.96

1st time Sampling. No filter

Agricultural Use: Boards horses in back part of lot.

Photo 27 Closeup of Well House

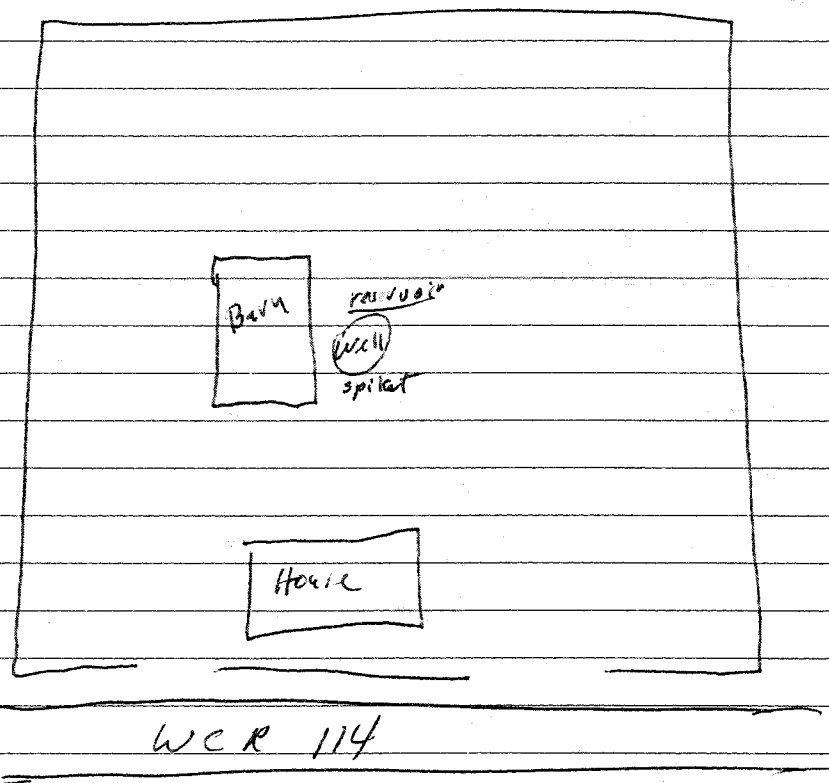
Photo 28 Far-off of Well House

GW 129 14:03
GW 123 Dup 14:18

5/21

5/21 GW-130 2000 WCR 114
Richard Creek

Sketch



Photography 29- Photo of well head looking toward barn

Purging

~~Reading~~ Initial	Time	Temp	pH	Cond
Initial	14:18	27.6	6.83	2.86
1	14:33	23.8	6.83	2.84
2	14:38	23.7	6.94	2.84
3	14:43	23.6	6.91	2.83

Sampled GW 130 at 2:44pm

5/21

Tank

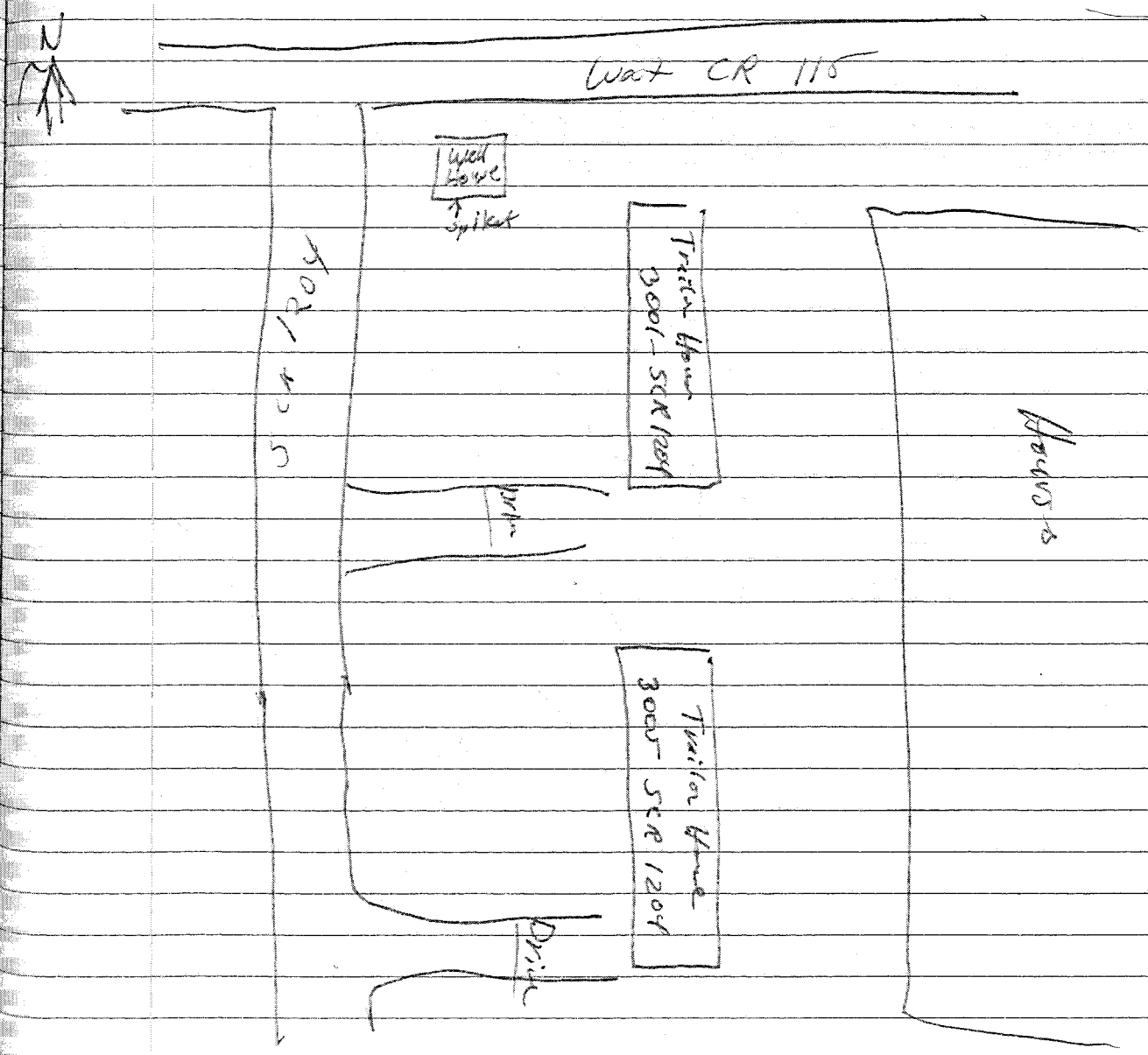
Tank

N

5/21 GW 132 Ratchel Gomez

For sites at 3001 and 3005 SCR 1204
Approx ½ mile from center
Talk Access Agreement obtained

Talk Need call from Toxicology to
Ratchel Gomez 432/238-6004



R Mueller

8/21 GW 132 Ratchel Gomez

Purgin

Reading	Time	Temp	pH	Cond
Initial	15:01	24.5	7.03	3.53
1	15:16	24.8	7.00	3.50
2	15:21	24.4	7.01	3.81
3	15:26	24.2	6.98	3.82

Sampled ~~at~~ GW 132 at 15:28

Photograph 30 - Photo taken looking north toward well house at corner of SCR 1204 and CR 115

102

[Keith Morgan
413-6110]

Referred

Shaw® Shaw Environmental, Inc.

Cody Goslin - 432-557-0214 - Will come to meeting on May 28th

Cindy Carlton 432-682-4976 Had well tested. No chrome in well

Scott Miles 432-230-3085 Outside area and well come to public meeting

Ernie Klatt - No Answer

Robert Macha 432/200-9667 - Attend Meeting

Gary Wiggins - Left invitation to attend public meeting

Francesco Alvarez Left invitation to attend public meeting

Jorge Ruiz - No Answer

David Davenport 432/687-4366

Susan Aubrey 432/686-9668 / {cell 432/352-6798}
Williams Tool Co Inc Rotating Control Heads
West of Mrs Aubrey. Use Chromium in process

6/9/9

7:00

~~8:00~~

7:30

5:00

3:34

7:05

6/9/9 W CR 112 GW PLUME SAMPLING
MIDLAND TX WEATHER CLEAR, CALM, WARM.
7:00 IRINA, DANI, + APRIL ~~DE~~ TRAVEL TO SITE.
~~8:00~~ AT SITE MEET CONTRACTOR, CONDUCT HEALTH
7:30 SAFETY MTG, DISCUSS PLANS FOR TODAY
MAIN SITE (JASON BROOKS, SHAW)
~~ALTERNATE~~ LOG IN / DANI ; THIS IS ALTERNATE
OR SECOND TEAM LOG

[REMIND DANI PH FROM EFFLUENT PORT]

8:00 Begin purging at Well #1
3109 S CR 1200 GW ~~150~~ 150, well at brick house
+ serving trailers
SOME BACKGROUND - HITS IN MID TO DEEP
RESULTS IN A FEW WEEKS, DANI WILL CALL
TESTING ONLY FOR HEX CHROME. THEY HAVE RUN
FULL SUITE TESTING AND DID NOT FIND OTHER COCS.
JUST HEX CHROME.

With one team probably 8 wells per day

USING ION EXCHANGE (CHLORIDE).
Send postcards about public meeting

8:34 Begin purge Well #2 @ 3109 S CR 1200 GW-151
~~South~~ EAST part of property, wells serving trailers

9:05 Begin purge Well #3 @ 3109 S CR 1200 GW152
serves southern, white house

6/9/9

9:55

10:22
10:24

10:30

10:30

10:56
11:11

12:00

12:26
12:29

6/09/09

2805 W CR 110 - Ramirez

9:55 GW-90A & C - begin purging

Reading	Time	Temp	pH	Cond
Initial	9:55	22.9	7.22	2.01
1	10:10	22.3	7.18	2.03
2	10:15	22.0	7.19	2.01
3	10:20	22.0	7.21	2.02

Totalizer Reading on Pump: 2004330

10:22 GW 90 A - take sample - influent, slight color

10:24 GW 90 C - take sample - no color (effluent) - difference in color noticeable

10:30 2901 W CR 110 - Billie Alland-Parish

GW 153

10:30 - begin purging

Reading	Time	Temp	pH	Cond
Initial	10:30	27.0	7.11	2.33
1	10:45	23.6	7.13	2.38
2	10:50	23.3	7.14	2.43
3	10:55	23.4	7.15 IA	2.48

10:56 GW-153 - take sample ~~Totalizer Reading: IA~~

11:11 GW-154 - duplicate - take sample

Photos 49 + 50 well and well house @ 2901 W CR 110, GW 153 due N, photographer = APRIL

12:00 2718 W CR 114 - Jose Uranga

GW-95 A & C

Reading	Time	Temp	pH	Cond
Initial	12:00	~~23.2~~	~~7.05~~	2.20
1	12:15	22.8	7.06	2.22
2	12:20	23.0	7.05	2.21
3	12:25	22.5	7.10	2.19

12:28 GW-95 A - take sample Totalizer: 0783090

12:32 GW-95C - take sample

4/9/9

13:08
13:10

13:53
13:55

Reading Time Temp pH Cond

1:30

6/09/09

GW-98A & C 2719 W CR 114 Mrs. Alsup

Reading	Time	Temp	pH	Cond
Initial	12:41	24.5	7.1	2.13
1	12:56	22.7	7.09	2.22
2	13:01	22.3	7.09	2.24
3	13:06	22.2	7.14	2.23

13:08 GW-98A - take sample
13:10 GW-98C - take sample Totalizer: 769945

GW-93 A&C 2714 W CR 114 James Dickens
~~GW-97A & C 2606 W CR 114 Della Holiedy~~ 1A

Reading	Time	Temp	pH	Cond
Initial	13:22	26.4	7.05	2.34
1	13:37	23.4	7.12	2.35
2	13:42	22.3	7.13	2.35
3	13:47	21.9	7.18	2.34
4	13:52	21.8	7.12	2.35

13:53 GW 93A - take Sample
13:55 GW 93 C - take sample Totalizer: 0075640

Another well at the front of the house - used as back up
- goes to a butane tank for storage - not for drinking
- requested to sample

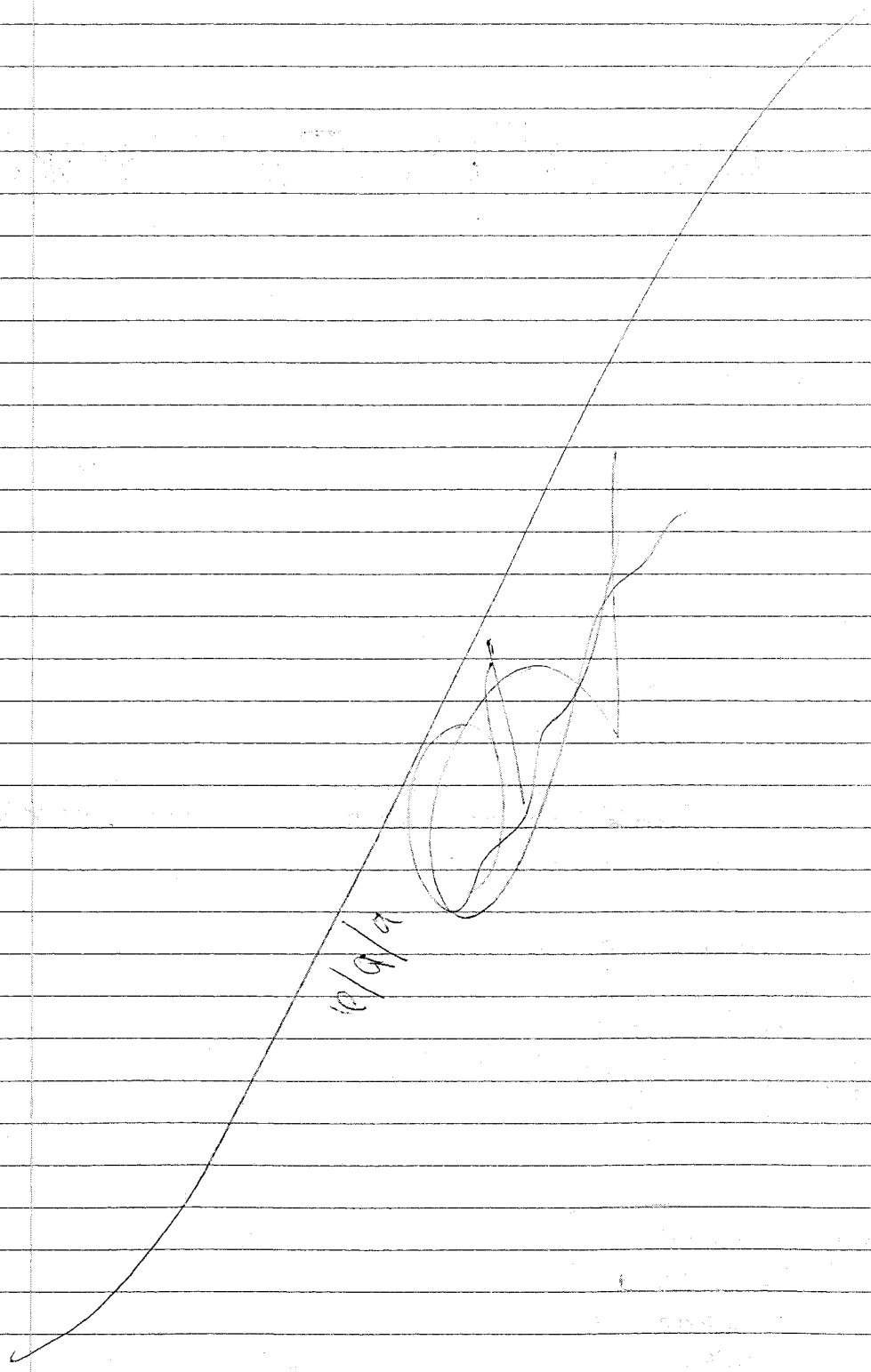
GW 92 A&C 2708 W CR 114 Aleta Elder

Reading	Time	Temp	pH	Cond.
Initial	14:17	25.4	7.21	2.35
1	14:32	25.0	7.15	2.28
2	14:37	23.5	7.19	2.31
3	14:42	22.8	7.14	2.31
4	14:47 ~~14:52~~	22.7	7.18	2.33 Totalizer - 72800

Reading Time Temp pH Cond
5 14:52 22.5 7.16 2.30

media onsite - video interview, video footage
- CBS National, ABC - local

1:30 - GW-93 - Commissioner Sanchez and Bob Bowcock, Kay Beauchamp (2700 W CR 114)
- Observed sampling, talked about sampling location, waterline location



14:53
14:55
14:45
~~14:53~~
~~14:5~~
15:28
16:25
17:00

14:53 GW 92 A - take sample
14:55 GW 92C take sample
14:45 Bob Patton came to 2708 w CR 114 for ~~an~~ a video interview with ABC local news

~~14:53~~
~~14:5~~

15:28 TO TOMMY FLORES Property, GW-29 + DUP GW-155
2609 W CR 114
Begin purging well

Reading	Time	Temp	pH	Cond
1	~~15:43~~ 15:28	25.7	7.14	2.02
2	15:43	26.1	7.11	1.99
3	15:48	25.1	7.10	1.99
4	15:53	23.0	7.10	2.04
5	15:58	22.7	7.16	2.07
6	16:03	22.5	7.11	2.04

Pump is set at 40' well depth 80'

Weather update humid, still, hot, sunny.

GW-29 sample time 16:05
GW-155 Sample time (DUP) 16:20

16:25 Depart site
17:00 Arrive at hotel (end of day)

6/9/9

700
730

744

820
828

~~8~~91

Cancelled
6/9/9

16/10/9 Sampling 2nd Day

700 Depart for site

730 Meet @ Mr HOWARD'S GW 95 A+C, 2701 W CR114
CONDUCT HEALTH SAFETY
WEATHER CALM, CLOUDY, HUMID, WARM

744 Begin purge HOWARD

READING	TIME	TEMP	PH	COND
initial	7:44	21.2	7.30	2.11
1	7:59	20.8	7.25	2.10
2	8:04	21.0	7.24	2.09
3	8:09	21.0	7.23	2.09
4				

Beverly Crach 2414 call w/specific time
Mr Phillips request call ahead, please change filter
Rodney Cargill, call an hour ahead
James Scoggins, not home thurs, but OK to sample
Avidio Ramos + Ring net not yet contacted

820 TO MAY BEAUCHAMP 2700W CR114, LOCK ON FILTER SHED
Luis Villanueva 2605 W CR114, GW96A+96C

828 Begin purge sampletime 8:55 8:57

READING	TIME	TEMP	PH	COND
initial	8:28	21.2	7.25	2.10
1	8:43	21.4	7.21	2.10
2	8:48	21.3	7.23	2.09
3	8:53	21.2	7.22	2.09

906 Head to GW 97 A+C, Della Holiedy,
2606 W CR114

6/10/9

9:

10:

11:

GW97-A + 97-C CONT 6/10/9

Reading	Time	Temp	pH	Cond
Initial	9:05	21.2	7.28	2.02
1	9:20	21.4	7.24	2.03
2	9:25	21.3	7.24	2.02
3	9:30	21.4	7.24	2.03
4				

GW-97A 9:31 GW-97C 9:34

9:45 TO SISSY BEAUCHAMP 2700 W CR114
GW-91A + GW-91C , DUP - GW-155
TIME 10:11 10:14 10:29

READING	TIME	TEMP	PH	COND
Initial	9:45	23.6	7.16	2.16
1	10:00	22.3	7.16	2.23
2	10:05	22.2	7.15	2.23
3	10:10	22.3	7.15	2.24

10:40 TO TOMMIE MITCHELL 2402 W CR114
GW-101A + GW-101C
SAMPLE 11:12 11:14

READING	TIME	TEMP	PH	COND
Initial	10:41	25.5	7.19	1.84
1	10:56	24.4	7.15	1.80
2	11:01	23.5	7.18	1.85
3	11:06	23.3	7.18	1.87
4	11:11	23.1	7.18	1.87

11:15 TO LARRY MITCHELL, 2500W CR114
GW100A + GW100C
Sample 11:50 11:52

10/10

CONT 8/10/9

11:19 WEATHER CLEAR, SLIGHT BREEZE, HOT!!

Reading	Time	Temp	pH	Cond.
Initial	11:19	24.2	7.25	2.10
1	11:34	24.1	7.22	2.11
2	11:39	23.1	7.22	2.11
3	11:44	23.1	7.20	2.11
4				

12:10 GW-125 A&C 2601 W CR 114 - Mr Philip (Bill Morgan)

Reading	Time	Temp	pH	Cond
Initial	13:10	25.6	7.13	1.86
1	13:25	24.6	7.14	1.94
2	13:30	23.1	7.17	1.96
3	13:35	22.9	7.14	1.99
4	13:40	22.9	7.13	1.96

13:41 GW-125A - collect sample
13:43 GW-125C - collect sample
13:45 Change in 5 micron filters Totalizer: 426367

13:55 GW-99 A&C 2501 W CR 114 - Larry Michell

Reading	Time	Temp	pH	Cond
1				
2	No purge - sample taken from large reservoir			
3				
Initial	14:00	25.7	7.54	1.90

14:02 GW-99A - collect sample
14:04 GW-99C - collect sample

14:15 GW 103 A&C 2414 W CR 114 Beverly Crouch
No purge - large tank

Reading	Time	Temp	pH	Cond
Initial	14:17	30.4	7.30	1.45

6/10/09

14:22
14:22

14:30

*

14:3
14:38
14:5

15:1
*

15:4
15:4
16:0
16:1
17:0

6/10/09 cont

14:20 GW 103 A - collect sample
14:22 GW 103 C - collect sample

14:30 GW 102 A&C + dup 2413 W CR 114 Danny Marchant
- No purge large tank
* Bypass valve was open

Reading	Time	Temp	pH	Cond.
Initial	14:35	33.2	7.56	1.49

14:37 GW 102 A - Collect sample
14:38 GW 102 C - collect sample
14:53 GW 157 - collect sample : duplicate

15:12 GW104 2604 S CR 1200 James Boggins
* valve A has a reducer on it so purging ~~and~~ ~~the~~ will be done through valve C

Reading	Time	Temp	pH	Cond
Initial	15:13	26.6	7.22	1.60
1	15:28	22.2	7.25	1.60
2	15:33	22.8	7.27	1.62
3	15:38	22.5	7.27	1.62 515425 - Totalizer
4	15:43	22.8	7.26	1.60

15:45 GW-104 A - Collect sample
15:47 GW-104 C - collect sample
16:02 GW-158 (dup) collect sample
16:15 left site to do site recon
17:00 Arrive at Hotel

7:30
8:0
8:05

8:21
8:5
8:5

9:0

6/10/19

9:36
9:38

9:4

6/11/09

7:30 Leave Hotel
8:00 Arrived at 2800 W CR 111
8:05 Site recon and prep
RigNet and Blazing Safety and Consulting - Byron Fender
2803 and 2801 W CR 111
GW 80 A&C

Reading	Time	Temp	pH	Cond
Initial	8:22	23.0	7.01	2.28
1	8:37	22.9	7.08	2.32
2	8:42	22.3	7.08	2.32
3	8:47	22.0	7.07	2.33
4	8:52	22.9	7.11	2.32

8:21 Safety meeting when started purging. Totalizer 200
8:53 GW 80 A - collect sample
8:55 GW 80C - collect sample

9:00 GW 81 A&C 2802 W CR 111 Petroplex

Reading	Time	Temp	pH	Cond
Initial	9:05	23.1	7.10	2.84
1	9:20	23.0	7.07	2.77
2	9:25	22.0	7.08	2.78
3	9:30	21.9	7.09	2.81
4	9:35	21.8	7.08	2.65

Totalizer: 0002321

9:36 GW 81 A - collect sample
9:38 GW 81C - collect sample

9:40 GW 86 A&C - 2800 W CR 114 Petroplex

Reading	Time	Temp	pH	Cond
Initial	9:40	22.4	7.07	3.18
1	9:55	22.8	7.10	3.19
2	10:00	22.0	7.14	3.22
3	10:05	21.8	7.13	3.32
4	10:10	21.6	7.16	3.21

Totalizer: 0000778

GW 86 A - 10:12 (yellow) GW 86 C - 10:14

10:4

*

11:20

11:11

11:26

*

11:5

12:1

1:3

7

G/S

14

6/11/9

10:40 GW 105 A & C & Dup. - Pete Alcer 2524 S CR 1200

Reading	Time	Temp	pH	Cond.
Initial	10:43	24.3	7.20	1.89
1	10:58	22.1	7.20	2.06
2	11:03	21.8	7.29	1.78
3	11:08	21.8	7.27	1.76

Totalizer 127617

* One faucet is not filtered - behind metal building. Y is off before filter system

11:09 GW 105 A - collect sample

11:11 GW 105 C - collect sample

11:20 GW 159 (dup) - collect sample

* Burning pile of unsorted trash and metal containers (oil?)

GW 126 A & C 2000 CR 1200 Ovidio Ramos

Reading	Time	Temp	pH	Cond
Initial	11:37	25.9	7.99	1.78
1	11:48	22.9	7.12	1.75
2	11:53	22.6	7.14	1.76
3	11:58	22.4	7.14	1.78

Totalizer 2284836

11:59 GW 126 A - collect sample

12:10 GW 126 C - collect sample

1:32 GW 160 Trace Engines 2800 W I-20

Reading	Time	Temp	pH	Cond
Initial	13:40	32.5	7.03	2.08
1	13:55	25.7	7.04	2.08
2	14:00	23.5	7.06	2.16
3	14:05	23.0	7.08	2.18
4	14:10	23.0	7.10	2.16

* (Clear)

* Haven't been drinking the water.

G/S N 31.96726°
W -102.10159°

14:11 GW 160 - collect sample

6/11/9

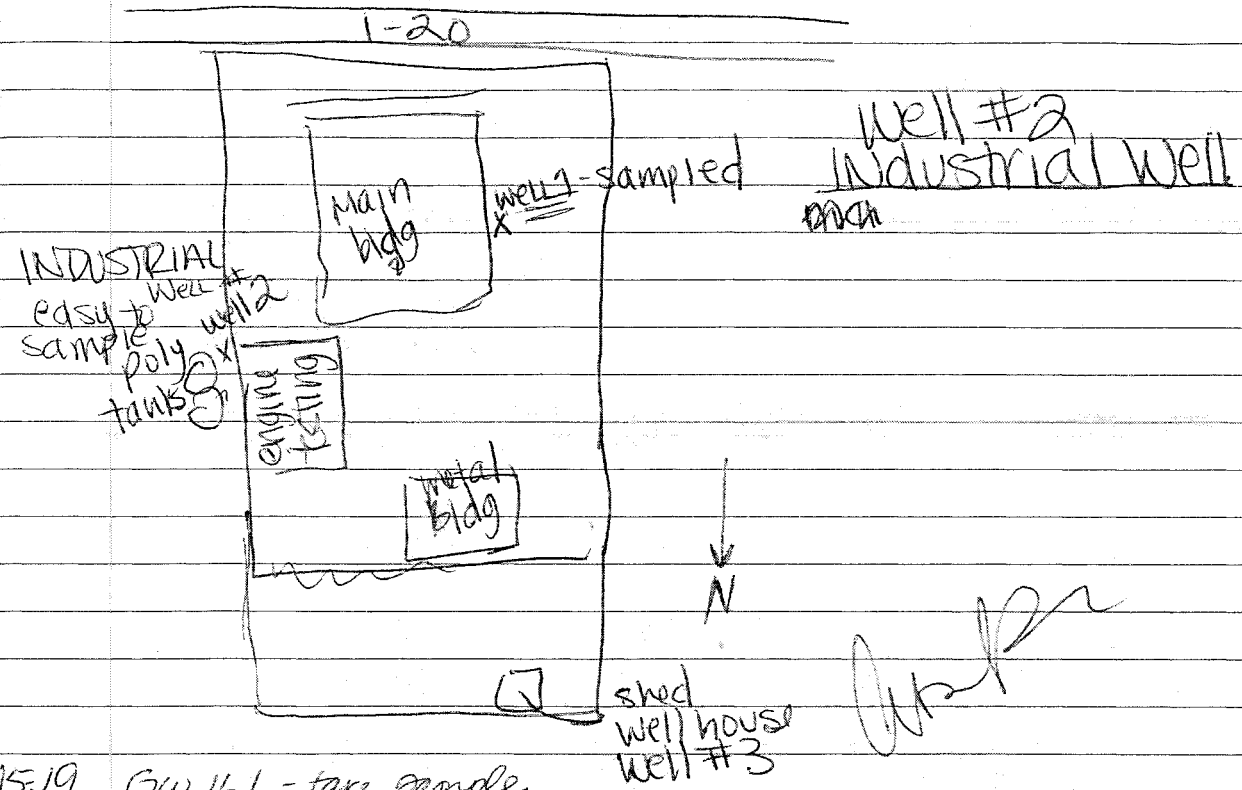
IN
ec
sa

15:1

G/S

6/11/9

GW-160 CONT
3 wells on property, one sampled. See sketch below



15:19 GW 161 - take sample
2817 SCR 1197 + 2824 SCR 1196 Artemio Ataupe
(James Chavez)
- Shared well (2 kids + 2 adults) + (2 kids + 2 adults)
- do not drink water, use it for showering
GIS 31.96191° N
- 102.08437° W

	Reading	Time	Temp	pH	Cond
Initial	~~[illegible]~~	@ 14:48	33.0°C	7.01	1.91
	1	15:03	23.5	7.11	1.93
	2	15:08	22.1	7.11	1.93
	3	15:13	22.0	7.12	1.96
	4	15:18	21.7	7.13	1.94

* well in small shed w/ no door

15

G
we

15:

16

G
we

16:
17:

15:30 GW 162 - 3007 SCR 1197 Rodolfo Sanchez
+ Dup GW 163 (2 adults, 2 children)

Reading	Time	Temp	pH	Cond.
Initial	15:32	26.6	7.22	1.68
1	15:47	26.8	7.11	1.61
2	15:52	26.9	7.04	1.75
3	15:57			

* Sample taken early due to loss of pressure, sediment load

GPS well 31.96053° N
-102.08443° W

* lots of sediment, brown water

15:55 GW 162 - Sample taken early due to dropping pressure; at least 3 readings are consistent

16:10 GW 163 Duplicate taken.

GW 164 - 3101 SCR 1198 Jeanne Butler

* Slow recharge, pressure is very low, but steady

Reading	Time	Temp	pH	Cond
Initial	16:10	30.0	6.85	3.82
1	16:25	25.5	6.90	3.74
2	16:30	23.9	6.91	3.78
3	16:35	23.6	6.92	3.79
4	16:40	23.5	6.93	3.78

* the well is on the SE corner of the property, and there used to be hook-ups for RVs

GPS well 31.95841° N
-102.08466° W

* sampled in front of house

16:41 GW 164 - collect sample

17:00 Depart Site. Finished for the day.

6/11/09

END OF EVENT

6/11/9

Reference 18

WCR112 TCEQ - SSDAP SAMPLING FIELD NOTEBOOK #4

6/15/09 Alan Anderson

0800 Tailgate safety meeting given by Micah. Present Craig Watts, Sam Lilly, Micah Beard, Alan Anderson

0820 Stopped at 2710 WCR 112 (Bowers) Bowers not home but Ms Bostwick (neighbor) let us into well house GW137

0825 begun purge 018742 totalizer reading

	Temp.	pH	Cond in (mS/cm)	Total
0825	25.7	7.05	3.13	018742
0840	23.4	7.10	3.01	
0845	22.4	7.09	3.01	
0850	22.1	7.09	2.99	
0855	22.1	7.10	3.00	018710

valves config correct

30 min 98

3.27 gpm

0859 Sampled GW137-B no preservative 500ml Groundwater, well depth unknown

0900 Sampled GW137-C no preservative 500ml GW, well depth unknown

0901 custody seal placed both bottles

0902 Well house door shut, samples to cooler

0908 Arrived 2700 WCR 112 Ms Brock GW138

0910 Showed me results from B. Bowcock 21 May 09 Total Chrome 980 ppb
Cr6 859 ppb
Cr6 in house ND
TPH ND

0913 Begun purge - Valves config correct

	Temp C.	pH	Cond	Totalizer
0913	27.3	7.14	3.39	037373
0928	24.5	7.19	3.37	
0933	23.1	7.20	3.32	
0938	22.5	7.20	3.33	037370
0943	22.2	7.21	3.32	2.8 gpm 57 gal

6/16/09 Last item Alan Anderson

6/16/09 [signature]

2

0943 Final totalizer 0373780.4
0945 Sampled GW138 B 500ml no pres at time
0946 Sampled GW138 C 500ml WB unknown
0948 Sampled GW200 C duplicate of GW138C
Sample time 1003 on manifest
0950 Custody seals placed all 3 bottles put in cooler. Left property
0955 Arrived 2604 WCR112 GW143
Laing Property Man away with key
Will return Wednesday
1001 Arrived 2514 WCR112 A Costa GW139
Totalizer Reading 0045190.6
1006 Began purge Temp C° pH Cond 000519

1006	25.2	7.19	2.25
1021	23.5	7.14	2.22
1026	22.9	7.14	2.23
1031	22.7	7.14	2.22

1033 Sampled GW139B 500ml no pres 0005240.5
1035 Sampled GW139C 500ml no pres. 2.0gpm 50gal
1040 Custody seals placed, put in cooler valves proper
1043 Called Clintons @ 2502 WCR112
1045 Arrived 2502 WCR112 (Clintons) 3489855 total
1045 Began purge Temp C° pH Cond

1045	23.1	7.12	2.13
1100	22.5	7.08	2.10
1105	22.3	7.08	2.09
1110	22.5	7.09	2.10

3490030
7.00gpm 175gal

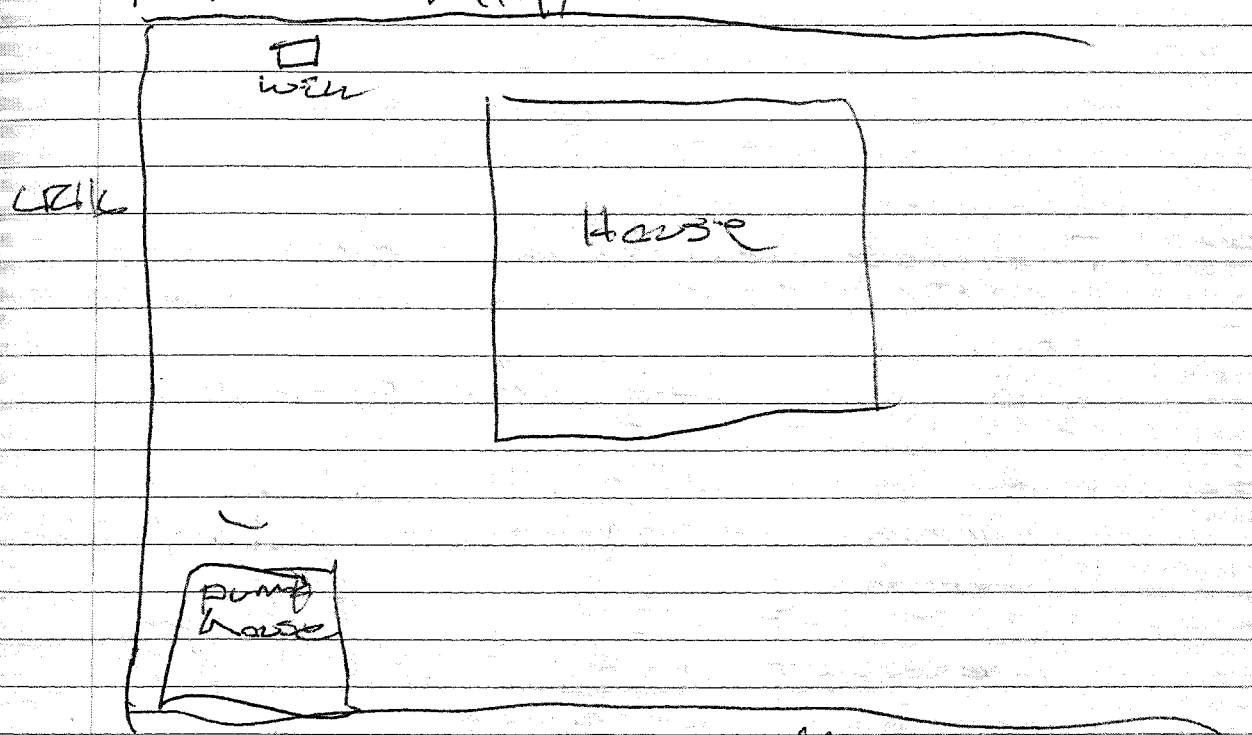
1113 Sampled GW142B 500ml
1114 Sampled GW142C 500ml
1115 Custody Seals placed put in cooler valves properly config
1128 Called Ms Navarrete GW-165
1131 Arrived @ 3100 SCR1197
LAST ITEM [signature] 6-16-09

6/16/09 Alan Hudson

House has no system but has 1100 gal poly tank.

1140 Pulled grab sample from poly tank. GW-16S

1147 Micah took photo inside shed facing poly tank & pressure tank



1150 Micah took photo of well looking NE

1154 Sam & Craig took GPS coord of well

1151 Left 3100 S. 1197

1152 Arrived 3018 S. 1197 GW 171 (Garcia) Sam and Craig sampled.

1225 Left Garcia house & went to lunch

1336 Arrived 2818 SCR 1197 (Subia) GW 170 well runs 2818, trailer behind & trailer NW Husband not home w/key. Coming now, 2700 gal black poly tank Trailer behind 2811 SCR 1197, NW trailer 2809

1354 Last Item Alan Hudson 6-16-09

6-16-06 Alan Henderson

4

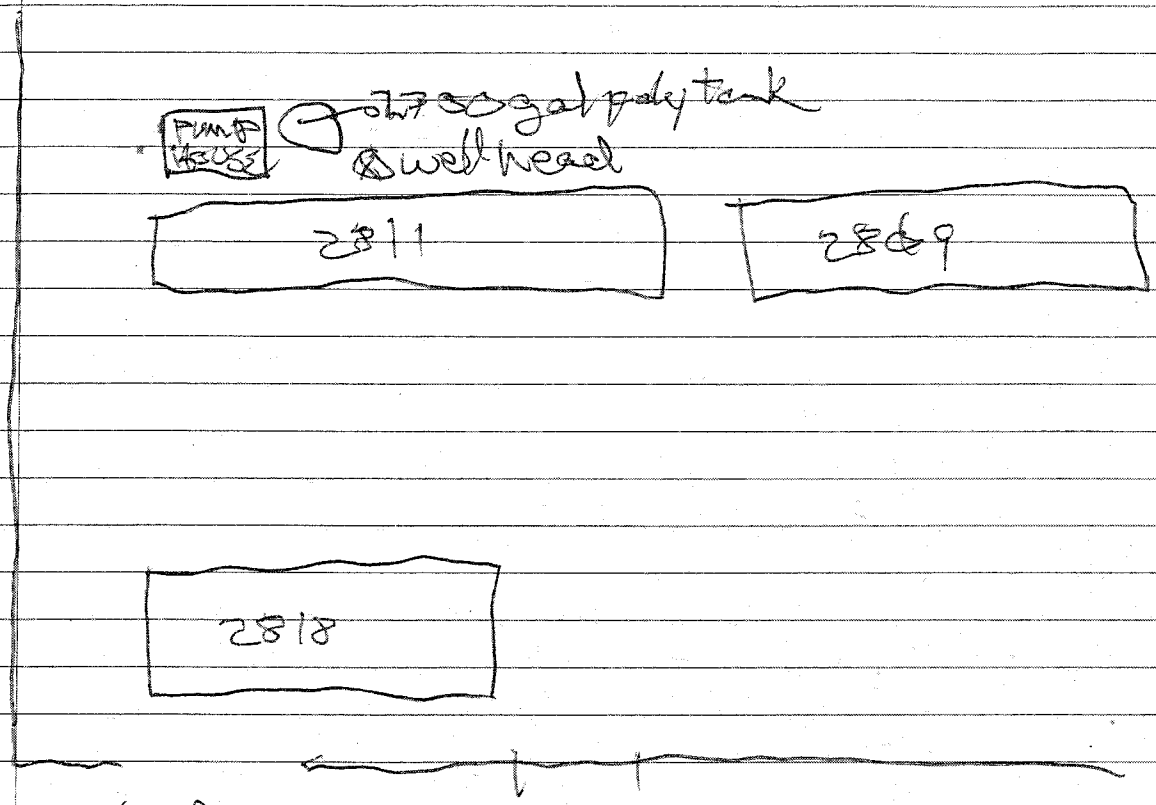
1356 Owner bled off pressure tank
Well pumps at 1 gpm
Well thru filter, thru pressure tank
to 2700 gal poly tank, then pumped
to house. Well pumps dry in about
13 minutes so purging for 10 minutes
then sampling
1400 Photo GW-170-156
Shows 2818 SCR 197 on left 2811 behind,
2809 on right rear. Looking West
Alan Henderson
1402 Photo emergency tank to store purge
water Henderson Looking West GW-170-151
1359 Began purging
1406 2700 gallon ~~poly~~ holding tank black poly
Photo GW-170-152
1409 Photo GW-170-153 well head on right
2700 gal poly tank on left looking NNW
Henderson
1411 Photo GW-170-154, 1100 gal poly tank,
pressure tank, prefilter inside
pumphouse, Henderson
1413 Take sample GW170
Photo of sample collection Henderson GW170
1415 Custody seals placed on sample bottle
1417 GPS reading - sketch next page(s)
1420 Left 2818 SCR 197

LAST ITEM

Alan Henderson 6-16-09

6-16-09 Alan Henderson

1420 Sketch of 2818 SCR 1197



1430 Arrived 2800 SCR 1197 GW-173
1438 Began Purging Temp°C pH Conductivity mS
1438 28.2 6.94 3.61
1453 25.2 6.95 3.56
1458 23.1 6.98 3.55
1503 23.0 6.98 3.54
1508 23.0 6.99 3.62
1442 Photo GW-173-156 Well house looking East
Henderson
1443 Photo GW-173-157 well inside well house
1451 Took GPS coord
1509 Collected Sample GW-173
1510 Collected Duplicate Sample GW-202
Duplicate of Sample GW-173, manifest # 001525
→ LAST ITEM Alan Henderson 6-16-09

6-16-09 Alan Henderson

1511 Custody Sealed samples & put in cooler
1515 Left 2800 SCR 1197 and went to 2801 SCR 1198
1516 Arrived 2801 SCR 1198 GW183
1518 Began purge

	Temp °C	pH	Conductivity
1518	24.9	7.18	2.18 mS
1533	23.4	7.18	2.15
1538	22.9	7.16	2.15
1543	22.8	7.19	2.12

1525 Received access agreement from Mr Jurado @ 2801 SCR 1198
1546 Received access agreement from Juan Jurado @ 2810 and 2812 SCR 1197
1546 Took sample GW183
1549 Put custody seal on sample & put in ice chest
Photo GW183-158 pump house @ 2801 SCR 1198 Looking NNW - Henderson
1555 Left 2801 SCR 1198
1558 Arrived 2810 SCR 1197. Wellis in front of 2810 and services 2810 & 2812. Water runs thru buried garden hose to 2812. Purging from front spigot of 2812 GW167 (2812 SCR 1197) MS Quintela. 2810 owned by Juan Jurado

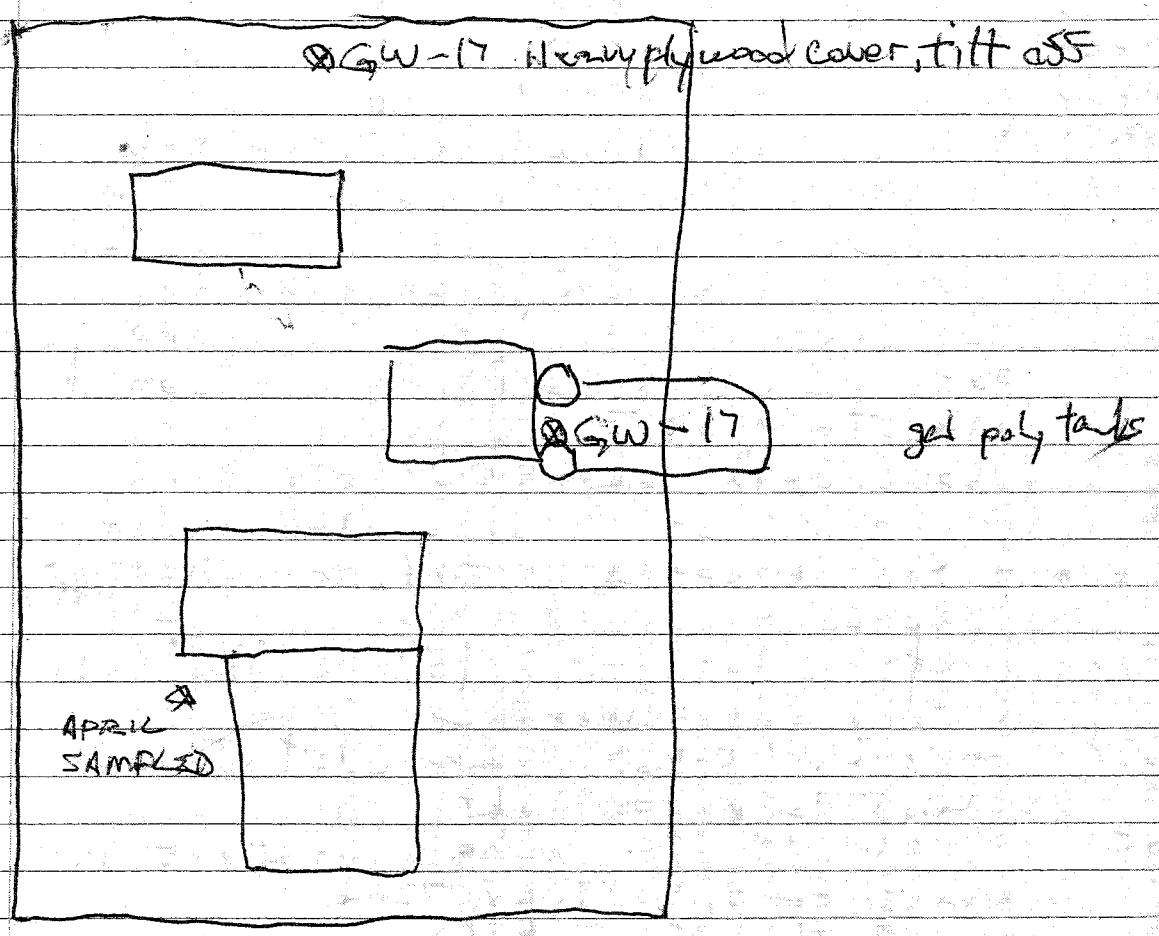
1609 Began purge

	Temp °C	pH	Conductivity
1609	31.3	7.301	2.18
1624	26.7	7.03	2.30
1629	24.6	7.07	2.35
1634	24.2	7.05	2.37
1639	24.0	7.08	2.33

1630 Sam GPS'd 2810 (2812) SCR 1197
1632 Sam GPS'd 2801 SCR 1198
1641 Took sample GW167
1642 Custody sealed sample & put in cooler. Took to Xenco
LAST ITEM Alan Henderson 6-16-09

6-17-09 [illegible]

0800 Tailgate Safety mtg. Emphasized heat stress
0812 Left for Trace to sample wells
0820 Arrived @ Trace Engines and signed in GW178, GW179



T20 North Access Rd

		Temp °C	pH	Conductivity
0835	Began purge			
0835		23.6	6.99	2.01
0850		23.8	7.03	1.97
0855		22.3	7.02	1.94
0900		21.9	7.04	1.95
0905		21.7	7.03	1.97

0910 Sampled and placed custody seal
0910 Gabriel brought sample results for pad water
Last entry [illegible] 6-17-09

6-17-09 Alan Henderson

0915 Moved to GW 178

		Temp °C	pH	Conductivity
0912	Began Purge			
0926		29.4	8.42	1.89
0936		30.4	8.55	1.87
0941		30.7	8.55	1.87
0946		30.4	8.56	1.87

0947 Took sample GW-178 added custody seals

0920 Talked to David Czarnecki of Trace (facilities manager) about an MW being drilled on Trace property. Schlumberger will be drilling in a few days. Told David we would like to have Shane geologist log the core and take split samples.

0935 Photo of GW-179-161 well on far north end of Trace property. Looking North Henderson

0936 Photo of GW-179-162 looking down at well inside plywood cover.

0950 Photo GW 178-163 looking West at well and 2-5Kgal poly tanks

0951 Photo GW 178-164 looking north at prefilter and spigot of south poly tank

0952 Photo GW 178-165 looking SW at polytank, cooling tower, pump building for cooling tower, dynamometer building (rear) and engine test building right.

0954 Note sample was pulled from south poly tank because no spigot directly off well. pH and Conductivity different because of chemicals added for cooling tower

1015 Stopped @ home residence. Not home. Left cell phone message

Last item Alan Henderson 6-17-09

6-17-09

		Temp °C	pH	Cond	Totalizer
1030	Began purging				
1035		26.1	7.36	2.48	0241396
1045		23.4	7.42	2.51	
1050		23.4	7.40	2.51	
1055		22.8	7.37	2.51	0241458

1100 Collected sample GW143B 248 g/min 62 gal
1105 Collected sample GW143C
System in breakthrough first tank
because GW143B pale green, GW143C clear.
1110 Left heading home
1112 Arrived Cotton Flat Green (GW146) 2405 SCR 114
1119 Collected sample GW146B
1119 Collected sample GW146C
Did not purge due to large poly tank
1120 Mr Stevenson stated that the Ultrapure piping has a leak that needs to be baked out
1145 Arrived at Natividad Residence (GW166) at 3119 SCR 1198. No one home. Called Mr Natividad who said wife would be there in about 10 minutes

		Temp °C	pH	Conductivity
1207	Began purge			
1207		37.0	7.37	2.71
1222		25.1	6.77	4.26
1227		23.8	6.78	4.23
1232		23.0	6.76	4.35
1237		22.8	6.79	4.19

Sam GPS'd well
1234 Photo GW166-166C well looking north taken by Henderson.
1240 Took sample GW166, labled and placed custody seal
1335 Arrived 3005 SCR 1205 (GW174).
Sprinkler running from well tap so only taking 5 minute purge intervals
No one home so leaving door tag hanger
Last item on this order 6-17-09

10 6-17-09 Alex Henderson

1334 Began purging Temp°C pH Conductivity

	Temp°C	pH	Conductivity
1337	24.6	7.29	2.02
1342	22.5	7.33	1.99
1347	22.1	7.29	2.01
1352	21.9	7.31	2.04

1345 Photo GW174-167 Well looking North taken by Henderson

1346 Photo GW174-168 Well house with trailer behind looking SE Taken by Henderson

1354 Took sample GW174, labled & placed custody seal

LAST ITEM Alex Henderson 6-17-09

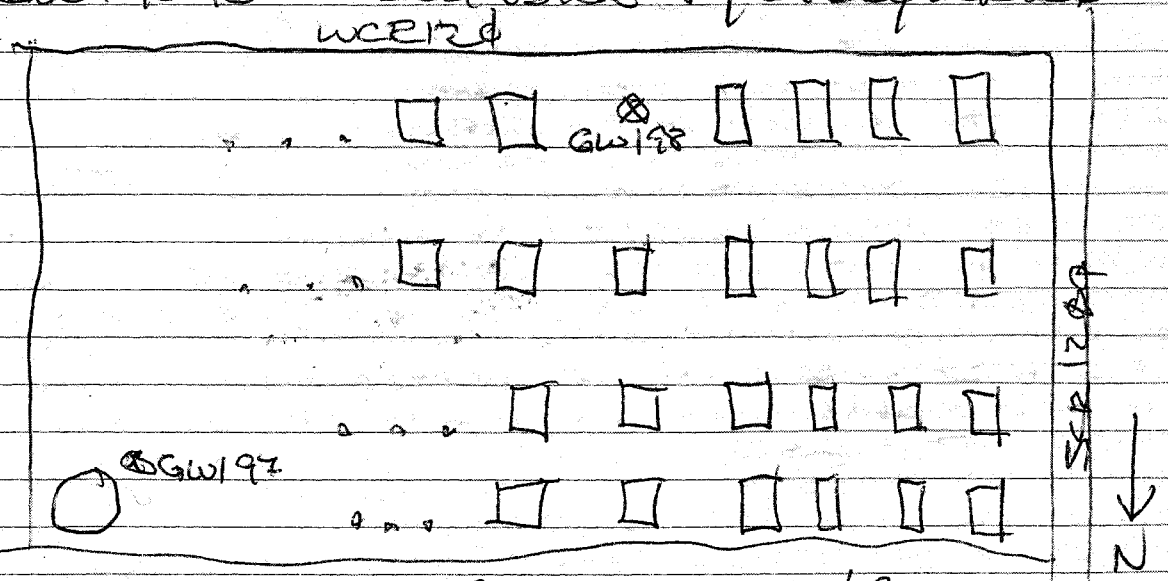
6-18-09 [illegible]

0800 Tailgate Safety Mtg.
0805 Arrived @ Johns Trailer Park (GW197 & GW198)
Both wells located in NE corner of trailer park. East well is GW198, west well is GW197. No pressure on spigot of ~~GW198~~ east well, maybe pump off.
0810 Photo GW197/~~198~~-169 looking north by Henderson
Photo GW197-170 looking east into well house by Henderson

0815 Began purge GW197

	Temp °C	pH	Conductivity
0815	22.1	6.90	3.11 mS
0830	21.9	6.94	3.07
0835	21.6	6.95	3.05
0840	21.7	6.97	3.06

0845 Sampled GW197
0845 Sampled GW197 duplicate #GW~~20~~197-204 Time 0900 on manifest
0848 Labeled and custody sealed samples.
0855 Talked to Mr. Jackson. East well is dead. GW198 is on southside of park by WCR120



LAST ITEM [illegible] 6-18-09

6-18-09 Alan Henderson

		Temp °C	pH	Conductivity
0857	Began purge GW198			
0857		22.2	6.88	3.34 mS
0912		21.5	6.85	3.28
0917		21.2	6.84	3.30
0922				

Photo GW198-171 Well house looking south toward WCR120, by Henderson

Photo GW198-172 Well w/ 3 pressure tanks toward NNE, by Henderson

PWS GW197 is #54 on WW Survey map G1650043A

PWS GW198 is #60 on WW Survey map G1650043B

0930 Took GW-198 sample, labeled & custody sealed.

0945 Arrived Vega residence. No spigot on well GW192

		Temp °C	pH	Conductivity
0958	Began purge			
0958		24.5	6.95	3.08 mS
1013		24.5	6.90	3.05 mS
1018		23.9	6.90	3.09 mS
1023		23.2	6.91	3.07 mS

Nearest faucet is in horse corral

Photo GW192-173 looking west into well house. No spigot but big black widow spider. by Henderson

Photo GW192-174 looking west at well house. Across fence from John's Trailer Park GW197, by Henderson

Photo GW192-175 nearest spigot in horse corral looking west by Henderson

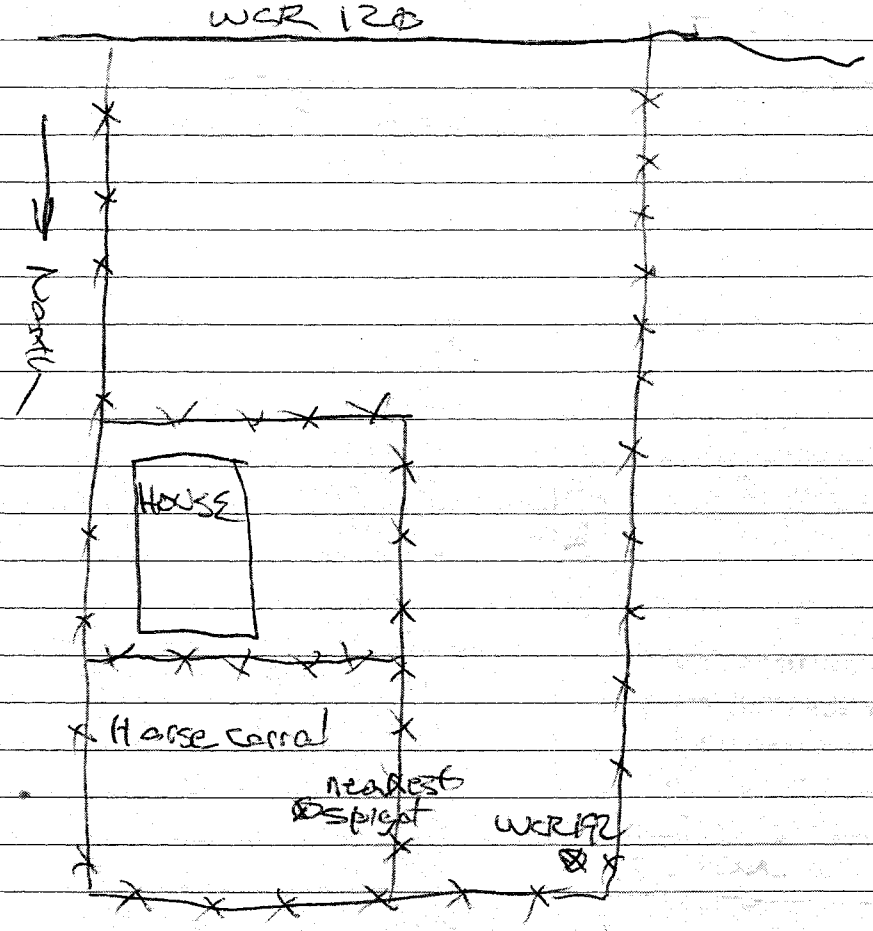
1026 Sampled GW192, labeled & custody sealed

1030 Left Vega residence went to 1916 WCR120

LAST ITEM

Last Item Alan Henderson 6-18-09

6-18-09 Alan Henderson
sketch of 2000 WCR120



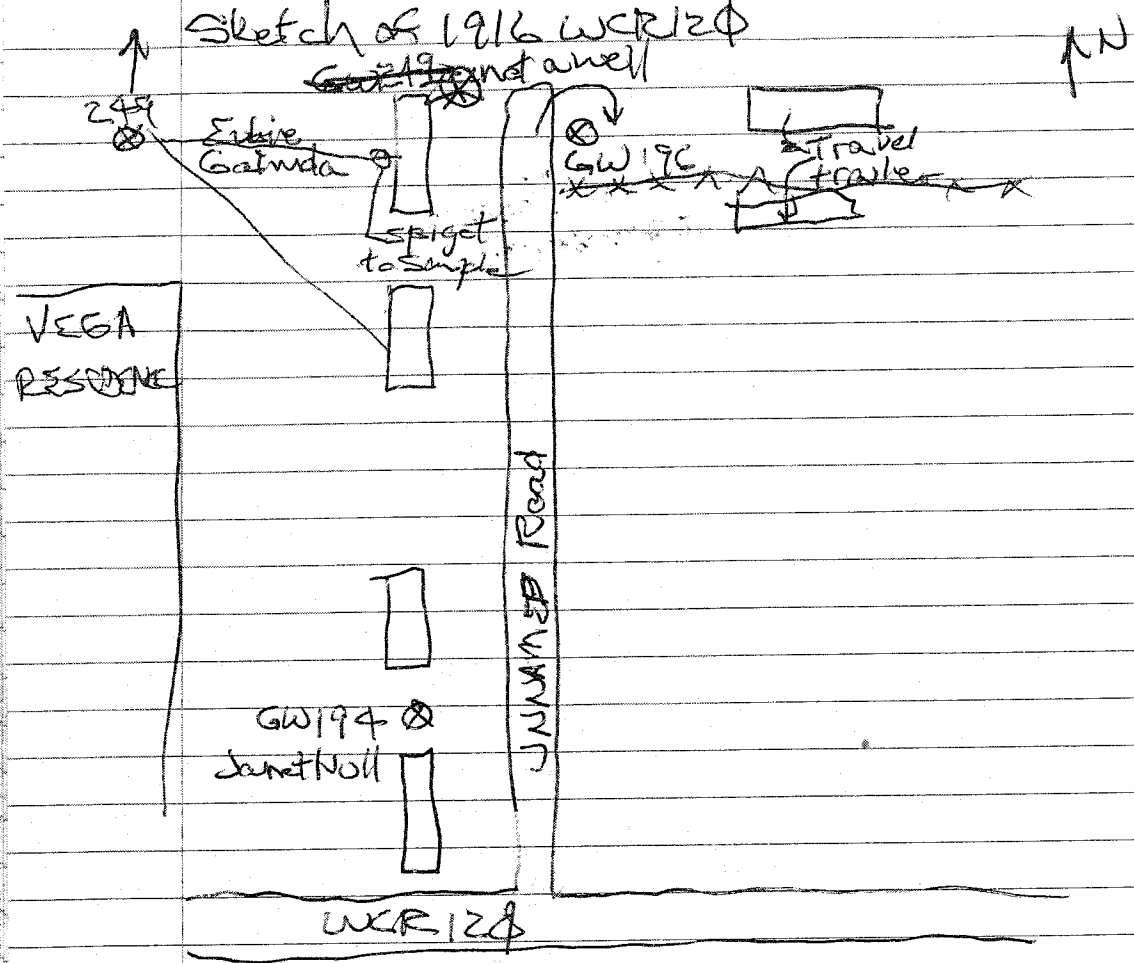
1045 Arrived @ 1916 WCR120 GW-194

		Temp °C	pH	Conductivity, mS
1048	Began purge			
1048		23.3	6.90	2.90
1103		22.2	6.91	2.86
1108		21.7	6.91	2.88
1113		22.0	6.92	2.87

1116 Sampled GW194. Labeled & custody sealed
1107 Micah GPS'd GW194
1108 Photo GW194-176 looking SSW into GW194 well house, by Henderson
1108 Photo GW194-177 looking S @ GW194 well house and white trailer nearest WCR120
Last item Alan Henderson 6-18-09

6-18-09 Alan Henderson

Sketch of 1916 WCR 120



1120 Arrived 1916 WCR 120 GW 196
1125 Photo GW196-178 looking west into GW196 well house by Henderson
Photo GW196-179 looking east from unnamed road - well house in foreground, two trailers in background, by Henderson

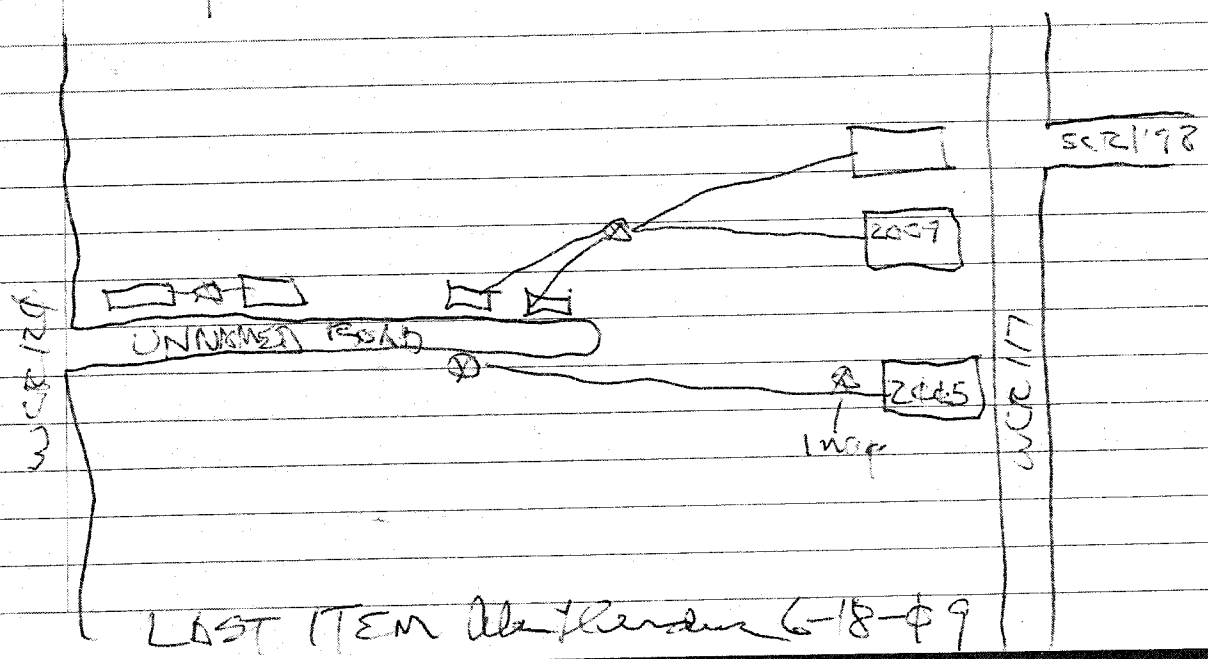
		Temp °C	pH	cond mS
1125	Began purge			
1125		23.4	6.94	2.91
1140		22.9	6.91	2.87
1145		22.4	6.90	2.88
1150		22.4	6.93	2.91

Micah GPS'd GW194 and GW196
Last item Alan Henderson 6-18-09

6-18-09 Alan Herndon

1155 Sampled GW196 and labeled/custody sealed

1147 Started purge on GW249 Temp°C pH Cond mS
1147 24.4 6.82 3.88
1202 23.9 6.83 3.87
1207 23.4 6.84 3.88
1212 23.2 6.84 3.84
1214 Sampled GW249, labeled & custody sealed
1330 Arrived at 2005 WCR117 (Ann Workman). She has three wells, one in back yard (no pump-dry) one on north end of unnamed road and one on south end of unnamed road (1916 WCR120). The north well supplies water to her house at 2005 WCR117 as well as 2 southmost trailers on Unnamed Road.
1345 Arrived @ 2009 WCR117 (Mary Flores). Her well is in pasture south of her house and supplies water to 2009 WCR117, the two northern trailers on unnamed Road and WCR117. We sampled her well GW249 instead of GW195.



LAST ITEM Alan Herndon 6-18-09

6-18-09 [illegible]

1355 Micah arrived 3100 SCR 1204 (GW199)

1400 Began purging

	Temp °C	pH	Cond mS
1400	24.6	7.03	3.56
1415	23.6	7.00	3.62
1420	23.1	6.98	3.73
1425	23.1	6.99	3.70

1419 Photo GW199-180 looking West into well house by Henderson

Photo GW199-181 looking West at well house attached to garage/shop, by Henderson

1429 Sampled GW199, labeled and custody sealed

1435 Left GW199 and headed to GW191

1440 Called GW199 left message could not find the well.

1448 GW199 called back and said well was behind house @ 3208 SCR 1200.

1450 Arrived @ 1915 WCR 14 (GW189)

Closest spigot to well is outside faucet behind house next to bypassed RO unit.

Well is in garage w/o spigot

1451 Purge began 1451 (GW189)

Photo GW-189-182 faucet on back of house, closest access to well in garage.

	Temp °C	pH	Cond mS
1451	31.4	7.07	2.45
1506	25.2	7.08	2.58
1511	24.8	7.07	2.67
1516	24.2	7.08	2.65

1518 Sampled GW199 labeled and custody tagged

1520 Took sample to Scott Craig. Done for today.

NEXT ITEM [illegible]

06/23/09 DAY 1 SUGAM SHRESTHA

0800 Arrived @ site

0810 Safety meeting - Jason, Sam, April, Sugam.

0825 Arrived @ GW-86 (Petroplex, 2800 WCR 111)

0830 Start purge from port C.

	temp	pH	cond (µs)
0830	28.9	7.10	3.70
0845	27.9	7.04	3.70
0850	27.8	7.03	3.70
0855	27.8	7.03	3.70

0857 Sampled GW-86 B (for Cr^{+6})

0859 Sampled GW-86 C (for Cr^{+6})

0859 Collected duplicate GW-206 from 86B

all the samples unpreserved

0910 Arrived @ GW 90 (Francisco Ramirez, 2805 WCR 110)

0911 Met with residents (strictly spanish speaking) but allowed us to collect samples

0916 Start purge from Port C

	temp	pH	cond (µs)
0916	24.8	7.30	2.05
0931	23.5	7.22	2.02
0936	22.9	7.21	2.04
0941	22.6	7.22	2.03

SUGAM SHRESTH

0943 Sampled GW 90 B (for Cr^{+6})

0945 Sampled GW 90 C (for Cr^{+6})

all samples unpreserved

0955 Arrived @ GW 91 (Kay Beauchamp) 2700 WCR 114

1000 Resident said she'd been researching filter systems and found that water softening prior to the filtration may help increase filter life

1000 start purge from Port C

	temp	pH	cond (µS)
1000	28.1	7.16	2.26
1015	25.6	7.15	2.24
1020	25.1	7.14	2.24
1025	24.8	7.15	2.24

totalizer

1026 Sampled GW 91 B Cr^{+6} 527990

1028 sampled GW 91C Cr^{+6}

all samples unpreserved

SUGAM SHRESTHA

1040 Arrived @ GW 97 (Della Holeiday, 2606 WCR 114)

1042 Resident didnot answer but showed up after started purging

1048 Start Purge from Port C (totalizer reading: 31613)

after sampling: 31616

	temp	pH	cond
1048	26.5	7.25	2.35
1103	25.4	7.23	2.33
1108	25.1	7.21	2.33
1113	25.0	7.23	2.33

1114 Sampled GW 97B for Cr^{+6}

1116 Sampled GW 97C for Cr^{+6}

all samples unpreserved

1125 Arrived @ GW 93 (James Dickons, 2714 WCR 114)

1126 Resident wants some gloves provided to change filters and needs more filters

1131 Start purge from Port C (totalizer reading: 78388.1

after sampling: 78426.3

	temp	pH	cond (µS)
1131	27.6	7.08	2.49
1146	25.5	7.06	2.47
1151	24.5	7.06	2.47
1156	24.3	7.07	2.47
1201	24.2	7.08	2.47

SUGAM SHRESTH

1203 sampled GW 93 B for Cr^{+6}

1205 sampled GW 93 C for Cr^{+6}

all samples unpreserved

collected duplicate 206 @ GW 93 from port C, because 206 from GW 86 was discarded as it was collected from Port B

1210 Break for lunch

1315 Arrived @ GW 94 (Rose Urunga, 2718 WCR 114)

1320 Resident didnot answer the door.

1332 start purge from Port C totalizer reading: 792262.7 after sample: 792280.5

	temp	pH	cond (µS)
1332	24.5	7.13	2.27
1347	24.0	7.07	2.26
1352	23.8	7.07	2.28
1357	23.5	7.05	2.29

1359 sampled GW 94 B (for Cr^{+6})

1401 Sampled GW 94 C (for Cr^{+6})

all samples unpreserved

SUGAM SHRESTHA

1405 Arrived @ GW 95 (Franklin Howard, 2701 WCR 114)

1410 Resident answered the door only after about 5 minutes

1412 Start purge from Post C Totalizer reading: 395365.6
after sampling: 395402.6

	temp	pH	cond (µs)
1412	32.4	7.22	2.15
1427	26.2	7.17	2.10
1432	24.7	7.15	2.15
1437	24.6	7.14	2.15
1442	24.6	7.14	2.14

1444 Sampled GW 95 B for Cr^{+6}

1446 Sampled GW 95 C for Cr^{+6}

collected duplicate 208 @ GW 95

all samples unpreserved

1450 Arrived @ GW 96 (Luis Villanueva, 2605 WCR 114)

1454 Resident ~~[illegible]~~ had the results from the prior sampling @ home so ~~[illegible]~~ explain the results.

1457 Start purge from Post C Totalizer reading
1123273.1
1123302.8

SUGAM SHRES

	temp	pH	cond (µS)
1457	27.8	7.19	2.16
1512	25.6	7.17	2.14
1517	25.3	7.19	2.13
1522	25.4	7.19	2.17

1524 sampled GW 96 B for Cr^{+6}

1526 sampled GW 96 C for Cr^{+6}

all samples unpreserved

1540 Arrived @ GW 105 (2524 SCR 1200 Pete Alcocer)

1543 Purge start from Port C ~~Totalizer~~ reading: 129733.7 after sample: 129751

	temp	pH	cond (µS)
1543	30.6	7.11	2.06
1558	27.1	7.10	2.10
1603	25.9	7.09	2.15
1608	25.7	7.12	2.12
1613	25.3	7.13	2.13

1615 sampled GW 105 B for Cr^{+6}

1617 sampled GW 105 C for Cr^{+6}

all samples unpreserved

06/24/09 SUGAM SHRESTHA

0800 Arrived @ site

0805 Safety meeting: Jason, Sam, April, Sugam attended the meeting

0815 Arrived @ GW 92 (Aleta Elder, 2708 W CR 114)

0820 Resident did not answer the door

0824 Purge start from Port C Totalizer reading: 76281.5
after sampling: 76496.5

	temp	pH	cond (µs)
0824	29.6	7.30	2.73
0839	purged for 5 more mins because of 220 gallon tank		
0844	24.4	7.27	2.63
0849	23.1	7.28	2.63
0854	22.9	7.27	2.64
0859	22.8	7.28	2.64

0901 Sampled GW 92 B for Cr^{+6}

0903 Sampled GW 92 C for Cr^{+6}

0925 collected dup GW 210

all samples unpreserved

0925 Arrived @ GW-185 (Monse Rocha, 2101 WCR 116)

0930 Nobody answered the door/phone. Big dog inside the fence. left a note to call

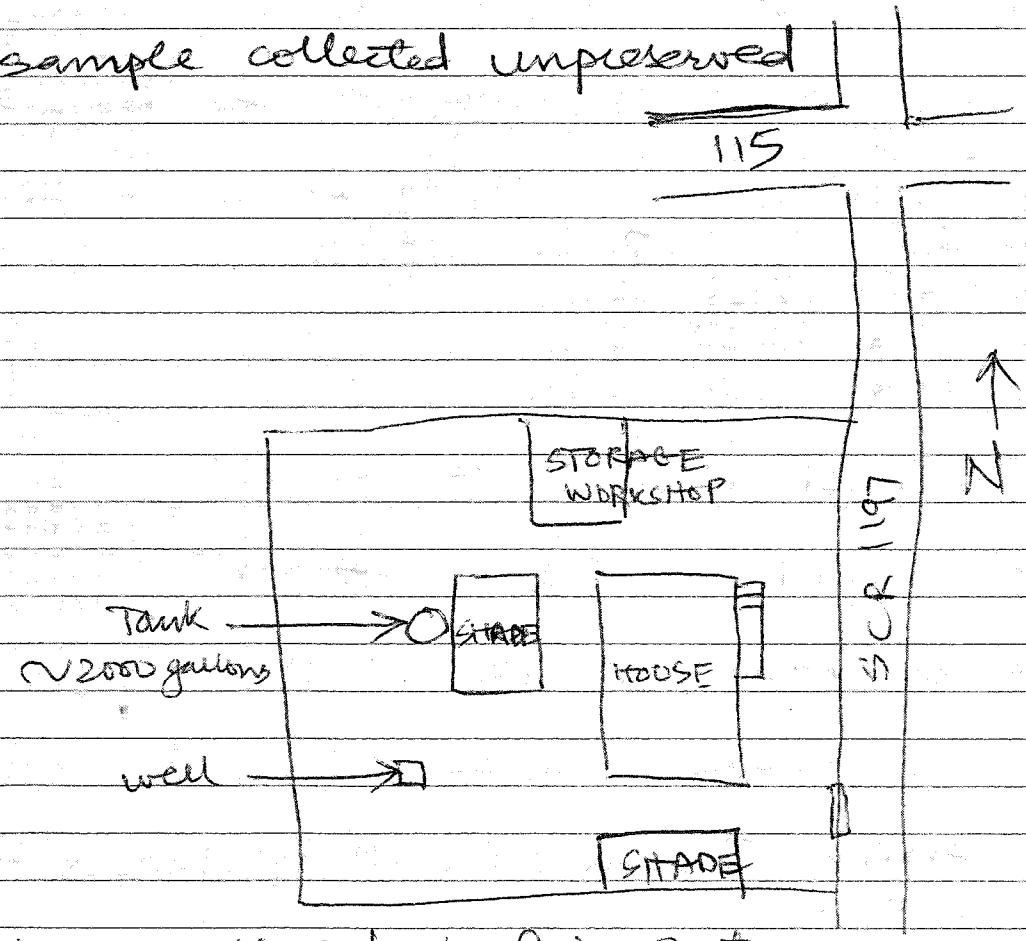
SUGAR SHREST

and schedule sampling

0930 Arrived @ GW 252 (David/Martha West, 3108 S CR 1197) - Pic 55: facing east ~~tank~~ of water tank, Pic 56: facing south of wa

0935 Resident showed the tank (~ 2000 gallon and said that the pump turns on ~~and~~ off in 30sec-1min intervals. Therefore collected a sample as soon as the pump turned on.

sample collected unpreserved



1000 picture of blue tank facing east

1001 picture of well facing south

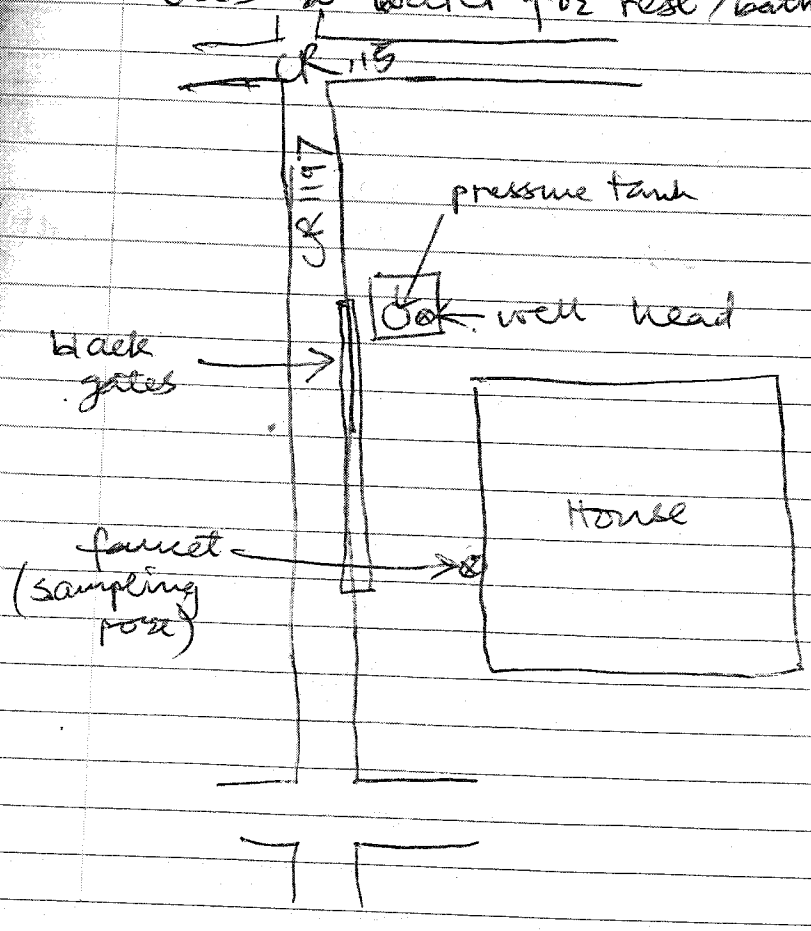
SUGAM SHRESTHA

1015 drove back to GW-185 but could not meet the resident. The ~~resident was~~ note was still hanging at the door.

1030 drove to Cory Farmers place, located the pressure tank, could not locate a faucet, and the circuit breaker was locked.

1100 Arrived @ GW 253 (Manuel Olvera (Jessica Olvera), 3011 S CR 1197) - Pic 59 facing west inside well house

1105 Resident (Jessica Olvera) filled out the AA form. Did not know the depth of well. Uses ~~to~~ water for rest/bath rooms, wash utensils, pots



SUGAN SHRESTHA

1107 Resident (Jessica)'s parent called and informed that the well is 65ft deep.

1108 Purge start

	temp	pH	cond (µs)
1108	30.8	7.18	2.04
1123	23.8	7.18	1.96
1128	23.4	7.17	1.94
1133	23.1	7.18	1.94

1135 sampled GW 253 for Cr^{+6}

1200 break for lunch

~~[illegible] Communications etc~~

1340 Arrived @ GW 255 (Cotton Flat Mobile Homes) (PIC 58 facing north inside well house; PIC 59 facing west of sampling port)

1350 Purge start time

	temp	pH	cond (µs)
1350	30.2	6.93	2.99
1405	23.4	6.89	2.53
1410	22.9	6.90	2.55
1415	22.7	6.91	2.53

1417 sampled GW 255

1451 sampled GW 211 duplicate

all samples unpreserved

Day 1 - Dani / Robert Musick

6/30/09 GW-135

2701 WCR 112

Time 7:45 am
Rain / Cloudy
Temp 75°F

2701 - WCR 112
Bosticks

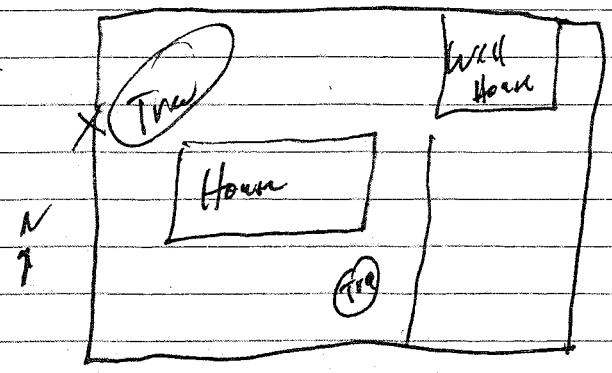
~~0650-0[illegible]~~ Totalizer = 0649944

Yield of Water ≈ 20 gallons / minute well / 35 gallons / Minute
87 ft deep
High Water

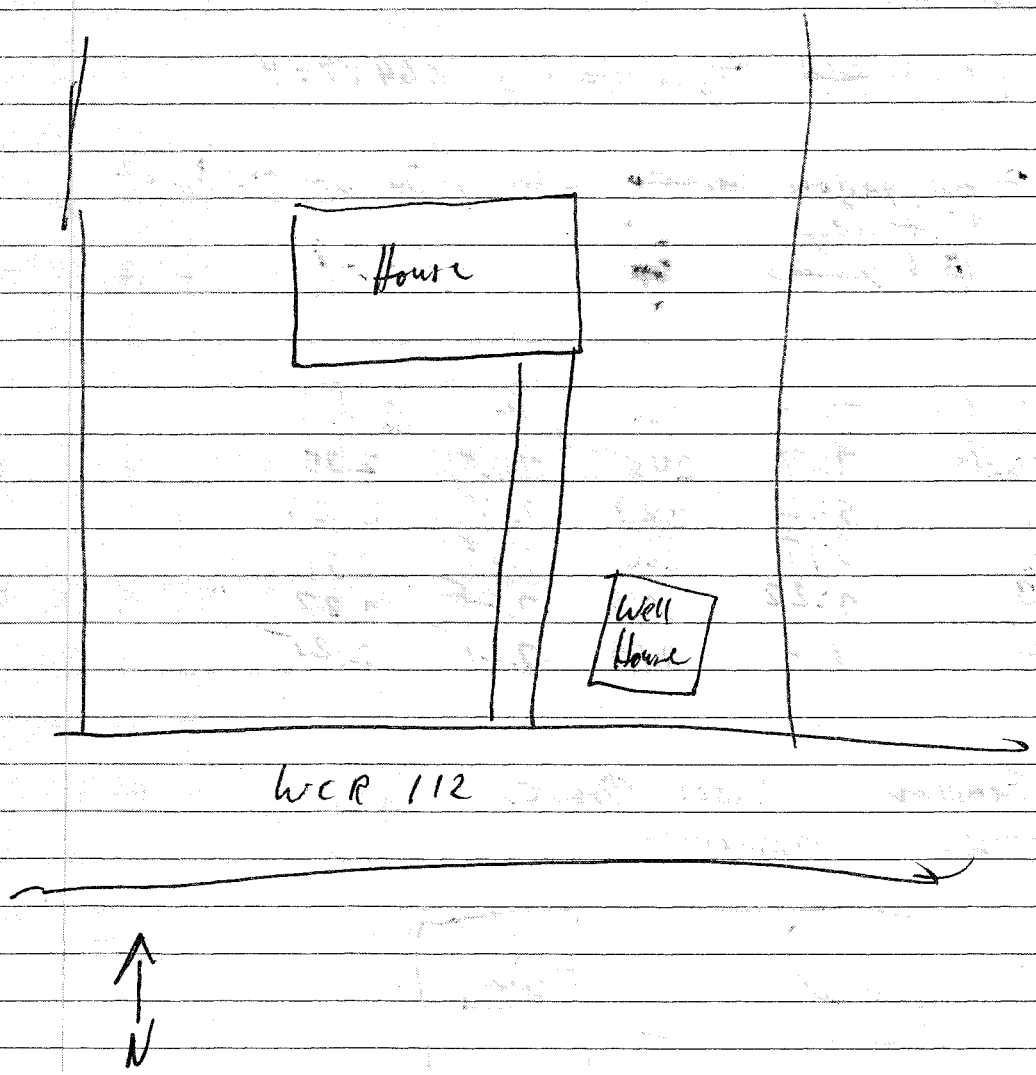
Ready	Time	Temp	pH	Cond
Initial	7:57	24.5	7.15	2.33
1	8:12	22.9	7.21	2.26
2	8:17	22.3	7.24	2.31
3	8:22	22.0	7.25	2.27
4	8:27	21.9	7.25	2.25

Sampler Jason Brooks
TCEQ R Musick

sketch



GW-136 - Moffitt
2615 - WCR 112



Day 1

6/30/09 GW-136 2615 W CR112

~8:30am Rita + William Moffit
2615 W CR 112

Sampler Jason Brooks
TCEQ R Musiall

Task Start Ultrapure to house to exchange filters
Done

Uses port C to water lawn.

Readings	Time	Temp	pH	Cond	
Initial	840	23.4	7.09	2.26	
1	855	21.5	7.33	2.26	
2	900	2.12	7.34	2.26	
3	9:05	21.1	7.32	2.25	- stable
4					

Totalizer = 352760

Departed site at 9am

Sample GW-136 B
GW-136 C

Day 1

6/30/09 GW-140 2601 WCR112
Sheldon / Debbie Johnson
Sampler Jason Brooks / R Musick - TCEQ
Arrival 9:05 am

Reading	Time	Temp	pH	Cond
Initial	9:16	22.3	7.40	1.95
1	9:31	22.0	7.36	1.86
2	9:36	21.8	7.39	1.86
3	9:41	21.8	7.39	1.86
4				

Totalizer Reading 1119.74

Left Brochure - Not at Home

Samples GW-140 b Port B
GW-140 c Port C

Day 1

6/30 WCR 2503 - Jim Rockwell (A.K.A. 2401 WCR 112)

GW-141 Jim Rockwell
well located behind trailer house in shed

Arrived 9:56am Jason Brooks - sampler
Robert Musick - TCEQ

Reading	Time	Temp	pH	Cond
Initial	9.58	22.6	7.32	235
1	10:13	22.0	7:35	239
2	10:18	21.7	7.37	2.41
3	10:23			
4				

Totalizer 0073364

Sample ID GW141C C Port
GW141B - B Port

Departed Site 10:25am

6/2

2
1
x
3

Day 1

6/20 Day 2 2505 WCR 110 GW 145
Mrs Aubrey

2
750
x 4
3000

Sampler Jason Brooks
TCEQ Robert Musick

Reading	~~Temp~~ Time	Temp	pH	Cond
Initial	11:01	25.2	7.19	2.29
1	11:16	22.3	7.21	2.23
2	11:21	21.6	7.22	2.22
3	11:26	21.4	7.22	2.21
4	11:31	21.2	7.23	2.22

Totalizer 0218893

Samples GW 145 B 11:32 Port B
GW 145 C 11:35 Port C

Departed Site at 11:40 am

Ex Mise

Gw.

Gu

Day 2

GW-144 Dup 214 (Port C)
2605 WCR110 - Frank Mendoza

Site at 12:53
Samplers Jason Brooks
TCEQ Robert Murrell
Started purging at 12:57 pm

Collect GW-144 and Duplicate GW-214

Reading	Time	Temp	pH	Cond
Initial	12:55	27.1	7.34	2.29
1	13.10	23.8	7.34	2.30
2	13.15	22.4	7.38	2.28
3	13.20	20.2	7.37	2.27
4	13.25	22.0	7.36	228

GW-144-b Sample Port B + C (2 Samples)

GW-144-c Dup is for Port C (1 Sample)

Departed site at 1:30 pm

Rob Mesch

Day 2

6W-05 2911 WCR 110
Wesley Clements

Arrival 1:36pm

Samplers Jason Brooks

Reading	Time	Temp	pH	Cond
Initial	13.38	26.1	7.42	2.18
1	1353	28.3	7.31	2.24
2	1358	28.7	7.34	2.28
3	14:03	28.4	7.30	2.21
4				

~~Sample Ports B+C~~

No Filter System Sample
~~Well~~ Well depth = 90-100 ft deep.
yield is good.

Sample 6W-05

Departed Site 230pm

Day 2

7/1/09 GW-58 Cecil Smith 2301 WCR 110

Arrived at 8am
Clear Skies, 75°F

TCEQ Robert Marcelc
Sampler- Jason Brooks

GAC Filtration System / 6 month rotation
Trichloroethane

Well - 75 feet, brackish water with high Sodium. Water at ≈ 35 feet.

Windmill - To 35-50 feet (Ogallala Aquifer Water) With Petro Calcic zone from near surface to 35 ft

Reading	Time	Temp	pH	Cond
Initial	7:52	21.7	7.50	2.06
1	8.07	21.5	7.66	2.02
2	812	21.3	7.73	2.04
3	817	21.2	7.75	2.03
4				

Totalizer 0004620

Sample GW 58 A

Departed 8:20 am

211

314 610- 73

Leroy
~~Leroy~~ 8:43

512 225-4369

Day 2

7/1/09 3010 SCR 110 Raul Granado

Arrived 8:25 am

Found well system in back of yard
Sampler Jason Brooks - Shaw
RMarrale - TCEQ

Reading	Time	Temp	pH	Cond
Initial	832	22.2	7.50	2.25
1	847	22.3	7.46	2.24
2	852	22.6	7.40	2.23
3	857	22.4	7.48	2.21
4				

Sample ID GW-64 - ~~Sampled~~ Sampled
well head. No Anion System
Sample called 9:00 am on 7/01/09

Departed 9:15 am from site.

RMM

7/01

Day 2

7/01

GW-71 Bryon Fender 2713 SCR 1206

Arrival ~~[illegible]~~ 7/01/09 @ 10:00am

Business is Expro at 2713 SCR 1206

Started purge at 10:15 am

Reading	Time	Temp	pH	Cond
Initial	10:15	23.8	7.74	2.05
1	10:30	22.7	7.75	2.04
2	10:35	22.0	7.72	2.07
3	10:40	22.0	7.74	2.06
4				

Well No GW-71 Collected at 10:
Sample-GW71

Sampler Jason Brooks
TCEQ R Murrah

Departed ~~[illegible]~~ 10:50am

432 813-5807

7/01

6W-83 Bob Dean 2500 Cotton Flat

Arrival 9:30am - No person at home - Left Brochure on Door.

Reading	Time	Temp	pH	Cond
Initial	9.28	22.7	7.47	2.01
1	943	22.0	7.47	1.99
2	949	21.8	7.45	2.01
3	953	21.7	7.44	2.01
4				

TCEQ - Robert Murdock
Jason Brooks Sampler

No Anion Filter System

Sample No. 6W-83 Stan

Departed Site at 10am - Went to 6W71
Located at 26B-SCR 1206

RMurdock

Day 2

GW-B2 2809 WCR 111 Petro plant

Sample location in front of Building No 15
at BAB Welding Services

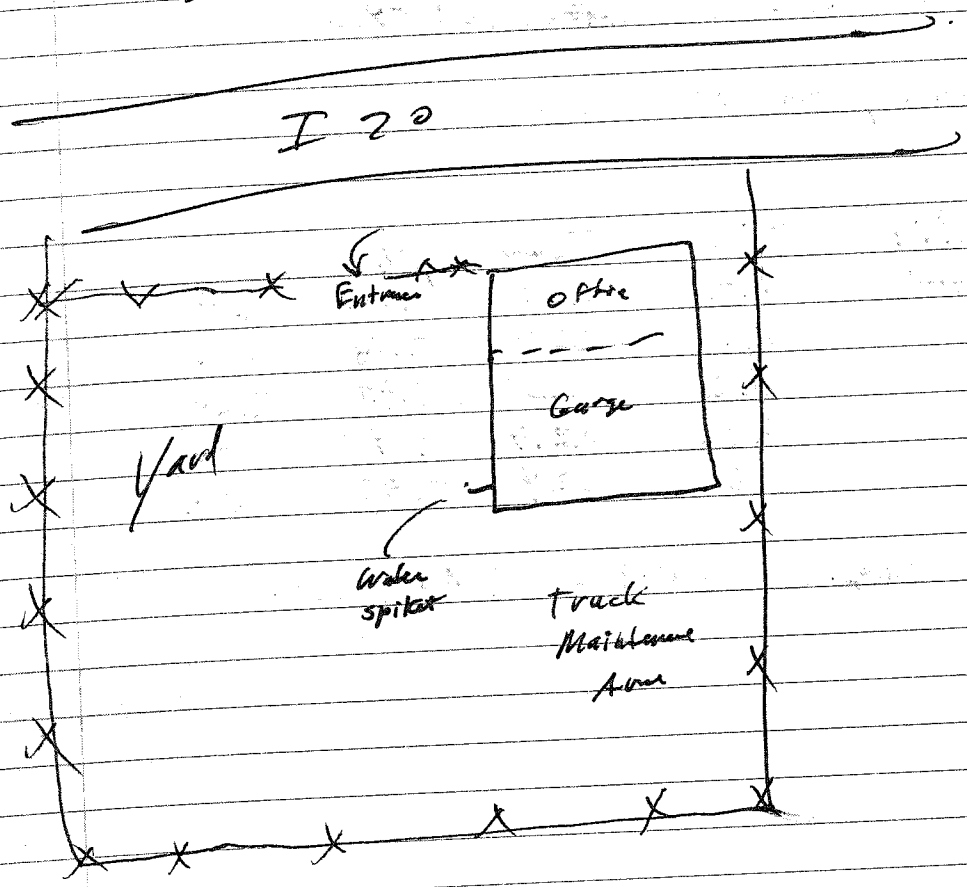
Arrival at site at ~~11am~~. 10:58am

Started purge at 11am.

Reading	Time	Temp	pH	Cond
Initial	11.01	28.3	7.44	2.40
1	11.16	23.7	7.48	2.32
2	11.21	22.5	7.43	2.28
3	11.26	22.4	7.48	2.30
4	11.31	22.4	7.48	2.32

Sample GW-B2 (No filter)

2815 - I 20 GW-107



Day 2 Don Meeks 2815 I20 GW 107
GW 217 (Dup)

GW 107

Arrived 12 35 pm. Sample location in supply yard on west side of Garage.

Collect sample from spigot on west side of maintenance shop in supply yard. Located behind office.

Started purging at 12:40 pm

Reading	Time	Temp	pH	Cond
Finished	1240	28.0	7.50	2.20
1	1255	24.8	7.51	2.20
2	1300	23.6	7.48	2.19
3	13:05	23.5	7.46	2.19
4	13:10	23.1	7.48	2.20

Samples GW 107 (No Filter System)
GW 217 Dup

Collected Sample at 1:12 pm

Departed at

GW 2

GW 261 Day 2 2308 SCR 1200 Robert Dock Scott

Arrival approx 2:15 pm at site
Drove into fence area past the first trailer with address 2308 1/2. Go past this trailer about 75 yards to a cinder-block house on right side of road. Open door (plywood) and turn on power (left side of door - at top). Also turn valve at back on as thru-way

to allow water to run into reservoir tank. Open valve at front near door - water is now purgeable.

Sampler Jason Brookl - Shaw
Robert Musick - TCEQ

Started purging water at 2:30 pm

Reading	Time	Temp	pH	Cond
Initial	14:32	28.7	7.53	1.62
1	14:47	24.8	7.45	1.60
2	14:52	23.7	7.49	1.60
3	14:57	23.5	7.47	1.60
4	15:02	23.2	7.46	1.60

Sample ID GW261
Sample Time 15:04

GPS N 31.96152° W 102.09082°

GW 262 Pilar Montoya 3200 SCR 1200

Arrived at 3:15 pm. Talked to Mr. Montoya about project.

Sampler Jason Brooks

Reading	Time	Temp	pH	Cond
Initial	15:25	31.6	7.20	2.83
1	15:40	25.6	7.24	2.73
2	15:45	23.8	7.25	2.77
3	15:50	23.6	7.28	2.79
4	15:55	23.4	7.26	2.80

Sample ID GW 262 Sample time 15:57

GPS N 31.95643 W 102.08822

END OF EVENT

N. JOHNSON

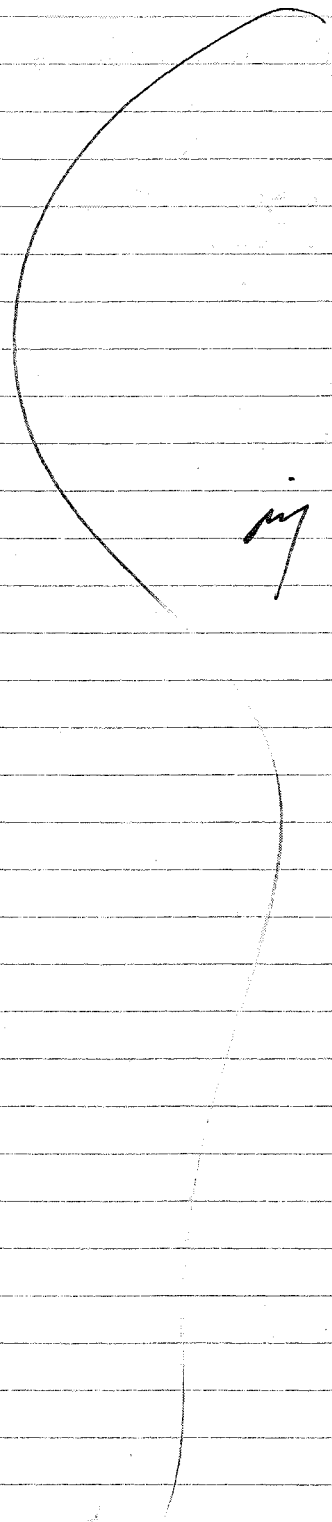
7/7/09 U. CR112 DAY 1

8:00 Safety meeting conducted by Jason Brooks

0805 SP-05/SP06 - Dug - GW259A + GW259C
Paul + Trina Burns
2701 S. CR 1200

SEE A. PALMIE'S NOTES

Gary Johnson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7/8/09 W CR 112 DAY 2

07:30 Arrived meeting place on Cotton Flat Rd
N. Johnson, April Palmer, Jason Brooks + ~~Mich~~ Micah BEARD
Safety meeting conducted

Arrived GW-92B and GW-92C
Aleta Elder, 2708 W CR 114
Left door hanger
08:09 Begin purge Jason Brooks, Sampler
Totalizer Begin 0079700 End 0079910

Time	Temp	pH	Cond.
08:09	24.8	7.27	2.37
08:24	23.9	7.23	2.32
08:29	23.0	7.20	2.33
08:34	22.8	7.26	~~2.31~~ 2.33
08:39	22.7	7.21	2.31

SAMPLES COLLECTED GW-92B 08:40
GW-92C 08:42
by Jason Brooks

Nancy Johnson

08

09

7/8/09 W CR 112 DAY 2

8:50 ARRIVED GW-93B + GW-93C
JAMES DICKENS
2714 W. CR 114
Left door hanger
Totalizer Begin 0081202 End 0081468

Time	Temp	pH	Cond.
08:50	25.0	7.19	2.62
09:05	23.2	7.21	2.54
09:10	22.5	7.27	2.56
09:15	22.2	7.23	2.57
09:20	22.2	7.27	2.56

SAMPLES COLLECTED GW-93B 09:22
by Jason Brooks ~~GW-93~~ 09:24
GW-93C

9:28 Arrived GW-94B + 94C - J. URANGA, 2718 W CR 114
Spoke w/ Mr. + Mrs. Uranga
Totalizer Begin 0799828 End 0799

Time	Temp	pH	Cond.
09:30	25.5	7.10	2.20
09:45	23.6	7.17	2.15
09:50	22.9	7.15	2.16
09:55	22.7	7.22	2.16
10:00	22.5	7.15	2.17

SAMPLES COLLECTED GW-94B 10:02
GW-94C 10:04
by Jason Brooks
Gary Jackson

η

07/08/09 W CR 112 DAY 2

10:17 Arrived ~~126~~ GW-126B + GW-126C + Dup 222 Port C
Ovidio Ramos, 3000 CR 1200
Spoke to office personnel - Ramos Trucking
Totalizer Begin 2315591

Time	Temp	pH	Cond.
10:19	24.8	7.15	1.81
10:34	22.6	7.17	1.81
10:39	22.2	7.21	1.80
10:44	22.1	7.18	1.80

SAMPLES COLLECTED GW-126B 10:45
GW-126C 10:47
Dup GW 222 ~~11~~ 11:02
of Port C by Jason Brooks

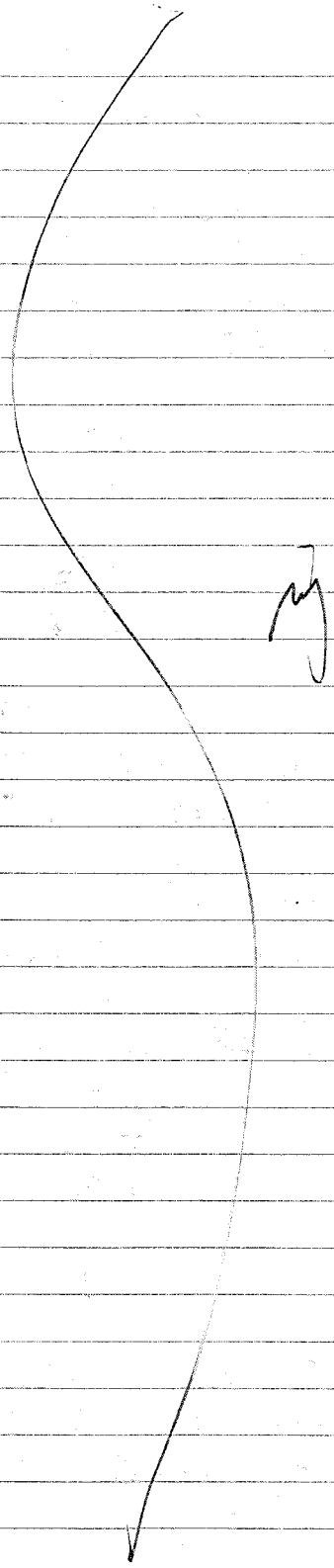
11:08 Arrived GW-90B + GW-90C Francisco Ramirez
2805 W CR 110
Totalizer Begin 2016653 End 2016910

Time	Temp	pH	Cond.
11:10	24.1	7.30	1.90
11:25	23.0	7.28	1.91
11:30	22.6	7.31	1.93
11:35	22.5	7.30	1.93

SAMPLES COLLECTED GW-90B 11:37
GW-90C 11:39
by Jason Brooks

Break for lunch 11:45

Gary Johnson



13:

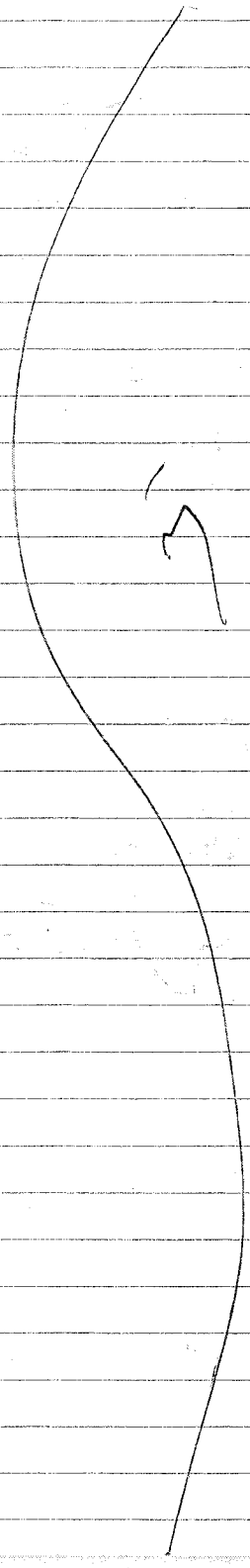
07/09/09 WCR 112 DAY 2

13:29 Arrived GW-19A and GW-19C + Dup GW-223
Maria Acosta, 2716 Cotton Flat Road
left door hanger w/ Spanish-speaking worker.
Totalizer Begin 0193175 End 0193420

Time	Temp	pH	Cond.
13:30	30.6	4.36	2.23
13:45	24.9	5.45	2.21
13:50	24.5	5.25	2.18
13:55	23.7	5.45	2.15
14:00	23.6	5.62	2.14
14:05	23.6	5.76	2.12

Sample time GW-19A 14:07
GW-19C 14:09
Dup GW-223 from Port C 13:54
Sampled by Jason Brooks

[illegible]



07/08/09 W CR 112 DAY 2

14:24 Arrived GW-01 Logan Roland 2800 W CR 114
~~Totalizer~~ No system here.

Time	Temp	pH	Cond.
14:25	30.2	7.23	2.01
14:40	24.0	7.27	2.02
14:45	~~22.2~~ 22.3	7.26	2.06
14:50	22.2	7.30	2.09
14:55	22.2	7.31	2.07

Sample time GW-01 14:56 by Jason Brooks

15:05 Arrive GW-40 Justin Roland 2806 W CR 114
No one answered knock on door. Dogs sound ANGRY. We will return when someone is at home. Called Mr. Roland; he will meet us @ ~~3:~~ 15:30

15:10 Arrive GW-16 Simon + Sherry Bernal 2901 W CR 114
Left door hanger. No filter system

Time	Temp	pH	Cond.
15:11	53.5	7.25	2.25
15:26	27.5	7.44	1.94
15:31	24.0	7.29	2.03
15:36	22.8	7.35	2.06
15:41	22.7	7.32	2.06
15:46	22.4	7.35	2.06

Sample time GW-16 → 15:47 by Jason Brooks
13:46 - Mr. Bernal arrived; he has another well that he uses for his horses - I'm barn by windmill
Larry Jahn

μ

07/08/2009 W CR 112 Day 2

15:55 Arrive GW-40 Justin Roland
2806 W. CR 114
No filter system

Time	Temp	pH	Cond.
15:56	25.2	7.32	1.83
16:11	22.6	7.38	1.80
16:16	22.5	7.31	1.79
16:21	22.2	7.38	1.81

Sample collected 16:22 GW-40
Sampler Jason Brooks

Gary Johnson

07

08

08

07/09/2009 DAY 3 @ CK112

07:40 Arrived meeting place on Cotton Flat Road
Gary Johnson April Palmer, Micah Beard
& Tom Elliott

07:45 Safety meeting conducted by Micah Beard

08:10 Began well purge @ GW-04
(Fender Prop.) Elite Treating Solutions
2715 S. CR 1206
Spoke to office personnel - obtained business card

Time	Temp.	pH	Cond.
08:11	22.8	7.13	2.24
08:26	22.5	7.31	2.11
08:31	22.3	7.33	2.11
08:36	22.0	7.31	2.10

Sample GW-04 collected 08:36 by Tom Elliott

8:45 Arrived GW-70 Wood Group 2612 S CR 1206
Spoke to office personnel.

Time	Temp	pH	Cond.
08:50	28.5	7.0	2.91
09:05	24.6	7.05	2.80
09:10	23.7	7.05	2.84
09:15	23.4	7.04	2.84

Collected GW-70 9:15 by Tom Elliott

Gary Johnson

07/0

09:

10:3

07/09/09 DAY 3 W CR 112

09:40 Arrived GW-75 Bio-Tech, 2611 S. CR 1207
Spoke w/ office personnel

Time	Temp.	pH	Cond.
09:48	25.7	6.97	3.33
10:03	23.6	7.03	3.39
10:08	23.1	7.02	3.38
10:13	22.8	7.04	3.39

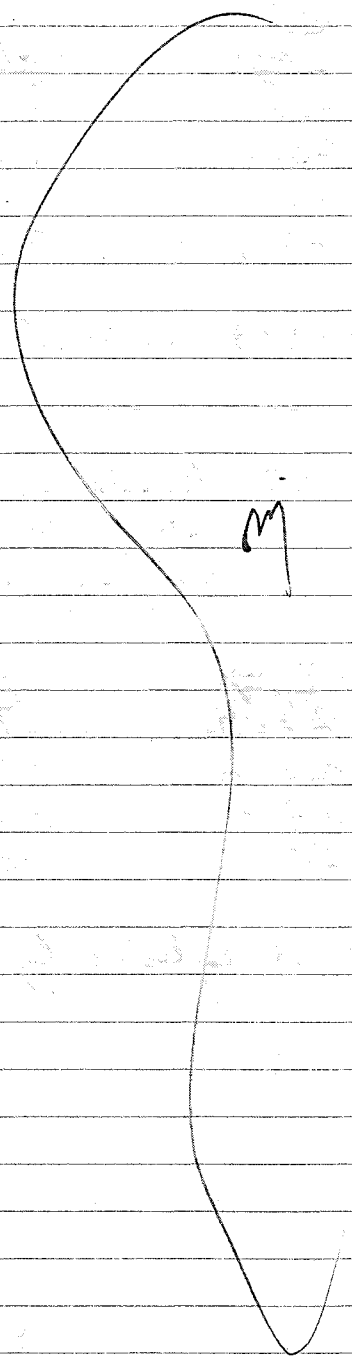
Sample time 10:13 GW-75 collected by Tom Elliott

10:35 Arrived GW-87 Bendeup Trailers
2800 S CR 1207
432/699-7000

Time	Temp	pH	Cond.
10:40	26.4	7.13	1.69
10:55	25.2	7.13	1.64
11:00	23.4	7.16	1.66
11:05	22.9	7.13	1.66

Sample time 11:05 collected by Tom Elliott

Ray Johnson



13

W CR112 07/09/09 DAY 3

Arrived GW-66 Robert White

Time	Temp	pH	Cond.
11:25	24.9	7.35	1.31
11:40	23.1	7.34	1.31
11:45	23.1	7.31	1.30
11:50	22.9	7.30	1.31

Sample time 11:50 collected by Tom Elliott

Break for lunch 11 55

13:05 Arrive GW-33 3001 S CR 1205
Rebecca Rodriguez

Time	Temp	pH	Cond.
13:05	26.8	7.14	2.36
13:20	22.9	7.19	2.43
13:25	22.9	7.22	2.44
13:30	22.4	7.4	2.43
13:35	22.5	7.22	2.43

Sample time 13:35 by Tom Elliott

Gary Johnson

07/09/09 W CR 112 DAY 3

3:43 Arrive ~~GW-129~~ + DUP 227 E. Alvarado
3005 S. CR 1205

Time	Temp	pH	Cond
13:45	25.6	7.34	1.81
14:00	23.8	7.36	1.80
14:05	23.7	7.34	1.81
14:10	22.3	7.38	1.80
14:15	22.2	7.39	1.81

GW-129 collected 14:15 by Tom Elliott.
Dup 227 collected 14:30 by Tom Elliott.

4:50 Arrive ~~GW 110~~ Thomas Flores 2909 W CR 115

Time	Temp	pH	Cond.
~~35.6~~ 14:55	35.6	7.11	1.94
15:10	27.0	7.16	1.91
15:15	23.4	7.16	1.91
15:20	23.6	7.18	1.95

Sample time 15:20 by Tom Elliott.

07/09/2009 ~~DAY~~ DAY 3 W CR 112

15:37 Arrive ~~CR 112~~ Larry Ochoa
2108 W CR 115

Time	Temp	pH	Cond.
15:38	30.1	7.13	2.52
15:53	25.6	7.15	2.52
15:58	24.4	7.22	2.51
16:03	24.5	7.23	2.55

Sample time 16:03 by Tom Elliott

End of Event

Larry Johnson

DAY 1 07/14/09

800 Arrived @ site

810 Safety Meeting - Jason, Micah, Ron, Sugam

840 Arrived @ GW-140

846 Start purge time

	temp	pH	cond (mS)	Totalizer
846	24.2	7.45	1.77	11716
901	23.0	7.40	1.97	11724
906	22.4	7.34	1.96	
911	22.7	7.33	1.94	

916 sampled GW-140 B for Cr^{+6}

918 sampled GW-140 C for Cr^{+6}

930 collected duplicate GW 228 @ GW 140

928 Arrived @ GW 139 Resident not home

930 Start purge time

	temp	pH	cond (mS)	Totalizer
930	23.4	7.26	2.06	1924
945	22.5	7.26	2.06	
950	22.0	7.24	2.06	
955	21.8	7.24	2.06	

957 sampled GW 139 B for Cr^{+6}

959 sampled GW 139 C for Cr^{+6}

1005 Arrived @ GW 142 (Brenda/Douglas Clinton, 2502 W CR 112)

1010 Purge start time

	temp	pH	Cond (m/s)	Totalizer
1010	27.8	7.15	2.04	3503010
1025	25.8	7.15	2.07	
1030	23.6	7.17	2.08	3503170
1035	22.3	7.19	2.08	
1040	22.0	7.23	2.08	
1045	21.7	7.23	2.05	

1047 Sampled GW 142 B for Cr+6

1049 Sampled GW 142 C for Cr+6

1055 Arrived @ GW 141 (Jim Rockwell

1057 Purge start time

	temp	pH	cond (m/s)	Totalizer
1057	25.1	7.3	2.5	90870
1112	23.5	7.25	2.43	91000
1117	22.8	7.23	2.49	
1122	22.5	7.24	2.48	

1127 Sampled GW 141 B for Cr+6

1129 Sampled GW 141 C for Cr+6

1135 Arrived @ GW 143 (Leisa/George Laing, 2604 W CR 112)

1137 Purge start time — Totalizer 207580

	temp	pH	cond (m/s)
1137	28.1	7.36	2.39
1152	23.9	7.40	2.35
1157	22.7	7.43	2.35
1202	22.3	7.43	2.35
1207	22.2	7.42	2.35

1210 Sampled GW 143 B

1212 Sampled GW 143 C

1215 Break for lunch

1330 Arrived @ GW 254 (Billy Parish / Resident 2901 WCR 110 / 2806 WCR 110)

1332 2811 written on the door of a small house east of house w/ white picket fence

1335 start purge

	temp	pH	cond (m/s)	Totalizer
1335	24.9	7.25	2.30	369270
1350	23.6	7.24	2.34	369370
1355	23.1	7.25	2.33	
1400	22.7	7.26	2.32	

1403 Sampled GW 254 B for Cr^{+6}

1405 Sampled GW 254 C for Cr^{+6}

1420 Collected dup GW 229 @ GW 254

1425 Arrived @ GW 108 (Eugene / Rodney Cogill, 2805 W I20)

1430 Start purge

	temp	pH	cond (m/s)	totalizer
1430	32.7	7.04	2.54	98
1445	25.1	7.18	2.41	
1450	23.4	7.22	2.40	
1455	23.1	7.24	2.41	
1500	22.8	7.26	2.42	

1503 collected GW 108 B sample for GRG

1505 sampled GW 108 C for GRG

1510 Arrived @ GW 54 (

did not purge as there is a 'big' poly tank.

	temp	pH	cond (ms)
1520	25.9	7.2	2.88

1522 collected grab sample @ GW 54

Arrived @ GW 261 (2808 SCR 1200, Robert Scott)

1616 Start purge

	temp	pH	cond	totalizer
1616	34.5	4.52	2.05	152710
1631	25.0	4.82	1.96	
1636	23.3	4.80	1.97	

	temp	pH	cond (ms)
1641	22.7	4.83	1.97

although temp wasn't within collection limits, ~~a~~ ~~was~~ sample was collected due to late ~~a~~ purge start time

1643 collected GW261B for Cr^{+6}

1645 collected GW 261 C for Cr^{6+}

1700 duplicated GW 23~~0~~1 collected @ GW261

1730 Reached hotel. End of Day 1

DAY 2 07/15/09

0800 Arrived @ site

0815 Safety Meeting: Jason, Micah, Ron, Sugam

0840 Arrived @ GW 94 (Jose Uranga, 2718 W CR 114)

0846 Purge Start

	temp	pH	cond (mS)	Totalizer
0846	22.3	7.27	2.28	803980
0901	21.7	7.28	2.26	
0906	21.4	7.26	2.27	
0911	21.4	7.27	2.26	

0913 collected GW 94 B for Cr^{+6}

0915 collected GW 94 C for Cr^{+6}

0930 duplicate GW 232 collected @ GW 94

0920 Arrived @ GW 98 (Mrs. Alsup, 2719 W CR 114)

0926 Purge Start

	temp	pH	cond (mS)	Totalizer
0926	26.6	5.06	2.7	797360
0941	24.3	5.14	2.65	
0946	22.6	5.29	2.65	
0951	22.0	5.45	2.64	

0952 collected GW 98 B for Cr^{+6}

0954 collected GW 98 C for Cr^{+6}

1020 Arrived @ ~~GW 99~~ (Larry Mitchell, 2501 WCR 114)

1023 purging not required because of a 1100 gallon water tank..

	temp	pH	cond (mS)	Totalizer
1025	31.9	7.78	2.02	49340

1027 collected grab sample GW 99 B

1029 collected grab sample GW 99 C

1035 Arrived @ ~~GW 101~~ (Tommie Mitchell, 2602 WCR 114)

1037 start purge

	temp	pH	cond	Totalizer
1037	28.5	7.29	2.07	589620
1052	25.7	7.39	2.01	
1057	25.0	7.3	2.01	
1102	24.0	7.4	2.02	
1107	23.6	7.43	2.02	

1108 collected GW 101 B sample for Cr^{+6}

1110 collected GW 101 C sample for Cr^{+6}

1035 Arrived @ GW 100 (Larry Mitchell, 2500 WCR 114)

1037 Start purge

	temp	pH	cond (mS)	totalizer
1041	28.8	7.46	2.46	
1056	27.1	7.42	2.44	243840
1101	25.5	7.45	2.42	
1106	24.5	7.47	2.41	
1111	24.0	7.46	2.39	

1115 Collected GW 100 B sample for Cr^{+6}

1117 collected GW 100 C sample for Cr^{+6}

1130 duplicate GW 234 sample @ GW100

1130 Arrived @ GW 103

1131 did not purge because of 1100 gallon water tank

	temp	pH	cond (mS)	totalizer
1131	31.9	7.63	2.08	313190

collected grab sample GW 103 for Cr^{+6}

1200 Break for lunch

1300 Arrived @ GW 102 (Danny Marchant, 2413 WCR 114)

1300 did not purge because of 1100 gallon tank

	temp	pH	cond (m/s)	Totalizer
1300	28.5	7.2	2.13	200770

1303 collected grab sample from GW 102B for Cr^{+6}

1305 collected grab sample from GW 102C for Cr^{+6}

1310 Arrived @ GW 125 (2601 WCR 114, Bill Morgan)

1313 Start purge

	temp	pH	cond (m/s)	Totalizer
1313	26.0	6.13	1.84	436160
1328	23.5	6.19	1.86	
1333	22.8	6.38	1.89	
1338	22.5	6.51	1.92	

1341 collected GW 125 B for Cr^{+6}

1343 collected GW 125 B for Cr^{+6}

1405 Arrived @ GW 105 (Pete Alcocer, 2524 SCR 1200 Cotton Flat))

1408 Start purge

	temp	pH	cond (m/s)	Totalizer
1408	27.5	7.25	2.09	139280
1423	24.0	7.3	2.22	

	temp	pH	cond (m/s)
1428	23.2	7.31	2.21
1433	22.5	7.28	2.15
1438	22.5	7.29	2.13

1442 collected GW 105 B for Cr^{+6}

1445 collected GW 105 C for Cr^{+6}

1448 Arrived @ 19 (Maria Acosta, 2716 Cotton Flat Road (SCR 1200))

1452 start purge

	temp	pH	cond (m/s)	Totalizer
1452	27.5	7.37	2.19	194700
1507	24.7	7.40	2.11	
1512	23.4	7.40	2.14	
1517	23.2	7.45	2.12	
1522	23.1	7.42	2.11	

1523 collected GW 19 A for Cr^{+6}

1525 collected GW 19 B for Cr^{+6}

1527 collected GW 19C for Cr^{+6}

1540 dup GW 235 collected @ GW-19

1530 Arrived @ GW-259 (Paul & Trina Burns, 2701 SCR 1200)

1536 Purge start

	temp	pH	cond	Totalizer
1536	29.0	5.84	2.68	410
				640

	temp	pH	cond (mS)
1551	23.5	6.36	2.61
1556	22.5	6.49	2.57
1601	22.4	6.61	2.57
1606	22.9	6.72	2.52

1610 collected GW 259 A sample for Cr^{+6}

1612 collected GW 259 B sample for Cr^{+6}

1615 collected GW 259 C sample for Cr^{+6}

1700 reached hotel. End of Day 2

DAY 3 07/16/09

0800 Arrived @ site

0810 Safety Meeting: Micah, Jason, Ron & Sugam

0820 ~~Purge start~~ ~~temp~~ Arrived @ GW 114 (Primitivo Saenz, 3101 SCR 1204)

0825 spanish speaking resident - called John Flores to let him explain sampling event

0830 left well survey package to the resident to give it to his son (next door property)

0836 Purge start

	temp	pH	cond (mS)
0836	24.3	7.06	5.63
0851	23.4	7.09	5.57
0856	22.5	7.09	5.53
0901	22.0	7.08	5.46
0906	21.9	7.09	5.53

0907 collected GW 114 sample for Cr^{+6}

0920 duplicate GW 237 collected @ GW 114

0920 Arrived @ GW 266 (Newpark Drilling Fluids, 2710 SCR 1207)

0922 business owner said they use gw only for restrooms and very limited washing

~~depth to gw [illegible] 75 ft~~
~~[illegible]~~

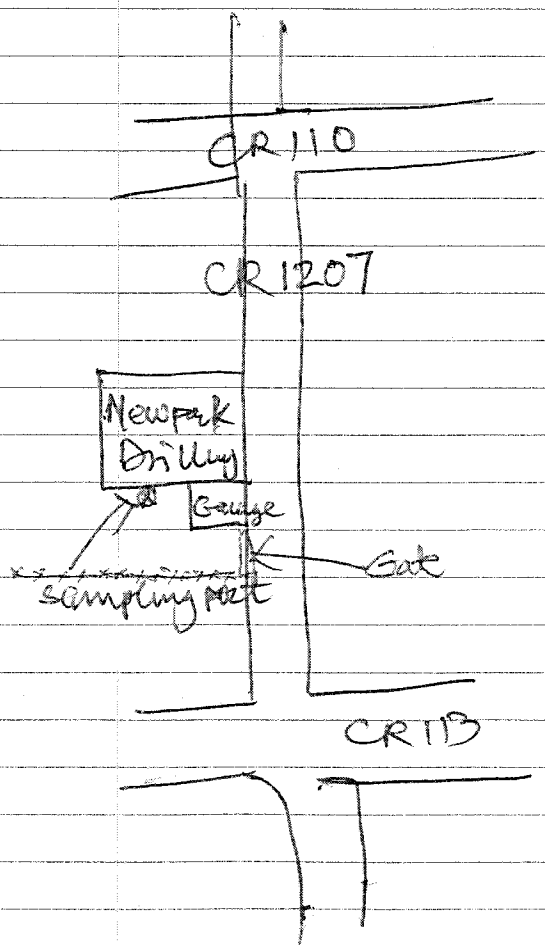
0923 depth to gw may be 78ft.

0924 ~~[illegible]~~ well runs for only limited time and then sand particles show up, therefore decided to purge for 10 minutes only.

0940 Start purge

	temp	pH	cond (m/s)	GPS
0940	24.1	7.24	2.78	31.96193° N
0950	25.8	7.18	2.78	102.10117° W
				off by ~ 32ft

PICTURES: 485
facing west & east



0955 Collected GW 266 sample for Gate

0958 Arrived @ GW 128 (Elden / Jesie Reams, 2811 WCR 116)

1013 Start purge

	temp	pH	cond (m/s)
1013	26.7	7.14	3.18
1028	23.2	7.15	3.22
1033	22.6	7.17	3.19
1038	22.5	7.17	3.21

1040 collected GW 128 sample for Cr+6

1050 Arrived @ GW 117 (Marshall Stephens, 2210 WCR 111)

1100 Start purge

	temp	pH	cond (m/s)
1100	24.2	7.23	2.05
1115	23.2	7.23	1.82
1120	22.8	7.28	1.69
1125	23.1	7.24	1.80

1130 collected GW 117 sample for Cr+6

1200 break for lunch

1315 Arrived @ GW 116 (Rosa Siferentes, 2909 SCR 114)

1341 Start purge

	temp	pH	cond (mes)
1341	25.9	7.38	2.46
1356	23.6	7.41	2.46
1401	22.6	7.43	2.46

	temp	pH	cond (m/s)
1406	22.4	7.44	2.46

1408 Collected GW 116 sample for Cr^{+6}

1420 duplicate GW 238 collected @ GW 116

1430 Arrived @ GW 65 (Rhonda Mizzles, 3011 SCR 1200)

1432 Purge start

	temp	pH	cond (m/s)
1432	33.7	7.15	2.09
1447	24.5	7.15	2.09
1452	22.6	7.23	2.09
1457	22.1	7.26	2.10
1502	22.0	7.24	2.10

1505 Collected GW 65 sample for Cr^{+6}

1510 Arrived @ GW 130 (Richard Creek, 2000 WCR 114)

1518 Purge start

	temp	pH	cond (m/s)
1518	24.8	7.34	2.83
1533	22.5	7.37	2.82
1538	22.1	7.38	2.80
1543	21.8	7.40	2.85

1548 Collected GW 130 sample for Cr^{+6}

Reference 19

WCR112 TCEQ-SSDAP SAMPLING FIELD NOTEBOOK #5

6/16/09 Craig Watts

8:00am Health & Safety Briefing @ Cotton Flat Grocery
Hospital Midland Memorial N. on Cotton Flat Rd
follow signs - right on Front St. left on
Garfield / Hwy 158

On-site Personnel cell #'s CW 6/16/09

432-230-3300 Sam Lilley ~~Cell phone #s~~
432-853-6376 Micah Beard > Shaw
512-468-3115 Buddy Henderson - TCEQ

8:25am

~~8:30am~~ 2701 WCR 112 GW-135 B&C Totalizer
CW 6/16/09

Temp.	pH	Cond.	Time	6375303.4
23.8	7.35	2.28	8:28am	
~~22.7~~	7.59	2.29	8:43am	GW-135B collected @ 8:55am
22.8	7.60	2.29	8:48am	by SLilley
22.7	7.56	2.29	8:53am	GW-135C collected @ 8:57am
				by Sam Lilley

9:10am 2615 WCR 112 GW-136 B&C Totalizer

Time	Temp	pH	Cond	~~3486.40~~ CW 6/16/09
9:11am	25.1	7.49	2.43	348643.8
9:26am	24.9	7.63	2.37	
9:31am	24.7	7.63	2.36	
9:36am	24.8	7.62	2.33	

CW 6/16/09

GW-136 B ~~9:37~~ collected by Sam Lilley @ 9:37am
GW-136 C " " " " @ 9:39am

9:50am 2601 WCR 112 GW-140 B&C Totalizer

Time	Temp	pH	Cond	106177.7
9:56am	26.1	7.55	1.90	
10:11am	24.8	7.72	1.88	GW-140B collected @
10:16am	23.9	7.81	1.88	10:23am by SLilley
10:21am	24.0	7.74	1.87	GW-140C collected @
				10:25am by SLilley

6/16/09 Craig Watts

Craig Watts

2 6/16/09

10:50am 2605 WCR 110 GW-144 B&C

Time	Temp	pH	Cond	Totalizer
~~10:56am~~	36.4	7.29	2.46	1224649.6
~~10:26am~~ cw 6/16/09				
~~10:41am~~	33.0	7.34	2.28	
11:11am	31.1	7.33	2.31	
11:16am				
11:21am	31.0	7.35	2.32	
11:26am	31.0	7.36	2.36	

Sample	Collection Time	Collected by
GW-144 B	11:28 am	Sam Lilley
GW-144 C	11:30 am	Sam Lilley

11:50am 3018 SCR 1197 GW-171 (first time sample)

Time	Temp	pH	Cond	Totalizer = N/A
11:55am	26.2	7.32	2.98	
12:10pm	24.0	7.49	2.99	
12:15pm	23.5	7.48	3.00	
12:20pm	23.4	7.49	3.01	
~~12:25pm~~ cw 6/16/09				

	Sample	Collection Time	Collected by
	GW-171	12:21 pm	Sam Lilley
Duplicate	GW-201	"1:00 pm"	~~Sam Lilley~~ cw 6/16/09

1:30pm 2401 W CR 112 GW 141 B&C

Time	Temp	pH	Cond	Totalizer
1:41pm	28.2	7.55	2.33	67121.7
1:56pm	26.0	7.58	2.37	
2:01pm	25.5	7.60	2.38	
2:06pm	25.3	7.59	2.38	

Sample	Collection Time	Collected by
GW-141 B	2:08 pm	Sam Lilley
GW-141 C	2:10 pm	Sam Lilley

6/09 Craig Watts

2:35pm 2806 S CR 1197 GW-175 (first time sample)

Time	Temp	pH	Cond
2:39pm	27.7	7.26	3.08
2:54pm	25.1	7.33	3.12
2:59pm	24.5	7.31	3.16
3:04pm	24.1	7.32	3.13

GPS coords.
31.96292 °N
102.08558 °W

Sample	Collection Time	Collected by
GW-175	3:06 pm	Sam Lilley

30pm 2805 W. I-20 GW-108 A, B & C

Time	Temp	pH	Cond	Totalizer
3:37pm	39.1	6.13	2.69	449.6
3:52pm	36.0	6.02	2.54	
3:57pm	34.4	6.16	2.58	
4:02pm	34.3	6.15	2.57	
4:07pm	34.2	6.16	2.57	

Sample	Collection Time	Collected by
GW-108 A	4:09 pm	Sam Lilley
GW-108 B	4:11 pm	Sam Lilley
GW-108 C	4:13 pm	Sam Lilley

Craig Watts
6/16/09

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6/17/09 Craig Walls

Sam Lilley & Micah Beard of Shaw & Buddy Henderson

8:00am Meet @ Cotton Flat Rd & W CR 114
Health & Safety meeting
CW 6/17/09

8:20am 2815 I-20 ~~GW-172~~ (DRM Companies) CW 6/17/09
Nearest faucet is approximately 30 yards ~~NW~~ NE of well head - ~~Sample taken @ that faucet - @ SW corner of building~~ CW 6/17/09
Robert Musick already sampled this well - GW-107
obtained Access Agreement from Stanley Williams of DRM Companies. Mr. Williams owns the Pondarosa Trailer Park @ 3900 S. CR 1200/Cotton Flat Rd.
Mr. Williams says there are 4 wells (3 w/ pumps) that feed into one line @ cinderblock well house (this well doesn't have pump)
Stanley Williams PH: 432-978-4053
3900 S. CR 1200
Midland, TX 79906

8:55am Arrive 2102 W CR 117 GW-176

Time	Temp	pH	Cond
9:00am	24.3	7.34	2.44
9:15	24.4	7.34	2.41
9:20	24.6	7.33	2.40
9:25	24.7	7.31	2.41

	Sample	Time	Collector
	GW-176	9:27am	Sam Lilley
duplicate	GW-203	"10:00 am"	Sam Lilley ~~large~~ CW 6/17/09

There is an above ground pool & ~~a fish tank~~ (~~dogs drink out of~~
a large water tank/trough with gold fish.
Dogs drink out of water trough.

Craig Walls
6/17/09

7/09 Craig Watt

0am 2505 W CR 110 GW-145 B & C

Awbrey's had concerns over spent particular filters. I explained to them that the filters are safe to handle & they can throw them away in the garbage.

me	Temp	pH	Cond	Totalizer
0am	38.7	7.40	2.37	214040.1
16am	37.2	7.46	2.26	
21	28.0	7.44	2.28	
26	27.6	7.51	2.29	
31	27.4	7.51	2.29	

Sample	Time	Collector
GW-145 B	10:34	Sam Lilley
GW-145 C	10:37	Sam Lilley

05am 2910 W CR 116 GW-177

Nearest faucet to well head approximately 40 yards NE through PVC pipe. Sample will be taken here.

me	Temp.	pH.	Cond.
10am	29.6	7.43	2.44
25am	29.0	7.44	2.31
30am	28.7	7.44	2.29
35am	28.4	7.43	2.29

Sample	Time	Collector
GW-177	11:37am	Sam Lilley

30pm 3412 CR 1200/ Cotton Flat Rd. GW-184

Time	Temp.	pH	Cond.
1:40pm	26.3	7.21	2.85
1:55pm	26.0	7.21	2.82
2:00pm	23.9	7.22	2.84
2:05	~~26~~ 23.6	7.21	2.87
2:10	CW 6/17/09		
	24.1	7.21	2.87

Sample	Time	Collector
GW-184	2:12	Sam Lilley

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6/17/89 Craig Watts

2:50pm Arrive 2708 W CR 114 GW-92 B&C

Time	Temp	pH	Cond	Totalizer
2:53	36.5	7.61	2.67	74318.5
3:08	30.0	7.71	2.49	
3:13	27.5	7.75	2.55	
3:18	27.4	7.75	2.54	
3:23	27.5	7.74	2.55	

Sample	Time	Collector
GW-92 B	3:25	Sam Lilley
GW-92 C	3:27	Sam Lilley

3:45pm Arrive @ 2901 W CR 115 GW-188

Time	Temp	pH	Cond
3:55pm	32.9	7.29	3.50
4:10pm	26.2	7.35	3.36
4:15pm	24.0	7.38	3.40
4:20pm	24.0	7.40	3.41
4:25pm	23.9	7.41	3.41

Sample	Time	Collector
GW-188	4:27pm	Sam Lilley

Craig Watts
6/17/89

6/18/09 Craig Watts

8:00am Meet Shaw (Sam Lilley & Micah Beard) & Buddy Henderson @ Cotton Flat Grocery. Conduct Health & Safety meeting.

8:10am Arrive 2900 S CR 1200 GW-180, GW-181, GW-182

~~Time~~ CW 6/18/09

purge GW-181 well

Time	Temp	pH	Cond	Sample	Time	Collector
8:45am	21.3	7.70	1.64	GW-181	9:12am	Sam Lilley
9:00am	21.2	7.69	1.65			
9:05am	21.2	7.69	1.64			
9:10am	21.3	7.68	1.64			

GW-180 well purge with Grundfos pump

Time	Temp	pH	Cond	Sample	Time	Collector
9:15am	22.6	7.51	2.21	GW-180	9:42am	Sam Lilley
9:30am	22.8	7.49	2.22			
9:35am	22.9	7.49	2.23			
9:40am	23.1	7.51	2.22			

GW-182 not taken. Well cap could not ~~cannot~~ be removed. CW 6/18/09

10:25 Arrive 2109 WCR 116 - nobody home GW-187

Time	Temp	pH	Cond	Sample	Time	Collector
10:28am	28.8	7.31	2.54			
10:43am	27.0	7.31	2.49	~~GW-180~~ CW 6/18/09		
10:48am	26.7	7.33	2.47	GW-187	10:55am	Sam Lilley
10:53am	26.4	7.32	2.48			

Sample taken from faucet located under house @ midway point

Craig Watts
6/18/09

8 6/18/09 Craig Watt

11:05 Arrive 2100 WCR 116 GW-186

No faucet in well house. Sample taken from faucet ~25 yards east of well house

Time	Temp	pH	Cond	Sample	Time	Collector
11:10am	28.5	7.46	2.02	GW-186	11:37am	Sam Lilley
11:25am	28.2	7.44	2.03			
11:30am	28.4	7.48	2.03			
11:35am	28.1	7.50	2.00			

1:20pm Arrive 2401 Neil st GW-190

~~Need~~ CW 6/18/09 Using Grundfos pump* to purge well. Texas Incinerator facility is on city water and does not use well.

Time	Temp.	pH	Cond	Sample	Time	Collector
1:30pm	28.2	7.37	2.67			
1:45pm	25.1	7.31	2.57	GW-190	2:02pm	Sam Lilley
1:50pm	23.5	7.33	2.54	GW-205	"2:35"	Sam Lilley
1:55pm	23.6	7.32	2.54	(Duplicate)		
2:00pm	23.6	7.33	2.51			

CW 6/18/09

* Used same tubing that was used @ GW-190 Didn't know that pump and extra tubing was needed for this well (GW-190). Pump was also not decontaminated.

3300 S. CR 1200 / Cotton Flat Rd. GW-191

Time	Temp	pH	Cond	Sample	Time	Collector
3:00pm	22.6	7.63	2.80	GW-191	3:29	Sam Lilley
3:15	22.6	7.59	2.81			
3:20	22.5	7.58	2.79			
3:25	22.1	7.59	2.80			

Craig Watt
6/18/09

APRIL PALMIE

9

W CR 112 GW SAMPLING 6/23/9

730 MOB TO SITE

800 MEET CONTRACTOR @ COTTON + FLAT GROCERY

WEATHER MILD, CLEAR, ~~WINDY~~ BREEZY

CONDUCT TAILGATE, WRS SAMPLERS JASON BROOKS + SAM

830 Begin purge PORT C GW-81 B+C 5060 LILLY

2802 W CR 111 0005230

TIME	TEMP	PH	COND
830	25.4	7.41	2.90
845	22.8	7.39	2.81
850	21.8	7.42	2.81
855	21.4	7.39	2.81
900	21.5	7.44	2.81

SAMPLED GW-~~81~~ 81B 9:01 + GW-81C 9:03

915 TO BILLY AALAND PARISH

WELL BEHIND 2806 W CR 110

NO MAIL HERE (?)

This well serves 2 houses, not sampled previously

GW-254 A+C GPS 31.96488 N + 102.09791°

~~PHOTO~~

TOTALIZER 363800 (no final)

TIME	TEMP	PH	COND
920	22.4	7.51	2.17
935	22.0	7.49	2.22
940	22.2	7.50	2.25
945	21.8	7.51	2.25

GW-254 A 9:47 GW-254 C 9:50

Photo 51 Filter, due E, APALMIE, 9:50 AM

52 well + tank, due W, APALMIE, 9:50 AM

6/23/19

6/23/9 CWP

1000 TO 2601 W CR 114 GW-125 B+C
[totalizer 0430605] + 430756

TIME	TEMP	PH 756	COND
10:02	28.0	7.40	1.54
10:17	24.1	7.51	1.48
10:22	22.8	7.54	1.52
10:27	22.5	7.48	1.54
10:32	24.4	7.50	1.55

SAMPLE TIME GW-125 B 10:33 GW-125C 10:35

1100 TO 2414 W CR 114 MRS CROUCH
GW 103 B+C
totalizer 307204

TIME	TEMP	PH	COND
11:03	25.8	7.73	1.92

No purge, from poly tank
GW-103B 11:05 GW-103C 11:08

1120 TO GW 102 Danny Marchant 2413 W CR 114

Time	Temp	PH	COND
11:20	29.9	7.72	1.64

~~11:20~~ AB SAMPLE TIME GW 102 B 11:24
GW 102 C 11:26
GW 207 (DUP OF C) 11:41
TOTALIZER 0193453, no purge poly tank

1150 TO 2501 W CR 114 Larry MITCHELL GW ~~101~~ 99 B+C
TOTALIZER 0044100

Time	temp	PH	COND
1150	29.6	7.94	1.94

Sample time GW 99 B 1154 GW99C 1156

4/23/9

6/23/03

1200 Meet w/ SUGAM & SAM, planning, coordination
1230-1330 LUNCH

1330 TO GW 101 B+C ~~LARRY~~ TOMMIE MITCHELL 2602 W CR 114
totalizer 0587025; 0587300

TIME	TEMP	PH	COND
13:26	28.8	7.44	1.86
13:41	24.8	7.50	1.85
13:46	24.1	~~4.49~~ 7.49	1.85
13:51	23.6	7.49	1.86
13:56	23.4	7.54	1.86
14:01	23.7	7.58	1.88

Sample times GW 101B 14:02 GW 101C 14:04

1405 Start GW 100 B+C 2500 W CR 114 - DUP GW 209 of 100C

totalizer 0241515 & 0241739

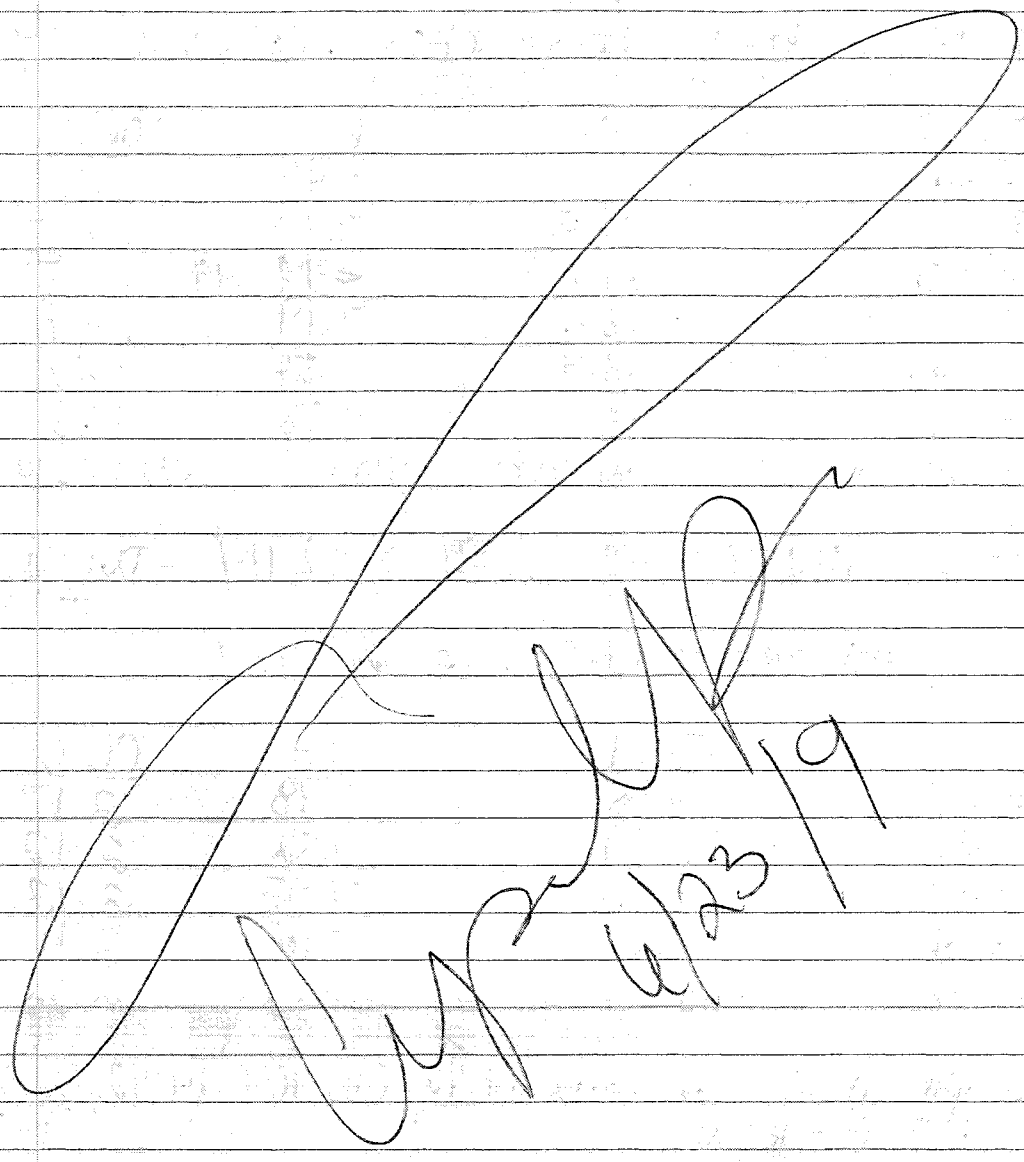
TIME	TEMP	PH	COND
1406	29.5	7.48	2.17
1421	25.9	7.52	2.12
1426	24.2	7.53	2.12
1431	23.8	7.60	2.11
1436	23.7	7.59	2.08

Sample time GW-100B 14:40, GW-100C 14:42, GW-209 14:57
NOTE B - yellow

1455 Start GW-126B+C Ramos 3000 CR 1200

TIME	TEMP	PH	COND

NEXT PG



GW-124 B+C 6/23/9

TIME	TEMP	PH	COND
14:55	35.7	7.87	2.00
15:10	26.4	7.43	1.70
15:15	23.7	7.43	1.72
15:20	23.5	7.41	1.74
15:25	23.4	7.43	1.73

Sampled GW-126 B 15:27 + GW-126 C 15:29

TOTALIZER 2300099 ; 2300221

1540 TO RIGNET GW80B + GW80C 2802 WCR111

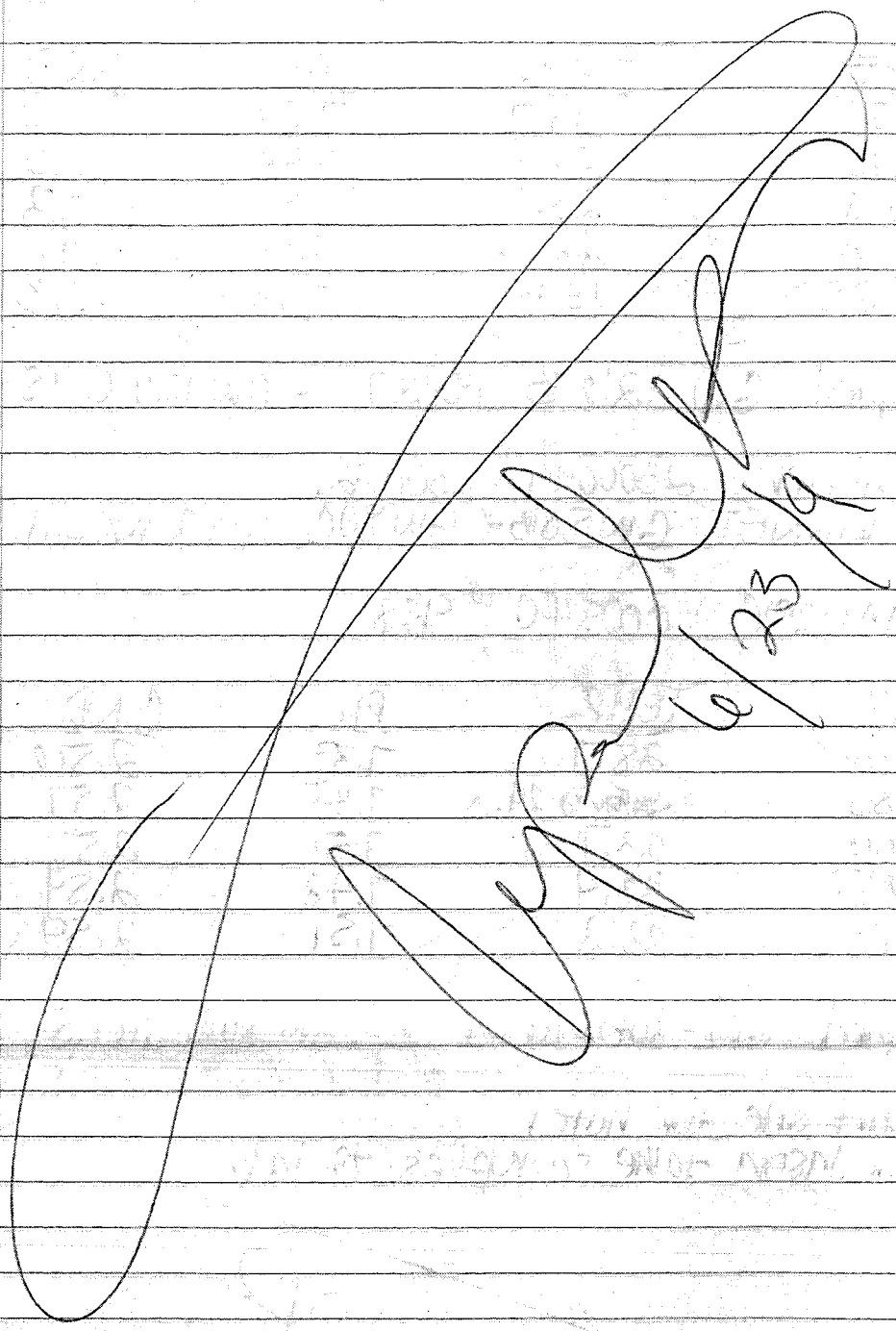
TOTALIZER 000840 ; 988

TIME	TEMP	PH	COND
1540	28.7	7.33	2.56
1555	~~25.8~~ 24.2	7.45	2.57
1600	23.7	7.51	2.57
1605	23.4	7.48	2.59
1610	23.2	7.51	2.59

Sampled GW-80B 1612 GW-80C 1615

1430 Depart site for hotel
Sam + Jason take samples to lab

6/23/9



6/24/9

APRIL NEEDS TO GET TOTALIZER readings for:
GW-86 997
GW-90 2010520

730 TO SITE
800 MEET @ COTTONWOOD FLAT GROCERY
CONDUCT TAILGATE MTG
820 TO MRS ALSUP GW-98B + GW-98C 2719 WCR 114
TALKED TO MRS ALSUP, she has a few concerns does not know how to change filters, wrench does not fit (too small), pressure is too high, she can't find how to get water to her barn. conveyed to Dan.

Collect TOTAL CHROME on A, Hex on B+C

TIME	TEMP	PH	COND
835	24.4	7.55	2.21
850	22.6	7.55	2.19
855	21.8	7.54	2.19
900	21.7	7.53	2.18
905			

TOTALIZER: 777485;

Sample ~~to~~ time GW-98A TOTAL 9:06
GW-98B 9:08 GW-98C 9:10

930 TO GW 250 LUIS LEAL 1907 WCR 115

Well is west of shop in building near the road. PLUMBED TO SHOP + HOUSE, AT + TRAILER
CORNER OF 1197 + WCR 115

6/24/9

6/24/9 19

GW 250 cont.
GPS coordinate : 31.96111 N 102.08450 W

Photos : 53 Shed-fav at DUE N, APALMIE,
Photos 54 well DUE N, " " ,

TIME	TEMP	PH	COND
9:37	23.6	7.60	1.38
9:52	22.5	7.61	1.39
9:57	22.6	7.64	1.42
10:02	22.6	7.60	1.40

GW-250 sampled 10:03

1005 Depart site to Rocha, see if resident is home
Continue site recon to find wells in area

1330 TO COTTON W FLAT MOBILE HOME PARK
2101 W CR 120 GW-256

2 wells, 1 ~~east~~ west just irrigation
1 ~~w~~ east/middle, by large tank

Signed access

SAMPLED 5/11/09 XENCO (ND) HEX CHROME

6/24/19

4/24/21

GW-256 COTTON FLAT MOBILE HOME PARK

1348 Begin purge, April collects access from Joe Eads + Daniel Dominguez

TIME	TEMP	PH	COND
1348	44.1	7.19	3.09
1403	27.1	7.15	2.69
1408	24.2	7.12	2.78
1413	23.8	7.14	2.79
1418	23.7	7.14	2.80

Sample collected GW-256 14:20

Photo 60, DUE E, well + inactive holding tank, sugam

1430 TD 35.0 SCL 11.98 Daniel Dominguez,
GW-257 GPS 31.95333, 102.08207
well along W fence under black barrell, nearest faucet in well house SW corner of property (well is well house is DRY)
PHOTO 62, DUE SOUTH, inside drum

OTHER GPS
GW 256 31.95326, 102.08357
GW 255 31.95280, 102.08462
GW 252 31.95853, 102.08454
GW 253 31.96035 102.08454

6/24/9

6/24/9 23

1433 Purge starts GW 25~~8~~7 Daniel Dominguez

TIME	TEMP	PH	COND
14:33	26.1	7.24	2.75
14:48	23.5	7.25	2.82
14:53	23.4	7.24	2.75
14:58	22.4	~~2~~7.24	2.80
15:03	22.7	7.23	2.79
15:08	22.4	7.25	2.80

GW-25~~8~~7 sampled 15:09

~~1520~~ MACARIO

1520 TO VILLARREAL* GW258 3418 SCR 1200

* GET ADDRESS FROM ACCESS AGREEMENT *

GPS: 31.95414, 102.08989

PHOTO ~~62~~ 63 Facing E, Sugam

TIME	TEMP	PH	COND
1523	31.7	7.11	2.78
1538	24.5	7.32	2.66
1543	22.8	7.25	2.74
1548	22.6	7.27	2.74
1553	22.4	7.26	2.75

SAMPLE TIME 15:54 GW-258

1600 TO GW-25~~8~~9 Paul + Trina Burns 2701 SCR 1200

GPS 31.96339, 102.08826

Photo ~~63~~ 64, DUE N, Sugam

6/24/9

1615 Start purge GW-259 + GW-212
well behind house

TIME	TEMP	PH	COND
1615	27.1	7.60	1.05
1630	24.0	7.65	1.89
1635	23.1	7.64	1.87
1640	22.8	7.57	1.82
1645	22.7	7.60	1.83

JASON IS HOLDING GW-257, 258, 259, 212 overnight, will seal cooler, + take in ~~a~~ morning b/c of late sample time. No one available at lab after 5pm

Sample time GW-259 16:46, GW-212 ~~16:~~ 17:01

1700 SITE RECON LOOK FOR POTENTIAL PWS E OF 1197. Cruised ~~F~~ CR 1196 - CR 1192 and CR 115 - 117 East of 1192.
FOUND Ø POTENTIAL PWS.
Area seems to be single family / small business.
1 appearant 3 or 4 plex on CR 1193, e side of rd.

1730 Depart site
1800 Arrive @ hotel

END of WK'S SAMPLING 6/24

6/24/9

H&S meeting @ 7:45pm

* Hex Chrome samples

6/30/09 at 7:50 ~~PM~~ AM
2710 WCR 112
GW-137B and GW-137C

* purged groundwater from the effluent of the system

Time	Temp	pH	Cond.
7:54	22.7	7.13	2.70
8:09	22.0	7.07	3.49
8:14	21.8	7.08	3.45
8:19	21.6	7.05	3.41
8:24	21.5	7.05	3.34

Totalizer Reading : 2016901

Samples collected from port 2 and 3 at 8:27 and 8:29, respectively.

GW-137B- had a slight yellow color to the gw collected.

Danielle Soule
6/30/09

QA/QC
2/2

* Hex chrome samples

6/30/09 ②
2700 WCR 112
GW-138B and GW-138C

* purged from the effluent end of the filtration system

Time	Temp	pH	Cond.
838	26.7	7.11	2.89
853	24.2	7.10	2.89
858	24.0	7.09	2.81
903	24.2	7.06	2.87

Totalizer Reading: 379350/379380

Gw 138B and 138C collected at 9:07 and 9:09 respectively

Danielle Sule
6/30/09

6.30.09 @ 9:15
GW-143B and GW-143C
~~WCR~~ 2604 W CR 112

Chrome +6 samples

* purged from the effluent part of the filtration system

TIME	Temp	pH	Cond
920	23.8	7.35	2.62
935	23.0	7.31	2.61
940	22.5	7.32	2.60
945	22.3	7.32	2.60

Totalizer Reading : 2054301

Samples GW-143B and GW-143C were collected at 950 & 953, respectively

Danielle Sale 6/30/09

June 30, 2009 at 10 AM
GW-139B, GW-139C, GW-213
2514 W CR 112

* purged from the effluent of the filtration system.

Time	Temp	pH	Cond.
1003	23.0	7.16	2.04
1018	22.6	7.10	2.06
1023	22.1	7.08	2.04
1028	22.0	7.05	2.06

Collected the dup from effluent end

Totalizer Readings - 14410 | 14430

GW-139B was collected at 1030
GW-139C " " 1034
GW-213 " " 1050

Danielle Soule 6/30/09

* Chrome +6 Samples only

June 30, 2009 at
GW 142B and GW 142C
2502 WCR 112

* purged gw from the effluent port of the filtration system

TIME	Temp	pH	Cond.
10:45	28.0	7.06	2.36
11:00	24.5	7.09	2.33
11:05	22.7	7.09	2.29
11:10	22.1	7.08	2.31
11:15	21.9	7.09	2.31

Totalizer Readings → 3494990 / 3495060

GW-142B collected at 11:17 and GW-142C collected at 11:20.

Danielle Sodl

6/30/09

June 30, 2009 @ 1250
GW-104A, GW-104B, & GW-104C
2604 [redacted] S CR 1200

* purged gw from the effluent port.

TIME	TEMP	pH	Cond.
13:02	24.6	7.26	1.72
1317	23.2	7.22	1.69
1322	22.5	7.20	1.70
1329	22.4	7.20	1.70

Totalizer Readings: 323470/32353

Hex chrome samples only collected.

* GW-104A, 104B, & 104C were collected at 1330, 1332, & 1334 respectively

Danielle Soule 6/30/09

June 30, 2009 at 1330.
GW-146B, GW-146C, GW-215
2405 WCR 114

This well could not be purge b/c their well does not have a faucet before the water enters the bottom of a 3,000 gallon poly tank. Thus, only grab samples were collected

Totalizer Reading → 81240

GW-146B, 146C, GW-215 were collected at 13:43, 13:46, and 1400 respectively.

Samuel Sale
6/30/09

7/1/09 at 7:50
GW-10
2707 S CR 1206

* Chrome+6 sample taken the closes faucet to the well, which is located around 125 ft. This is the second time we sampled the well

TIME	Temp	pH	Cond.
755	22.4	7.39	2.12
810	23.7	7.16	2.12
815	24.0	7.14	2.13
820	24.0	7.14	2.13

The hexavalent chrome GW-10 was collected at 823.

7/1/09

7/1/2009 at 8:32
GW-29
2609 WCR 114

This will be the third Chrome +6 sample collected from this well/~~site~~ sample location.

Time	Temp	pH	Cond.
850	22.0	7.12	2.21
905	21.5	7.13	2.20
910	21.5	7.059	2.20
915	21.4	7.10	2.20

* sample collected at 9:18A

Sample was collected from a faucet located outside on the ~~est~~ east side of the well shed.

Janelle Sule
7/1/2009

Danielle Soule 7/1/09

7/1/2009 at. 9:29 AM
GW-36 & GW-216
2802 S CR 1200

* This is the second sample for Chrome +6 collected at the gw-36 site

Time	Temp	pH	Cond.
931	24.7	7.04	2.83
946	22.9	~~7.00~~ 6.98	2.86
951	21.8	6.98	2.90
956	21.6	6.96	2.85

* Duplicate was collected from the site
* The sample was collected from ~~the~~ an outside faucet on the east side of the building where the well head is located.
* GW-36 was collected at 958

Danielle Soule
7/1/09

Danielle Bale 7/1/09

7/1/2009 at 10:00 AM
GW-55
2801 SCR 1200

GW-55 is a grab "only" sample b/c there is no faucet located before a 2,500 thus we did not purge the well. The sample was collected from a faucet located after the 2,500 poly tank and a water softener system that may not be in use at the time we sampled.

Sample collected at 10:07

Chrome +6 sample

Danielle Soule
7/1/2009

Danielle Gale 7/1/09

July 1, 2009 @ 10:15
GW-57
2715 Cotton Flat Dr

~~[illegible]~~ The groundwater was purged aprox. 30 minutes from the closes faucet located to the well head. ~~[illegible]~~ The faucet was located a few feet south of the well.

Time	Temp	pH	Cond.
10:20	27.7	7.21	1.99
10:35	24.0 ~~28.8~~	7.09	1.98
10:40	24.4	7.05	1.98
10:45	24.1	7.09	1.98

* This will be the second Chrome +6 sample collected at this groundwater sample locations.

* GW-57 was collected at 10:48 AM

Daniell Soule 7/1/09

7/1/09 at 11:04
GW-38
2804 S CR 1205

Groundwater was purged from the closes faucet to the well. The faucet is located inside the Auto body shop which is last of the well ~~house~~ head.

Groundwater was purged aproximately for 20-30 minutes.

Time	Temp	pH	Cond.
11:06	25.8	7.14	2.23
11:21	22.6	7.19	2.22
11:26	21.8	7.15	2.20
11:31	21.7	7.15	2.20

GW-38 is a chrome +6 only sample and it was collected at 11:33AM

Samuel Sile 7/1/09

7/1/2009 @ 12:55
GW-150A and GW-150F

GW was purged from the effluent port of the filtration system.

Time	Temp	pH	Cond
1315	23.3	7.10	2.65
1330	23.4	7.09	2.65
1335	22.9	7.06	2.65
1340	22.6	7.08	2.64

Totalizer Reading 0241230/

Samples GW-150A and GW-150F were collected at 13:43 and 13:45 respectively.

7/1/09

1152

Transcribe

7/1/2009 at 2:27 pm
GW-264 and GW-218
2910 WCR115

The well was purged from the faucet closes to the well, which was located outside the front yard.

Time	Temp	pH	Cond.
1430	29.1	7.02	2.28
1445	24.5	7.08	2.28
1450	23.0	7.01	2.24
1455	22.6	7.02	2.26
1500	22.6	7.02	2.28

GW-264 and GW-218 were collected at 1502 & 1525, respectively

North facing photo of the faucet where GW-264 was located/collected.

GPS: 31.958563°N
102.099029°W

[illegible] 7/1/2009

Turn over

WCR 112 SAMPLING 7/7/9

0800 MEET JASON, TAILGATE MTG
WEATHER overcast, calm
STAFF APRIL PALMIE, NANCY JOHNSON, JASON BROOKS

0810 TO BURNS 2701 S CR 1200
GRAB SAMPLE FROM POOL SP-05, SP-06

SP-05 08:10 SP-06 08:25
Photo 1 E, Pool, Palmie

GPS SP-05 31.96292 102.08842

0820 TO BURNS WELL + FILTER SYSTEM
GW-259 A + C

BEGIN PURGE TOTALIZER 0000071 BEGIN
~~END~~

Photo 2: E, of well, PALMIE
Photo 3: N, filter system, PALMIE

TIME	TEMP	PH	COND
8:21	43.0	5.64	2.80
8:36	23.4	5.05	2.79
8:41	22.0	5.13	2.32
8:46	21.5	5.20	2.36
8:51	21.5	5:03	2.34

* PH out of A 7.32, water out of filter is hot (43.0) + pH 5.64

SAMPLE TIME GW-259 A 0854
GW-259 C 0854

Blank

7/7/9

0905 ARRIVE AT PETRO PLEX, CHECK IN W/ PHIL

0910 START PURGE GW-81 B+C 2802 W CR 111

TOTALIZER START 8420 END 8570

TIME	TEMP	PH	COND
9:10	23.2	7.03	2.87
9:25	23.4	7.08	2.78
9:30	22.4	7.05	2.79
9:35	22.2	7.05	2.78
9:40	22.1	7.10	2.78

SAMPLE TIME GW-81B 09:42 GW-81C 09:44

950 ACROSS STREET TO RIGNET 2803 W CR 111
MEET Byron Fender GW-80B + GW-80C
Start purge Reading 2138 END 2277

TIME	TEMP	PH	COND
950	28.2	7.03	2.65
1005	24.2	7.10	2.54
1010	22.9	7.14	2.60
1015	22.5	7.15	2.59
1020	22.4	7.19	2.57

Sample time GW-80B ~~[illegible]~~ 10:22
GW-80C 10:24

1030 Across street to Petroplex 2800 W CR 111
GW-86B + GW-86C

Cuerpo

Original

GW86B + GW86C 1/7/9

1030

TIME	TEMP	PH	COND
10:30	26.6	7.09	3.59
10:45	22.5	7.18	3.49
10:50	22.1	7.20	3.47
10:55	21.7	7.25	3.58
11:00	21.6	7.21	3.59

SAMPLE TIME GW-86B 11:02 GW-86C 11:04

totalizer reading 1300 end 1490

1130 TO MITCHELLS GW-101B+C 2602 W CR 114
TOTALIZER reading 588145 end 588324

TIME	TEMP	PH	COND
11:29	30.1	7.06	1.95
11:44	25.7	7.24	1.88
11:49	24.0	7.30	1.87
11:54	23.4	7.27	1.87
11:59	23.2	7.22	1.87
12:04	22.9	7.27	1.87

Sample time GW-101B 1205 GW-101-C 12:07
+ GW 219 DUP

Also Purge GW100B+C MITCHELL 2500 W CR114

TIME	TEMP	PH	COND
11:33	28.5	7.09	2.43
11:48	23.8	7.42	2.36
11:53	23.2	7.48	2.36
11:58	22.9	7.45	2.34
12:03	22.8	7.48	2.31

Sample time GW-100B 12:08 GW-100C 12:10
GW-219 12:25 TOTALIZER reader 242771 end 242989

Transfer

7/1/9

13:20 TO CROUCH GW 103 B&C, DUP GW-220
NO PURGE - poly tank 2414 W CR 114

TIME	TEMP	PH	COND
13:20	32.9	7.50	2.00

Sample time GW-103 B 13:22
GW-103C 13:25
GW-220 13:40

TOTALIZER reading 309712

13:35 TO DANNY MARCHANT GW 102B and 102C
/ 2413 W CR 114
NO PURGE - POLY TANK

TIME	TEMP	pH	COND
13:35	37.9	7.61	1.63

SAMPLE TIME GW-102B 13:36
GW-102C 13:38

TOTALIZER 194910

Incipit

7/7

13:46 TO LARRY MITCHELL GW-99B and GW-99C
2501 W CR 114

NO PURGE - POLY TANK

TIME	TEMP	pH	COND.
13	34.0	7.67	2.02

SAMPLE TIME 13:48 GW-99B
13:50 GW-99C

TOTALIZER 0047602

14:05 TO MR. PHILIP GW125B and GW 125C
2601 W CR114

TOTALIZER START 433260 END 433370

14:08 BEGIN PURGE

	TIME	TEMP	pH	COND
	14:08	30.8	7.25	1.45
14:23	~~14:23~~	24.6	7.27	1.49
	14:28	23.4	7.26	1.51
	14:33	23.1	7.25	1.51
	14:38	23.0	7.33	1.52

SAMPLE TIME GW-125B 14:40
GW-125C 14:42

Larry Johnson

Irene

14:49 TO DELLA HOLIEDY 6W-97B + 6W-97C
2606 W. CR 114

TOTALIZER START ~~37~~ 323486 END 323770

TIME	TEMP	pH	COND
14:49	29.8	7.21	2.10
15:04	24.4	7.34	2.14
15:09	23.4	7.25	2.16
15:14	23.0	7.30	2.17
15:19	23.1	7.32	2.14

SAMPLE TIME 6W-97B 15:20
6W-97C 15:22

NEW ABOVE-GROUND SWIMMING POOL

Penny Jackson

Transcribe

7/7

15:34 TO LUIS VILLANUEVA GW-96B + GW-97C
2605 W CR 114 DUP GW 221

TOTALIZER BEGIN 1137333 END 1137537

TIME	TEMP	pH	COND
15:34	28.0	7.24	2.05
15:49	23.4	7.21	1.99
15:54	23.5	7.27	2.00
15:59	23.2	7.26	2.02

SAMPLE TIME GW-96B 16:00
GW-96C 16:02
DUP 16:17

16:08 TO KAY BEAUCHAMP GW-91B + GW-91C
2700 W CR 114

TOTALIZER BEGIN - 544202 END - 544450

TIME	TEMP	pH	COND
16:08	27.2	7.18	2.21
16:23	23.4	7.19	2.42
16:28	23.1	7.21	2.45
16:33	22.8	7.18	2.36
16:38	22.6	7.21	2.29

SAMPLES COLLECTED 16:40 GW-91B
16:42 GW-91C

Collected flakes from pre-filter into plastic bag.

Gary Goldman

Recipe

DAY 2 7/8/9

730 Meet shaw @ pool hall on 1200.
On site April, Nancy, Jason Brooks, Micah Beard

800 TO MR HOWARD GW-95 B+C, 2701 WCR 114
TOTALIZER 400630, 400690

TIME	TEMP	PH	COND
803	26.7	7.13	2.22
818	25.1	7.12	2.31
823	24.0	7.16	2.30
828	22.8	7.14	2.30
8:33	22.2	7.15	2.28
8:38	21.8	7.15	2.27

SAMPLE TIME GW 95 B 8:40 GW95C 8:42

850 TO MRS ALSUP GW-98B + 98C 2719 WCR 114

TIME	TEMP	PH	COND
855	25.0	7.12	2.34
910	23.5	7.13	2.30
915	22.7	7.13	2.29
920	22.6	7.12	2.30
~~925~~			

TOTALIZER 794110, 794200

SAMPLE TIME GW 98 B 9:23 GW98C 9:25

Unreal

7/8/9

9:40 TO ALCOCER GW 105 B+C, 2524 SCR

TIME	TEMP	PH	COND
945	24.5	7.11	2.56
1000	25.1	7.10	2.58
1010	24.1	7:10	2.55
1015	22.9	7:13	2.54
1020	22.7	7:11	2.54
10:25	22.5	7:09	2:55

LOST POWER @ 10:00

TOTALIZER 137020; 137115

SAMPLE TIMES GW 105B 10:27 GW 105C 10:29

{TO RAMOS, MEET JASON + NANCY
MICAH TO DENTIST}

1025 to 1330 see other log.

1330 BACK TO 1200 JASON + NANCY take GW 19A+C
APRIL + MICAH TO NEW WELLS

1335 TO GW-265 2806 S CR 1200, found well but only 1 faucet for whole house, + when turned on no water.

Called Keith Morgan left message

1350 TO WCR 112 vacant next to 2502 WCR 112 no electricity, walked property, could not find well. No water from faucet.

OK

7/5/7

1405ar
~~1405~~ TO Pedro + Delma Castillo 2602 W CR 115
GW 263 + DUP GW-224

1405ar
~~1420~~ Begin purge, nearest faucet in shed/stable behind house
GPS 31.96025 -102.09296
Photo 4 N, of well house GW263, Palmie
Photo 5 E, of faucet, Palmie

TIME	TEMP	PH	COND
14:20	29.0	7.12	3.36
14:35	24.4	7.13	3.36
14:40	23.2	7.14	3.36
14:45	23.0	7.14	3.37
14:50	22.8	7.23	3.34

SAMPLE TIME GW-263 1452 DUP GW-224 1507

1500 TO EUGENE WILLIAMS GW-13 2604 W CR 115

TIME	TEMP	PH	COND
1505	27.5	7.31	1.55
1520	24.4	7.24	1.88
1525	23.5	7.25	1.82
1530	23.3	7.24	1.99
1535	23.0	7.23	2.01

SAMPLE TIME GW-13 1538

1/8/19

7/8/9

1600 TO GW-37 JEFF ROLAND 2915 W CR 114

TIME	TEMP	PH	COND
1605	26.0	7.19	2.03
1620	23.4	7.18	2.00
1625	22.0	7.20	1.98
1630	21.6	7.20	2.00
1635	21.8	7.21	2.00

Sample Time GW-37 16:37

LAST SAMPLE

END OF DAY

Cmpl
7/8/9

BOB 2277

0745 MEET AT POOL HALL, HEALTH AND SAFETY 7/9/9
ON-SITE TOM ELLIOT, MICAH BEARD, APRIL PALMIE,
& NANCY JOHNSON

WEATHER WARM (SOON HOT), LIGHT BREEZE

800 TO GW-39 CAPP ELECTRIC 2611 SCR 1206

	TIME	TEMP	PH	COND
start	815	27.4	7.23	1.88
	830	26.0	7.25	1.82
	835	24.8	7.26	1.83
	840	23.9	7.27	1.81
	845	24.2	7.27	1.83

SAMPLE TIME GW-39 0849

855 TO MUSTANG FIELD SERVICES 2716 SCR 1207 GW-88
DUP GW 225

	TIME	TEMP	PH	COND
start	900	29.2	7.04	2.44
	915	24.1	7.04	2.47
	920	23.0	7.07	2.44
	925	22.6	7.06	2.47
	930	22.7	7.10	2.47

SAMPLE TIME GW-88 9:35 DUP GW-225 9:50

7/9/19

945 TO MR + MRS KING GW-184 DUP GW-226
3412 SCR 1200

MICAH PROCEEDS WITH SAMPLING.
APRIL MEETS W/ MRS KING TO LISTEN TO
HER CONCERNS REGARDING HER HEALTH,
HUSBANDS, & HEALTH OF ANIMALS.

MRS. KING SHOWS ME ANIMALS W/ TUMORS
& DISCUSSES THE HEALTH PROBLEMS OF HER
+ HUSBAND (cancer, brain lessions, tumors)

SHE HAS A LOT OF CONCERNS.

AT THIS LOCATION WE ARE COLLECTING
HEXCHROME, VOA, TPH, DUP OF ALL,
FIELD BLANK

SHE HAS HAD WATER SAMPLED several times.
SAYS ~~WA~~ one time strontium at high levels

Time	TEMP	PH	COND
955	23.9	6.97	3.09
1010	23.0	6.98	3.07
1015	22.7	7.00	3.06
1020	22.7	6.99	3.07

SAMPLE TIME FB-01 10:10 ; GW-184 10:35, GW-226

1040 Depart ~~the~~ King property

Cur 7/9/9

7/9/9

1135 TO GW-74 Fender Prop / Wood Group
2713 + 2715 SCR 1208

DISCUSS PREVIOUS RESULTS, SEE SAMPLE LOCATION, Realize can not sample until after lunch b/c of test being conducted.

Will return after lunch.

1150 TO TOM + NANCY PLAN NEXT ACTIONS.

1300 TO GW-74 WOODS GROUP 2713 + 2715 SCR 1208

TIME	TEMP	PH	COND
1310	27.2	7.16	1.74
1325	23.3	7.20	1.80
1330	22.8	7.16	1.81
1335	22.5	7.16	1.80

SAMPLE TIME GW-74 @ 1338

1345 PICK UP SAMPLES from Tom + Nancy, MEET @ POOL HALL TO GIVE TO ZENCO.

1405 MR. PHILIPS CAME BY SAID PRESSURE DROPPED BY 1/2 AFTER WE SAMPLED. MICAH & I WENT TO MAKE SURE EVERYTHING SHUT DOWN PROPERLY (went ahead & changed filters)

7/9/19

7/9/9

1420 TO GW-30 Glen Young 2804 S CR 1200

Time	TEMP	PH	COND
1430	29.9	6.97	2.91
1445	24.6	7.08	2.60
1450	23.5	7.09	2.50
1455	23.2	7.10	2.45
1500	23.0	7.11	2.39

Sample time GW-30 1504

1505 TO GW-131 Robert Buck 2715 WCR 116

No purge faucet extends directly from well head

Time	TEMP	PH	COND
1510	23.8	7.38	3.48

SAMPLE TIME GW-131 1515

1520 TO GW-111 & GW-124 DUSTY FRIDAY
2801
No electricity + no water. She has moved.

TO GW-119 Hector Enriquez 2709 WCR 116

Time	TEMP	PH	COND
1530 ~~TO GW-131~~			
1545	25.6	6.96	4.26
1600	23.2	6.99	4.23
1605	22.8	6.97	4.23
1610	22.1	7.02	4.09

Sample time GW-119

7/9/7

7/9/9

1620 TO POOL HALL, MEET TOM + NANCY
TO merge samples for transport
to labs

1635 Depart site

end of event

Cupell
7/9/9

7/9/9

Ron Dildine
TCEQ
7/14/09

Day 1

08:00 Arrive @ site

08:10 safety meeting

GW-135 B-C ; ~~Ron + Brenda Bowen~~
Janest Paby Bostwick 2701 ~~2710~~ WCR 112
Flow rate = 662220-I, 662457-F
sprinkler on in front yard
arrival time = 8:30

Time	Temp	pH	Cond
8:30	23.5	7.37	2.30
8:45	21.7	7.08	2.35
8:50	21.5	7.06	2.35
8:55	21.7	7.06	2.33

sample time: 8:57 -B
8:59 -C

- GW-137 mistakenly written on GW-135 well (board on wall)

GW-137 , Ron + Brenda Bowen, 2710 WCR 112

arrival time = 9:03 , Totalizer = 202140, 222400

Time	Temp	pH	Cond
9:08	24.2	7.00	3.07
9:23	22.1	7.02	2.93
9:28	21.5	7.00	3.10
9:33	21.5	7.05	3.14
9:38	21.4	7.10	3.14

Sample time =
9:39 - B
9:41 - C
- Landowners not home

CeW-136, Rita + William Moffitt, 2615 WCR 112

Arrival time = 9:45 Totalizer = 362598, 362844

Time	Temp	pH	Cond
9:50	24.2	7.14	2.42
10:05	22.5	7.09	2.43
10:10	21.8	7.09	2.43
10:15	21.7	7.09	2.39
10:20	21.8	7.14	2.31

Sample time = 10:22 - B
10:24 - C

CeW-138, Debra Brook, 2700 WCR 112

Arrival time = 10:29 Totalizer = 381910, 382177

Time	Temp	pH	Cond
10:34	24.2	7.09	2.97
10:49	23.3	7.15	2.93
10:54	22.9	7.14	2.96
10:59	22.1	7.19	2.94

Sample time = 11:00 - B
11:03 - C

- Jason Brooks had to leave, Tom Elliott replaced him.

CEW-144, Frank Mendoza, 2605 UCR 110

Arrival Time = 11:15 Totalizer = 1227514
1227676

Time	Temp	pH	Cond
11:20	28.5	7.10	2.26
11:35	28.7	7.11	2.29
11:40	23.8	7.07	2.29
11:45	23.1	7.11	2.27
11:50	23.1	7.11	2.28

Sample time = 11:50 - D
11:53 - C

CEW-146, M. Stephenson, 2405 WCR ~~120~~ 114

Arrival time = 1:25 Totalizer = 104135

Time	Temp	pH	Cond
1:30	29.4	7.46	2.24

- spoke w/ Ms. Stephenson, basic CERCLA process.
- ≈ 3,000 gallon holding tank, did not purge as volume was too great. Took sample after one parameter reading.

Sample = 13:30 - B
13:35 - C

GW-145, Rick + Susan Aubrey, 2505 WCR 110

Arrival time = 13:45 Totalizer: 221005
224190

Time	Temp	pH	Cond
13:50	27.6	7.09	2.22
14:05	22.2	7.06	2.27
14:10	21.9	7.03	2.27
14:15	21.5	7.11	2.27

Sample time = 14:18 - B
14:20 - C

DUP → GW-230, 14:35

- spoke w/ Ms. Aubrey

GW-150, Mr + Mr. Henderson, 3109 SCR 1200

Arrival time = 14:55 Totalizer = 251059
251148

Time	Temp	pH	Cond
15:00	28.7	7.04	2.18
15:15	25.8	7.07	2.22
15:20	23.7	7.04	2.27
15:25	23.5	7.05	2.28

sample time = 15:25 - A
15:30 - F

- Landowner not home
- Site has 3 systems in parallel; water input splits head 3 ways, treats it and outputs it as one flow. A valve can be in any system and is outside on the grounds

1. call Charmaine about ES milestone ltr
a. Isiah Glover (call)
x1761

GW-104, James Scoggins, 2604 SCR 1200

Arrival time: 15:40 Totalizer: 329957
330072

Time	Temp	pH	cond
15:45	24.4	7.29	1.58
16:00	25.4	7.32	1.62
16:05	24.3	7.39	1.64
16:10	24.9	7.33	1.63

sampled: 16:10 - A
16:15 - C

- spoke w/ Landowner

- end day @ 17:30

Day 2 7/15/09 Ron Dilding
TCEQ

Arrive site 08:00

GW-95, Franklin Howard, 2701 WCR 114

Arrival time = 8:32 Totalizer = 406690
406871

Time	Temp	pH	Cond
8:32	23.1	7.36	2.07
8:52	22.2	7.27	2.10
8:57	21.9	7.27	2.10
9:00	21.8	7.27	2.10

sampled: 9:04 - B
9:09 - C

- spoke w/ Landowner

GW-91, Kay Beauchamp, 2700 WCR 11Y

Arrival time = 9:07 Totalizer = 0552407
552664

Time	Temp	pH	Cond
9:12	26.4	7.37	2.23
9:27	23.6	7.28	2.20
9:32	22.3	7.32	2.19
9:37	22.1	7.29	2.16
9:42	22.0	7.31	2.1[illegible]

Sampled = 9:44 - B
9:46 - C
- spoke to Landowner

GW-92, Aleta Elder, 2708 WCR 11Y

Arrival time = 9:57 Totalizer = 85762
86057

Time	Temp	pH	Cond
9:52	28.7	7.13	2.39
10:07	26.0	7.18	2.30
10:12	24.8	7.19	2.32
10:17	24.2	7.20	2.32
10:22	23.[illegible]	7.18	2.33
10:27	23.6	7.19	2.30

Sampled = 10:30 - B
10:32 - C
- Landowners not home

GW-93, James Dickens, 2714 WCR 114

Arrival time = 10:35 Totalizer = 83263
83572

Time	Temp	pH	Cond
10:40	25.1	7.13	2.28
10:55	23.7	7.18	2.32
11:00	22.3	7.18	2.36
11:05	22.2	7.21	2.37
11:10	22.3	7.24	2.37

Sampled = 11:12 - B
11:14 - C

- DUP taken, GW-233 @ 11:29
(DUP of C)

GW-96, Luis Villanueva, 2605 WCR 114

arrival time = 11:19 Totalizer = 114554.8

Time	Temp	pH	Cond
11:24	25.9	7.31	2.45
11:39	23.8	7.33	2.44
11:44	24.0	7.35	2.37
11:49	24.2	7.39	2.34

Sampled = 11:50 - B
11:52 - C

- Talked to landowner

GW-97, Della Holiady, 2000 WCR 114

Arrival time = 12:50 Totalizer = 335215
335452

Time	Temp	pH	Cond
12:55	26.5	7.38	2.15
13:10	23.1	7.45	2.11
13:15	20.3	7.49	2.15
13:20	22.2	7.44	2.15
13:25	21.2	7.46	2.16

sampled = 13:27 - B
13:29 - C
- Talked to landowner

GW-126, Ovidio Ramos, 3000 SCR 1200
Arrival time = 13:38 Totalizer = 2321830

Time	Temp	pH	Cond
13:43	26.9	7.12	1.82
13:58	23.6	7.16	1.81
14:03	22.1	7.18	1.81
14:08	22.5	7.17	1.82
14:13	22.5	7.16	1.80

- Sampled = 14:15 - B
14:17 - C.
- Talked to Landowner

GW-86, Petroplex, 2800 WCR 14

Arrival time: 14:25 Totalizer: 2060
2334

Time	Temp	pH	cond
14:30	40.9	7.05	3.85
14:45	23.7	7.28	3.53
14:50	22.3	7.25	3.56
14:55	21.8	7.24	3.54

sampled = 15:01 - B
15:03 - C

- Talked to landowner

GW-81, Petroplex, 2802 WCR 14

Arrival time = 14:25 Totalizer = 11047
11240

Time	Temp	pH	cond
14:38	30.5	7.32	2.69
14:53	22.9	7.42	2.80
14:58	21.7	7.35	2.79
15:03	21.7	7.35	2.79

sampled = 15:06 - B
15:08 - C

~~Dup taken~~

- Talked to landowner

CW-80, Rig Det + Blazing Safety, 2801 + 2803 WCR 111

Arrival time = 15:13 . Totalizer = 2662
2860

Time	Temp	pH	Cond
15:18	22.1	7.15	2.52
15:33	24.3	7.19	2.49
15:38	23.3	7.22	2.47
15:43	23.0	7.21	2.45
15:48			

Sampled = 15:50
15:52

- Talked to staff @ facility
- Dup (CW-236) taken @ 16:07
(Dup of C)

CW-90, Francisco Ramirez, 2805 WCR 110

Arrival time = 15:55 Totalizer = 2021495
2021757

Time	Temp	pH	Cond
16:00	25.4	7.35	1.96
16:15	24.0	7.28	1.88
16:20	22.6	7.32	1.92
16:25	22.5	7.34	1.91
16:30	22.6	7.35	1.97

sampled = 16:30 - B
16:32 - C

- Talked to Landowner . End day @ 17:00

Ron Dildine
TCEQ

Day 3 7/14/09

arrive site = 08:00

GW-58, Mr. Chavez, 2805 SCR 1200

arrival time = 08:20

Time	Temp	pH	Cond
8:25	22.9	7.01	3.37
8:40	22.4	7.11	3.12
8:45	22.1	7.18	3.17
8:50	21.9	7.17	3.07

- sampled @ 8:52
- Talked to Landowner
- No Filtration

GW-60, Frankie McKinney, 2900 SCR 1200

arrival time = 13:15, visited twice

Time Temp pH Cond

No Purge or parameter stabilization

- No Filtration
- sampled @ 13:40
- outside well head outlet disfunctional; had to sample inside house only took a grab sample.

GW-31, Carmen Mendez, 2705 WCR 115

Arrival time = 9:27

Time	Temp	pH	Cond
9:32	26.4	6.87	3.09
9:47	23.5	6.97	3.04
9:52	22.5	7.00	3.04
9:57	22.5	7.01	3.07
10:02	22.4	7.00	3.07

- Landowner not home, tried phone # but could not get through
- Not sure if this right house, No address on house, seems correct based on location.
- sampled @ 10:04 - from street @ 2701 its the trailer on the right.
- No Filtration

GW-76, Jesus Garciaroiz, 2804 WCR 115

arrival time = 10:10

Time	Temp	pH	Cond
10:15	25.4	7.12	2.43
10:30	22.6	7.14	2.51
10:35	22.6	7.16	2.50
10:40	22.3	7.15	2.52

- Spoke to landowner family member
- sampled @ 10:42
- No Filtration

Stcoe
339-2378

Jason (Shaw)
432-813-5809

= James Scoggins, 432-683-9413
2604 SCR 1200
Ultrapure told him something
was unhooked

6W-109, Robert Elliott, 2806 WCR 116

Arrival time = 11:03 - No filtration

Time	Temp	pH	Cond
11:08	28.7	6.90	3.21
11:23	24.7	6.96	3.16
11:28	22.8	7.00	3.17
11:33	22.6	6.99	3.18
11:38	22.6	6.99	3.14

sampled @ 11:40

- sampled from water hose on east side of ~~hou~~ yard not from wells directly. There are 2.

- Talked to landowner by phone.

106, Johnnie Thomas, 2700 SCR 1198

GW-~~[illegible]~~, ~~Frankie McKinney~~

Arrival Time: 13:47 - No filtration

Time	Temp	pH	Cond
13:52	28.8	7.11	1.68
13:57	23.5	7.24	1.76
14:02	22.5	7.17	1.77
14:07	22.2	7.23	1.78
14:12	22.3	7.24	1.77

- Cut back on purge time from 15 to 5 minutes based on landowner comments that water runs 24 hrs/day

- sampled @ 14:14

- Spoke w/ Landowner

GW-132, Ratchel Gomez, 3001 + 3004 SCR 1204

arrival time: 14:27 - No filtration

Time	Temp	pH	Cond
14:32	26.3	6.96	3.30
14:47	23.8	7.09	3.21
14:52	22.7	7.07	3.11
14:57	22.7	7.08	2.90
15:02	22.6	7.12	2.88

- sampled @ 15:05

- Landowner not home

GW-68, Dr. Rodriguez, 2801 SCR 1207

arrival time - 15:20 No filtration

Time	Temp	pH	Cond
15:29	33.3	6.97	2.46
15:44	24.4	7.14	2.41
15:49	23.1	7.18	2.48
15:54	22.8	7.15	2.51
15:59	22.7	7.12	2.51

sampled @ 1600

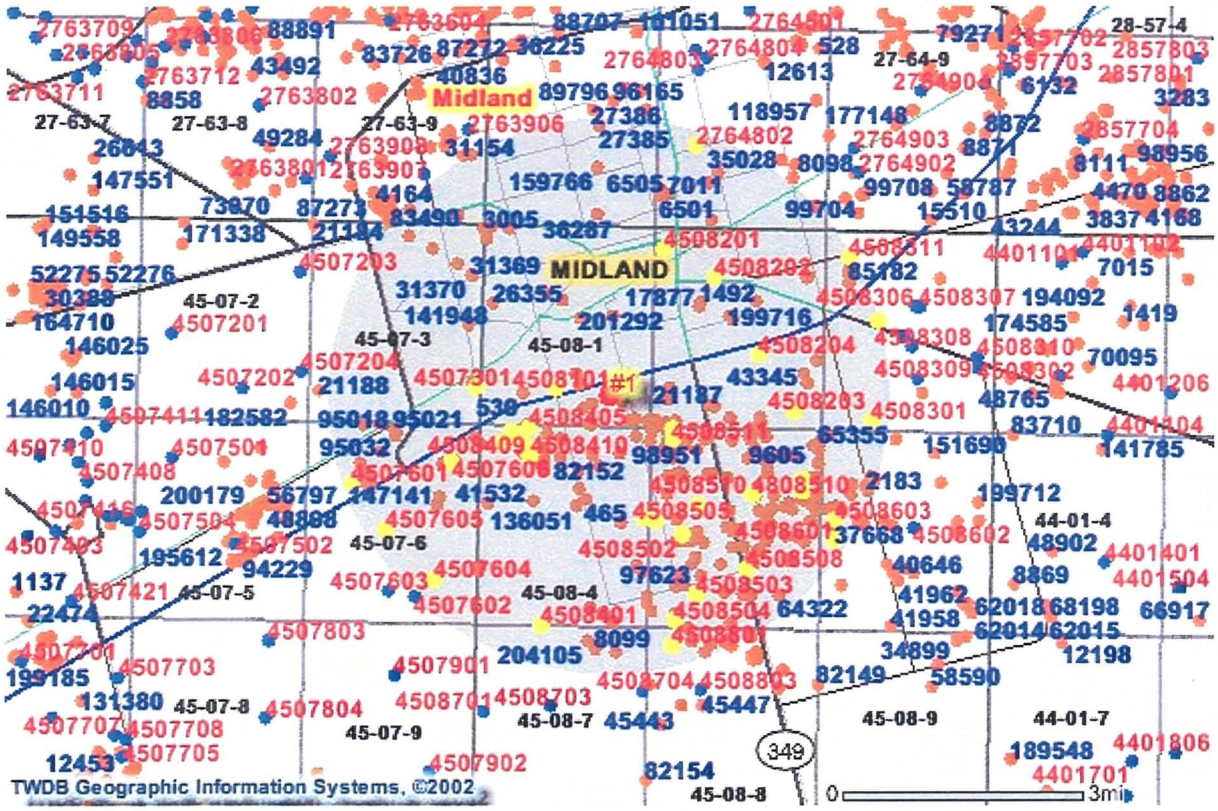
- Landowner not present

Reference 20

Texas Water Development Board

Water Information Integration & Dissemination System

WCR 112 Wells in 4-mile TDL



Legend

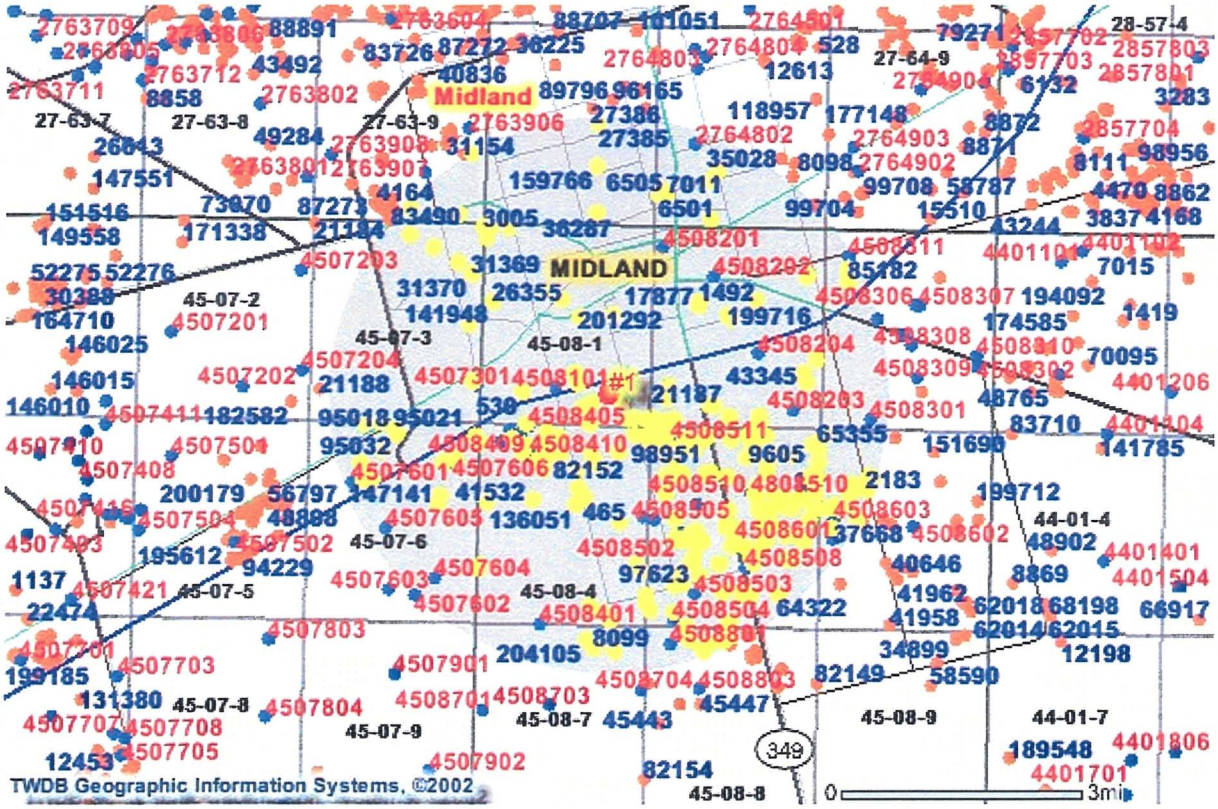
- theSBLayer
- Selected Features
- TWDB Groundwater Data
- Submitted Driller's Reports
- State Hwy
- FM & RM Roads
- Other State Roads
- Interstate Hwy
- US Hwy
- 7.5' USGS Grid
- 2.5' State Grid
- Counties
- Major Streets

20 001

Texas Water Development Board

Water Information Integration & Dissemination System

WCR 112 Wells in 4-mile TDL



Legend

- theSBLayer
- Selected Features
- TWDB Groundwater Data
- Submitted Driller's Reports
- State Hwy
- FM & RM Roads
- Other State Roads
- Interstate Hwy
- US Hwy
- 7.5' USGS Grid
- 2.5' State Grid
- Counties
- Major Streets

20 002

Submitted Drillers Reports

Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
1	41455452	199716	Adrian Munoz	Midland	1619 S. Terrell	Midland		Sat, 16 Apr 2005 00:00:00	no	Domestic	315855	1020355
2	41461342	1796	Caralot Kennel & Training	Midland	311 ECR 119	Midland	79706	Fri, 20 Jul 2001 00:00:00	no	Domestic	315739	1020352
3	41471908	12610	K & S Land Co.	Midland	4512 S. Hwy 349	Midland	79706	Wed, 4 Sep 2002 00:00:00	no	Domestic	315629	1020351
4	41471953	12454	Arnulfo Natividad	Midland	1618 WCR 121	Midland	79705	Sat, 31 Aug 2002 00:00:00	no	Domestic	315712	1020445
5	41472057	12693	Jim Kennepohl	Midland	4712 S. Hwy 349	Midland	79706	Mon, 16 Sep 2002 00:00:00	no	Domestic	315617	1020352
6	41472894	13447	Larry Roan	Midland	3600 SCR 1187	Midland	79706	Thu, 3 Oct 2002 00:00:00	no	Domestic	315722	1020350
7	41476834	17452	Tom Hellier	Midland	5900 W. Hwy 80	Midland	79706	Fri, 31 Jan 2003 00:00:00	no	Domestic	315730	1020859
8	41477153	17877	Ramon Sanchez	Midland	1409 S. Main	Midland	79701	Mon, 24 Feb 2003 00:00:00	no	Domestic	315902	1020421
9	41479582	20019	Midland Community Development	Midland	501 Dallas Ave.	Midland	79701	Tue, 25 Mar 2003 00:00:00	no	Domestic	320007	1020412
10	41480181	20914	Templo Bautistala Hermos	Midland	1514 WCR 121	Midland	79706	Wed, 16 Apr 2003 00:00:00	no	Domestic	315708	1020442
11	41480315	21185	Junior Boiles	Midland	2404 WCR 135	Midland	79706	Tue, 6 May 2003 00:00:00	no	Domestic	315747	1020406
12	41480317	21187	Junior Boiles	Midland	2404 WCR 135	Midland	79706	Tue, 6 May 2003 00:00:00	no	Domestic	315748	1020410
13	41481386	22077	BENJAMIN OLVERA	Midland	2201 FAIRPARK RD	MIDLAND	79701	Thu, 12 Jun 2003 00:00:00	no	Domestic	315925	1020247
14	41481388	22079	BENJAMIN OLVERA	Midland	2201 FAIRPARK RD	MIDLAND	79701	Thu, 12 Jun 2003 00:00:00	no	Domestic	315926	1020246
15	41481394	22085	MIDLAND COMMUNITY DEVELOP MENT	Midland	501 N. DALLAS	MIDLAND	79701	Thu, 10 Apr 2003 00:00:00	no	Domestic	320007	1020412
16	41483299	24056	TMP Truck & Trailer	Midland	5700 East I-20 Service Rd	Midland	79703	Thu, 7 Aug 2003 00:00:00	no	Domestic	315802	1020605
17	41483300	24057	TMP Truck & Trailer	Midland	5700 East I-20 Service Rd	Midland	79703	Thu, 7 Aug 2003 00:00:00	no	Domestic	315810	1020608
18	41485524	26345	Tom's Water Well	Midland	3804 W 118	Midland		Thu, 7 Aug 2003 00:00:00	no	Domestic	315707	1020635
19	41485525	26346	Noel Rodriguez	Midland	1617 WCR 120	Midland		Fri, 8 Aug 2003 00:00:00	no	Domestic	315719	1020447
20	41485624	26355	Stan Bippen	Midland	3709 Cedar Springs	Midland		Thu, 14 Aug 2003 00:00:00	no	Domestic	315902	1020722
21	41486619	27385	Advance Backhoe	Midland	4601 Tan Foran	Midland		Wed, 18 Jun 2003 00:00:00	no	Domestic	320116	1020552
22	41489998	30962	Tom Arnold	Midland	3807 CR 1185	Midland	79705	Mon, 10 Nov 2003 00:00:00	no	Domestic	315716	1020330
23	41490238	31165	WEIDNER PROPERTIES/CYPRES S POINTE	Midland	3601 ANDREWS H WY	MIDLAND	79703	Mon, 22 Dec 2003 00:00:00	no	Irrigation	320007	1020754
24	41490243	31170	WEIDNER PROPERTIES/CYPRES S POINTE	Midland	3601 ANDREWS H WY	MIDLAND	79703	Tue, 23 Dec 2003 00:00:00	no	Irrigation	320007	1020754
25	41490444	31370	WEIDNER PROP/AVALON SPRIN GS APTS	Midland	4000 W. ILLINOIS	MIDLAND	79703	Mon, 12 Jan 2004 00:00:00	no	Irrigation	315923	1020741
Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
26	41490570	31369	WEIDNER PROP/AVALON SPRIN GS APTS.	Midland	4000 W. ILLINOIS	MIDLAND	79703	Fri, 9 Jan 2004 00:00:00	no	Irrigation	315922	1020741
27	41493878	34901	DALILA MARTINEZ	Midland	SAME			Wed, 4 Feb 2004 00:00:00	no	Domestic	315622	1020158
28	41493880	34903	LEROY LEDFORD	Midland	1314 ECR 128	MIDLAND		Fri, 6 Feb 2004 00:00:00	no	Domestic	315706	1020234
29	41493902	34925	SHAEFER CONSTRUCTION	Midland	5101 W. I-20			Sun, 4 Jan 2004 00:00:00	no	Domestic	315701	1020803
30	41493952	34946	DAVID LUNA	Midland	SAME	MIDLAND		Sat, 10 Jan 2004 00:00:00	no	Domestic	315554	1020420
31	41493955	34949	DAVID CHAPPELL	Midland	SAME	MIDLAND		Sun, 11 Jan 2004 00:00:00	no	Domestic	315555	1020331
32	41493960	34954	RICARDO SANCHEZ	Midland	SAME	MIDLAND		Sat, 24 Jan 2004 00:00:00	no	Domestic	315626	1020320
33	41494001	34900	ALBERTO OCHOA	Midland	SAME			Mon, 2 Feb 2004 00:00:00	no	Domestic	315736	1020440
34	41495287	36257	NORMAN NIEDECKEN	Midland	3815 C.R. 1192	MIDLAND	79705	Sat, 10 Apr 2004 00:00:00	no	Domestic	315714	1020421
35	41495433	36287	Weidner Properties	Midland	4715 W. Wadley	Midland	79707	Tue, 30 Mar 2004 00:00:00	no	Domestic	320010	1020552
36	41495474	36421	Holly McSwain	Midland	1603 Nth CR West	Midland	79760	Fri, 16 Apr 2004 00:00:00	no	Domestic	315612	1020419
37	41496033	36932	Ann Fisk	Midland	1607 Est CR 133	Midland	79706	Thu, 22 Apr 2004 00:00:00	no	Domestic	315612	1020422
38	41496064	36933	David Pool	Midland	1703 Wst CR 134	Midland	79706	Fri, 23 Apr 2004 00:00:00	no	Domestic	315606	1020424
39	41496065	36934	Jose Carrossco	Midland	1601 CR 133	Midland	79706	Tue, 27 Apr 2004 00:00:00	no	Domestic	315613	1020419
40	41496066	36935	Charles Hudnell	Midland	1611 Wst CR 133	Midland	79706	Tue, 27 Apr 2004 00:00:00	no	Domestic	315610	1020424

41	41496068	36937	Don Farmer	Midland	1606 Wst CR 134	Midland	79706	Wed, 28 Apr 2004 00:00:00	no	Domestic	315611	1020423
42	41496109	37100	Ronny Hobbs	Andrews	1300 N.E. CR 1300	Andrews	79714	Tue, 4 May 2004 00:00:00	no	Domestic	315611	1020423
43	41499961	40841	PILAR LARA	Midland	301 S.C.R. 1220	MIDLAND	79707	Fri, 21 May 2004 00:00:00	no	Domestic	315714	1020421
44	41500064	41099	Lilly Hughes	Midland	3403 SCR 1215	Midland	79706	Fri, 2 Jul 2004 00:00:00	no	Domestic	315704	1020639
45	41500631	41532	Jack Burk	Midland	1300 SR 1121	Midland	79701	Fri, 7 Mar 2003 00:00:00	no	Domestic	315634	1020643
46	41501905	42797	James Hendry	Midland	same	same	79707	Wed, 28 Jul 2004 00:00:00	no	Domestic	315623	1020240
47	41502170	43196	Don Manley	Midland	CR 150	Midland	79702	Wed, 16 Jun 2004 00:00:00	no	Irrigation	315451	1020353
48	41502263	43308	Big Dog Drilling	Midland	CR-116	Midland	79705	Fri, 30 Jul 2004 00:00:00	no	Domestic	315806	1020245
49	41502375	43285	T.C. Tubbs	Midland	CR 142	Midalnd	79705	Mon, 21 Jun 2004 00:00:00	no	Domestic	315519	1020502
50	41502416	43345	BIG DOG DRILLING	Midland	1612 E CR 115	MIDLAND	79706	Wed, 4 Aug 2004 00:00:00	no	Domestic	315813	1020248
Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
51	41503224	44225	PILAR GARCIA	Midland	3200 S. CR. 1200'	MIDLAND	79706	Tue, 31 Aug 2004 00:00:00	no	Domestic	315724	1020514
52	41504020	45061	ROY BROOKESHIRE	Midland	601 E. CR. 153	MIDLAND	79706	Thu, 16 Sep 2004 00:00:00	no	Domestic	315619	1020314
53	41504204	45240	MARK LEAK	Midland	4801 S. CR. 1185	MIDLAND	79706	Fri, 17 Sep 2004 00:00:00	no	Domestic	315641	1020328
54	41504978	46006	Terry Burkes	Midland	5808 SCR 1200	Midland	79706	Wed, 1 Sep 2004 00:00:00	no	Domestic	315512	1020437
55	41505188	46201	Gary Goodman	Midland	Same			Mon, 30 Jun 2003 00:00:00	no	Domestic	315709	1020336
56	41508023	49111	MARVIN HOLLEY	Midland	408 WAKE FIELD	MIDLAND	79703	Tue, 23 Nov 2004 00:00:00	no	Domestic	315703	1020752
57	41508086	49102	Frank Ortega	Midland	4807 SCR 1178	Midland		Mon, 3 Nov 2003 00:00:00	no	Domestic	315639	1020237
58	41508137	49195	SYLVIA COLE	Midland	1601 W. CR 135	MIDLAND	79706	Wed, 24 Nov 2004 00:00:00	no	Domestic	315606	1020430
59	41515216	56316	Gilbert Garcia	Midland	606 East CR 120	Midland	79706	Mon, 7 Mar 2005 00:00:00	no	Domestic	315732	1020328
60	41515755	56858	GREG DAVIS	Midland	1300 E. CR. 126	MIDLAND	79706	Fri, 15 Apr 2005 00:00:00	no	Domestic	315719	1020239
61	41516087	57000	David Guillermo	Midland	3500 Rankin Hwy. 349	Midland	79706	Wed, 6 Apr 2005 00:00:00	no	Domestic	315725	1020412
62	41516310	57427	AGELESS HOMES	Midland	CR 1200 COTTON FLAT	MIDLAND	79706	Fri, 22 Apr 2005 00:00:00	no	Domestic	315451	1020422
63	41516984	58122	STEVE MASON	Midland	1600 W.CR. 133	MIDLAND	79706	Tue, 3 May 2005 00:00:00	no	Domestic	315622	1020437
64	41517685	58762	Loretta Triano	Midland	5903 SCR 1200	Midland	79706	Tue, 10 May 2005 00:00:00	no	Domestic	315501	1020426
65	41518589	59668	David Guillermo	Midland	ERC 130	Midland	79706	Thu, 5 May 2005 00:00:00	no	Domestic	315656	1020235
66	41518590	59669	David Guillermo	Midland	ECR 130	Midland	79706	Fri, 6 May 2005 00:00:00	no	Domestic	315655	1020240
67	41521429	62571	BUDDY LAMB	Midland	E.CR. 132	MIDLAND	79706	Fri, 8 Jul 2005 00:00:00	no	Domestic	315647	1020327
68	41523301	64315	DREW CRUTCHER	Midland	WCR 58	MIDLAND	79703	Tue, 26 Jul 2005 00:00:00	no	Domestic	315727	1020226
69	41523304	64318	JERRY DICKENS	Midland	5511 S.C.R. 1185	MIDLAND	79706	Mon, 1 Aug 2005 00:00:00	no	Irrigation	315526	1020306
70	41523308	64322	OSCAR STRAIN	Midland	1410 W.C.R. 120	MIDLAND	79706	Tue, 2 Aug 2005 00:00:00	no	Domestic	315526	1020306
71	41524072	65355	David Guillermo	Midland	East CR 126	Midland	79706	Tue, 9 Aug 2005 00:00:00	no	Domestic	315722	1020233
72	41526791	67950	JUAN VILLANUEVA	Midland	3105 S.C.R. 1194	MIDLAND	79706	Wed, 21 Sep 2005 00:00:00	no	Domestic	315722	1020431
73	41526792	67951	JUAN VILLANUEVA	Midland	3105 S.C.R. 1194	MIDLAND	79706	Tue, 20 Sep 2005 00:00:00	no	Domestic	315722	1020430
74	41526799	67958	GEORGE PALMA	Midland	3114 S.C.R. 1194	MIDLAND	79704	Fri, 23 Sep 2005 00:00:00	no	Domestic	315719	1020431
75	41527125	68199	JUAN VILLANUEVA	Midland	3105 S.C.R. 1194	MIDLAND	79706	Fri, 16 Sep 2005 00:00:00	no	Domestic	315721	1020431
Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
76	41527565	68531	JESSE RAMOS	Midland	722 E.C.R. 135	MIDLAND	79706	Wed, 5 Oct 2005 00:00:00	no	Domestic	315611	1020301
77	41528049	69220	ALEX ALEMAN	Midland	210 E.C.R. 135	MIDLAND	79706	Tue, 11 Oct 2005 00:00:00	no	Domestic	315607	1020318
78	41528080	69222	ALEX ALEMAN	Midland	210 E.C.R. 135	MIDLAND	79706	Wed, 12 Oct 2005 00:00:00	no	Domestic	315607	1020319
79	41528158	69341	J-R'S WATER WELL	Midland	6006 S. HWY 349	MIDLAND	79706	Mon, 19 Sep 2005 00:00:00	no	Domestic	315505	1020348
80	41529242	70330	R.D. Bryan	Midland	IH 20 N. Service Road	Midland	79701	Fri, 28 Oct 2005 00:00:00	no	Industrial	315646	1020905
81	41530712	71833	Agri-Empressa	Midland	Hwy 80 S. Service Road	Midland	79703	Mon, 21 Nov 2005 00:00:00	no	Industrial	315709	1020857

82	41531696	72917	Restructure Petro Marketing Svcs	Midland	1308 N Lemesa Road	Midland	79701	Thu, 8 Dec 2005 00:00:00	no	Industrial	320043	1020407
83	41531889	73063	JUAN DURAN	Midland	W.C.R. 135	MIDLAND	79706	Sun, 30 Oct 2005 00:00:00	no	Irrigation	315617	1020220
84	41537759	79006	Rayford Calhoun	Midland	6100 SCR 1210	Midland	79706	Thu, 2 Mar 2006 00:00:00	no	Domestic	315442	1020528
85	41537932	79349	Lee Glover	Midland	3503 SCR 1210	Midland	79706	Thu, 9 Feb 2006 00:00:00	no	Domestic	315657	1020604
86	41538126	79262	BRAD HAWLEY	Ector	CR 1040	GREENWOOD	79702	Tue, 7 Mar 2006 00:00:00	no	Domestic	315602	1020348
87	41540889	82143	GREG FROST	Midland	3912 C.R.1185	MIDLAND	79706	Fri, 10 Mar 2006 00:00:00	no	Domestic	315705	1020319
88	41540898	82152	LARRY STROUD	Midland	SAME	MIDLAND	79706	Wed, 5 Apr 2006 00:00:00	no	Irrigation	315707	1020620
89	41541708	83027	Hunt Oil	Upton	RD. 160	N/A		Sat, 13 May 2006 00:00:00	no	Industrial	315714	1020634
90	41543254	84663	Pat Leary	Midland	Off Rankin Hwy.	Midland		Sat, 17 Apr 2004 00:00:00	no	Domestic	315616	1020346
91	41543295	84675	Pat Leary	Midland	Off Rankin Hwy.	Midland		Sun, 18 Apr 2004 00:00:00	no	Domestic	315616	1020346
92	41543906	85181	Kelly Beal	Midland	Fairgrounds RD. & Hwy. 307	Midland	79706	Tue, 16 May 2006 00:00:00	no	Domestic	315932	1020210
93	41543907	85182	Kelly Beal	Midland	Fairgrounds RD. & Hwy. 307	Midland	79706	Thu, 25 May 2006 00:00:00	no	Domestic	315928	1020210
94	41546871	88441	Fender Investment Group	Midland	2709 SCR 1207	Midland	79706	Mon, 5 Jun 2006 00:00:00	no	Domestic	315744	1020601
95	41546876	88446	Kelly Beal	Midland	Fairgrounds RD & Hwy 307	Midland	79706	Tue, 23 May 2006 00:00:00	no	Domestic	315922	1020210
96	41549035	90432	Leroy Ledford	Midland	207 ECR 140	Midland	79706	Tue, 1 Aug 2006 00:00:00	no	Domestic	315550	1020329
97	41552198	93738	R.D. Bryan Construction	Midland	6300 W. I-20	Midland	79703	Thu, 14 Sep 2006 00:00:00	no	Industrial	315700	1020915
98	41552255	93767	EDWIN McKINLEY	Midland	1612 W. CR. 135	MIDLAND	79701	Sat, 12 Aug 2006 00:00:00	no	Domestic	315608	1020436
99	41552300	93783	LOUIS OLIVAS	Midland	1910 CR. 125	MIDLAND	79703	Sat, 12 Aug 2006 00:00:00	no	Domestic	315641	1020446
100	41552345	93666	Allen & Lucchi	Midland	N. side of I-20 - 1/2 M W. Of Loop 250	Midland	79703	Thu, 7 Sep 2006 00:00:00	no	Industrial	315646	1020910
Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
101	41553451	95027	A. T. N. I. ATTN: Don Hoffman	Midland	5801 W. Industrial	Midland	79706	Fri, 6 Oct 2006 00:00:00	no	Domestic	315727	1020845
102	41553456	95032	A. T. N. I. ATTN: Don Hoffman	Midland	5801 W. Industrial	Midland	79706	Wed, 11 Oct 2006 00:00:00	no	Domestic	315724	1020844
103	41553658	95018	A. T. N. I. ATTN: Don Hoffman	Midland	5801 W. Industrial	Midland	79706	Mon, 9 Oct 2006 00:00:00	no	Domestic	315726	1020846
104	41553659	95019	A. T. N. I. ATTN: Don Hoffman	Midland	5801 W. Industrial	Midland	79706	Thu, 5 Oct 2006 00:00:00	no	Domestic	315727	1020845
105	41553661	95021	A. T. N. I. ATTN: Don Hoffman	Midland	5801 W. Industrial	Midland	79706	Mon, 9 Oct 2006 00:00:00	no	Domestic	315726	1020846
106	41556023	97623	Area Custom Builders	Midland		Midland		Thu, 9 Nov 2006 00:00:00	no	Domestic	315533	1020430
107	41557529	98951	EDWARD MESA	Midland	SAME	MIDLAND	79706	Sat, 15 Jul 2006 00:00:00	no	Domestic	315722	1020414
108	41559928	101486	Area Wide Builders	Ector		Midland		Wed, 13 Dec 2006 00:00:00	no	Domestic	315534	1020436
109	41559936	101494	Area Wide Builders	Midland				Mon, 11 Dec 2006 00:00:00	no	Domestic	315534	1020436
110	41565363	107047	Area Custom Builders	Midland	N.E. Corner of S. CR 1200 & W. CR 140	Midland		Fri, 16 Mar 2007 00:00:00	no	Domestic	315532	1020437
111	41568918	110674	Neal Kessler	Midland	3101 Bankhead Hwy	Midland	79701	Fri, 9 Mar 2007 00:00:00	no	Domestic	315905	1020621
112	41570091	111889	David Guillermo	Midland	CR 120	Midland	79706	Wed, 14 Mar 2007 00:00:00	no	Domestic	315717	1020433
113	41570132	111901	David Guillermo	Midland	3506 South Hwy 349	Midland	79706	Sun, 11 Mar 2007 00:00:00	no	Domestic	315724	1020411
114	41572679	114410	Vince Ochoa	Midland	1905 W. CR 137	Midland	79706	Fri, 27 Apr 2007 00:00:00	no	Rig Supply	315549	1020423
115	41576905	118821	Danny Shutt	Midland	612 ECR 130	Midland	79707	Wed, 4 Jul 2007 00:00:00	no	Domestic	315641	1020312
116	41581753	123687	Gary Austin	Midland	3504 S CR 1206	Midland	79707	Sat, 11 Aug 2007 00:00:00	no	Domestic	315701	1020546
117	41585329	127392	Jesus Ortega	Ector	4306 WCR 115	Odessa		Mon, 20 Feb 2006 00:00:00	no	Domestic	315720	1020702
118	41585765	127821	Almand Construction	Midland	3605 WCR 145	Midland	79707	Tue, 30 Oct 2007 00:00:00	no	Rig Supply	315446	1020544
119	41589795	131953	Omar Ruiz	Midland	CR 125 & CR 1195	Midland	79703	Mon, 22 Oct 2007 00:00:00	no	Domestic	315657	1020435
120	41589796	131954	Omar Ruiz	Midland	CR 125 & CR 1195	Midland	79703	Wed, 24 Oct 2007 00:00:00	no	Domestic	315656	1020438
121	41589797	131955	Omar Ruiz	Midland	CR 125 & CR 1195	Midland	79703	Fri, 7 Dec 2007 00:00:00	no	Domestic	315606	1020436
122	41589798	131956	Omar Ruiz	Midland	CR 125 & CR 1195	Midland	79703	Fri, 7 Dec 2007 00:00:00	no	Domestic	315657	1020436
123	41590454	132588	Ovidio Ramos	Midland	3000 South County Road 1200	Midland	79706	Mon, 21 Jan 2008 00:00:00	no	Domestic	315736	1020520

124	41593746	135951	Midland ISD	Midland	3500 Neeley	Midland	79707	Wed, 6 Feb 2008 00:00:00	no	Irrigation	320053	1020744
125	41593932	136051	A.T.N.I. Attn: D. Hoffman	Midland		Midland		Tue, 19 Feb 2008 00:00:00	no	Domestic	315631	1020605
Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
126	41594159	136443	Jesus Barrera	Midland	SCR 1202	Midland		Tue, 25 Jan 2005 00:00:00	no	Domestic	315750	1020527
127	41594172	136456	Alicia Barraza	Midland	4901 SCR 1178	Midland		Mon, 24 Jan 2005 00:00:00	no	Domestic	315631	1020236
128	41598915	141117	MARK HARRELL	Midland	2400 E.C.R 113	MIDLAND	79705	Thu, 1 May 2008 00:00:00	no	Domestic	315823	1020237
129	41599451	141780	Tom's Water Well	Midland	2411 WCR 142	Midland		Sun, 6 Apr 2008 00:00:00	no	Domestic	315513	1020458
130	41599503	141766	Tom's Water Well	Midland	2411 WCR 142	Midland		Tue, 8 Apr 2008 00:00:00	no	Domestic	315513	1020458
131	41599523	141795	R & W Construction	Ector	8822 Heather Lane	Odessa		Tue, 1 Apr 2008 00:00:00	no	Domestic	315607	1020245
132	41599680	141939	Fiberod	Midland	I-20 Service Road	Midland		Wed, 14 May 2008 00:00:00	no	Domestic	315646	1020912
133	41599689	141948	Tom's Water Well	Midland	rogers Ford	Midland	79706	Thu, 17 Apr 2008 00:00:00	no	Domestic	315845	1020743
134	41602271	144643	JOHN STEWARD	Midland	HWY 349	MIDLAND	79706	Tue, 10 Jun 2008 00:00:00	no	Domestic	315654	1020353
135	41602565	144980	Henry Gonzales	Midland	2101 W CR 150	Midland	79706	Mon, 23 Jun 2008 00:00:00	no	Domestic	315443	1020410
136	41604361	146847	Ben Rios	Midland	606 E. Co. Rd. 132	Midland	79706	Tue, 27 May 2008 00:00:00	no	Domestic	315632	1020314
137	41604453	146806	Integrity Industries	Midland	6313 W. C.R. 112	Midland		Wed, 16 Jul 2008 00:00:00	no	Domestic	315653	1020910
138	41604781	147139	Darla Vuelta (Ken Huseman)	Midland	South of West Loop 250 and I-20	Midland	79706	Tue, 24 Jun 2008 00:00:00	no	Stock	315542	1020730
139	41604783	147141	Darla Vuelta (Ken Huseman)	Midland	South of West Loop 250 and I-20	Midland	79706	Wed, 25 Jun 2008 00:00:00	no	Stock	315630	1020807
140	41604785	147143	Darla Vuelta (Ken Huseman)	Midland	South of West Loop 250 and I-20	Midland	79706	Fri, 27 Jun 2008 00:00:00	no	Stock	315544	1020729
141	41609033	151451	Schull, Jo Ann	Midland	40 yds E of FM 715 & 375 yds N of CR 1 30	Midland		Wed, 7 May 2008 00:00:00	no	Irrigation	315657	1020148
142	41609349	151776	Steve Taylor	Midland	E. CR 127 & S. CR 1 184	Midland	79706	Wed, 27 Aug 2008 00:00:00	no	Domestic	315658	1020318
143	41609543	151954	Schull, Jo Ann	Midland	127 yds. E of FM 71 5 & 500 yds. S of CR 130	Midland		Tue, 6 May 2008 00:00:00	no	Irrigation	315655	1020144
144	41609688	152141	Chad Chastain	Midland	3414 Bedford Ave	Midland	79703	Wed, 9 Jul 2008 00:00:00	no	Domestic	315959	1020725
145	41616550	159083	DAVID GUILLERMO	Midland	1305 ECR 130	MIDLAND	79706	Thu, 30 Oct 2008 00:00:00	no	Rig Supply	315655	1020235
146	41617207	159799	Olivia Fierro	Midland	5800 SCR 1210	Midland		Mon, 27 Jun 2005 00:00:00	no	Domestic	315505	1020532
147	41617235	159744	Luis Oldias	Midland	125 & Cottonflat	Midland		Thu, 14 Jul 2005 00:00:00	no	Domestic	315653	1020444
148	41617315	159766	George Sosa	Midland	1606 N. Scarborough	Midland		Thu, 9 Jun 2005 00:00:00	no	Domestic	320045	1020553
149	41617317	159768	Aaron Garcia	Midland	3407 SCR 1204	Midland		Thu, 9 Jun 2005 00:00:00	no	Domestic	315711	1020528
150	41618323	160838	Heartland Equipment Co.	Midland	1700 Dayton Rd	Midland	79706	Tue, 27 Sep 2005 00:00:00	no	Domestic	315801	1020446
Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
151	41618655	161096	Leonardo Natividad	Midland	4902 S CR 1172	Midland		Mon, 1 Aug 2005 00:00:00	no	Domestic	315643	1020205
152	41618924	161133	Connie Noland	Midland	1406 W CR 143	Midland		Fri, 5 Aug 2005 00:00:00	no	Domestic	315528	1020354
153	41618927	161136	Robert Marquez	Midland	2707 W CR 140	Midland		Fri, 5 Aug 2005 00:00:00	no	Domestic	315524	1020502
154	41618933	161142	Jose Luis Hernandez	Midland	Cottonflat	Midland		Tue, 13 Sep 2005 00:00:00	no	Domestic	315541	1020433
155	41620299	162743	Joseph Luchini	Midland	CR 135	Midland		Sun, 15 Aug 2004 00:00:00	no	Domestic	315542	1020506
156	41620302	162747	Tom's Water Well	Midland	600 E CR 132	Midland		Sat, 14 Aug 2004 00:00:00	no	Domestic	315632	1020313
157	41620348	162765	Marco Garcia	Midland	4100 W CR 115	Midland		Fri, 20 Aug 2004 00:00:00	no	Domestic	315716	1020651
158	41620604	162789	Tom's Water Well	Midland	S CR 1218	Midland		Mon, 13 Sep 2004 00:00:00	no	Domestic	315710	1020653
159	41620609	162794	Elise Barton	Midland	4800 S. Hwy 349	Midland		Thu, 16 Sep 2004 00:00:00	no	Domestic	315617	1020353
160	41621533	164121	Mike Perkins	Midland	2205 Carter	Midland	79701	Tue, 23 Dec 2008 00:00:00	no	Domestic	315854	1020536
161	41623226	165830	Delmar Carrasco	Midland	3116 S CR 1193	Midland		Fri, 11 Nov 2005 00:00:00	no	Domestic	315734	1020446
162	41623228	165832	James Shepard	Midland	1804 Bates	Midland		Thu, 10 Nov 2005 00:00:00	no	Domestic	320011	1020837
163	41623286	165861	Antomas Flores	Midland	2909 W. CR 115	Midland		Thu, 29 Sep 2005 00:00:00	no	Domestic	315732	1020554

164	41623287	165862	Antomas Flores	Midland	2909 W. CR 115	Midland		Thu, 29 Sep 2005 00:00:00	no	Domestic	315748	1020553
165	41623325	165871	Tom's Waterwell	Midland	CR 127	Midland		Fri, 16 Sep 2005 00:00:00	no	Domestic	315716	1020234
166	41625557	168127	Erica Valdez	Midland	1501 W CR 117	Midland		Tue, 21 Dec 2004 00:00:00	no	Domestic	315731	1020444
167	41625566	168136	Roman Leyva	Midland	5109 S CR 1172	Midland		Thu, 2 Dec 2004 00:00:00	no	Domestic	315625	1020158
168	41625567	168137	Eddie Helbert	Midland	5906 W Hwy 80	Midland		Tue, 30 Nov 2004 00:00:00	no	Domestic	315729	1020913
169	41625570	168140	Luis Sanchez	Midland	2908 S CR 1213	Midland		Tue, 9 Nov 2004 00:00:00	no	Domestic	315725	1020632
170	41626745	169384	Jesse Villegas	Midland	3905 S. Co. Rd. 121 0	Midland	79706	Sat, 31 Jan 2009 00:00:00	no	Domestic	315636	1020557
171	41627043	169706	DARRELL CRASS	Midland	4632 PRINCETON	MIDLAND	79703	Thu, 12 Feb 2009 00:00:00	no	Irrigation	315951	1020837
172	41627812	170431	Double A Builders	Midland	5605 SCR 1213	Midland		Tue, 20 Jan 2009 00:00:00	no	Domestic	315515	1020551
173	41628301	170949	Robert Savage	Midland	4705 S. CR 1172	Midland	79706	Thu, 12 Mar 2009 00:00:00	no	Domestic	315651	1020204
174	41628708	171272	Lujan, Ruben	Ector	165 Sir Barton	Odessa	79763	Thu, 19 Feb 2009 00:00:00	no	Domestic	315711	1020305
175	41628836	171285	Esquibel, Delores	Midland	3115 SCR 1217	Midland		Mon, 23 Feb 2009 00:00:00	no	Domestic	315731	1020650
Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
176	41629663	172360	Eddie Elliott	Midland	4601 W. I-20	Midland		Tue, 24 Mar 2009 00:00:00	no	Domestic	315721	1020735
177	41629750	172433	Roberto Lozaya	Midland	1721 S Mineola	Midland		Thu, 3 Jun 2004 00:00:00	no	Domestic	315853	1020352
178	41629900	172526	Tom's Water Well	Midland	W CR 135	Midland		Mon, 14 Jun 2004 00:00:00	no	Domestic	315547	1020511
179	41629962	172573	Gregorio Salgado	Midland	3019 S CR 1196	Midland		Wed, 21 Jul 2004 00:00:00	no	Domestic	315736	1020457
180	41629963	172574	Johnny Bustamante	Midland	1700 W CR 150	Midland		Fri, 23 Jul 2004 00:00:00	no	Domestic	315449	1020405
181	41629974	172585	Tom's Water Well	Midland	1000 Denton	Midland		Thu, 22 Jul 2004 00:00:00	no	Domestic	315950	1020729
182	41630074	172778	E. E. & G. Company	Midland	2400 South Loop 25 0	Midland	79704	Mon, 9 Mar 2009 00:00:00	no	Domestic	315721	1020845
183	41631349	174030	David Garcia	Midland	3018 SCR 1197	Midland		Wed, 25 May 2005 00:00:00	no	Domestic	315736	1020504
184	41631351	174032	David Garcia	Midland	3018 SCR 1197	Midland		Wed, 25 May 2005 00:00:00	no	Domestic	315736	1020504
185	41632458	175083	Andy Dalager	Midland	4500 W. Cuthbert Av e.	Midland	79703	Wed, 15 Apr 2009 00:00:00	no	Domestic	315942	1020816
186	41632786	175414	Jim Garner	Midland	3110 Travis Ave	Midland	79701	Thu, 16 Apr 2009 00:00:00	no	Domestic	315910	1020636
187	41637547	180303	Bobby Marguez	Midland	5130 SCR 1183	Midland		Mon, 10 Oct 2005 00:00:00	no	Domestic	315610	1020250
188	41637659	180434	Morgan Dulin	Midland	SCR 114 & 1192	Midland		Sun, 2 Jul 2006 00:00:00	no	Domestic	315726	1020446
189	41637660	180435	Morgan Dulin	Midland	SCR 114 & 1192	Midland		Sun, 2 Jul 2006 00:00:00	no	Domestic	315756	1020446
190	41637665	180440	Tom's Water Well	Midland	E CR 119	Midland		Tue, 18 Jul 2006 00:00:00	no	Domestic	315740	1020326
191	41637695	180441	Tom's Water Well	Midland	E CR 119	Midland		Tue, 18 Jul 2006 00:00:00	no	Domestic	315740	1020326
192	41637722	180468	Tom's Water Well	Midland	4209 S CR 1175	Midland		Mon, 24 Jul 2006 00:00:00	no	Domestic	315634	1020218
193	41637828	180487	Joe Eads	Midland	3510 CR 1198	Midland		Sat, 22 Jul 2006 00:00:00	no	Domestic	315713	1020453
194	41643992	186762	Jose Marquez	Midland	801 ECR 133	Midland		Wed, 7 Jun 2006 00:00:00	no	Domestic	315631	1020256
195	41643995	186765	Bobby Richardson	Midland	301 ECR 137	Midland	79706	Thu, 8 Jun 2006 00:00:00	no	Domestic	315600	1020325
196	41643996	186766	Morgan Dublin	Midland	SCR 114 & 1192	Midland		Thu, 8 Jun 2006 00:00:00	no	Domestic	315752	1020447
197	41643998	186768	Jaime Grimaldo	Midland	1306 ECR 132	Midland		Wed, 7 Jun 2006 00:00:00	no	Domestic	315643	1020235
198	41644073	186706	Tom's Water Well	Midland	Raykin	Midland		Tue, 6 Jun 2006 00:00:00	no	Domestic	315603	1020338
199	41644075	186708	Tom's Water Well	Midland	W CR 135	Midland		Fri, 23 Jun 2006 00:00:00	no	Domestic	315605	1020413
200	41644204	187066	Tom's Water Well	Midland	WCR 113	Midland		Thu, 24 Jun 2004 00:00:00	no	Domestic	315721	1020620
Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
201	41644209	187071	Luis Marrufo, Jr.	Midland	809 ECR 133	Midland		Mon, 28 Jun 2004 00:00:00	no	Domestic	315632	1020257
202	41644289	187044	Tom's Water Well	Midland	418 B N Midland	Midland		Sat, 25 Sep 2004 00:00:00	no	Domestic	315931	1020754
203	41644372	187271	Roy Brookshire	Midland	601 E CR 135	Midland	79706	Tue, 31 Aug 2004 00:00:00	no	Domestic	315619	1020322
204	41644783	187633	Joe Dale Price	Midland	3503 S. CR 1210	Midland		Fri, 19 Jun 2009 00:00:00	no	Domestic	315644	1020603

205	41645608	188328	Darla Vuelta (Ken Huseman)	Midland	South of West Loop 250 & I-20	Midland	79706	Wed, 17 Jun 2009 00:00:00	no	Domestic	315632	1020723
206	41646264	189063	BLAIN SLATTON	Midland	5700 SH 349 S	MIDLAND	79701	Wed, 15 Jul 2009 00:00:00	no	Irrigation	315526	1020331
207	41646361	189103	MAGDA GONZALES	Midland	1504 WCR 121	MIDLAND	79706	Fri, 24 Jul 2009 00:00:00	no	Domestic	315712	1020443
208	41646636	189218	Gordon Jarman	Midland	1302 CR 138	Midland	79706	Tue, 21 Jul 2009 00:00:00	no	Domestic	315549	1020358
209	41647754	190617	Charles Roberts	Midland	Sec 27 WCR 150	Midland	79706	Thu, 2 Jul 2009 00:00:00	no	Domestic	315454	1020347
210	41648169	191056	Midland Monossori School	Midland	1006 Austin St.	Midland	79701	Sat, 22 Aug 2009 00:00:00	no	Irrigation	315958	1020709
211	41649700	192572	Greg Kitchens	Midland	4701 South County Rd 1180	Midland	79706	Fri, 24 Jul 2009 00:00:00	no	Domestic	315639	1020248
212	41651786	194627	Gary Goodman	Midland	3805 SCR 1185	Midland	79706	Mon, 20 Sep 2004 00:00:00	no	Domestic	315710	1020318
213	41652568	195457	Jeff Neely	Midland	3811 South County Road 1198	Midland	79706	Fri, 2 Oct 2009 00:00:00	no	Domestic	315655	1020445
214	41455517	199723	Tom's Water Well	Midland	1414 ECR 130	Midland		Sun, 17 Apr 2005 00:00:00	no	Domestic	315553	1020259
215	41455570	199747	Marshall Pearcy	Midland	1406 WCR 150	Midland		Mon, 25 Apr 2005 00:00:00	no	Domestic	315454	1020347
216	41455993	200172	Jesus Chavez	Midland	4711 SCR 1180	Midland		Tue, 15 Feb 2005 00:00:00	no	Domestic	315637	1020243
217	41457014	201292	Penguinn Refrigeration	Midland	948 Advance	Midland		Wed, 28 Dec 2005 00:00:00	no	Domestic	315852	1020605
218	41457037	201246	Gracie Valles	Midland	4710 S CR 1185	Midland		Fri, 18 Nov 2005 00:00:00	no	Domestic	315628	1020317
219	41457042	201251	Toms Water Well	Midland	1001 E CR 127	Midland		Sun, 13 Nov 2005 00:00:00	no	Domestic	315711	1020256
220	41457062	201271	Toms Water Well	Midland	3501 S CR	Midland		Mon, 12 Dec 2005 00:00:00	no	Domestic	315636	1020805
221	41457064	201273	Mike Benavides	Ector	407 Dobbs	Odessa		Tue, 13 Dec 2005 00:00:00	no	Domestic	315636	1020805
222	41457066	201275	Mike Rodriguez	Midland	3806 S. Rankin Hwy	Midland		Mon, 19 Dec 2005 00:00:00	no	Domestic	315636	1020805
223	41457667	201677	Abelardo Duarte	Midland	1414 Wayside	Midland		Fri, 1 Dec 2006 00:00:00	no	Domestic	315907	1020331
224	41457668	201678	Onofre	Midland	203 ECR119	Midland		Thu, 28 Dec 2006 00:00:00	no	Domestic	315656	1020411
225	41457670	201680	Tom's Water Well	Midland	3303 SCR 1215	Midland		Wed, 27 Dec 2006 00:00:00	no	Domestic	315704	1020635
Rec	**OBJECT**	**Tracking Number**	**Well Owner**	**County**	**Well Address**	**Well City**	**Zip Code**	**Date of Well Completion**	**Undesirable Water Quality**	**Well Type**	**Latitude**	**Longitude**
226	41457671	201681	Silvino M Payan	Midland	Midkiff & WCR 140	Midland		Sat, 21 Apr 2007 00:00:00	no	Domestic	315511	1020540
227	41457681	201691	Juan Esquivel	Midland	943 N Ft. Worth	Midland		Tue, 15 Aug 2006 00:00:00	no	Domestic	320035	1020415
228	41457783	201963	Pedro Vega	Midland	2000 W CR 120	Midland		Tue, 2 Mar 2004 00:00:00	no	Domestic	315720	1020502
229	41457861	201983	Mark Garciaroiz	Midland	3612 S CR 1182	Midland		Fri, 19 Mar 2004 00:00:00	no	Domestic	315725	1020320
230	41457867	201989	Monte Scott	Midland	4501 W. Industrial	Midland		Tue, 23 Mar 2004 00:00:00	no	Domestic	315802	1020738
231	41457963	202169	Jim Warner	Midland	3007 SCR 1200	Odessa		Wed, 10 Dec 2003 00:00:00	no	Domestic	315737	1020515
232	41458012	202189	Joe Garcia	Midland	1901 WCR 117	Midland		Thu, 20 Nov 2003 00:00:00	no	Domestic	315728	1020500
233	41458035	202296	Maria Crespo	Midland	4802 FM 715	Midland		Wed, 5 Nov 2003 00:00:00	no	Domestic	315650	1020152
234	41458154	202292	Daniel Rodriguez	Midland	1600 ECR 135	Midland		Tue, 11 Nov 2003 00:00:00	no	Domestic	315631	1020213
235	41458807	202935	Claudio Lujan	Midland	SCR 1206	Midland	79701	Fri, 22 Jun 2007 00:00:00	no	Domestic	315709	1020552
236	41458814	202942	Tom's Water Well	Midland	ECR 140	Midland		Sat, 27 Jan 2007 00:00:00	no	Domestic	315553	1020255
237	41459521	203741	Tom's Water Well	Midland	CR 135	Midland		Sat, 6 Jan 2007 00:00:00	no	Domestic	315653	1020240
238	41459852	204105	Chase Chastain	Midland	CR 145	Midland	79706	Mon, 4 Jan 2010 00:00:00	no	Domestic	315450	1020553
239	41460058	560	Eddie Edge	Midland	1213 WCR 125	Midland	79706	Tue, 13 Mar 2001 00:00:00	no	Domestic	315657	1020411
240	41460084	530	CMS Oil and Gas	Midland	2115 Warehouse Rd	Midland	79703	Sat, 17 Feb 2001 00:00:00	no	Industrial	315755	1020654
241	41460088	561	Rudy Granado	Midland	3103 SCR 1195	Midland	79706	Tue, 20 Feb 2001 00:00:00	no	Domestic	315733	1020451
242	41460136	455	Tommy Watts	Midland	3311 SCR 1215	Midland	79706	Fri, 5 Jan 2001 00:00:00	no	Domestic	315657	1020634
243	41460233	465	Vanderlinden Dairy	Midland	3208 WCR 124	Midland	79706	Mon, 8 Jan 2001 00:00:00	no	Domestic	315619	1020526
244	41460295	625	Juan Villanueva	Midland	3105 SCR 1194	Midland	79706	Wed, 21 Feb 2001 00:00:00	no	Domestic	315735	1020448
245	41460508	816	Benito Jurado	Midland	SCR 125	Midland	79706	Mon, 23 Apr 2001 00:00:00	no	Domestic	315655	1020432
246	41460509	817	Benito Jurado	Midland	SCR 125	Midland	79706	Tue, 24 Apr 2001 00:00:00	no	Domestic	315654	1020434
247	41461009	1597	Eddie Edge	Midland	1213 WCR 125	Midland	79706	Tue, 3 Jul 2001 00:00:00	no	Domestic	315657	1020407

248	41461014	1602	Rogelio Valenzuela	Midland	403 ECR 132	Midland	79706	Mon, 9 Jul 2001 00:00:00	no	Domestic	315630	1020325
249	41461077	1492	Adam Zamarripa	Midland	1311 S. Main Street	Midland	79701	Fri, 1 Jun 2001 00:00:00	no	Domestic	315905	1020420
250	41461346	1800	Rolltex Bearing	Midland	4807 South Hwy 349	Midland	79706	Wed, 25 Jul 2001 00:00:00	no	Domestic	315615	1020343
Rec	OBJECT	Tracking Number	Well Owner	County	Well Address	Well City	Zip Code	Date of Well Completion	Undesirable Water Quality	Well Type	Latitude	Longitude
251	41461604	2182	David Guillero	Midland	Hwy 349 & CR 120	Midland	79706	Fri, 13 Jul 2001 00:00:00	no	Domestic	315725	1020413
252	41461605	2183	Carmen Zubia	Midland	4810 FM 715	Midland	79706	Tue, 31 Jul 2001 00:00:00	no	Domestic	315646	1020150
253	41461606	2184	Harland Valiquette	Midland	4908 SCR 1185	Midland	79706	Thu, 26 Jul 2001 00:00:00	no	Domestic	315617	1020319
254	41462611	3005	Steve Hopkins	Midland	3511 Princeton	Midland	79703	Wed, 12 Sep 2001 00:00:00	no	Domestic	315958	1020732
255	41465580	6130	Vince Bogner	Midland	3401 SCR 1215	Midland	79706	Wed, 6 Mar 2002 00:00:00	no	Domestic	315700	1020635
256	41465581	6131	Moses Martinez	Midland	1602 WCR 140	Midland	79706	Mon, 25 Mar 2002 00:00:00	no	Domestic	315540	1020415
257	41465584	6134	Mrs. Gil Auldridge	Midland	4808 SH 349	Midland	79706	Tue, 12 Feb 2002 00:00:00	no	Domestic	315614	1020348
258	41465989	6501	John Muldrow	Midland	609 Watson	Midland	79701	Fri, 5 Apr 2002 00:00:00	no	Domestic	320025	1020458
259	41465992	6504	Kevin Macanally	Midland	4 Edinburgh	Midland	79707	Wed, 3 Apr 2002 00:00:00	no	Domestic	320028	1020455
260	41465993	6505	Kevin Macanally	Midland	4 Edinburgh	Midland	79707	Thu, 4 Apr 2002 00:00:00	no	Domestic	320026	1020457
261	41466440	7011	Pinehurst Apt. c/o John Muldrow	Midland	604 Watson	Midland	79701	Wed, 10 Apr 2002 00:00:00	no	Domestic	320026	1020451
262	41467504	8099	Calvin Neatherlin	Midland	CR 145 & Midkiff Rd.	Midland	79706	Wed, 5 Jun 2002 00:00:00	no	Domestic	315444	1020546
263	41468263	8887	Tommy Watts	Midland	North of ECR 120	Midland	79706	Wed, 12 Jun 2002 00:00:00	no	Domestic	315736	1020325
264	41468264	8888	Mrs. W. J. Switzer	Midland	3605 SCR 1185	Midland	79706	Fri, 14 Jun 2002 00:00:00	no	Domestic	315727	1020332
265	41469149	9702	Mrs. W. J. Switzer	Midland	3605 SCR 1185	Midland	79706	Thu, 11 Jul 2002 00:00:00	no	Domestic	315725	1020335
266	41469213	9605	John Daniels	Midland	3701 SCR 1185	Midland	79706	Wed, 26 Jun 2002 00:00:00	no	Domestic	315723	1020333
267	41469216	9608	Jana Whitaker	Midland	1105 WCR 143	Midland	79706	Sun, 23 Jun 2002 00:00:00	no	Domestic	315527	1020338
268	41471336	11827	Terry St. John	Midland	900 E. CR125	Midland	79706	Fri, 19 Jul 2002 00:00:00	no	Domestic	315712	1020307
269	41471698	12344	Roberto Malhoara	Midland	2715 SCR 1223	Midland	79706	Mon, 19 Aug 2002 00:00:00	no	Domestic	315716	1020730
270	41471872	12606	Wright Cowden	Midland	804 ECR 132	Midland	79706	Fri, 6 Sep 2002 00:00:00	no	Domestic	315636	1020259
271	41471906	12608	Wright Cowden	Midland	804 ECR 132	Midland	79706	Tue, 3 Sep 2002 00:00:00	no	Domestic	315633	1020302

Texas Water Development Board Groundwater Data

Rec	OBJECT	State Well Number	Owner	Water Use	Elevation	Well Depth	Water Level	Water Quality	Aquifer Code	Latitude	Longitude	COUNTY_CODE	WELL_TYPE
1	46156065	2764802	T.E. Simpson	H	2775	68	C	N	121OGLL	320103	1020427	329	W
2	46190283	4507301	J.E. Simms No.1		2824		N	N	NOT-APPL	315759	1020735	329	P
3	46190307	4507601	Clarence Scharbauer,	S	2843	69	M	Y	121OGLL	315645	1020922	329	W
4	46190310	4507604	Clarence Scharbauer,	S	2807		N	N	121OGLL	315534	1020808	329	W
5	46190311	4507605	Clareence Scharbauer,	S	2841	110	M	N	121OGLL	315611	1020852	329	W
6	46190312	4507606	Westgate Mobile	P	2818	80	M	N	121OGLL	315702	1020755	329	W
7	46190328	4508101	Mrs. Brinson	U	2806	90	C	N	121OGLL	315759	1020625	329	W
8	46190329	4508201			2785	76	H	N	121OGLL	315945	1020453	329	W
9	46190330	4508202			2775	84	H	N	121OGLL	315924	1020408	329	W
10	46190331	4508203		U	2763		M	N	121OGLL	315745	1020256	329	W
11	46190332	4508204	J.E. Simmons	S	2748		H	N	121OGLL	315827	1020328	329	W
12	46190333	4508301	J Baker	U	2760	129	M	Y	121OGLL	315739	1020148	329	W
13	46190336	4508304	Crawford Estates	S	2735	40	H	Y	121OGLL	315854	1020144	329	W
14	46190343	4508311	Texas Dept. of Water	U	2748	91	N	N	121OGLL	315941	1020210	329	T
15	46190344	4508401		I	2815		M	N	121OGLL	315501	1020634	329	W
16	46190345	4508402	Elsie & Clara CAmpbell		2776		N	N	NOT-APPL	315623	1020506	329	P
17	46190346	4508403	J. A. Baze	H	2812	85	N	Y	121OGLL	315717	1020712	329	W
18	46190347	4508404	Ray Merworth	I	2812	71	N	Y	121OGLL	315726	1020704	329	W
19	46190348	4508405	Melvin Jones	H	2808	92	N	Y	121OGLL	315729	1020648	329	W
20	46190349	4508406	Pete Haman	H	2807	97	M	Y	121OGLL	315720	1020657	329	W
21	46190350	4508407	Jerry Knandel	H	2808	92	M	Y	121OGLL	315724	1020654	329	W
22	46190351	4508408	Roscoe Lewis	N	2805	97	M	Y	121OGLL	315714	1020649	329	W
23	46190352	4508409	Don Dagenhart	H	2802	90	N	Y	121OGLL	315709	1020648	329	W
24	46190353	4508410	Don Murphree	H	2799	97	N	Y	121OGLL	315709	1020646	329	W
25	46190354	4508501	B.E. O'Neal	I	2795	150	M	N	121OGLL	315633	1020419	329	W
Rec	OBJECT	State Well Number	Owner	Water Use	Elevation	Well Depth	Water Level	Water Quality	Aquifer Code	Latitude	Longitude	COUNTY_CODE	WELL_TYPE
26	46190355	4508502	W Rayburn	I	2787	95	H	N	121OGLL	315611	1020432	329	W
27	46190356	4508503	Davis		2780	120	H	N	121OGLL	315526	1020419	329	W
28	46190357	4508504	Carl D. Glaze	U	2776	90	H	N	121OGLL	315507	1020437	329	W
29	46190358	4508505		I	2781	120	M	N	121OGLL	315621	1020456	329	W
30	46190359	4508506	El Paso Natural Gas	N	2777	152	N	N	121OGLL	315645	1020247	329	W
31	46190360	4508507		I	2740		M	N	121OGLL	315654	1020248	329	W
32	46190361	4508508	Ruth Dowlin	H	2775	80	M	Y	121OGLL	315546	1020335	329	W
33	46190362	4508509	South Midland WS	P	2758	80	M	N	121OGLL	315730	1020442	329	W
34	46190363	4508510	Dale Vines	H	2774	120	N	Y	121OGLL	315642	1020331	329	W
35	46190364	4508511	Manuel Rendon	H	2750		N	Y	121OGLL	315722	1020442	329	W
36	46190365	4508601		I	2755		M	N	121OGLL	315609	1020219	329	W
37	46190367	4508603	Phillip Medellin	H	2775	110	N	Y	121OGAL	315624	1020218	329	W
38	46190372	4508801	W.N. Lockler	I	2770	68	H	N	121OGLL	315448	1020439	329	W
39	46194462	4808510	Dale Vines	H	2774	120	N	Y	121OGLL	315642	1020331	329	W

Well_Type Codes
W= Withdrawl of water (domestic or irrigation)
T= Test well
P= Oil or Gas
Water Use Codes
H= Domestic
S= Stock
P= Public Supply
U= Unused
I= Irrigation
N= Industrial