Kirtland Air Force Base Fuel Spill Geological Field Trip Handout
October 21, 2014

Introduction – Leakage of aviation gasoline and jet fuel from the Kirtland AFB bulk fuel facility migrated through ~150 feet of alluvial fan sediments, and into the underlying Sierra Ladrones Formation, a thick sequence of sediments deposited by the ancestral Rio Grande. The Sierra Ladrones Formation is a highly productive aquifer that contains NNE-SSW trending zones of high hydraulic conductivity corresponding to axial river deposits of sand and gravel. This field trip will examine outcrops of alluvial fan and Sierra Ladrones sediments exposed in lower Tijeras Arroyo, and visit a USGS monitoring well drilling site. Geologists and water professionals from the N.M. Environment Department, the U.S. Geological Survey, the N.M. Bureau of Geology, the Albuquerque Bernalillo County Water Utility Authority, the U.S. Air Force, the Air Force Civil Engineering Center and CB&I will be available for questions and discussion.

More detailed information on the investigation and cleanup of the fuel spill will be presented at a poster session and public meeting to be held on Thursday, October 23, 2014, starting at 5:30 p.m. at the African American Performing Arts Center, State Fair Grounds, 310 San Pedro NE, Albuquerque.

Logistics – Transportation to the field stops, departing from the Chavez Community Center, will be provided on a first-come, first-serve basis. You can also drive your own vehicle, but carpooling is recommended. Bring sunscreen, a hat, drinking water, a bag lunch, hiking boots, layers of clothing appropriate for fall weather, and a clip board for field trip handouts. Stop 1 will involve a roundtrip hike of about 1.2 mile, with about 180 feet of elevation climb and descent, sometimes on uneven terrain with loose sediment.

Sierra Ladrones river gravel

Alluvial fan sediment

Itinerary –

10:00 a.m. – Gather at the Chavez Community Center parking lot (south of the building), 7505 Kathryn Ave. SE. Participants will board vehicles and depart.

10:30 a.m. to 1:00 p.m., including lunch break
Stop 1 – Montessa Park, Off Road Vehicle Area, Los Picaros Road. Observe outcrops of axial Rio Grande deposits in the Sierra Ladrones Formation and overlying alluvial fan sediments. KAFB bulk fuel facility tanks will be visible across Tijeras Arroyo to the NE. Discussion topics:

- Regional geology and stratigraphy (Dan Koning, NMBG)
- Regional hydrogeology (Nathan Myers, USGS)
- Water supply wells, water level changes, vertical hydraulic gradients (Rick Shean, ABCWUA)
- Regional groundwater chemistry and contamination (Dennis McQuillan, NMED)
- Reactive minerals (Adria Bodour, AFCEC)
- *In situ* bio-denitrification, Mountainview pilot project (Eric Nuttall, UNM, retired).

1:30 p.m. to 2:45 p.m.
Stop 2 – Bullhead Park, 1606 San Pedro Blvd. SE. The KAFB fuel spill area will be visible from across the fence, and we will be standing over the core of the groundwater contamination plume ~480 feet below ground surface. Discussion topics:

- KAFB fuel spill and soil vapor extraction (Wayne Bittner, USAF)
- LNAPL, petroleum hydrocarbon and EDB plumes; Stiff diagrams (Diane Agnew, CB&I)
- Intrinsic biodegradation of hydrocarbons and EDB (Patrick Longmire, NMED)
- Options for cleaning up drowned LNAPL (Stephen Reuter, NMED)
- Collapsing the EDB plume (Adria Bodour)

3:00 p.m. – 4:00 p.m.
Stop 3 – Return to Chavez Community Center. Drill cuttings and geophysical logs will be on display, and we will walk to the USGS well drilling site north of the building. For your safety please do not cross into the active drill-site area. Discussion topics:

- Geophysical logs (Sid Brandwein, NMED)
- Drill cuttings (Nathan Myers)
- Influence of sedimentary lithology on aquifer properties (Nathan Myers)
- Protection of water-supply wells:
    - ABCWUA Water Quality Protection Policy and Action Plan (Rick Shean)
    - Sentinel wells for early detection; monthly sampling of supply wells (Dennis McQuillan)

Figure 1. Generalized Block Diagram of the Middle Rio Grande Basin in Albuquerque.
(Modified from Bjorklund and Maxwell, 1961)

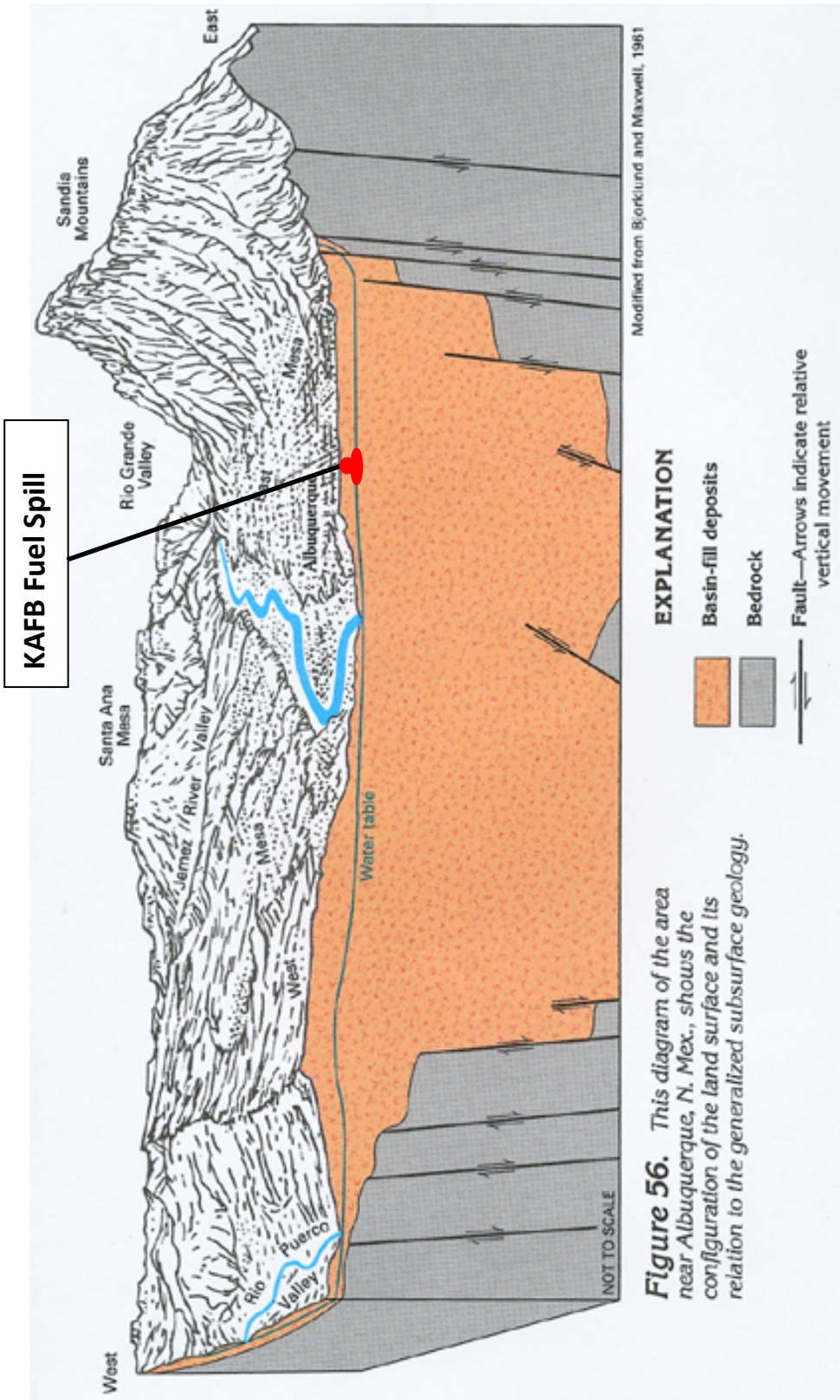


Figure 2. Geologic Map and Cross Section. (From Connell, 2008)

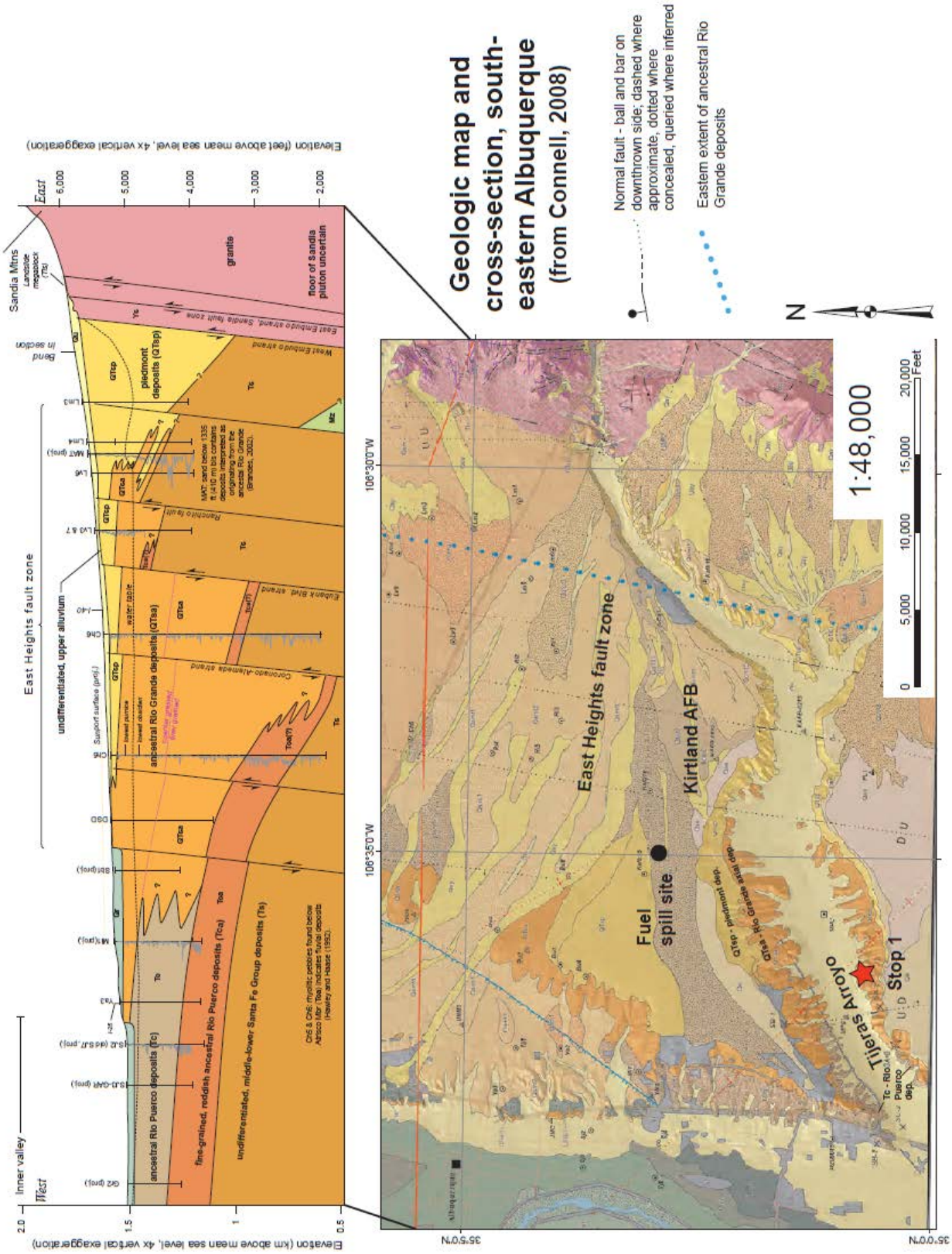


Figure 3. Stratigraphic Sections.

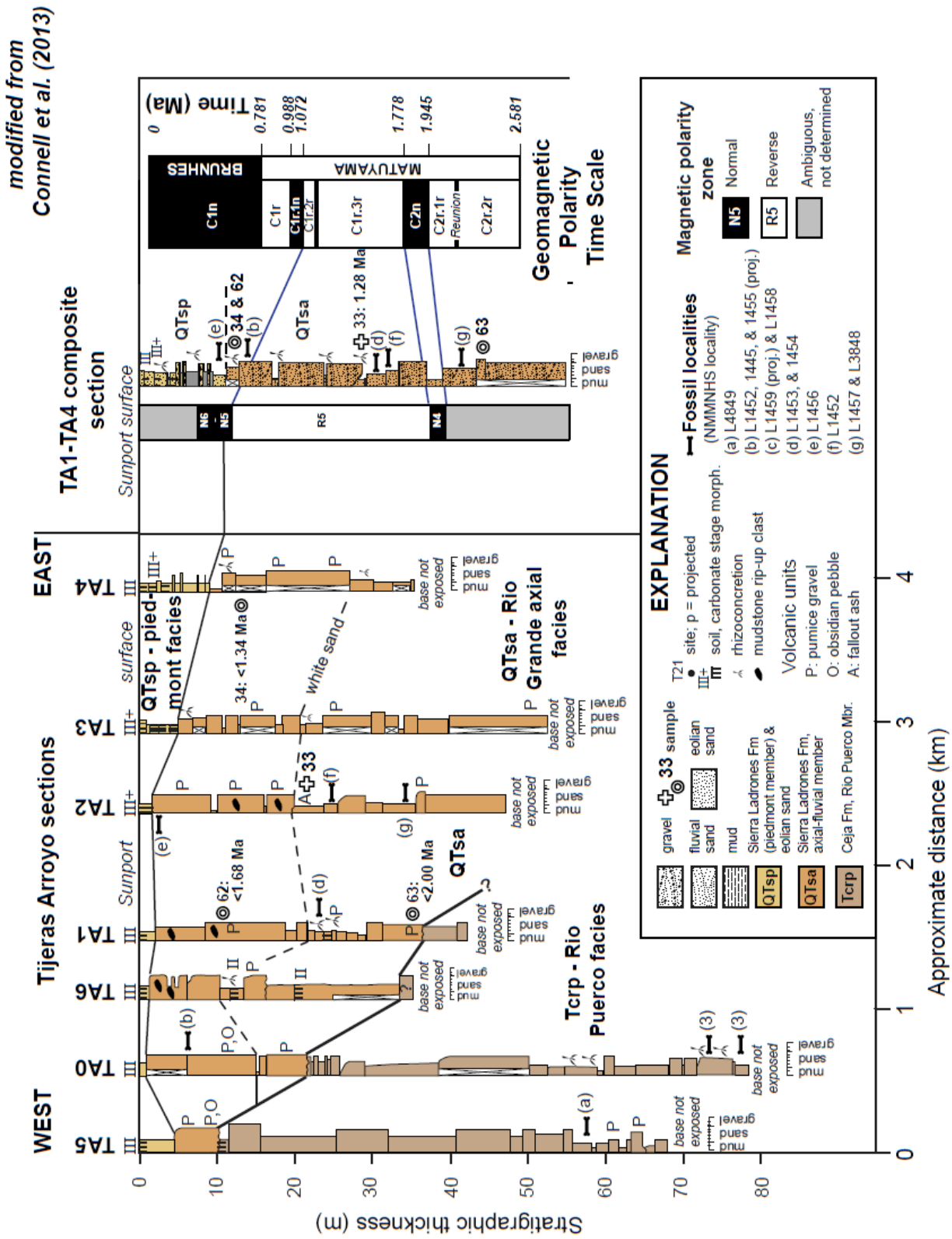


Figure 4. Gravity Anomalies in the Middle Rio Grande Basin. (From Grauch, Rodriguez and Deszcz-Pan, 20)

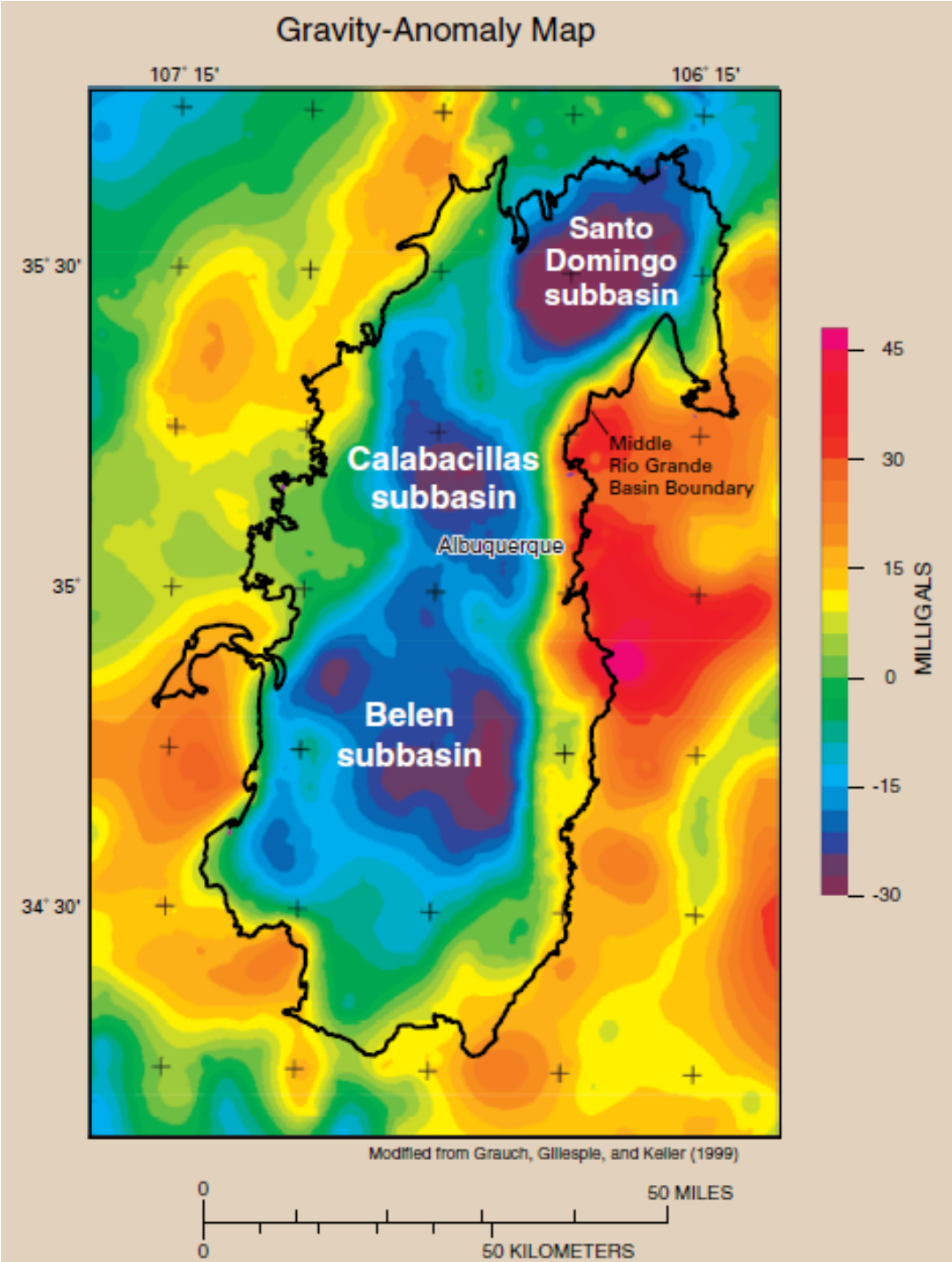


Figure D.1.—Gravity data for the entire Middle Rio Grande Basin and surrounding area. The Santa Fe Group has much lower density than the surrounding bedrock, producing low values (shown in blue and purple) on the gravity-anomaly map .

Figure 5. Inferred lateral extent of major lithostratographic units during the Pliocene in Middle Rio Grande Basin, central New Mexico. (Plummer et al. 2004, modified from Connell et al. 1999)

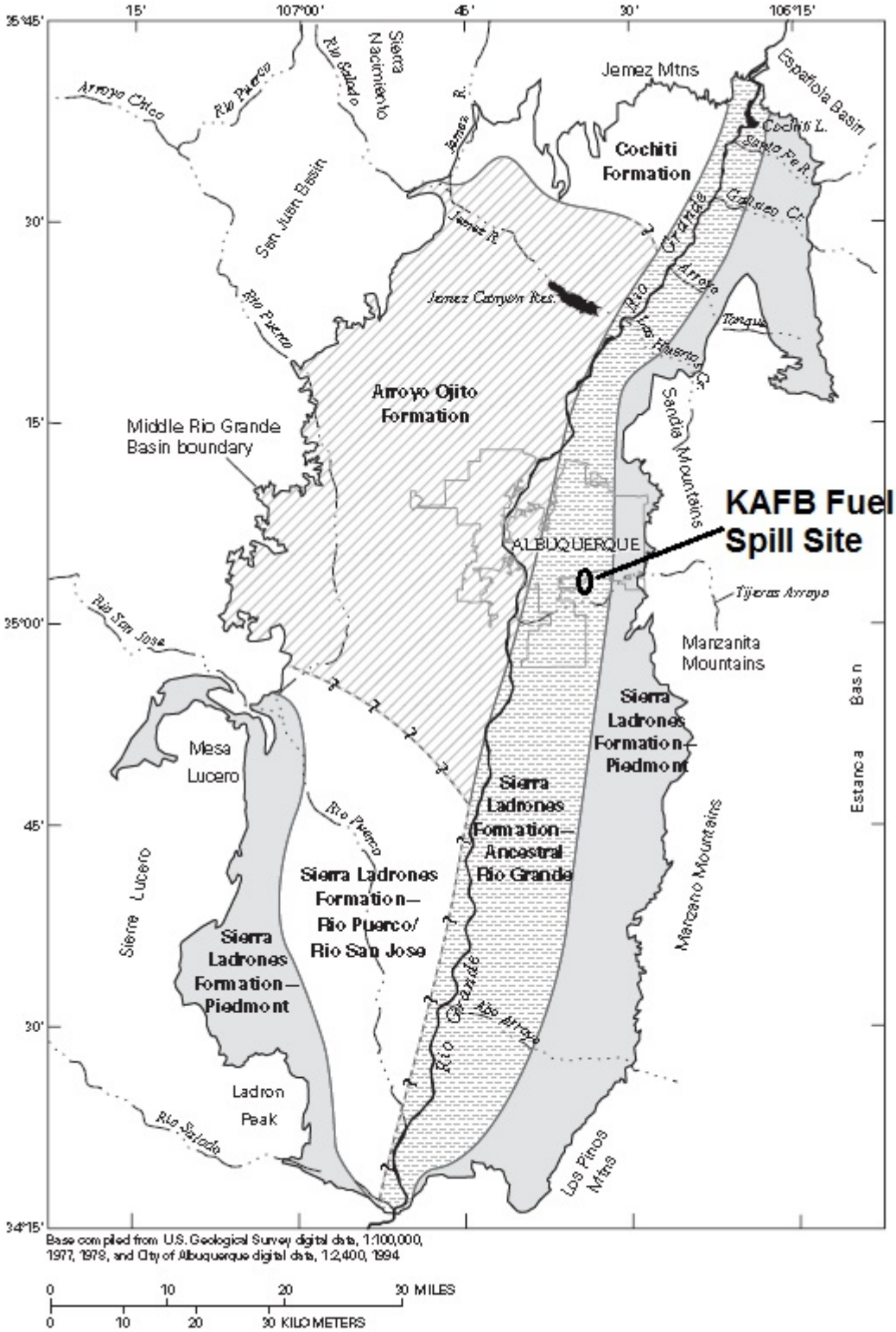


Figure 6. Stratigraphic Correlation of Wells Near KAFB Fuel Spill.

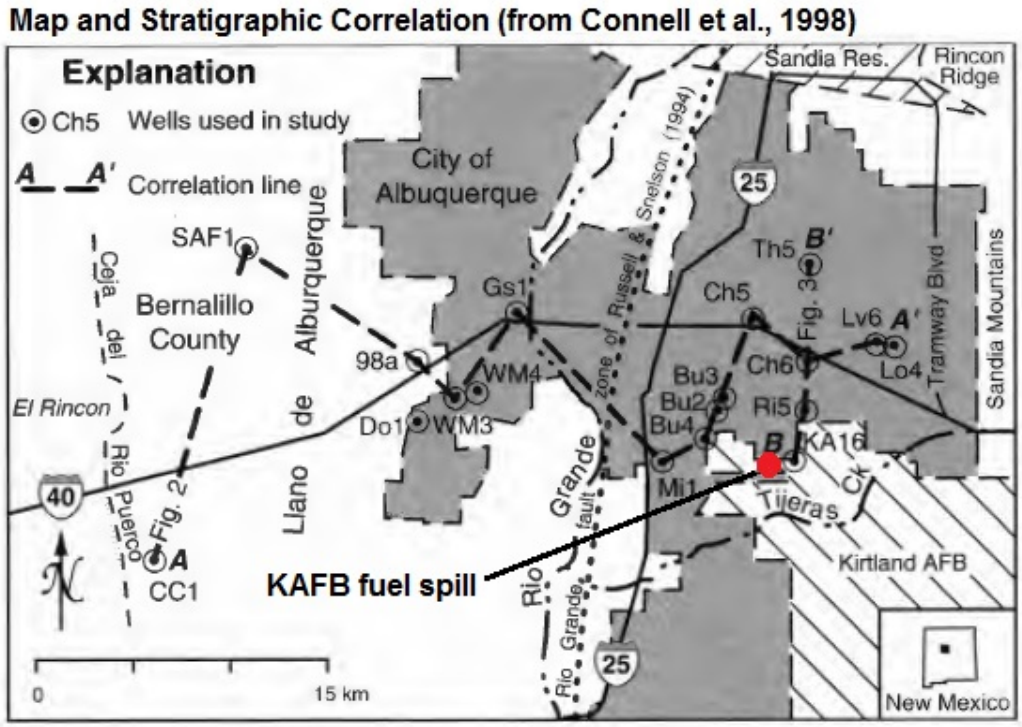


FIGURE 1—Study area illustrating stratigraphic correlation lines and wells referred to in text. Correlation diagrams are in Figs. 2 and 3.

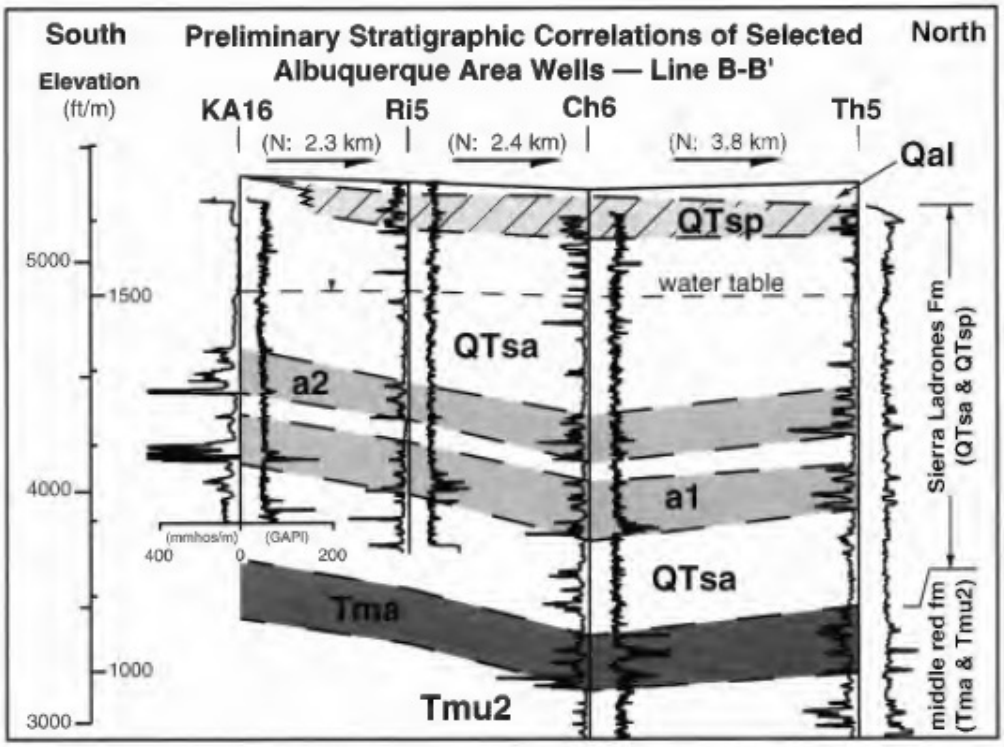


FIGURE 3—Preliminary stratigraphic correlation diagram along line *B–B'* of Fig. 1 illustrating stratigraphic correlations of basin-floor facies of the Santa Fe Group, the Atrisco member and marker beds. Refer to Fig. 2 for explanation of symbols.

Figure 7. Lithologic Log for the VA Hospital Well.

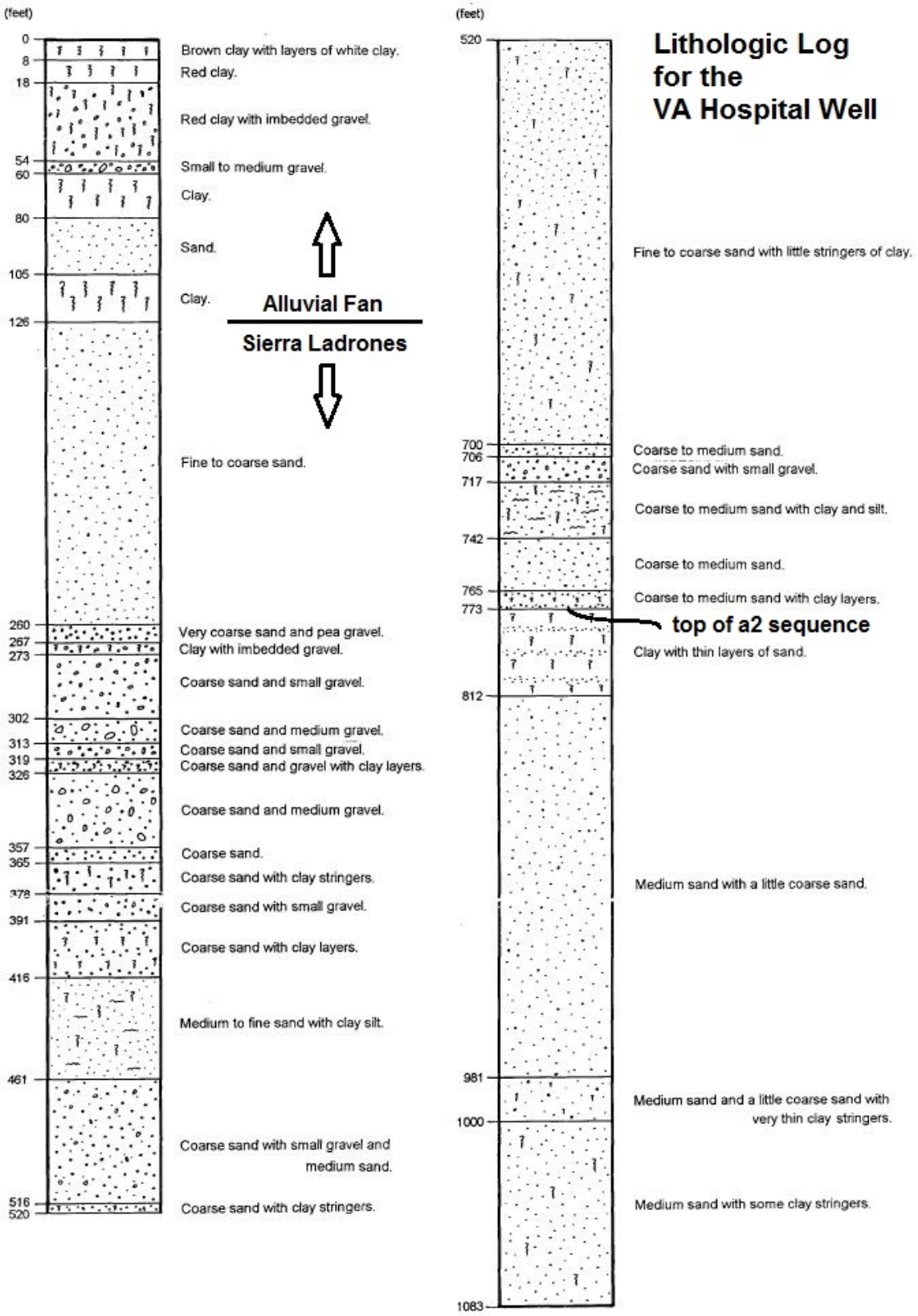


Figure 8. Hydraulic Conductivity of the Uppermost Aquifer in the Middle Rio Grande Basin. Modified by Bartolino and Cole (2002), from simulations of McAda and Barroll (2002)

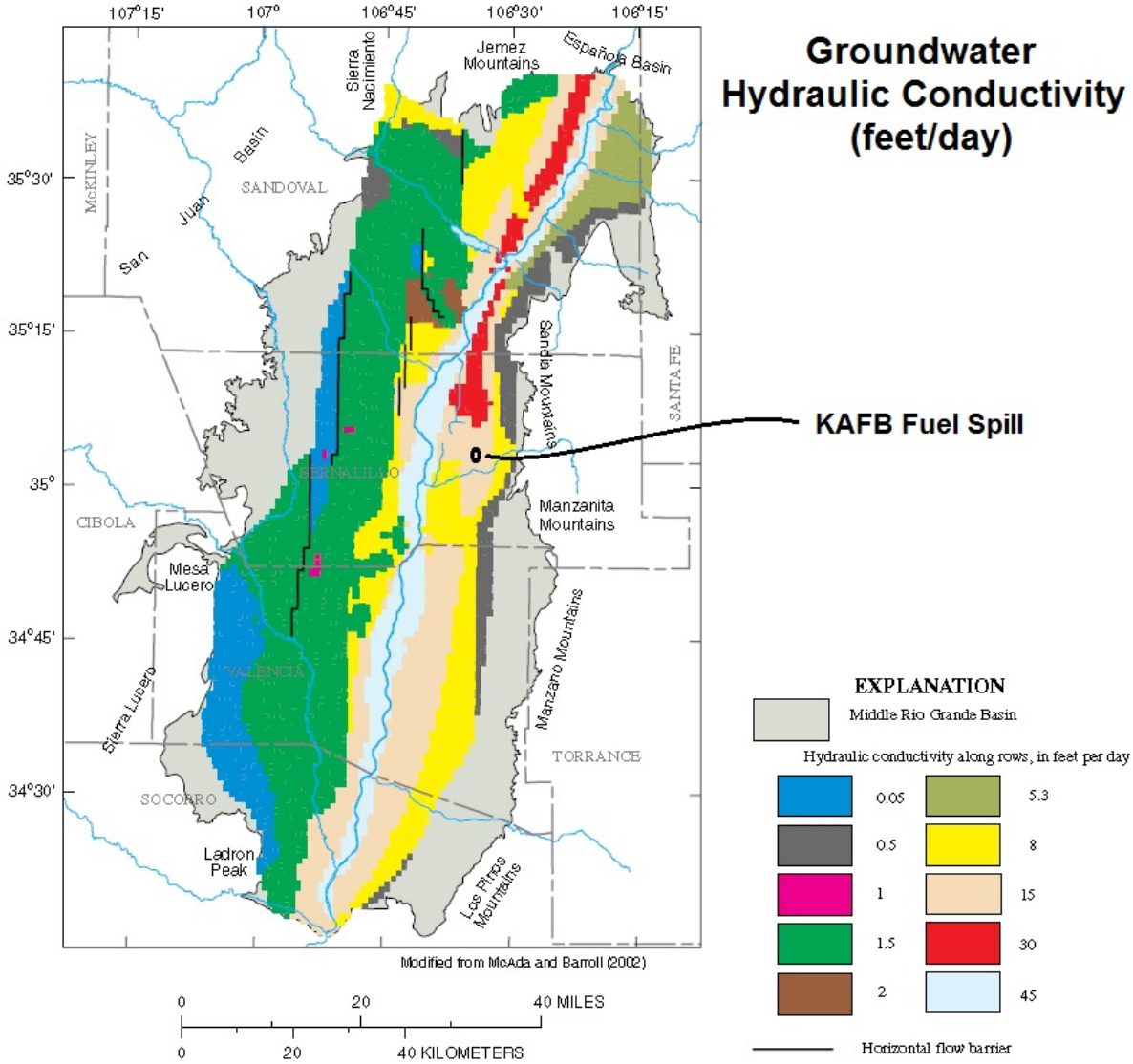


Figure 9. Pre-Development Water Levels. (From Bexfield and Anderholm, 2000)

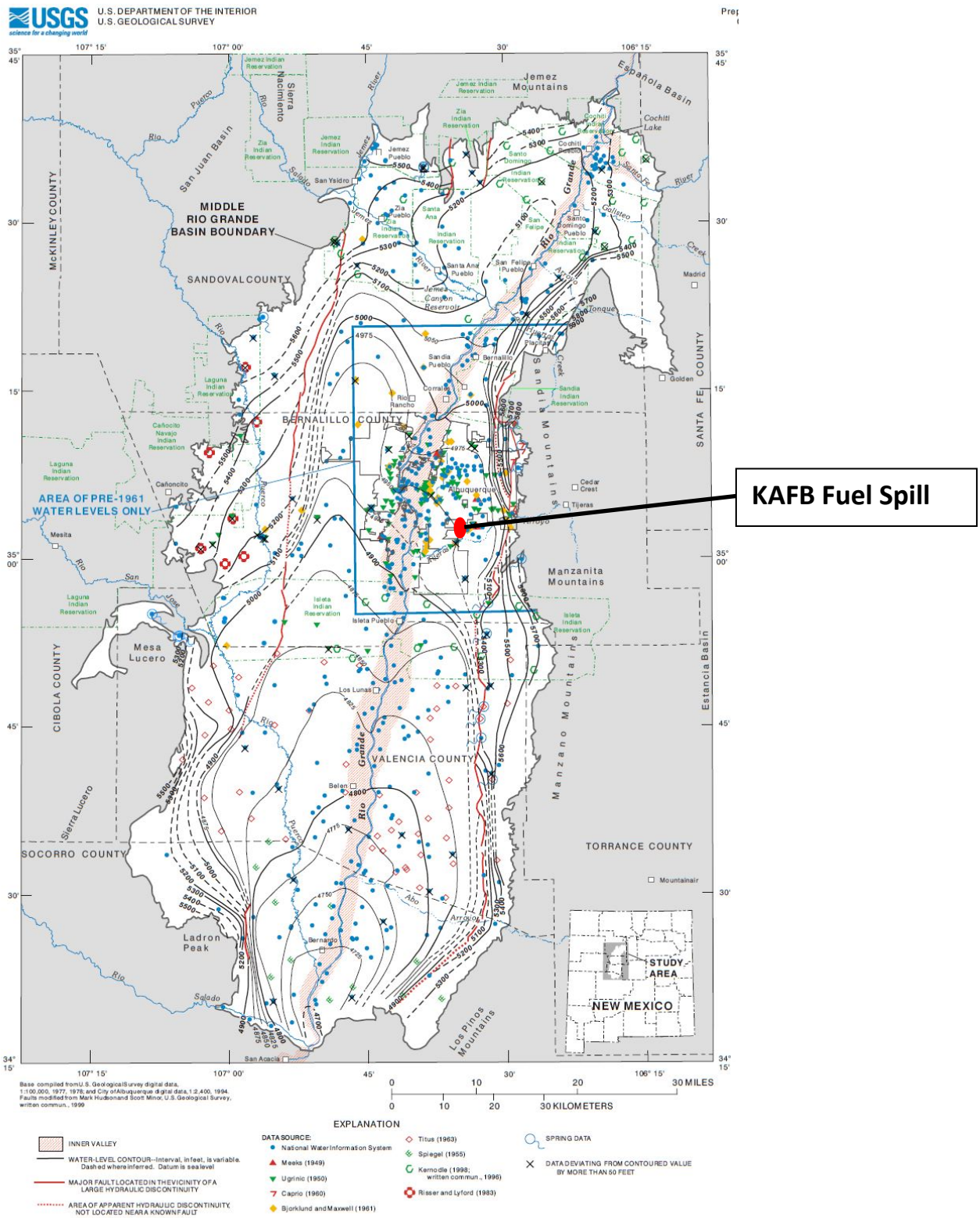


Figure 10. 2008 Water Levels and Water Level Change from Pre-Development. (From Falk, et al., 2011)

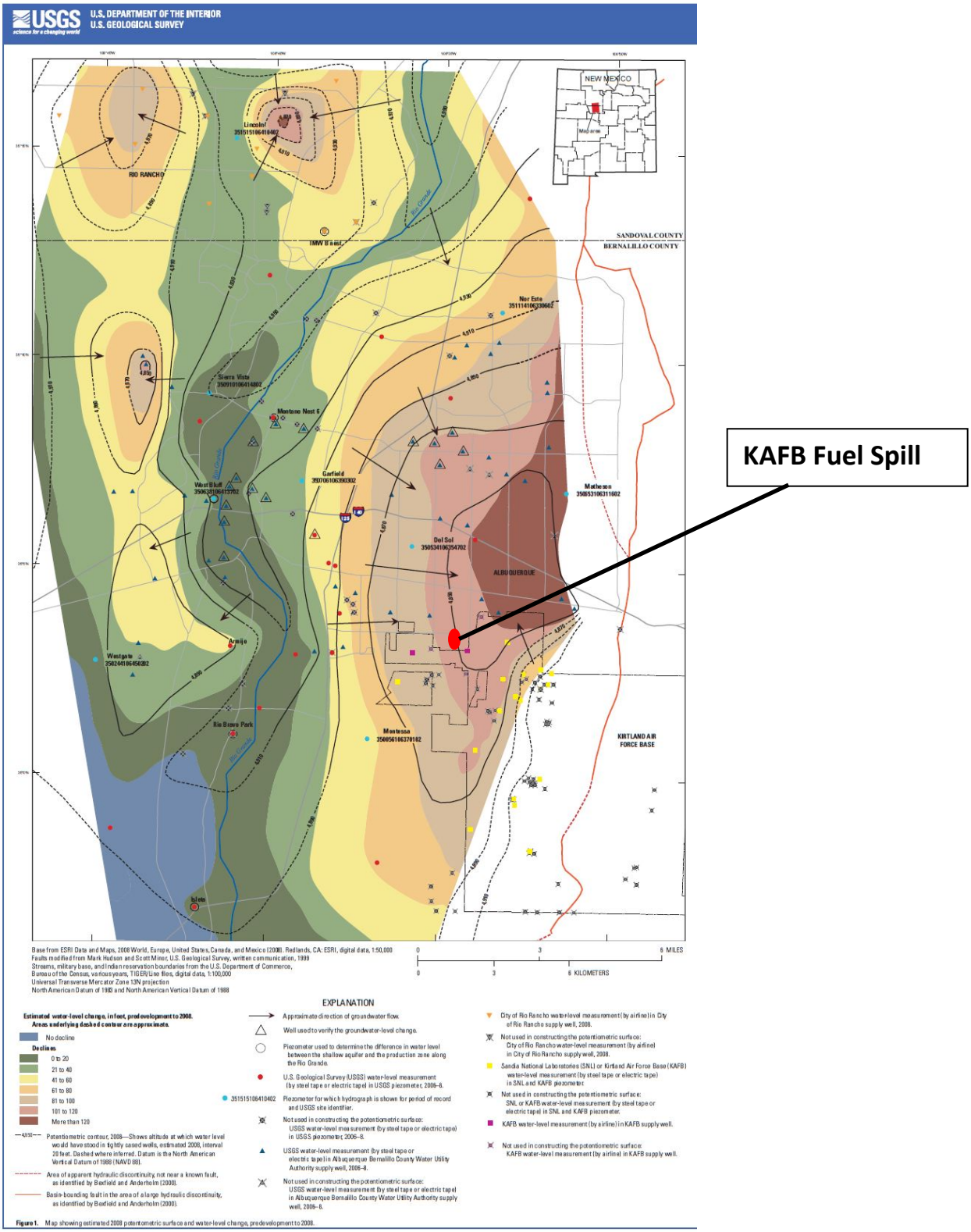


Figure 11. 2012 Water Levels, Water Level Change from Pre-Development, and Hydrographs Showing 2009-12 Water Level Rise. (From Powell and McKean, 2012)

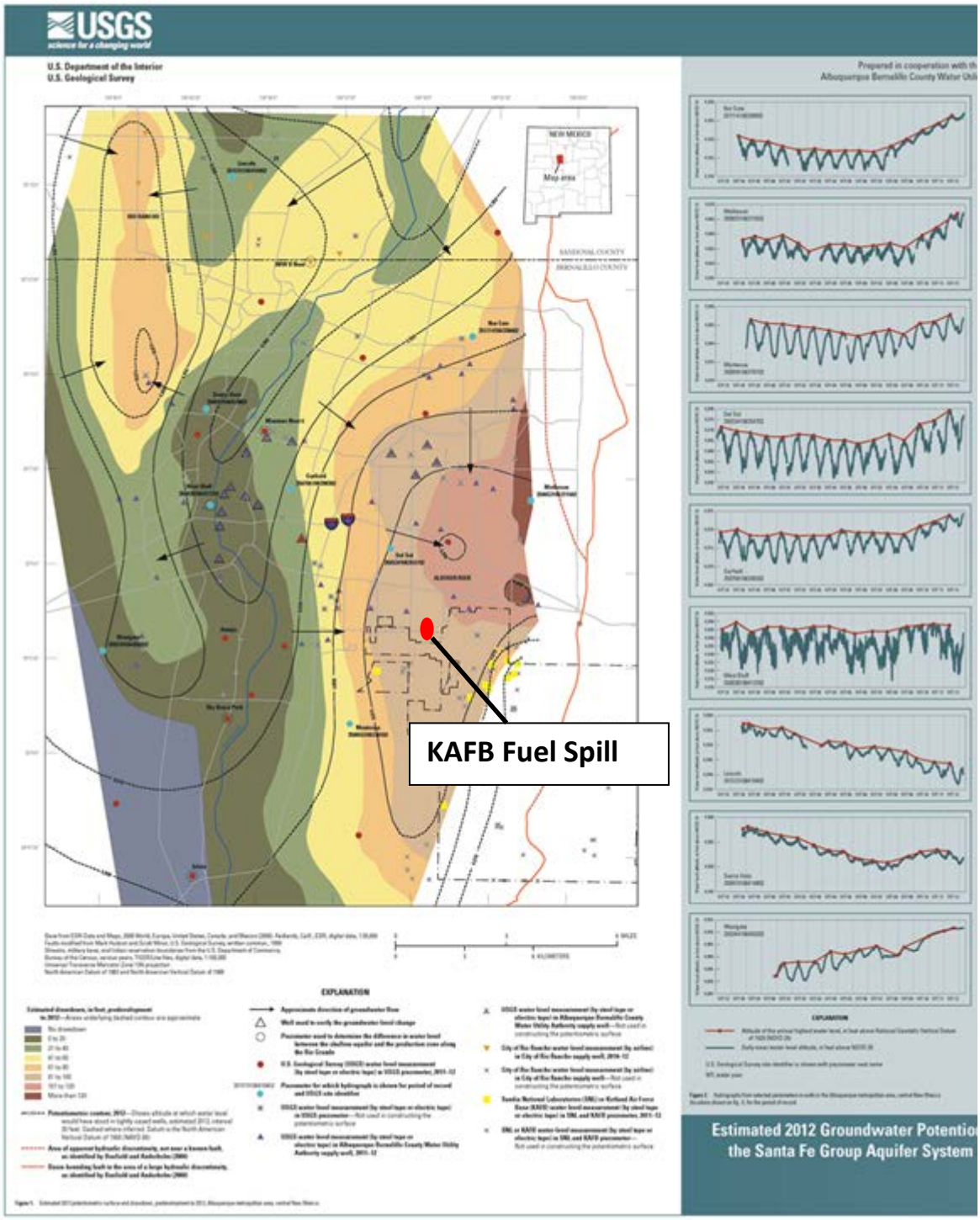


Figure 12. Trumbull Piezometer Nest Water Levels, 6/20/14. (raw data from USGS.gov)

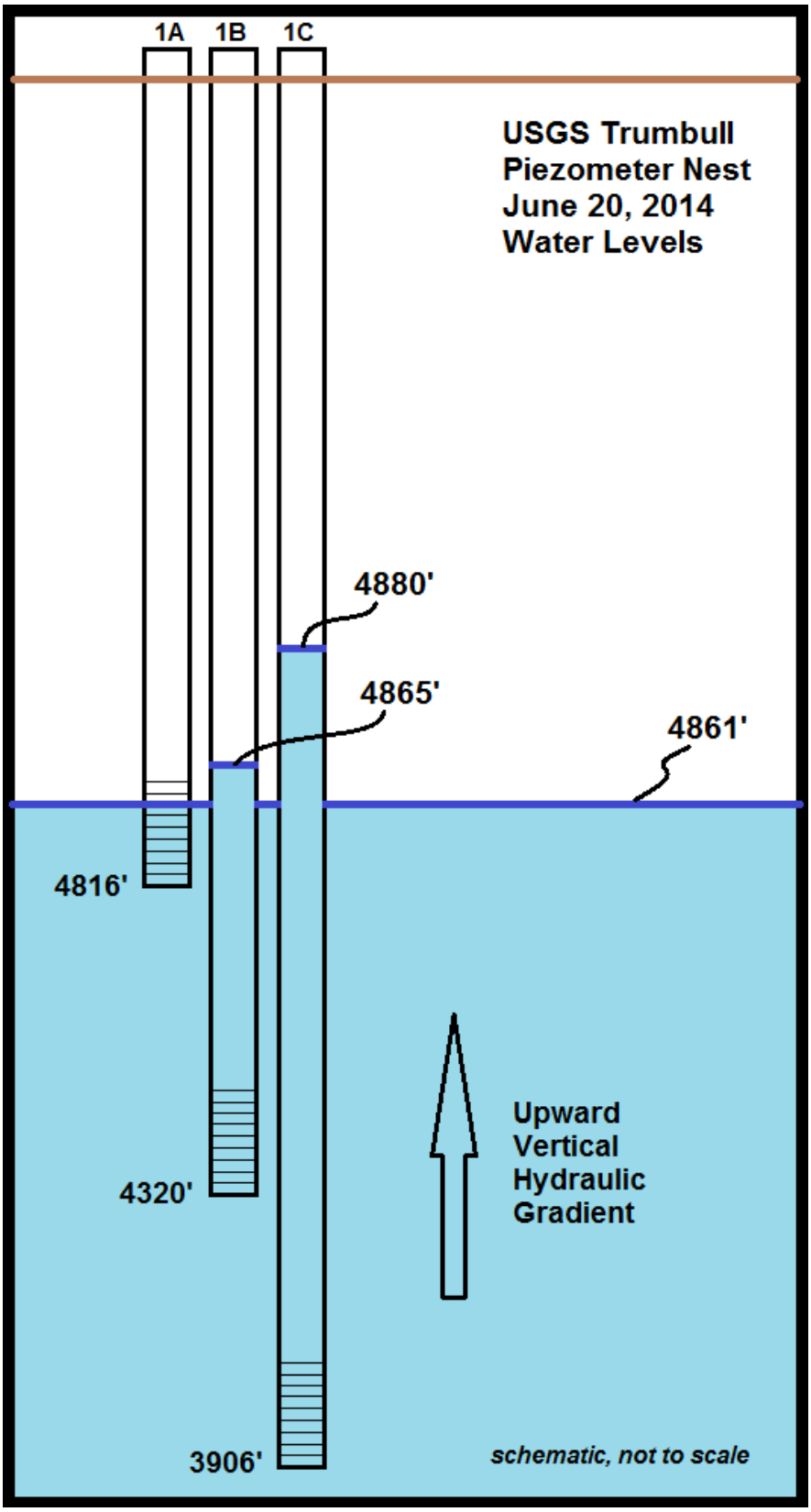


Figure 13. Trumbull Piezometer Nest Hydrographs. (raw data from USGS.gov)

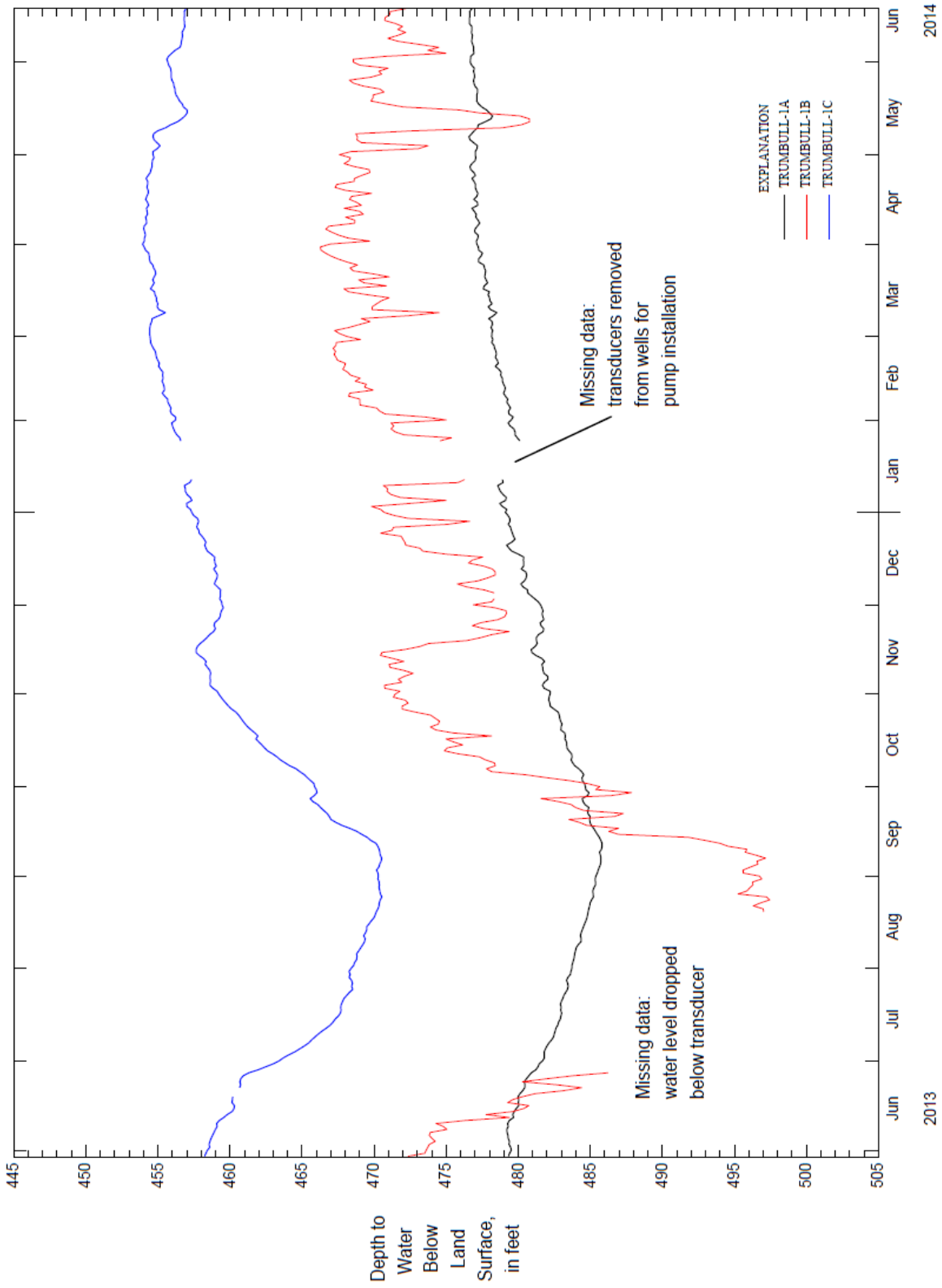


Figure 14. Hydrochemical Zones in the Middle Rio Grande Basin. (From Bexfield, 2010)

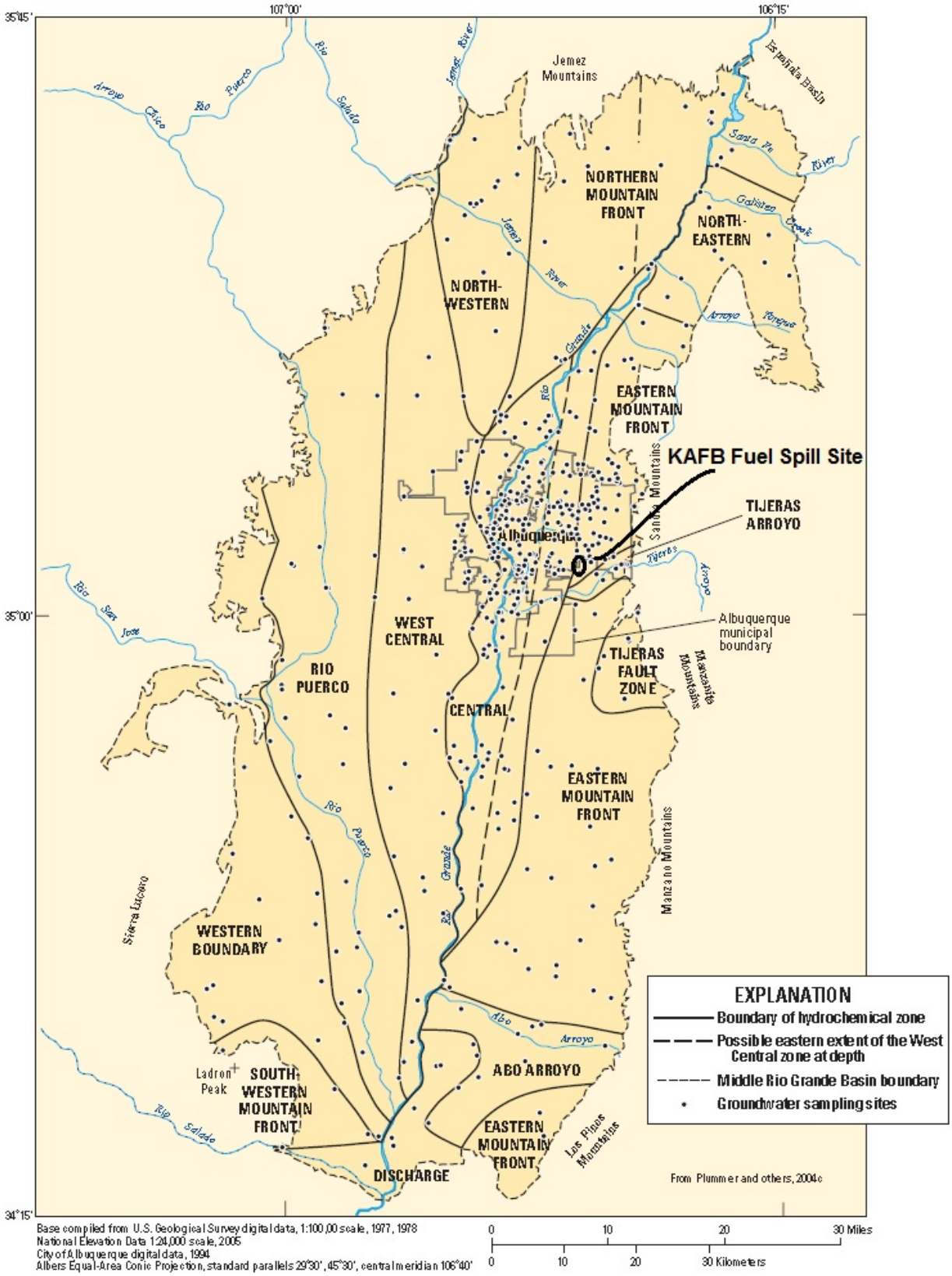


Table 1. Hydrochemical Zone Water Quality Parameters. (From Bexfield, 2010)

Median values of selected water-quality parameters by hydrochemical zone for the Middle Rio Grande Basin, New Mexico.

[Specifice conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C). **Abbreviations**: µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; pmC, percent modern carbon]

Hydrochemical zone	Specific conductance (µS/cm)	Field pH	Dissolved oxygen (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Alkalinity (mg/L as HCO_3)	SO_4 (mg/L)	Cl (mg/L)	F (mg/L)	SiO_2 (mg/L)
Northern Mountain Front	340	7.49	5.12	38.5	6.1	20.0	4.9	137	19.5	5.6	0.35	53.3
Northwestern	400	7.84	6.68	33.9	4.2	49.9	5.7	160	44.8	8.5	0.61	30.1
West Central	535	8.22	3.00	12.0	2.5	103	4.2	174	92.0	13.4	0.99	34.5
Western Boundary	4,572	7.70	4.09	135	56.4	589	15.2	300	793.	820	1.64	22.5
Rio Puerco	2,731	7.50	3.73	135	42.7	290	10.4	190	1,080	185.8	0.63	21.8
Southwestern Mountain Front	462	8.11	4.43	52.6	13.5	27.8	2.5	202	53.0	15.0	1.02	17.6
Abo Arroyo	1,055	7.45	6.23	92.5	34.4	49.2	3.1	148	346	25.9	0.90	24.0
Eastern Mountain Front	382	7.67	5.16	45.0	5.1	29.2	2.2	157	31.0	10.5	0.60	28.4
Tijeras Fault Zone	1,406	7.42	4.66	171	36.0	95.0	6.1	599	100	139	1.27	18.9
Tijeras Arroyo	677	7.39	6.97	89.4	24.5	29.3	3.8	240	115	56.6	0.60	19.5
Northeastern	1,221	7.50	6.44	141	29.5	81.8	4.8	208	390	22.7	0.51	38.5
Central	436	7.74	0.12	42.9	8.0	31.0	6.4	158	66.0	16.6	0.44	47.0
Discharge	1,771	7.70	0.08	93.0	31.0	190	10.5	157	290	280	1.40	39.0

Hydrochemical zone	Nitrate (mg/L as N)	As (µg/L)	Fe (mg/L)	Mn (mg/L)	Mo (µg/L)	Sr (mg/L)	U (µg/L)	V (µg/L)	δD (per mil)	$\delta^{18}O$ (per mil)	$\delta^{13}C$ (per mil)	^{14}C (pmC)
Northern Mountain Front	0.56	3.2	0.060	0.005	1.7	0.31	1.0	6.4	-77.7	-10.9	-8.50	33.4
Northwestern	2.44	9.8	0.030	0.002	3.4	0.57	2.7	15.6	-64.7	- 8.73	-6.93	29.6
West Central	1.24	23.2	0.028	0.002	8.2	0.20	3.7	27.9	-96.7	-12.7	-7.18	8.80
Western Boundary	0.86	1.8	0.213	0.041	9.9	2.09	4.4	5.7	-64.4	- 9.12	-4.70	6.19
Rio Puerco	0.88	1.0	0.130	0.015	7.0	3.92	6.0	3.4	-61.6	- 8.51	-7.65	36.4
Southwestern Mountain Front	1.12	0.2	0.030	0.007	3.0	0.86	0.9	1.0	-53.5	- 7.74	-5.76	40.0
Abo Arroyo	1.40	5.2	0.105	0.004	3.4	1.48	5.4	9.5	-65.2	- 9.05	-6.72	24.1
Eastern Mountain Front	0.31	2.0	0.031	0.003	2.0	0.32	3.6	7.5	-81.0	-11.4	-8.70	47.2
Tijeras Fault Zone	1.09	2.2	0.111	0.023	3.7	1.11	7.3	6.3	-74.2	-10.3	-0.98	9.70
Tijeras Arroyo	3.79	1.0	0.050	0.005	1.9	0.47	3.7	3.0	-75.7	-10.3	-6.80	72.8
Northeastern	0.64	2.7	0.170	0.004	6.7	1.72	8.5	3.8	-68.6	- 9.72	-6.40	28.5
Central	0.08	5.4	0.041	0.015	5.0	0.40	3.6	9.3	-95.4	-12.8	-8.87	61.0
Discharge	0.42	9.9	0.080	0.010	10.3	3.02	3.9	7.1	-90.8	-12.1	-7.00	10.8

Table 2. Water Quality of Public Supply Wells in the Vicinity of the KAFB Fuel Spill.
DO, dissolved oxygen; ND, not detected; --, not reported; $NO_3 + NO_2$, nitrate plus nitrite; ORP, oxidation-reduction potential; SC, specific conductance; TDS, total dissolved solids.

Parameter mg/L unless given	**KAFB Well #3 1/21/14**	**KAFB Well #15 1/21/14**	**Ridgecrest Well #3 ~1980**	**Ridgecrest Well #3 6/22/96**	**VA Well #2 11/4/98**	**VA Well #2 1/21/14**
Calcium	42	31	42	39	30	37
Magnesium	5	8	3	4	5	7
Sodium	25	37	25	22	22	21
Potassium	2	6	4	3	4	4
Chloride	22	44	28	25	22	31
Bromide	0.075	0.085	--	0.11	--	0.064
Sulfate	26	31	26	22	28	24
Bicarbonate	107	89	139	132	126	92
$NO_3 + NO_2$ as N	0.35	ND	0.18	0.4	0.2	ND
SC, μS/cm or μmho/cm	344	403	391	329	326	352
TDS	--	--	234		252	--
pH, standard units	8.5	7.95	7.88	7.8	8.37	6.88
DO	7.34	4.83	--	4.6	--	4.08
ORP, mV	+174	+181	--	--	--	+183

Data Sources:
KAFB Wells #3 and #4; VA Well #2, 1/12/14 (CB&I, 2014)
Ridgecrest Well #3, ~ 1980; VA Well #2, 11/4/98 (NMED Drinking Water Bureau)
Ridgecrest Well #3, 6/22/96 (Plummer et al., 2004)

Figure 15. Groundwater Contamination in the Albuquerque South Valley, 1987.
(Gallaher et al., 1987)

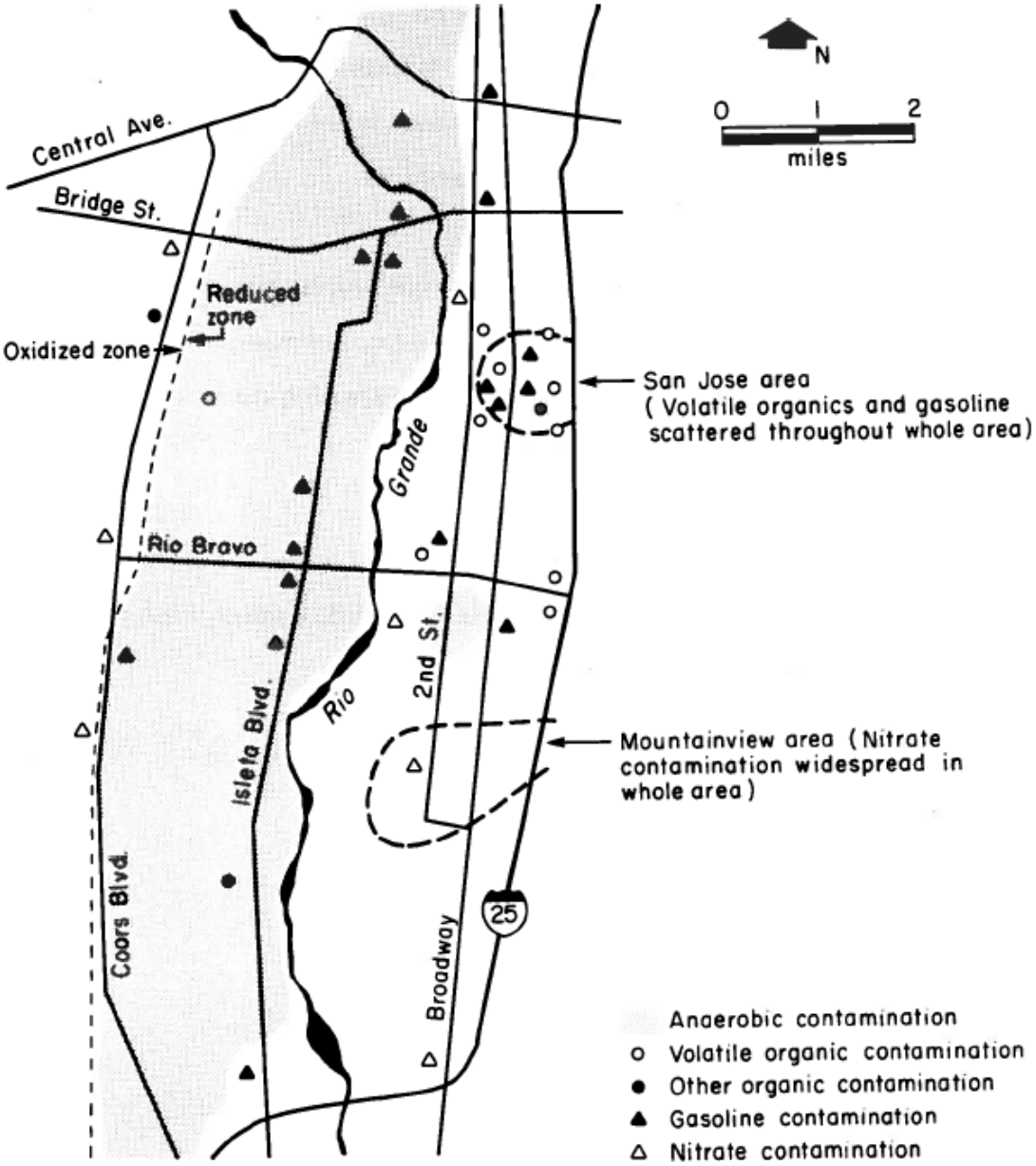


Figure 16. Public Water Supply Wells, Permitted Facilities, and Contaminant Release Sites in the Albuquerque Area. (NMED Source Water Protection Atlas, http://gis.nmenv.state.nm.us/SWPA/)

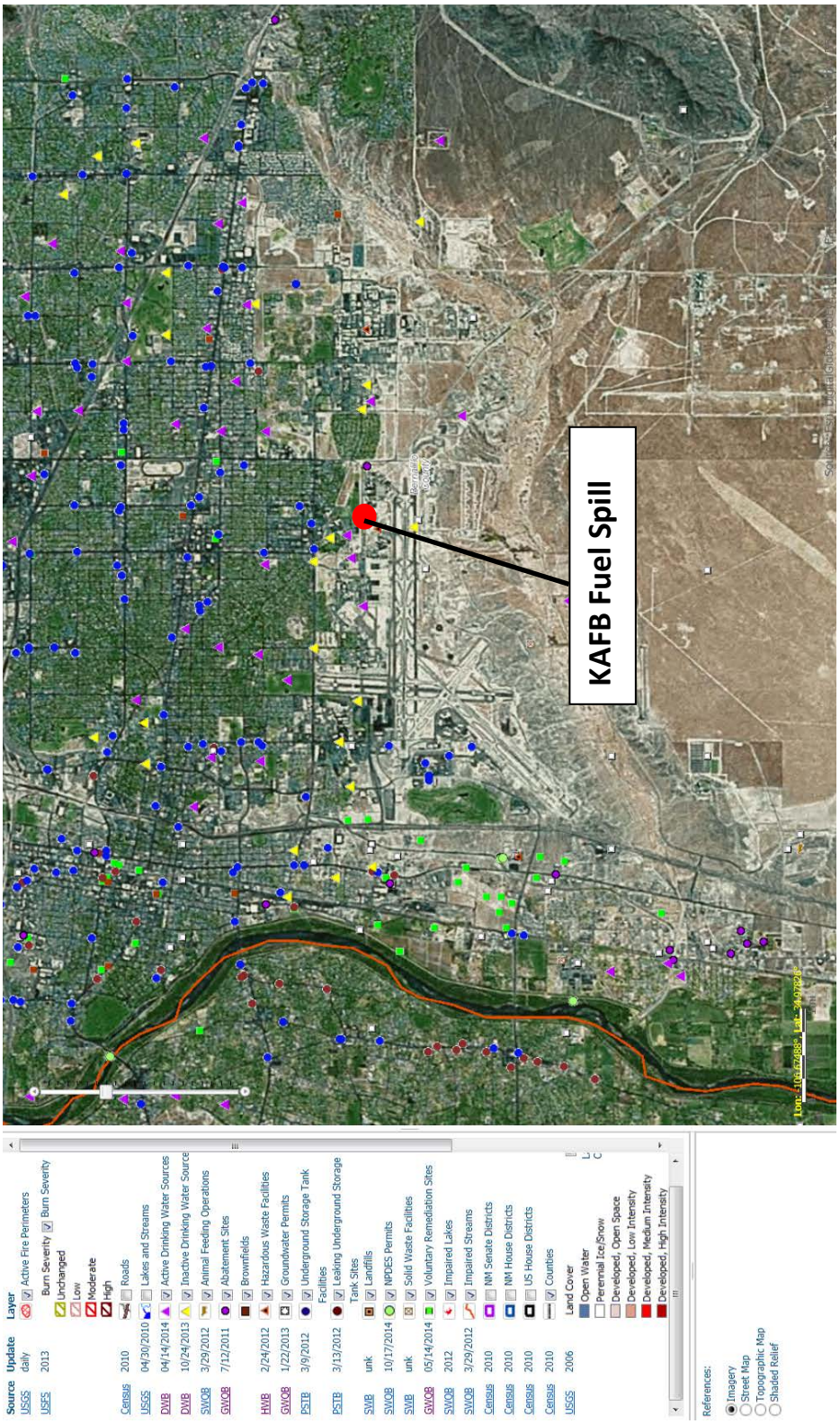


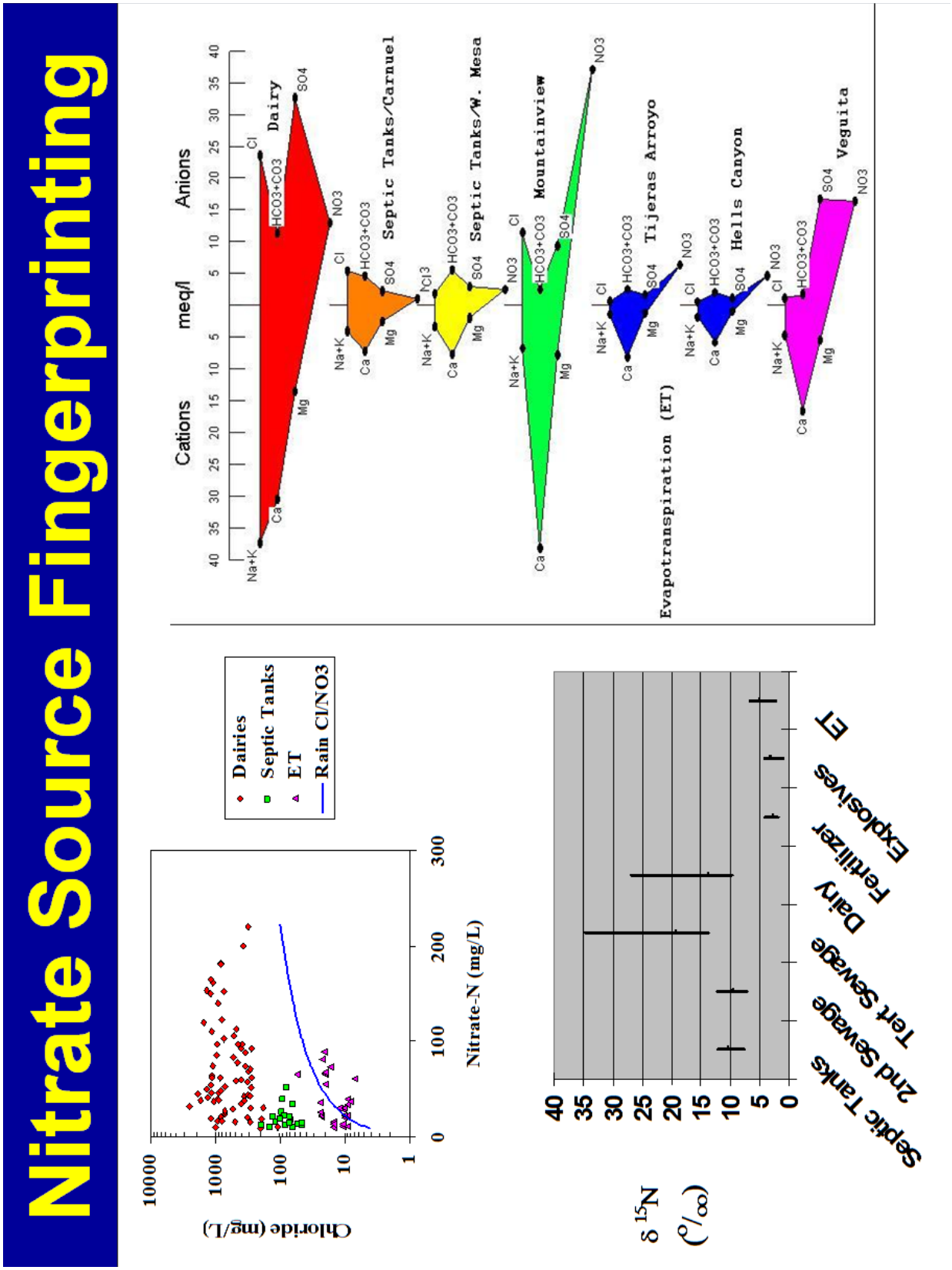
Table 3. Groundwater Nitrate Contamination Geochemistry Examples, Albuquerque Area. (NMED unpublished data) ET, evapotranspiration; ND, not detected; $NO_3 + NO_2$, nitrate plus nitrite; SC, specific conductance; TDS, total dissolved solids.

Parameter mg/L unless given	**Tijeras Canyon**	**Tijeras Arroyo**	**Hells Canyon**	**KAFB Sewage**	**ABQ West Mesa**	**Mountain-view**
Nitrate Source(s)	septics and marine rocks	natural ET	natural ET	sewage	septics	fertilizer
Calcium	173	70	117	91	155	568
Magnesium	37	10	11	18	24	51
Sodium	47	20	37	22	73	195
Potassium	6	6	10	ND	8	4
Chloride	84	23	20	51	64	338
Sulfate	152	36	54	59	139	460
Bicarbonate	390	147	124	183	340	132
$NO_3 + NO_2$ as N	24	21	65	19	35	269
$d^{15}N$ (‰)	+8.5	+6.3	+4.3	+17	+12.2	+6.9
TDS	898	422	774	424	904	3010
pH (units)	8.16	8.01	7.96	7.55	8.15	7.57

Table 4. Groundwater Nitrate Contamination Geochemistry Examples, Other Areas. (NMED unpublished data) ET, evapotranspiration; ND, not detected; $NO_3 + NO_2$, nitrate plus nitrite; SC, specific conductance; TDS, total dissolved solids.

Parameter mg/L unless given	**Poison Springs, Union Co.**	**Hobbs WWTP**	**Clovis Dairy**	**Clovis Farm**	**Hobbs Explosives Plant**	**LANL TA-50**
Nitrate Source(s)	marine rocks	sewage	dairy	fertilizer	explosives	nitric acid
Calcium	303	141	92	73	150	65
Magnesium	676	36	88	35	18	3
Sodium	232	158	44	12	46	102
Potassium	23	17	14	5	ND	12
Chloride	100	180	126	33	60	24
Sulfate	2400	196	54	21	111	25
Bicarbonate	56	473	491	195	249	226
$NO_3 + NO_2$ as N	320	21	26	43	44	38
$d^{15}N$ (‰)	+17.7	+22.86	+25.7	+2.9	+3.45	+2.3
TDS	5270	1090	866	562	768	538
pH (units)	7.07	7.42	8.15	7.75		7.13

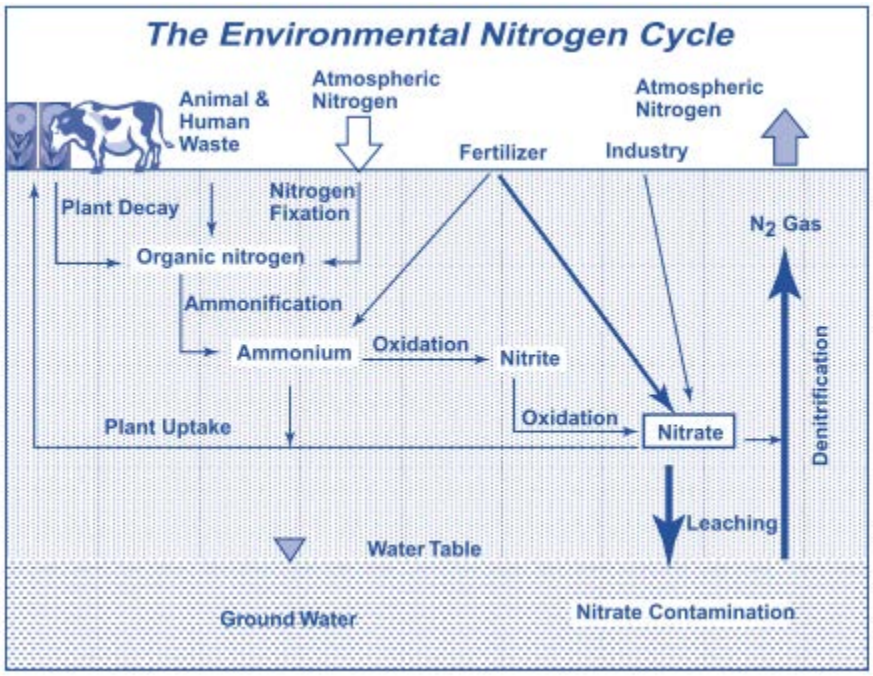
Figure 17. Nitrate Source Fingerprinting.



Mt. View-Denitrification Site

Eric Nuttall, Ph.D.
Emeritus Professor
Chemical/Nuclear Engineering

Figure 18. Nitrogen Cycle.



Denitrification Reaction—greatly simplifed

$$5C + 4NO_3^- + 2H_2O \longrightarrow 2N_2 + 4HCO_3 + CO_2$$

Figure 19. Mt. View Field Site at Holcium's

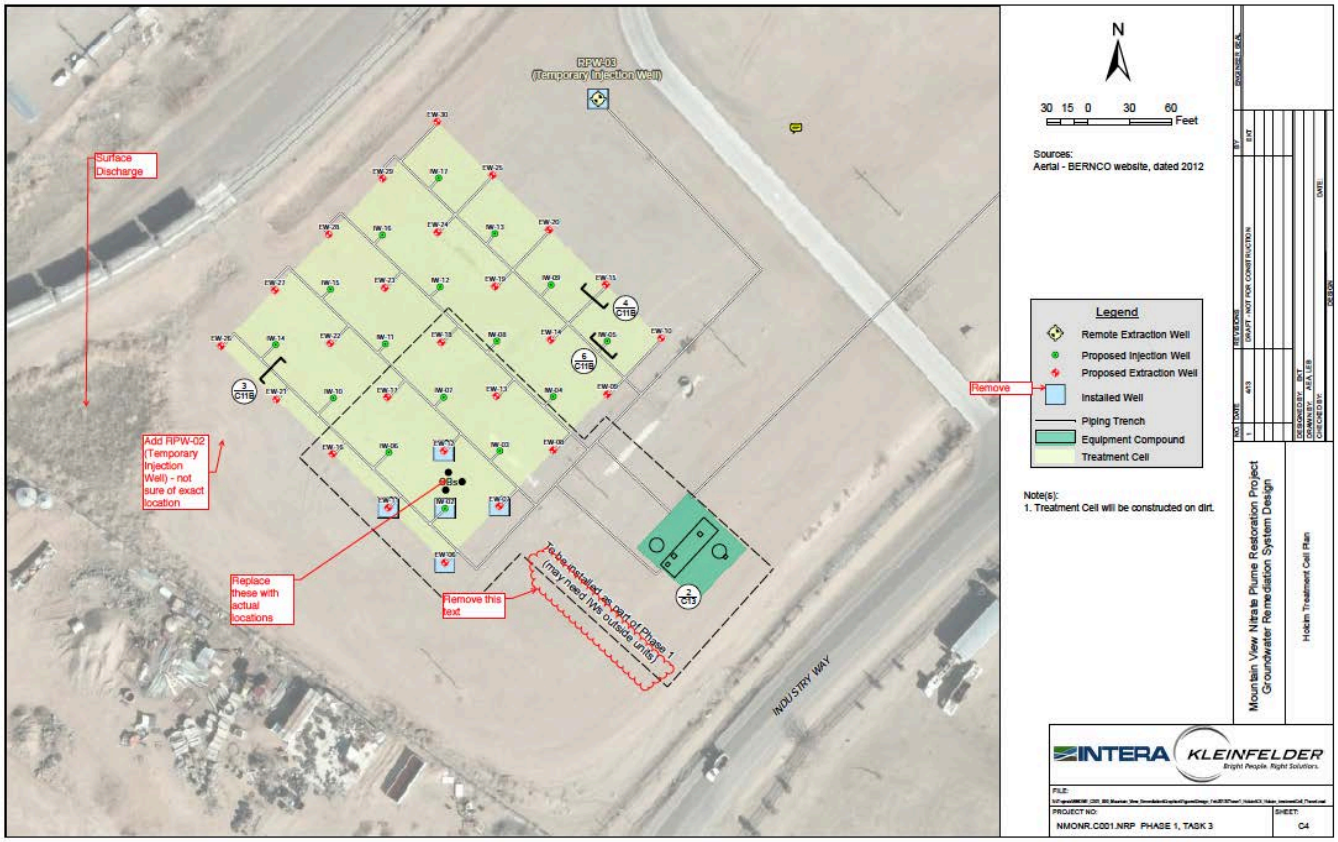


Figure 20. KAFB Fuel Spill Diagram.

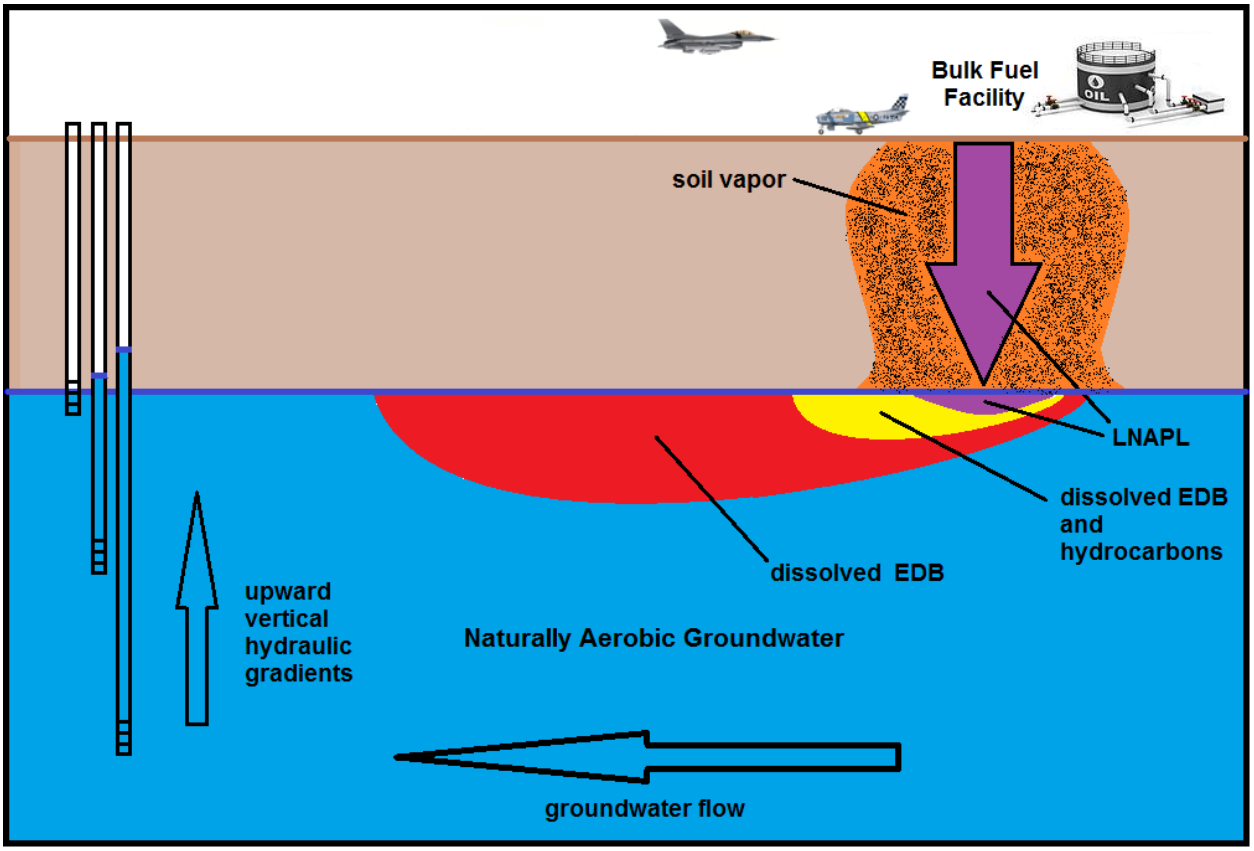


Figure 21. Fuel Recovered by Soil Vapor Extraction, 3.5M pounds, 500,000 gallons.

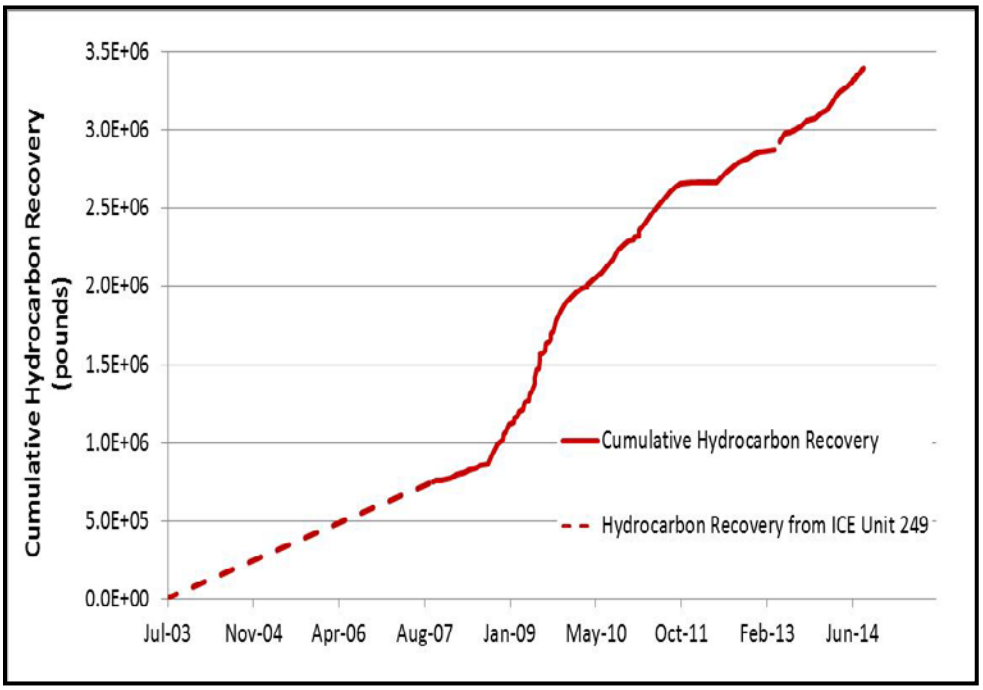


Figure 22. Benzene in Shallow Groundwater. (From CB&I, 2014)

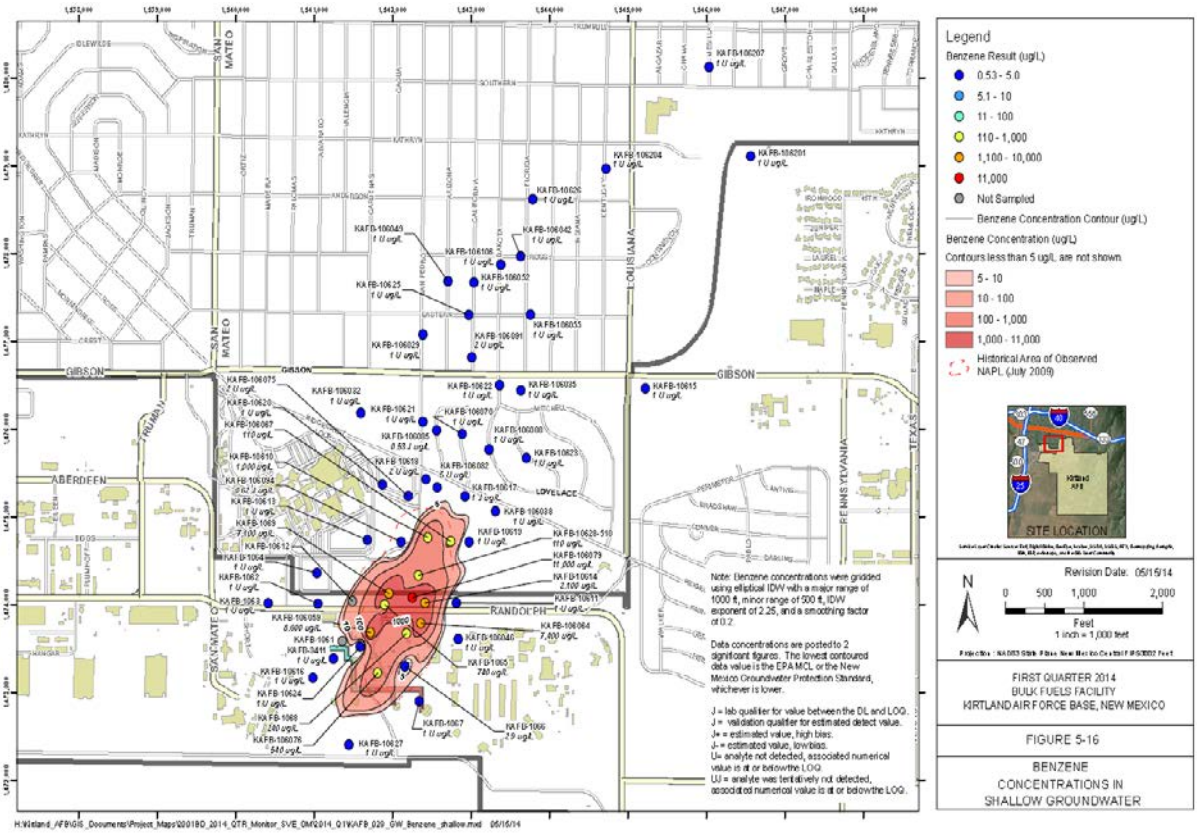


Figure 23. Benzene Versus Total Carbonate Alkalinity/Benzene in the Regional Aquifer. (raw data from CB&I, 2014)

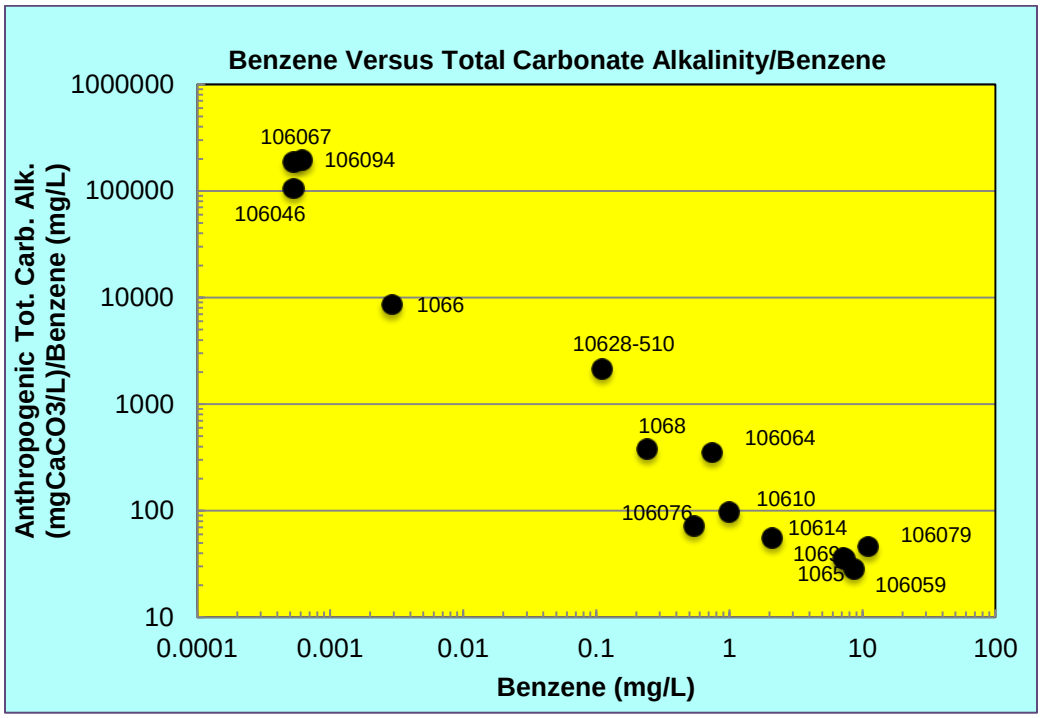


Table 5. Transport Properties of EDB, Benzene, and 1,2-DCA (modified from Falta, 2004)

Property	EDB	Benzene	1,2-DCA
Molecular Weight (g/mol)	187.86	78.11	98.96
Aqueous Solubility (mg/L)	4,321	1,750	8,520
Vapor Pressure (kPa)	1.47	8.00	8.10
Organic Carbon Partition Coefficient, KOC (mL/g)	44.0	83.0	14.0
Henry's Constant (dimensionless)	0.029	0.220	0.050
Groundwater Retardation Coefficient, f_{oc} = 0.001	1.17	1.31	1.05
Gas Phase Retardation Coefficient, Foc = 0.001	46.9	8.20	23.1

[a]Montgomery, 1979; [b]Bedient et al., 1999; [c]Charbeneau, 2000; [d]bulk density = 1.50 g/cm^3, porosity = 0.4; and [f]water saturation = 0.50

Figure 24. Br/Cl(1000) Versus EDB in the Regional Aquifer. (raw data from CB&I, 2014)

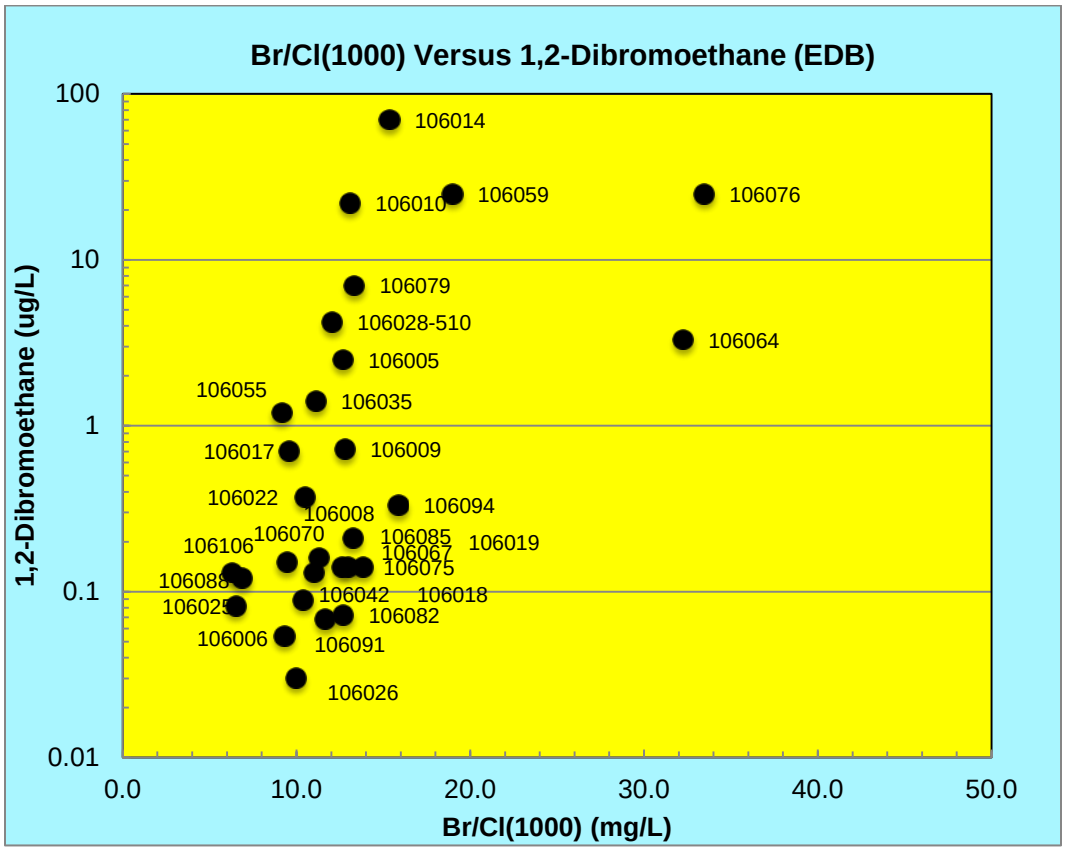


Figure 25. Benzene and EDB in Shallow Groundwater, with Elevated Alkalinity and Bromide. (Modified from CB&I, 2014)

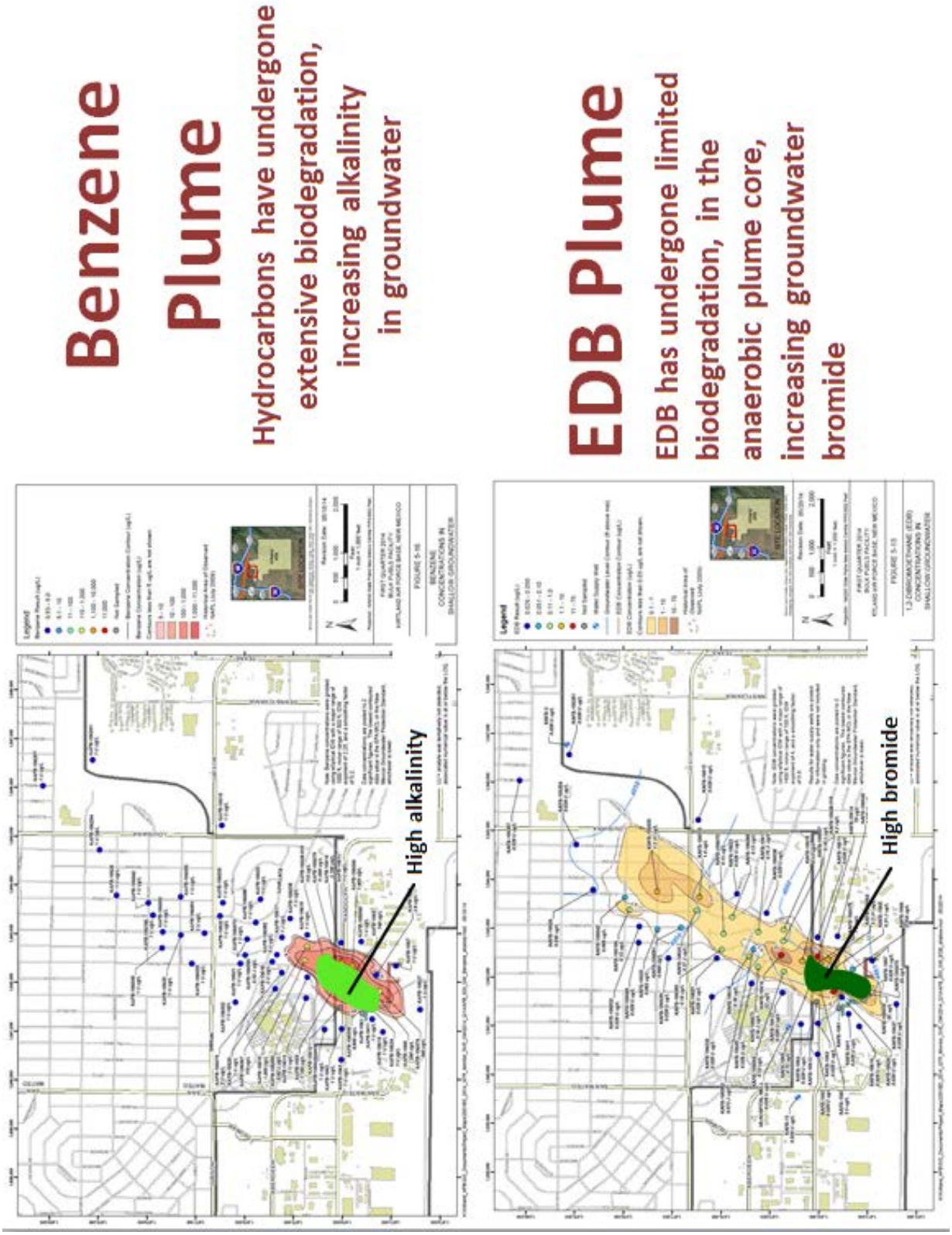


Figure 26. EDB Versus Bromide/EDB in the Regional Aquifer. (raw data from CB&I, 2014)

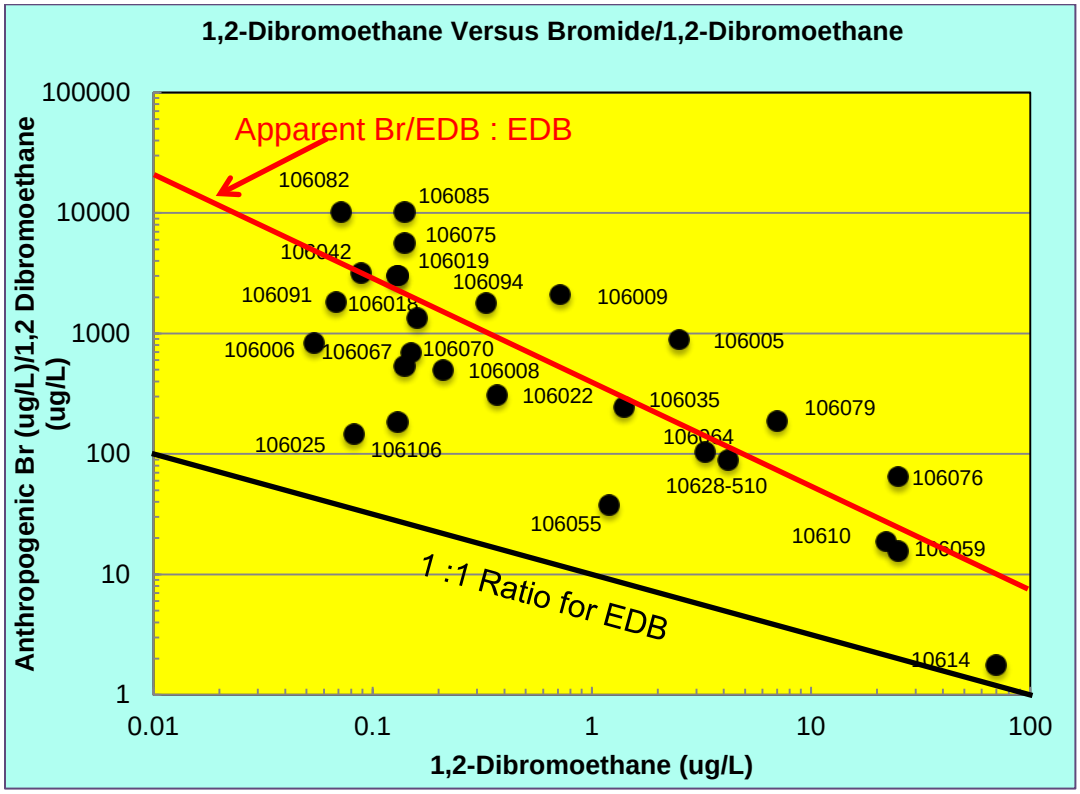


Figure 27. Measured EDB Versus Calculated EDB Reduced in the Regional Aquifer. (raw data from CB&I, 2014)

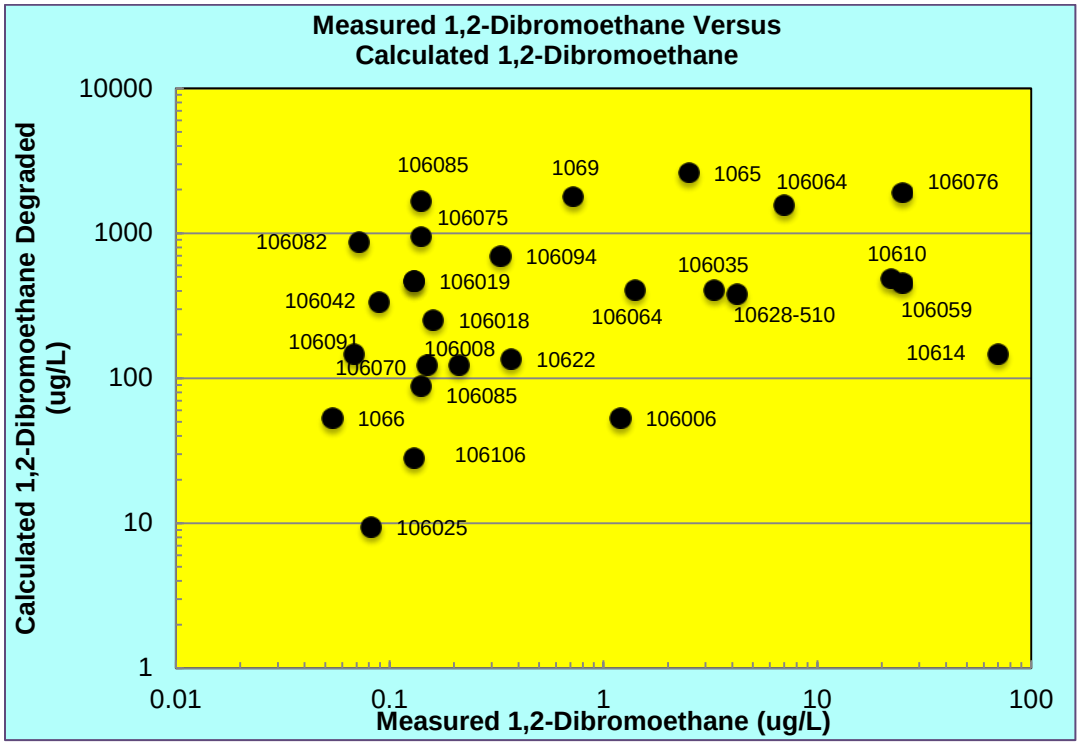


Figure 28. Total Carbonate Alkalinity/Benzene Versus EDB in the Regional Aquifer.
(raw data from CB&I, 2014)

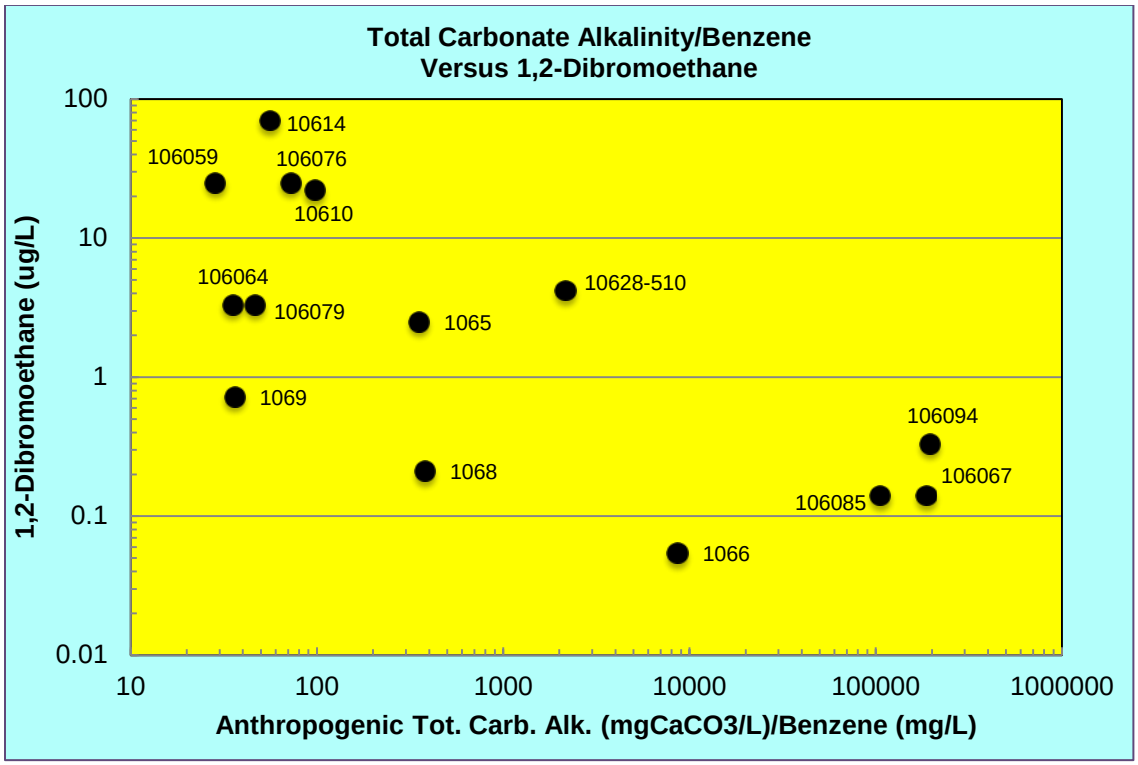


Figure 29. Anthropogenic Total Carbonate Alkalinity Versus EDB in Regional Aquifer.
(raw data from CB&I, 2014)

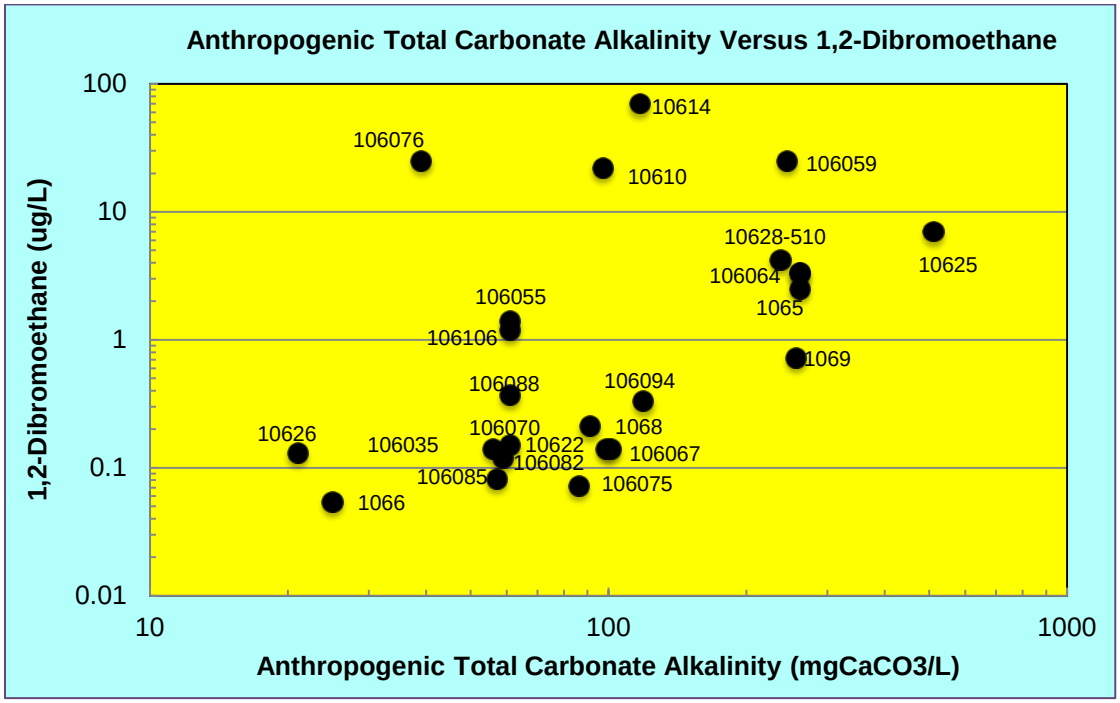


Figure 30. Drill Core with Drowned LNAPL.

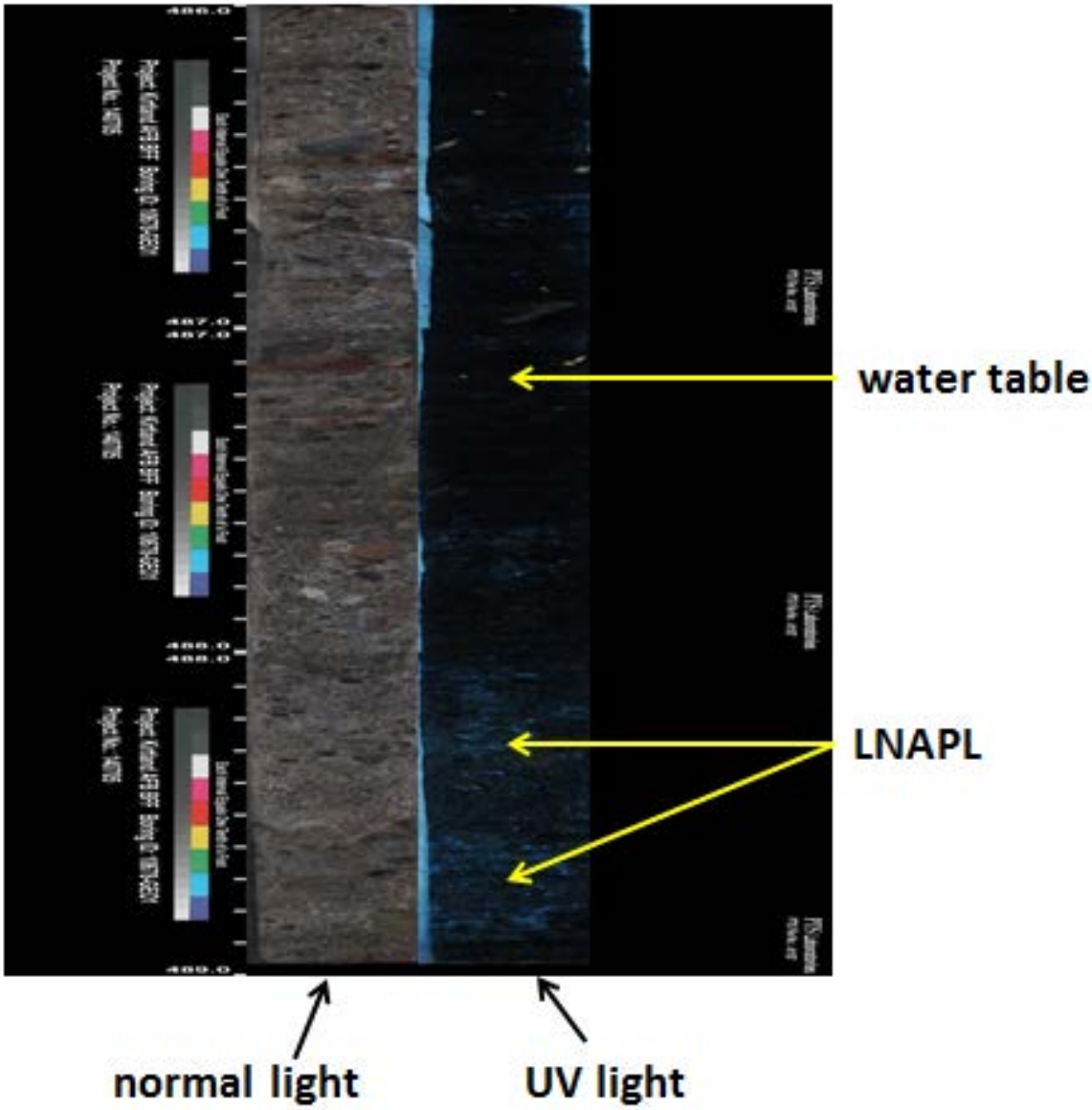
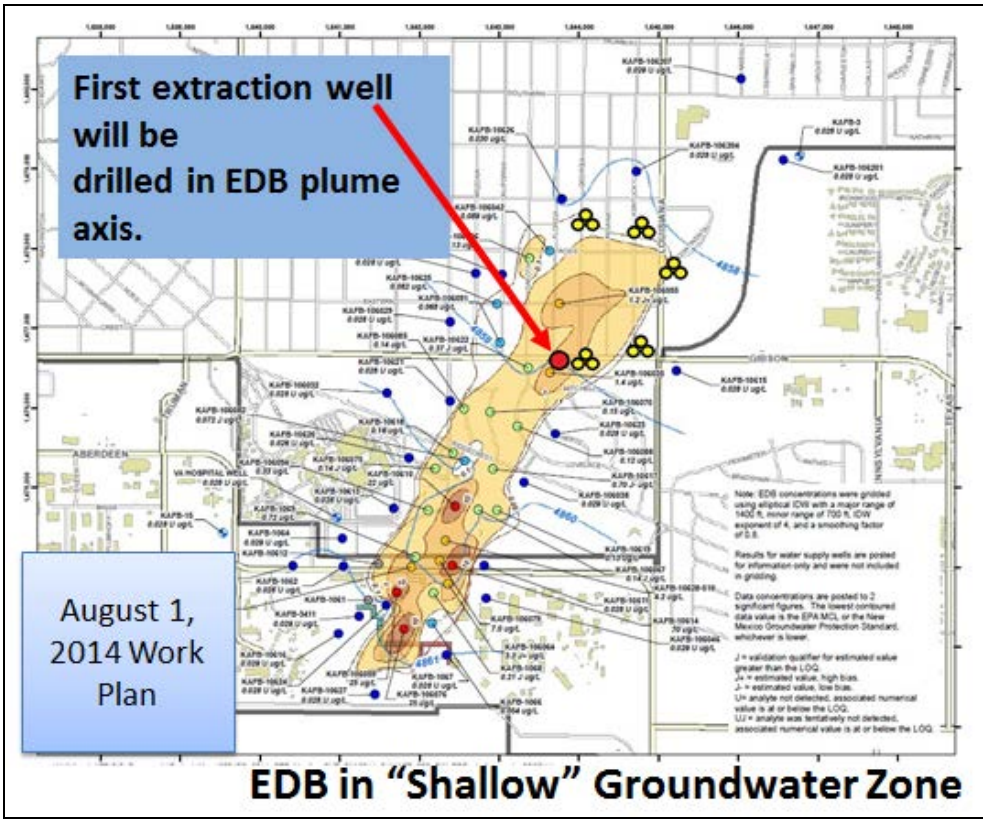


Figure 31. Extraction Well Location in "Shallow" and "Deep" Groundwater Zones.



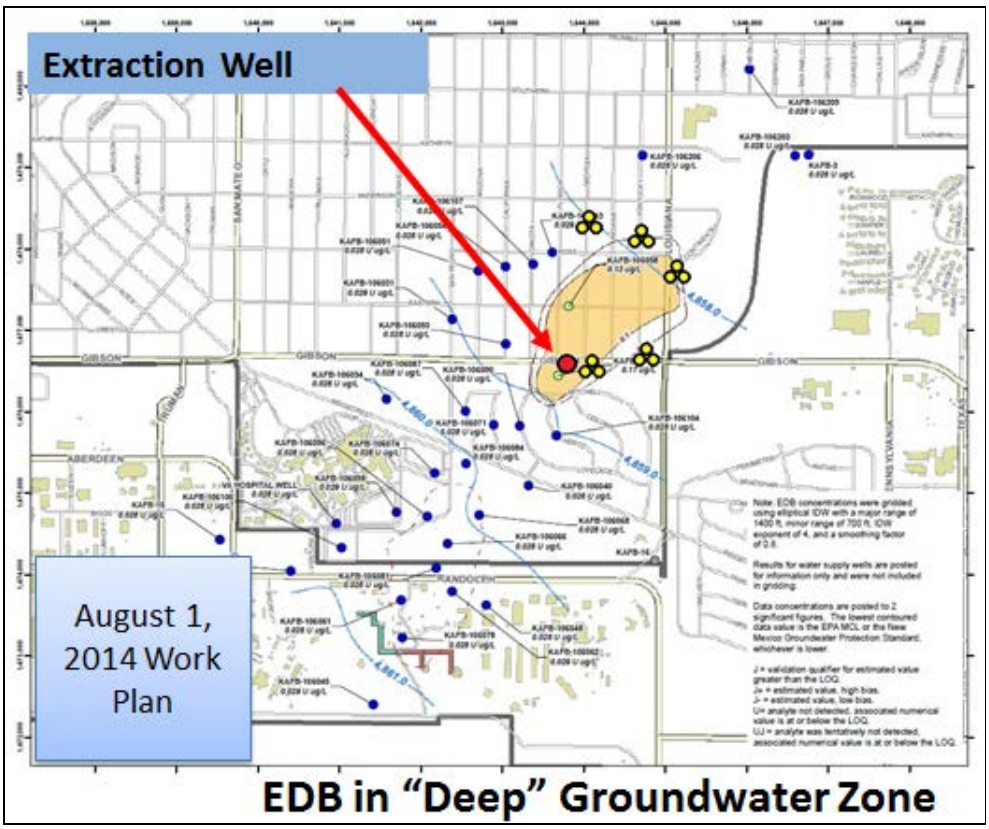


Figure 32. Hypothetical responses of various borehole geophysical tools to alluvial deposits of contrasting texture and saturation and to volcanic rock units.

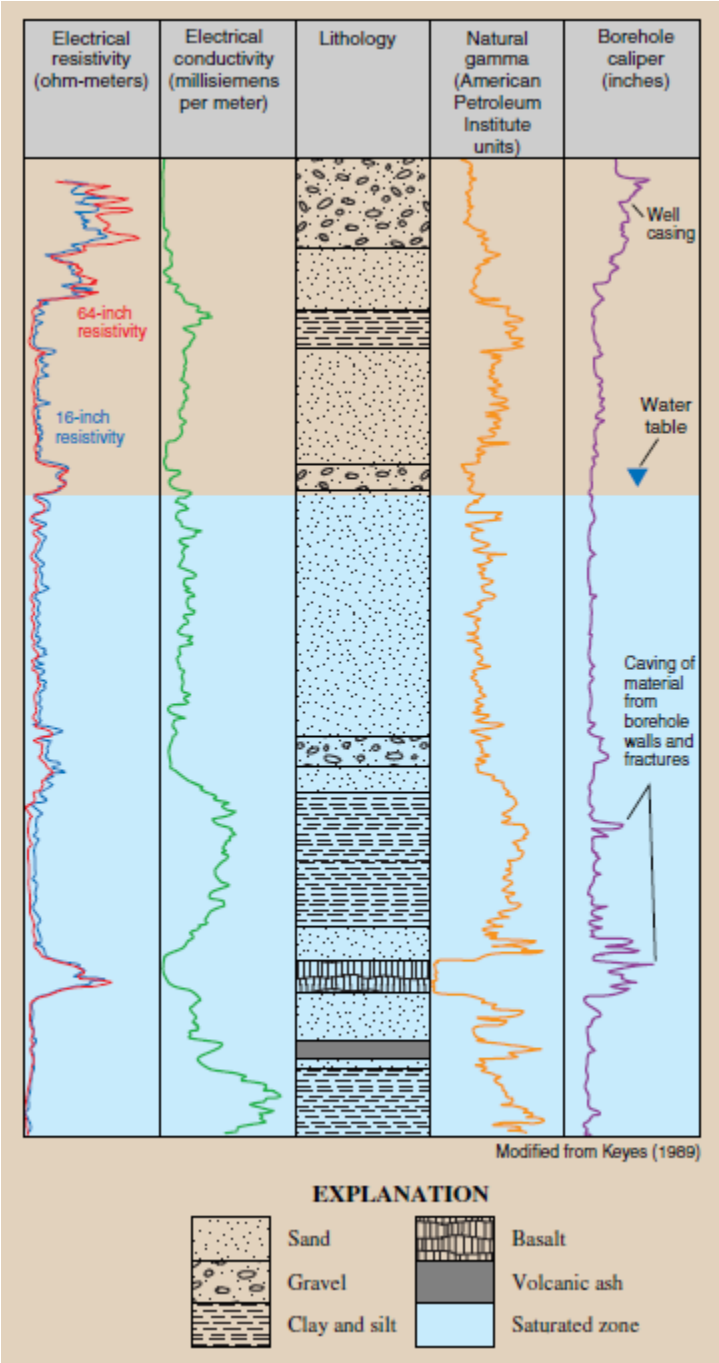


Figure 33. Geophysical Logs for Wells Near the KAFB Fuel Spill. Alluvial fan deposits and the A1 and A2 fine-grained sediment sequences in the Sierra Ladrones Formation are shown.

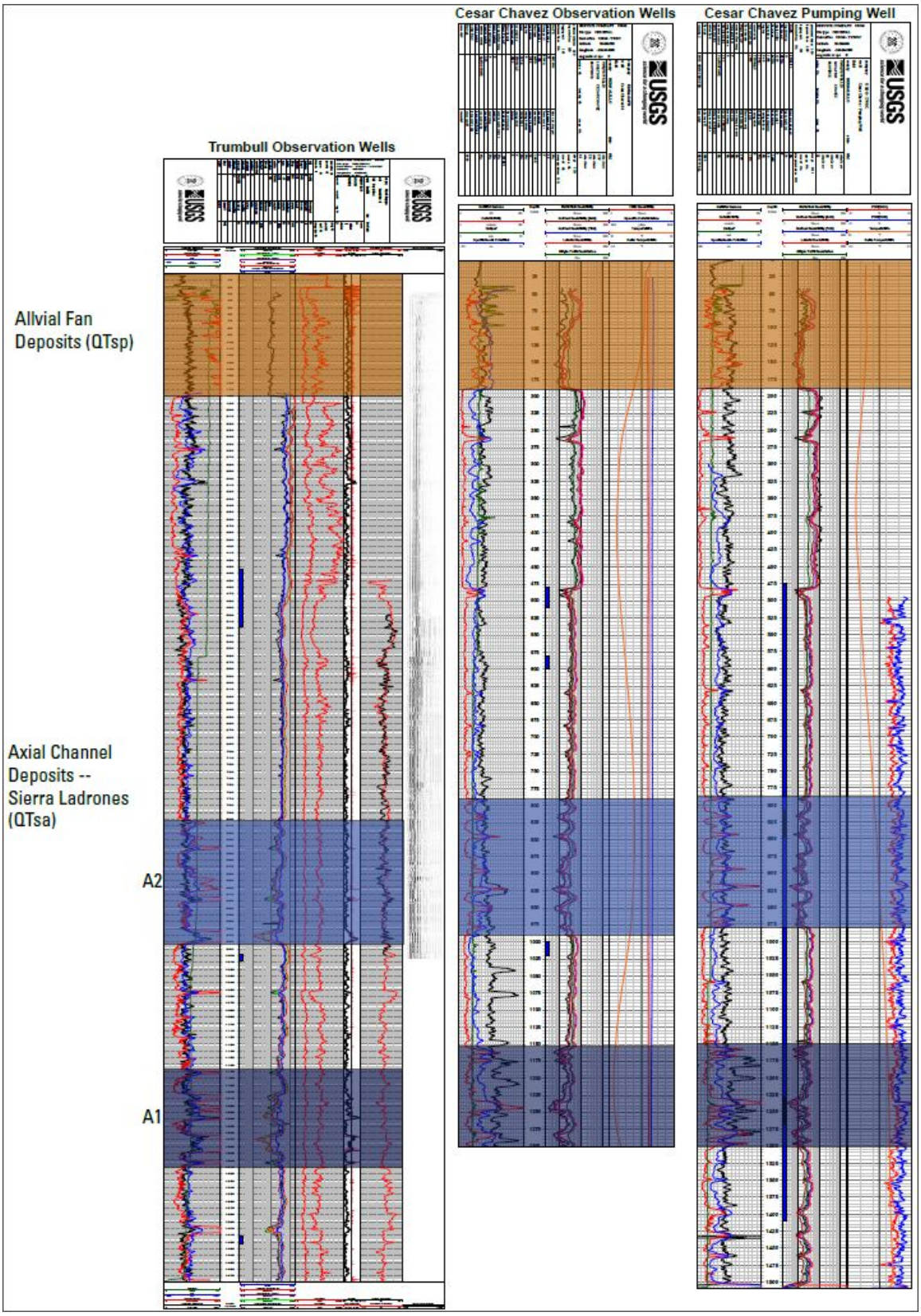


Figure 34. Geophysical Logs for Wells Near the KAFB Fuel Spill. The a1 and a2 fine-grained sediment sequences are shown.

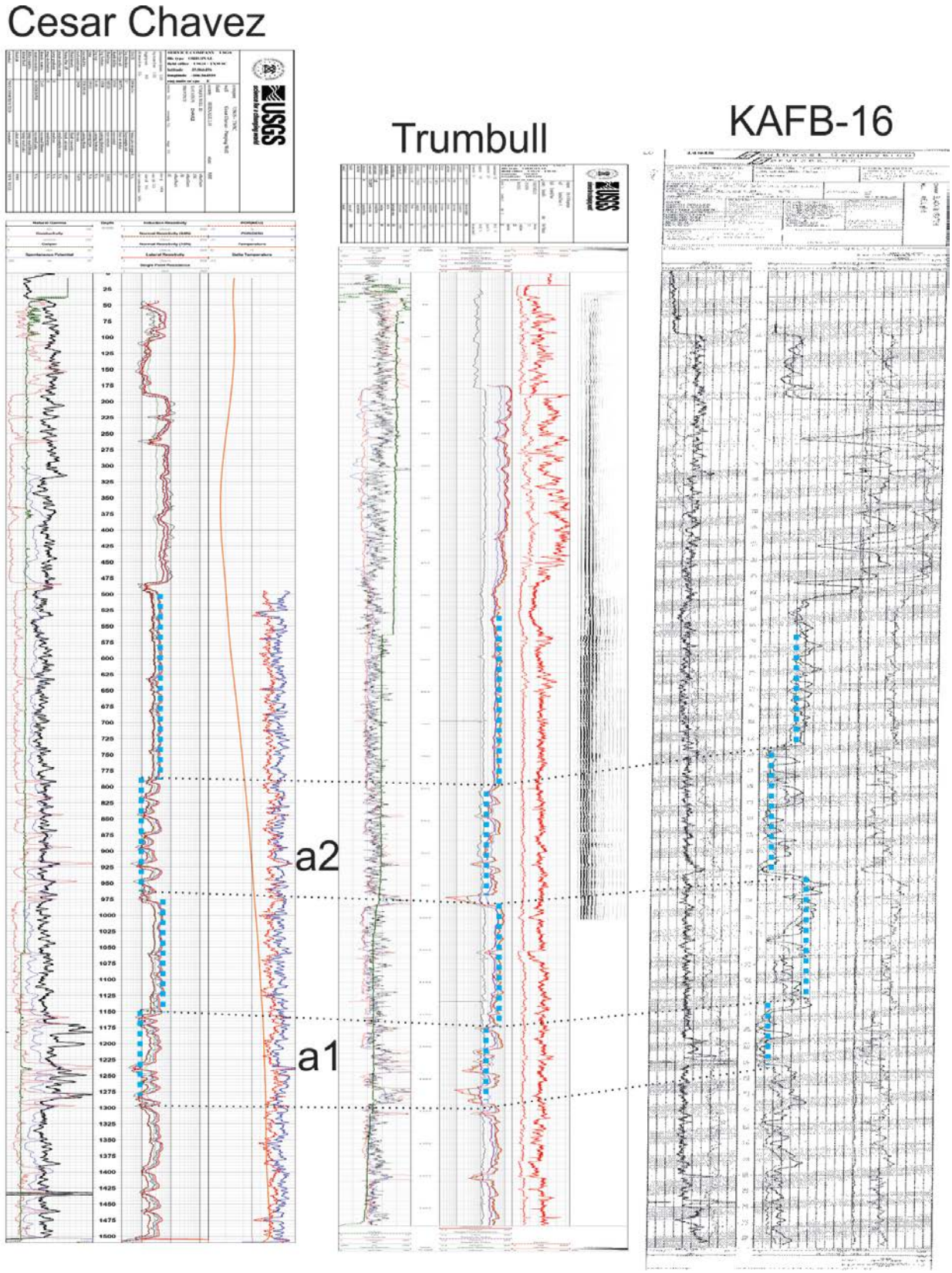
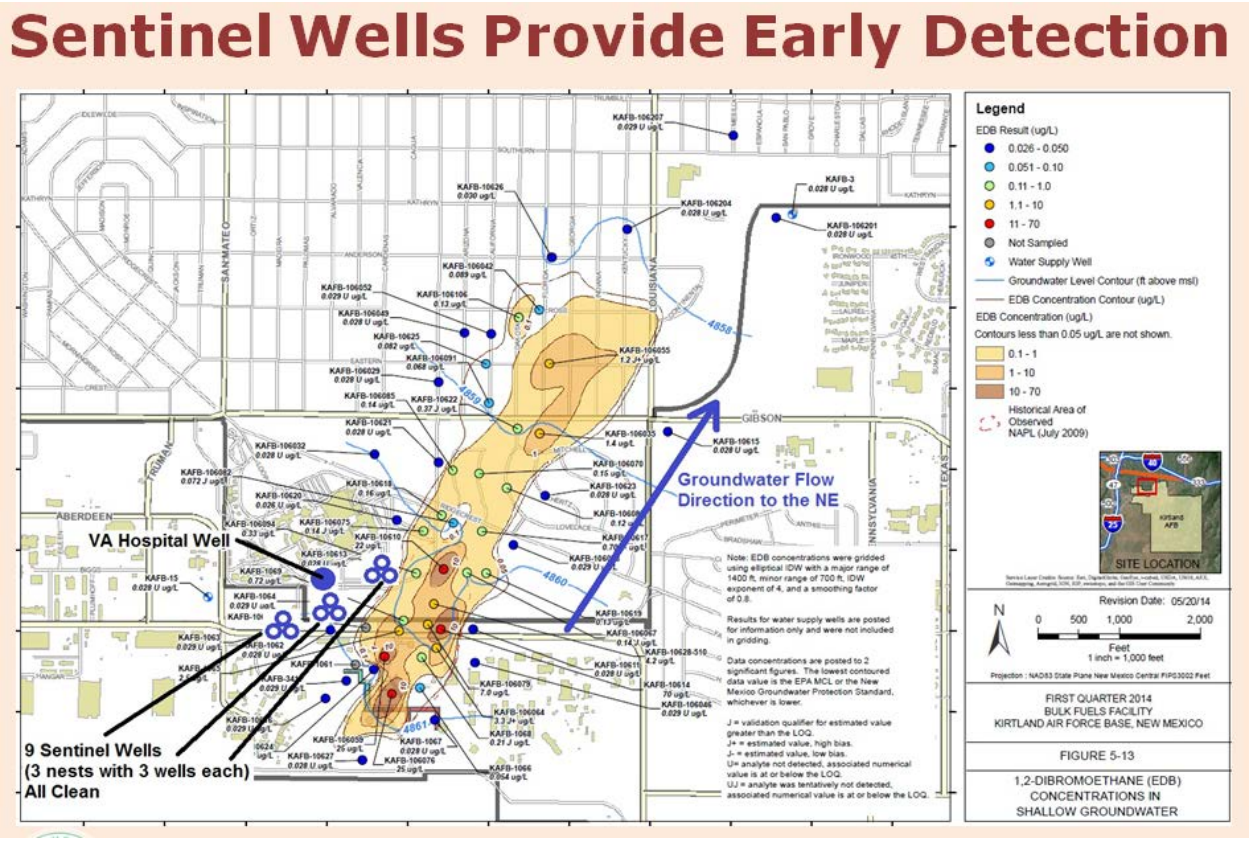


Figure 35. Sentinel Wells near the VA Hospital Well.



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