Kirtland AFB (KAFB) Bulk Fuels Facility (BFF)
Public Field Trip Handout
April 18, 2015

Introduction – Leakage of aviation gasoline and jet fuel from the Kirtland AFB bulk fuel facility (BFF) 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 Tijeras Arroyo, and visit the actual fuel spill site where soil vapor extraction has removed 500,000 gallons of fuel since 2003. Geologists and water professionals from the N.M. Environment Department, the U.S. Air Force, the Albuquerque Bernalillo County Water Utility Authority (ABCWUA), the U.S. Geological Survey, the N.M. Bureau of Geology, CB&I and INTERA Inc. will be available for questions and discussion.

Logistics – Transportation in a motor coach, departing from the Chavez Community Center, will be provided for those who registered by the March 27, 2015 deadline. You can also drive your own vehicle to visit Stop 1 only, but you must be on the bus to enter the base.

You will need photo-identification to enter the base. Also bring sunscreen, a hat, drinking water, a bag lunch, hiking boots, layers of clothing appropriate for spring 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

9:45 a.m. to 10:00 a.m. – Gather at the Chavez Community Center parking lot (south of the building), 7505 Kathryn Ave. SE, to check in and board the bus. The bus will depart at 10:00 a.m., sharp.

10:00 a.m. to 10:30 a.m. – The bus will drive through and pull off the road at the San Jose Superfund site and the Mountainview nitrate contamination site. Participants will not disembark from the bus, but NMED will explain the site histories.

10:30 a.m. to 1:15 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 stratigraphy (Dan Koning, NMBG)
- Regional hydrogeology (Nathan Myers, USGS)
- ABCWUA water resources portfolio (Rick Shean, ABCWUA)
- Regional groundwater chemistry and contamination (Dennis McQuillan, NMED)
- Microbiology and reactive minerals (Dr. Adria Bodour, USAF)
- *In situ* bio-denitrification, Mountainview pilot project (Dr. Eric Nuttall, UNM Emeritus).

1:45 p.m. to 2:30 p.m., enter Kirtland Air Force Base
Stop 2 – Coarse-grained alluvial fan deposits near wooden trestle. Discussion topics:

- Local stratigraphy (John Gillespie, USAF)
- Sequenced stratigraphy (Tom Champion and Colin Plank, AECOM)
- Local hydrogeology (Dr. John Sigda, INTERA)

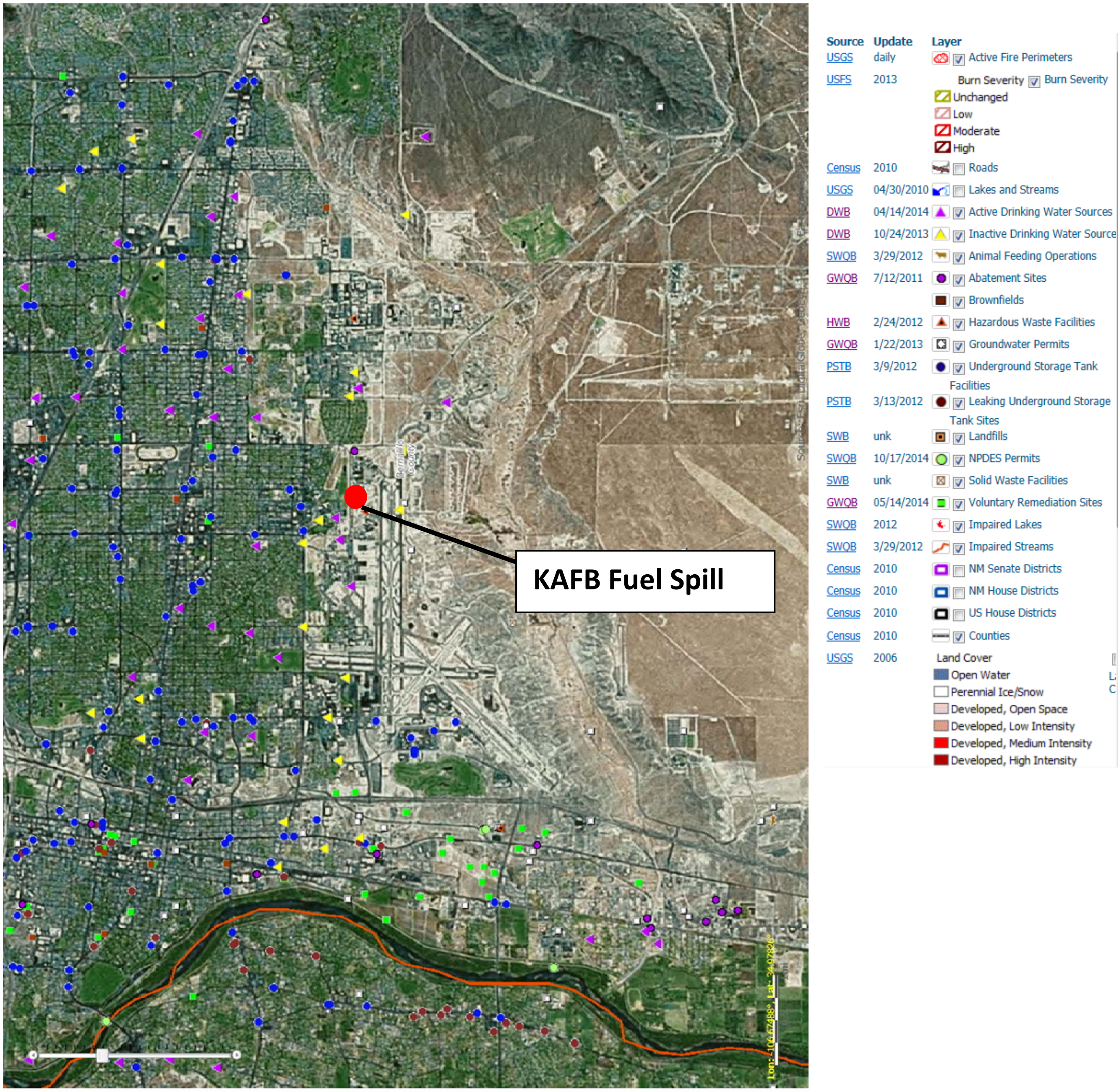
2:45 p.m. – 3:45 p.m.
Stop 3 – Kirtland Air Force Base (KAFB) Remediation Technologies Discussion topics:

- KAFB BFF and history of spill (Wayne Bitner, USAF)
- Soil Vapor Extraction treatment units and monitoring well (Diane Agnew, CB&I)
- Intrinsic biodegradation of hydrocarbons and EDB (Dr. Patrick Longmire, NMED)
- Collapsing the EDB plume and groundwater contamination footprint (Dr. Adria Bodour, USAF and Jason Tarbert, CB&I)
- Protection of water-supply wells (Dennis McQuillan, NMED and Rick Shean, ABCWUA)
- Groundwater "ant farm" model (Shannon McQuillan and Mallika Singh, ATC School)

4:00 p.m. – Return to Chavez Center

Figure 1. Map of Kirtland AFB Restoration Team Geologic Field Trip Locations

Figure 2. 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/)



Kirtland Air Force Base (KAFB)
Bulk Fuels Facility (BFF)
Public Field Trip

WINDOW STOP - Legacy contamination in Albuquerque South Valley

Understanding what has worked in the past will help address contamination at the Bulk Fuels Facility

Speaker:

Dennis McQuillan, New Mexico Environment Department

WINDOW STOP A – ALBUQUERQUE SOUTH VALLEY SUPERFUND SITE

(Dennis McQuillan, New Mexico Environment Department [NMED])

The City of Albuquerque developed a well field in the San José community in the 1940s, at which time land use in the area was agricultural and residential. Industrial development occurred in the 1950s-60s with the construction of manufacturing plants and petroleum product pipelines and storage tanks. In 1980, two San José municipal wells were shut down due to contamination with chlorinated solvents. Investigations revealed extensive groundwater contamination in the area with both chlorinated solvents and petroleum hydrocarbons originating from multiple sources. Clean up of petroleum contamination, including light non-aqueous phase liquid (LNAPL) floating on the water table, was done under the authority of N.M. Water Quality Control Commission Regulations and is nearly complete. Petroleum cleanup technologies include LNAPL recovery, air sparging, soil vapor extraction, bioventing, pump and treat, and monitored natural attenuation. Pump and treat cleanup of chlorinated solvents is ongoing under federal Superfund authority using air stripping and granular activated carbon treatment followed by re-injection.

EPA Superfund Site Status Report

http://www.epa.gov/earth1r6/6sf/pdffiles/south-valley-nm.pdf

NOTES:

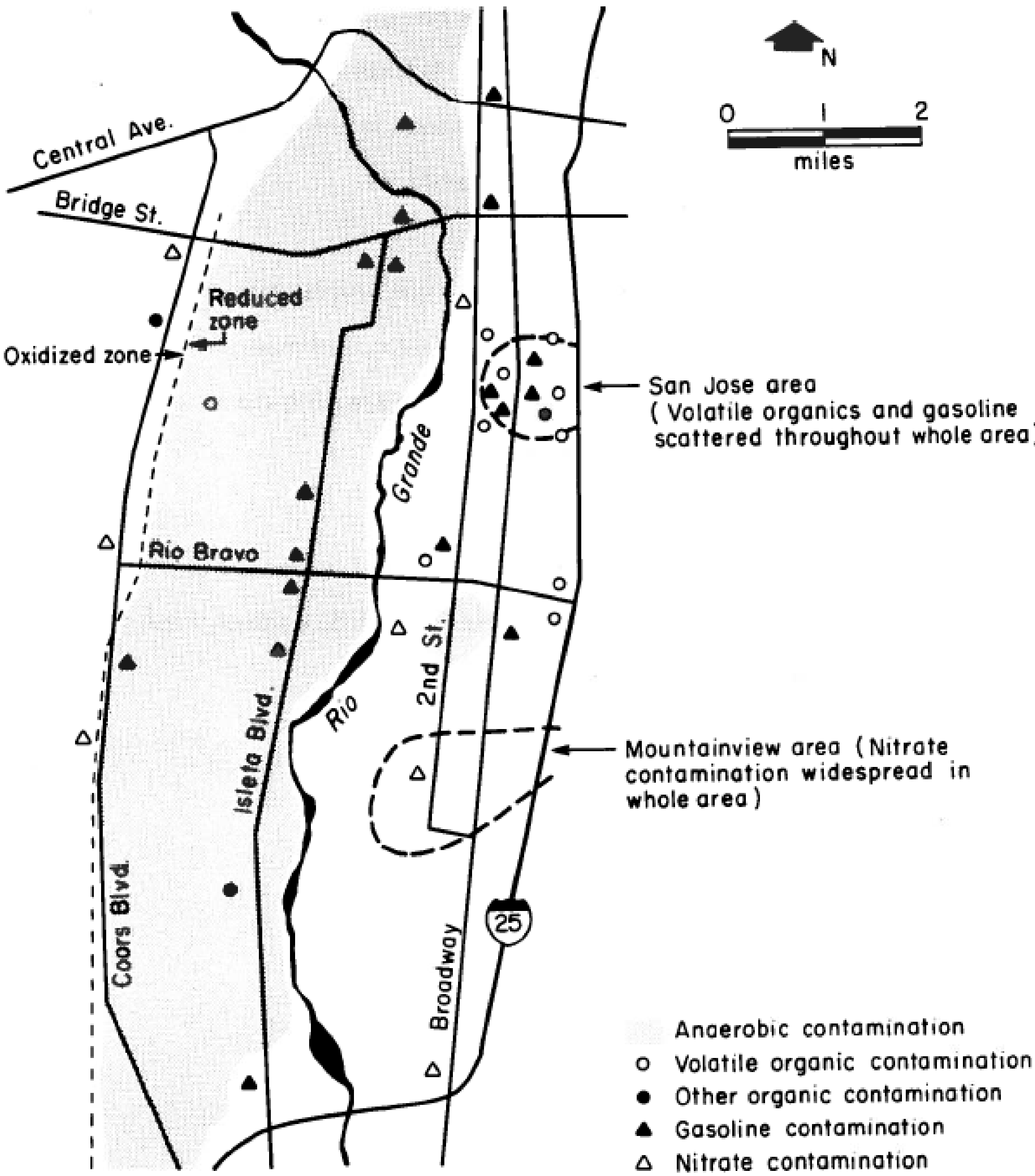
WINDOW STOP B – MOUNTAINVIEW NITRATE CONTAMINATION

(Dennis McQuillan, New Mexico Environment Department [NMED])

Samples collected by the U.S. Geological Survey from wells in Tijeras Arroyo (Montessa Park) and in Hells Canyon on Isleta Pueblo in the 1950s contained very high levels of nitrate (100+ mg/L nitrate as N) with low chloride concentrations. After an infant living in Carnuel was treated for methemoglobinemia (Blue Baby Syndrome) in 1961, the U.S. Geological Survey sampled water supply wells along the Tijeras watercourse from Carnuel in Tijeras Canyon down into the Mountainview community in the South Valley. Widespread nitrate contamination was discovered in the Mountainview community with concentrations in the range of several 100 mg/L as N. Public health officials with the state, county and city continued to monitor nitrate concentrations in Mountainview well water and documented a southward migration of the highest nitrate levels. In 1980 another non-fatal case of the Blue Baby Syndrome occurred in Mountainview, resulting in state legislation and funding to extend water and sewer lines south along Second Street to serve the residential Mountainview area. Investigations revealed multiple sources of nitrate. Tijeras Canyon nitrate was largely caused by onsite wastewater systems. Evaporative concentration of atmospheric deposition was largely responsible for the high nitrate and low chloride contamination in the Arroyo area between the mountain front and inner valley. The extraordinarily high nitrate levels in Mountainview were caused by over-fertilization at a former vegetable farm that was located in the area northeast of the intersection of Tijeras Arroyo and Second Street. Efforts to clean up the nitrate contamination using an enhanced in-situ anaerobic bioremediation (denitrification) process are ongoing (see Nuttall, this guidebook).

NOTES:

Figure 3. Groundwater Contamination in the Albuquerque South Valley, 1987
(Gallaher et al., 1987)



Kirtland Air Force Base (KAFB)
Bulk Fuels Facility (BFF)
Public Field Trip

STOP 1 - Regional Foundations

Understanding geology and hydrogeology on a basin scale

Speakers:

Dan Koning, New Mexico Bureau of Geology

Nathan Myers, U.S. Geological Survey

Rick Shean, Albuquerque Bernalillo County Water Utility Authority

Dennis McQuillan, New Mexico Environment Department

Dr. Adria Bodour, U.S. Air Force

Dr. Eric Nuttall, University of New Mexico Emeritus

Figure 4. Montessa Park, Off Road Vehicle Area, Los Picaros Road

STOP 1 – REGIONAL STRATIGRAPHY

(Dan Koning, New Mexico Bureau of Geology (NMBG))

The Albuquerque basin near the Kirtland Air Force Base consists of 9,500-10,000 ft of basin-fill sediment that overlies more cemented and less permeable, older sedimentary rocks. The fuel spill lies at ~500 ft depth in sand, gravelly sand, and silty-clayey fine sand (axial deposits of Sierra Ladrones Formation) that were laid down by a south- to southwest-flowing ancestral Rio Grande 1-3 million years ago. Eastward, these deposits interfinger with sand, gravelly sand, and minor silt-clay (eastern piedmont deposits of the Sierra Ladrones Formation) deposited on a west-sloping alluvial fan at the mouth of Tijeras Arroyo. The west end of this alluvial fan shifted westward since 2 million years ago and overlies the axial deposits at the fuel spill site.

NOTES:

Figure 5. Generalized Block Diagram of the Middle Rio Grande Basin in Albuquerque Modified from Bjorklund and Maxwell (1961). Note that the subsurface model has been updated by Grauch and Connell (2013), which is shown in the next figure.

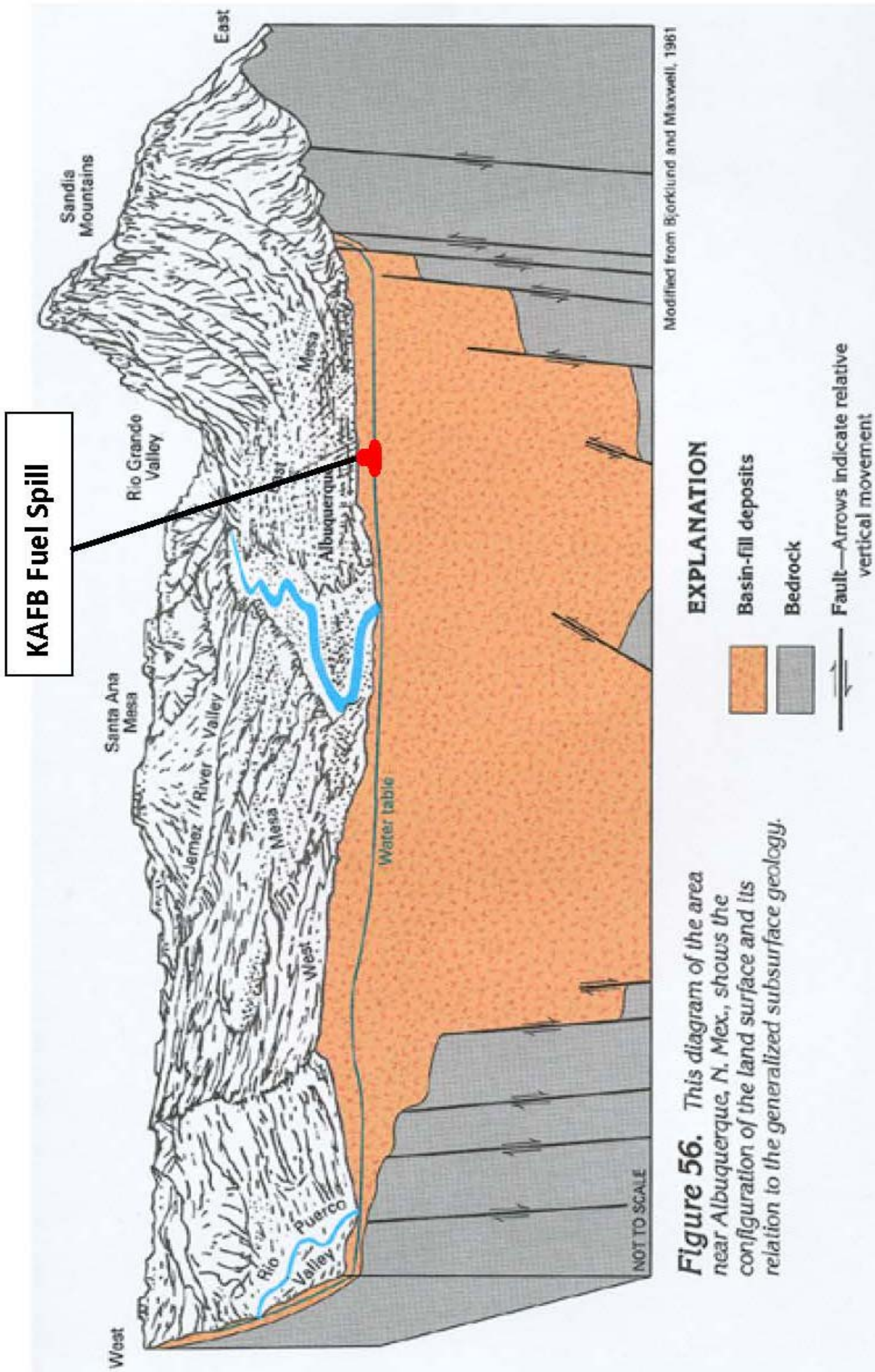
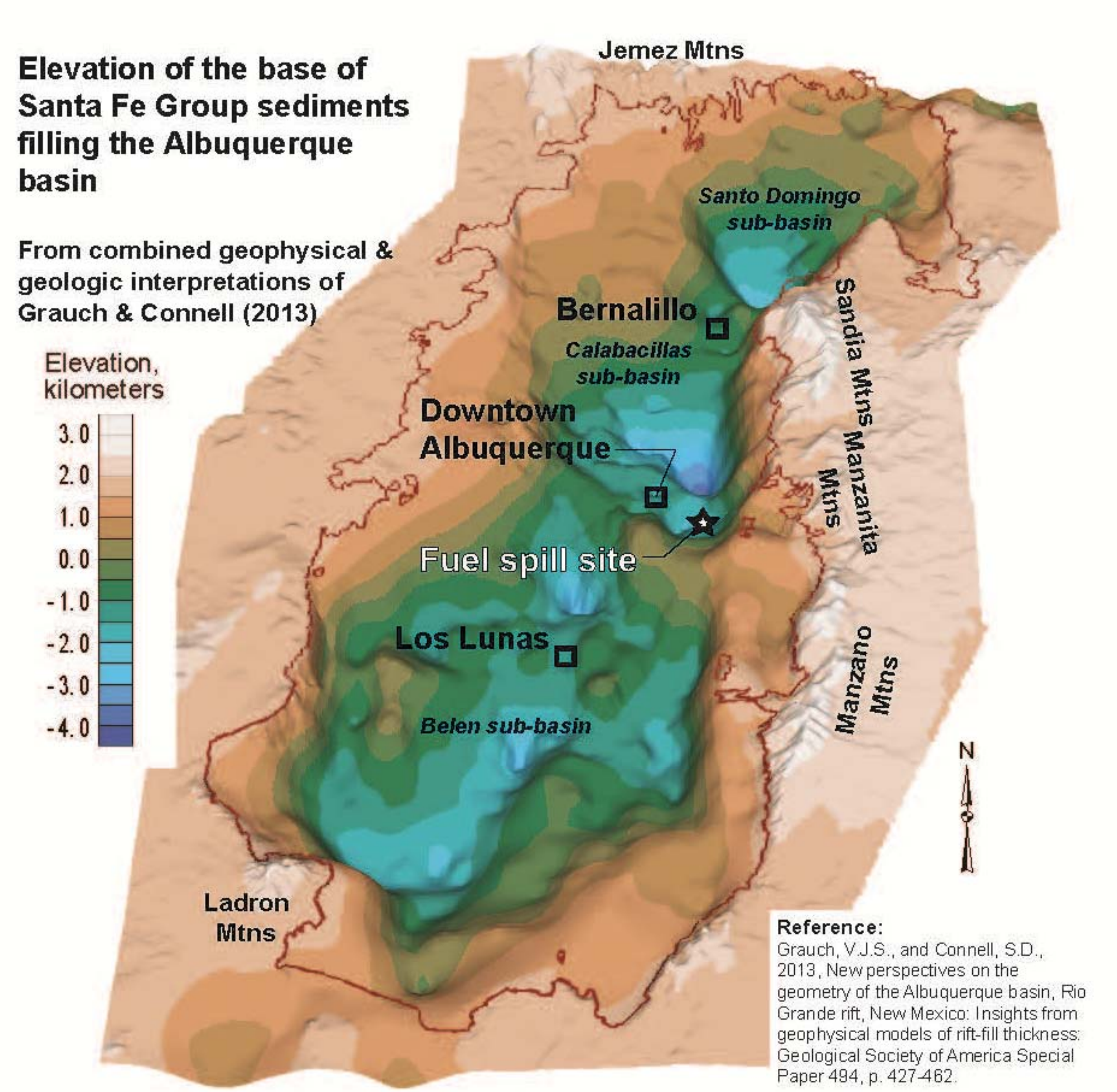
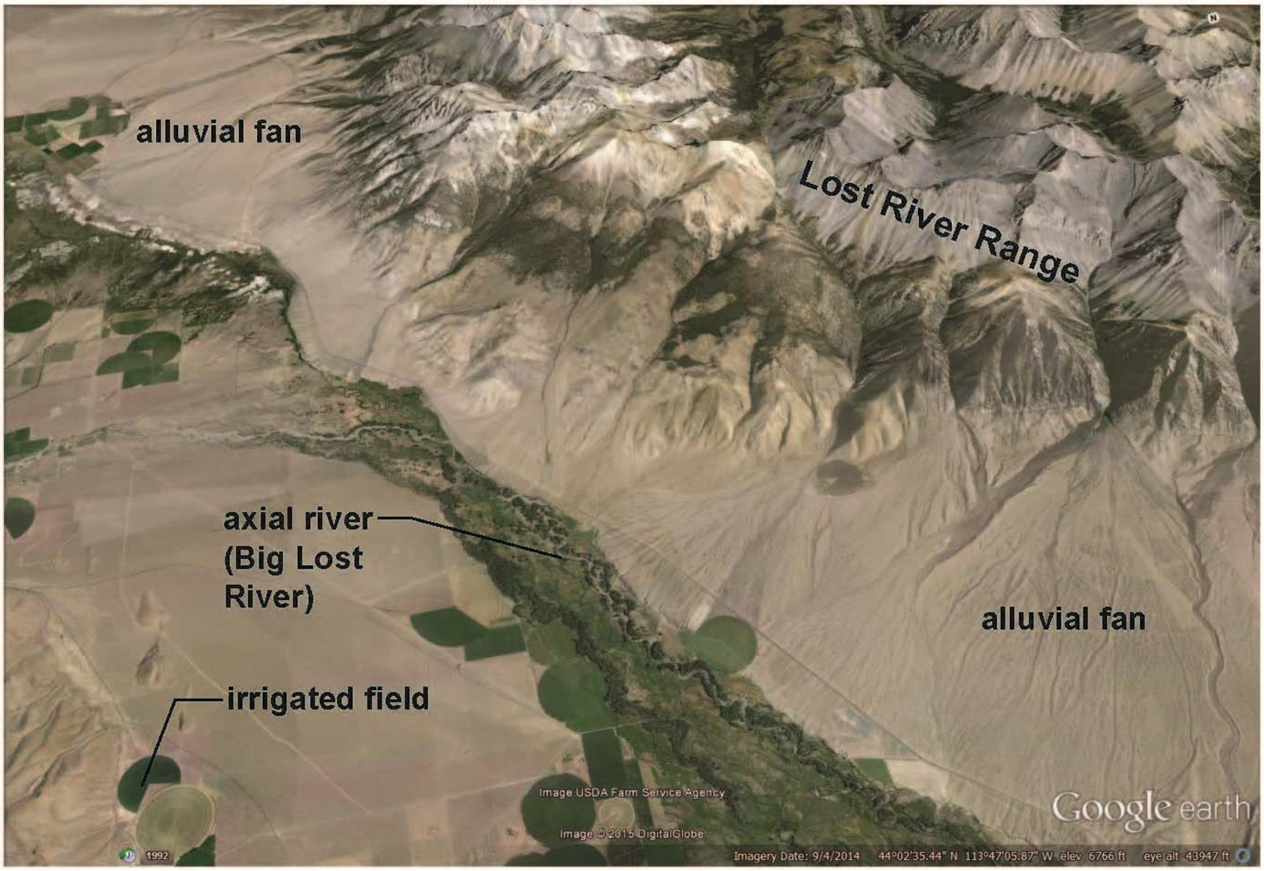


Figure 6. 3-D Perspective of the Base of the Santa Fe Group, Albuquerque Basin



The Albuquerque basin was formed over the past 30 million years by fault-controlled subsidence and tilting of the Earth's crust. Between Albuquerque and Bernalillo, the biggest faults lie close to the base of the Sandia Mountains (near Eubank Avenue) and trend north-south. As the Earth's crust sank down, the resulting low area on the surface was continually filled in by sediment. This sand, silt, clay, and gravel was brought in by a south-flowing, ancestral Rio Grande and also deposited by streams and rivers sourced in the surrounding highlands. This sediment is generally less cemented and more permeable than older (pre-30 million year old) rocks and is called the Santa Fe Group. The above image shows an up-to-date model of the elevation of the base of the Santa Fe Group. Note that the Calabacillas sub-basin, located just north of the fuel spill site, is where the Santa Fe Group attains its greatest thickness (~18,000 ft). The fuel spill site lies at the very top of this thick pile of basin-fill sediment at a depth of ~500 ft, which is interpreted to be 2 to 3 million years old.

Figure 7. A Modern-Day Example of an Axial River Flanked by Alluvial Fans



The above Google Earth image is of part of the Big Lost River Valley in Idaho. Note the two different sets of drainages: 1) an axial river flowing to the south-southeast, and 2) steeper-sloped alluvial fans deposited episodically by smaller streams sourced in the adjacent Lost River Range. A similar situation existed when Santa Fe Group sediment was deposited 2-3 million years ago, but the pattern of the axial river was different (braided, as shown in the next figure).

Figure 8. Photograph of a Braided Stream Near Deadhorse, Alaska This is interpreted to be similar to the nature of the ancestral Rio Grande during 2 to 3 million years ago, when the river sediment at ~500 ft depth was deposited. (Lunt et al., 2004)

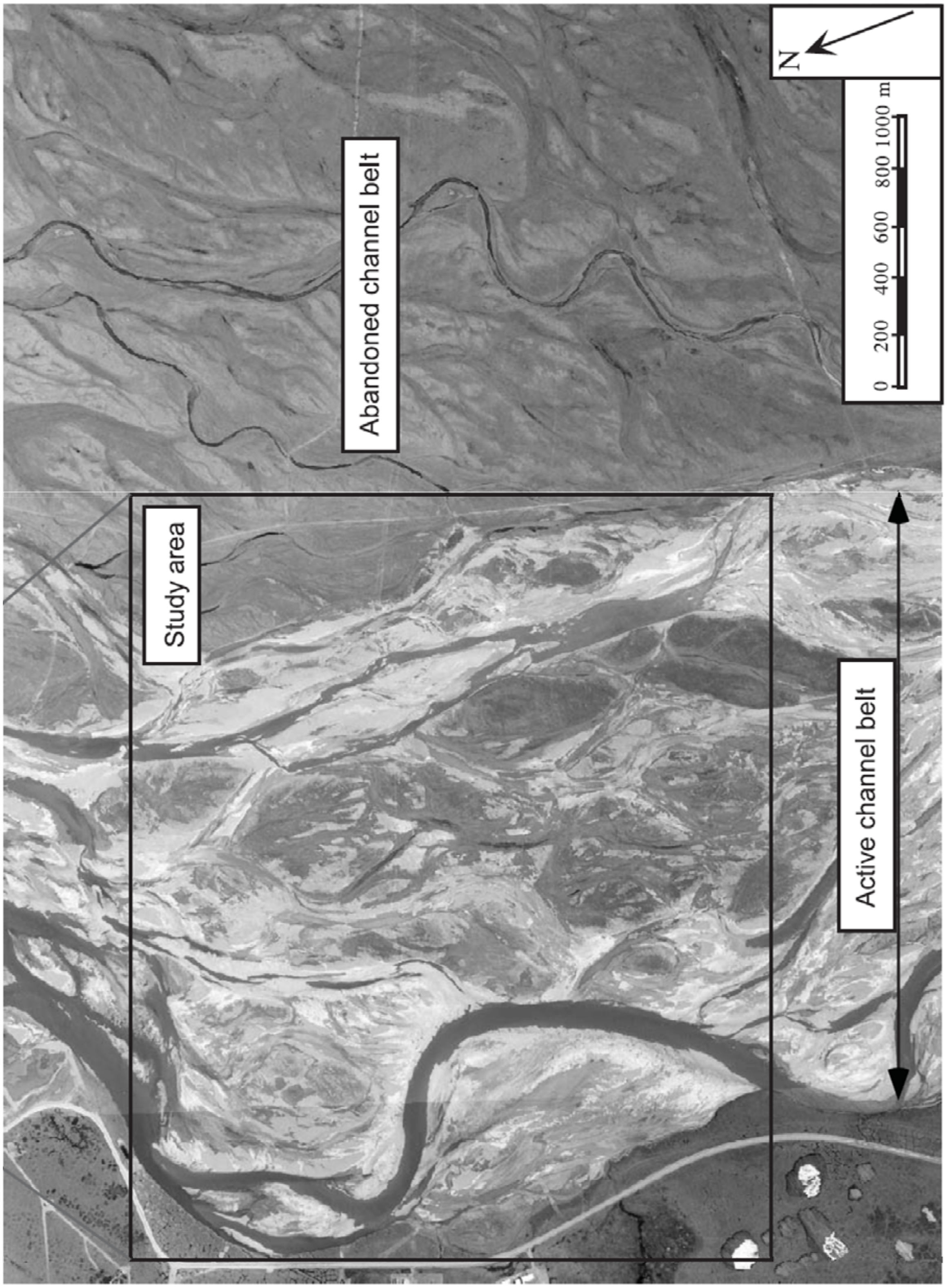


Figure 9. Inferred Lateral Extent of Major Lithostratographic Units During the Pliocene in Middle Rio Grande Basin, Central New Mexico (Slightly modified from Plummer et al. 2004, and Connell et al., 1999). The Ceja Formation on the west was deposited by the Rio Puerco and streams draining the southern Jemez Mountains.

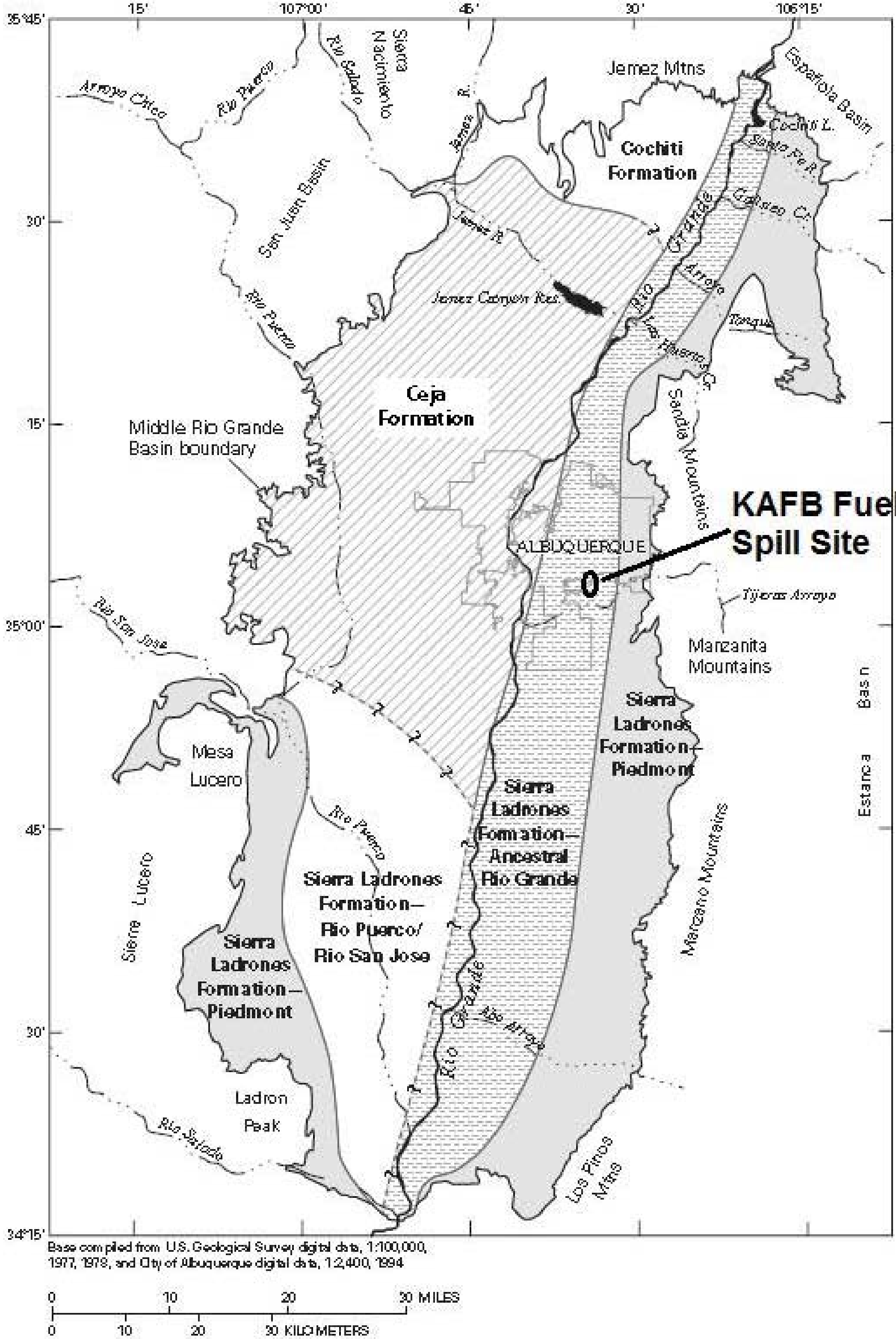


Figure 10. Geologic Map and Cross-Section, Southeastern Albuquerque (Connell, 2008)

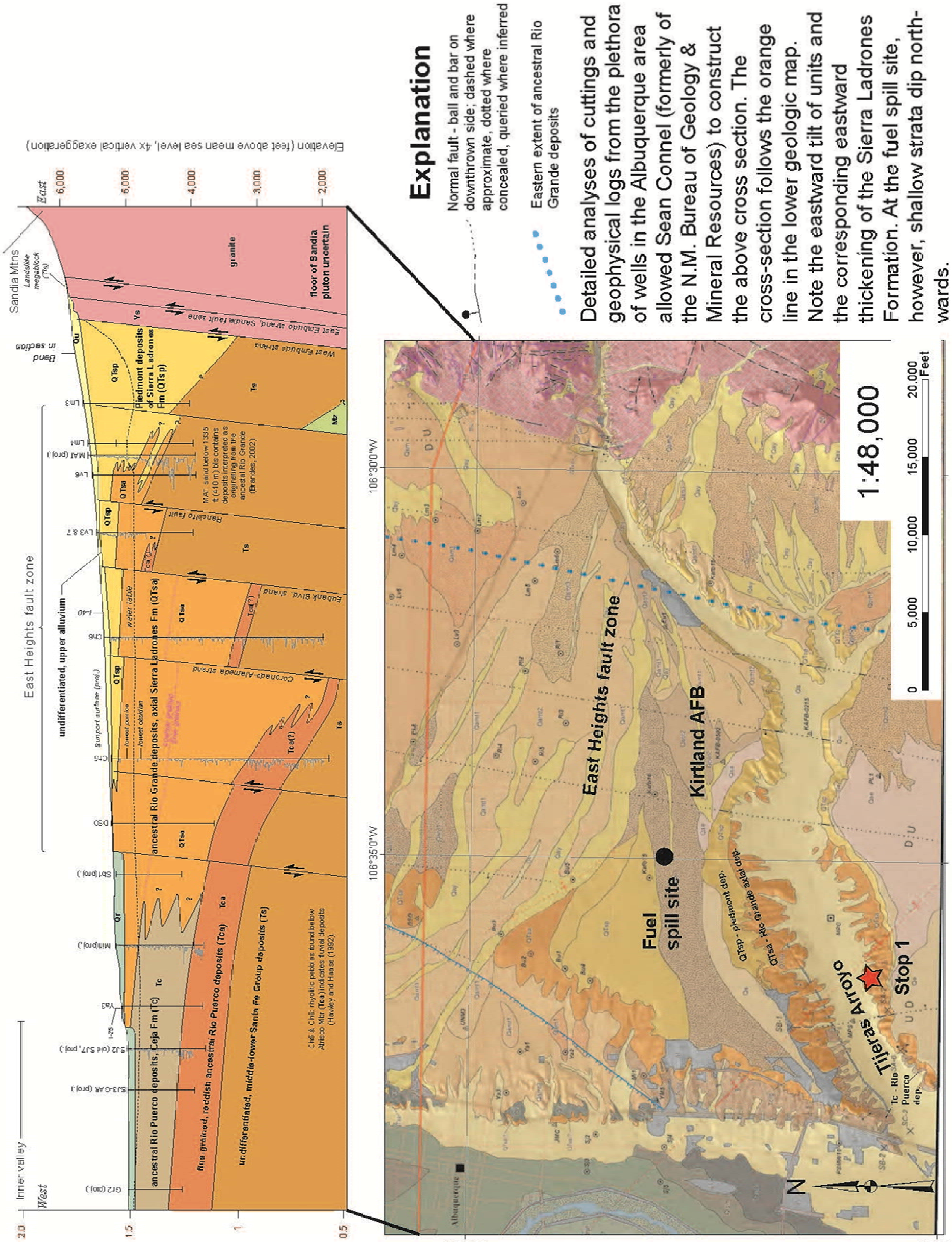
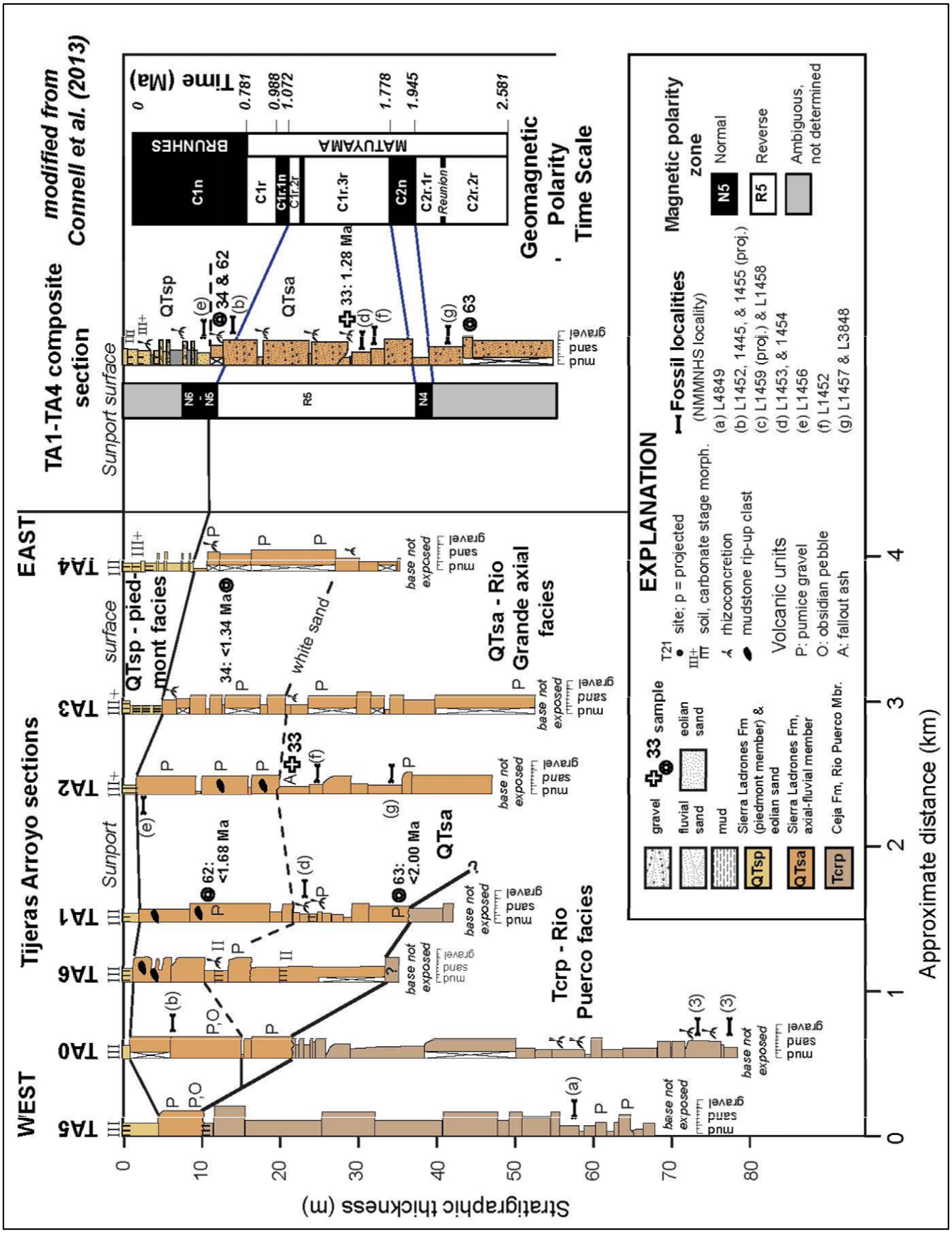


Figure 11. Correlation of Stratigraphic Sections Measured Along the Exposed Sides of Tijeras Arroyo



Tijeras Arroyo sections
WEST
EAST
TA5
TA0
TA6
TA1
TA2
TA3
TA4
Sunport surface
TA1-TA4 composite section
modified from Connell et al. (2013)
Time (Ma)
Geomagnetic Polarity Time Scale
BRUNHES
MATUYAMA
C1n
C1r
C1r.1n
C1r.2r
C1r.3r
C2n
C2r.1r
Reunion
C2r.2r
0
0.781
0.988
1.072
1.778
1.945
2.581
N6 - N5
R6
N4
QTsp
QTsa
34 & 62
33: 1.28 Ma
63
62: <1.68 Ma
63: <2.00 Ma
34: <1.34 Ma
white sand
QTsp - piedmont facies
QTsa - Rio Grande axial facies
Tcrp - Rio Puerco facies
base not exposed
mud
sand
gravel
Stratigraphic thickness (m)
Approximate distance (km)
EXPLANATION
gravel
fluvial sand
mud
eolian sand
33 sample
QTsp Sierra Ladrones Fm (piedmont member) & eolian sand
QTsa Sierra Ladrones Fm, axial-fluvial member
Tcrp Ceja Fm, Rio Puerco Mbr.
T21 site; p = projected
III+ soil, carbonate stage morph.
rhizoconcretion
mudstone rip-up clast
Volcanic units
P: pumice gravel
O: obsidian pebble
A: fallout ash
Fossil localities
(NMMNHS locality)
(a) L4849
(b) L1452, 1445, & 1455 (proj.)
(c) L1459 (proj.) & L1458
(d) L1453, & 1454
(e) L1456
(f) L1452
(g) L1457 & L3848
Magnetic polarity zone
N5 Normal
R5 Reverse
Ambiguous, not determined

STOP 1 - REGIONAL HYDROGEOLOGY

(Nathan Meyers, U.S. Geological Survey [USGS])

On a regional scale, groundwater generally flows from areas of groundwater recharge to areas of discharge (the river, wells, or springs). Before the widespread installation of large-capacity water-production wells and the reengineering of the Rio Grande, precipitation falling on the mesas and highlands west, north, and east of the Middle Rio Grande Basin recharged the groundwater aquifer; the groundwater then flowed towards and discharged to the Rio Grande. From the 1960's through the 1980's a number of large capacity water-production wells were drilled in the Albuquerque area to supply water for public, industrial, and other uses. Groundwater extracted by these wells has created a large area of lowered groundwater levels in southeastern Albuquerque that has changed the direction of groundwater flow in the area -- including the area occupied by the fuel plume. Based on groundwater-flow model simulations, the direction of groundwater flow in the vicinity of the fuel plume changed from southwest to northeast in the late 1970s to early 1980s.

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Figure 12. 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)

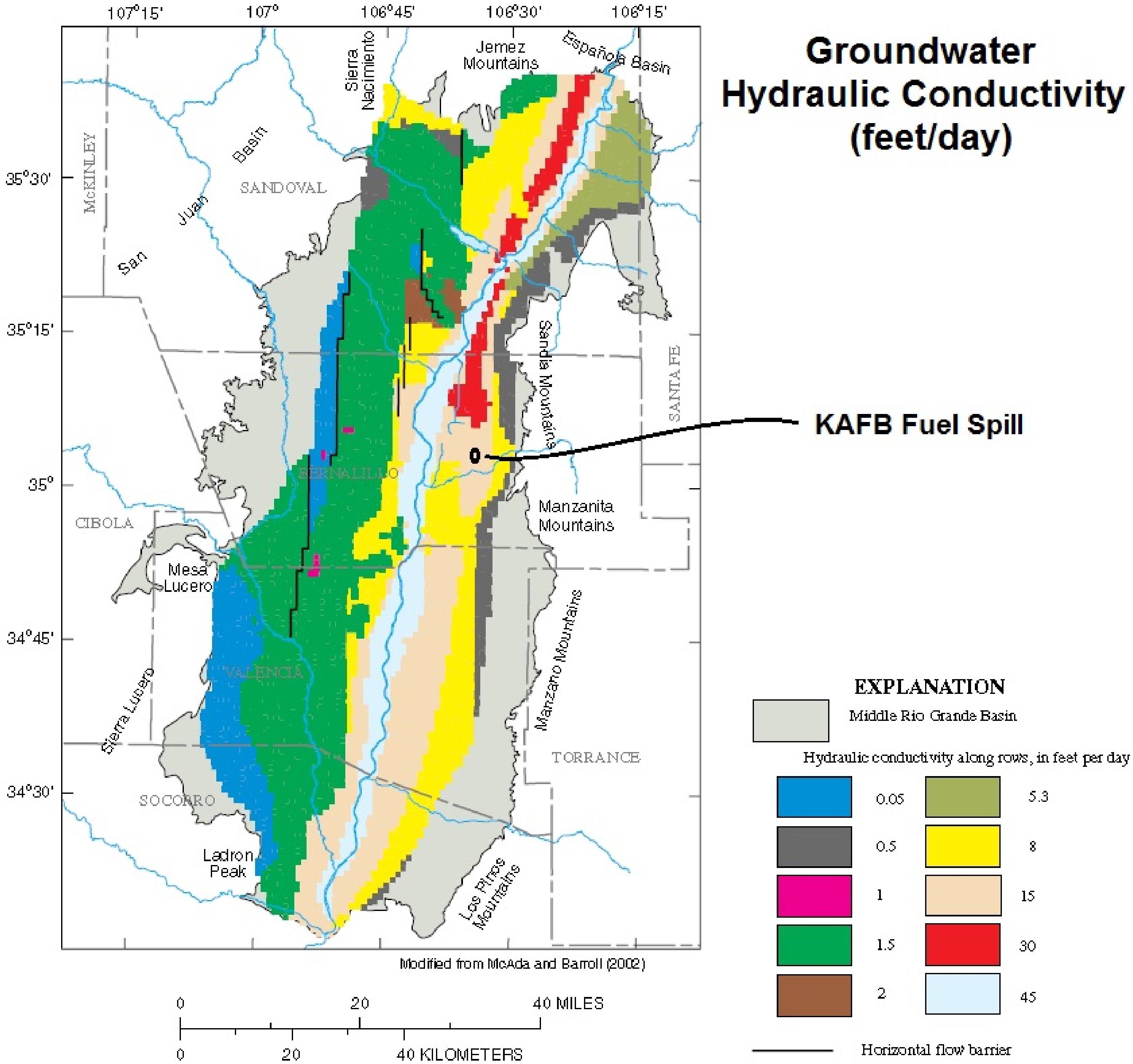


Figure 13. Pre-Development Water Levels (Bexfield and Anderholm, 2000)

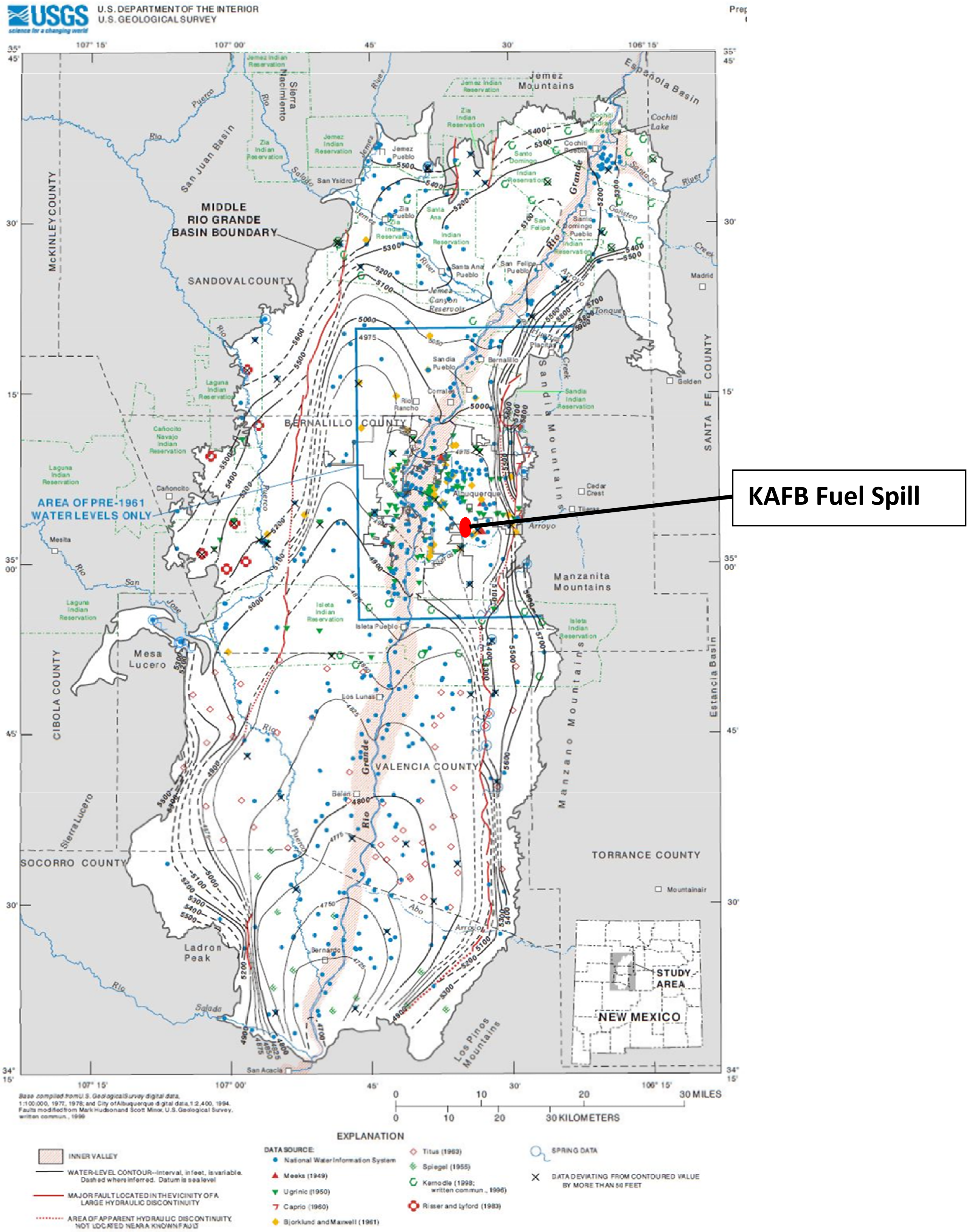


Figure 14. 2008 Water Levels and Water Level Change from Pre-Development
(Falk, et al., 2011)

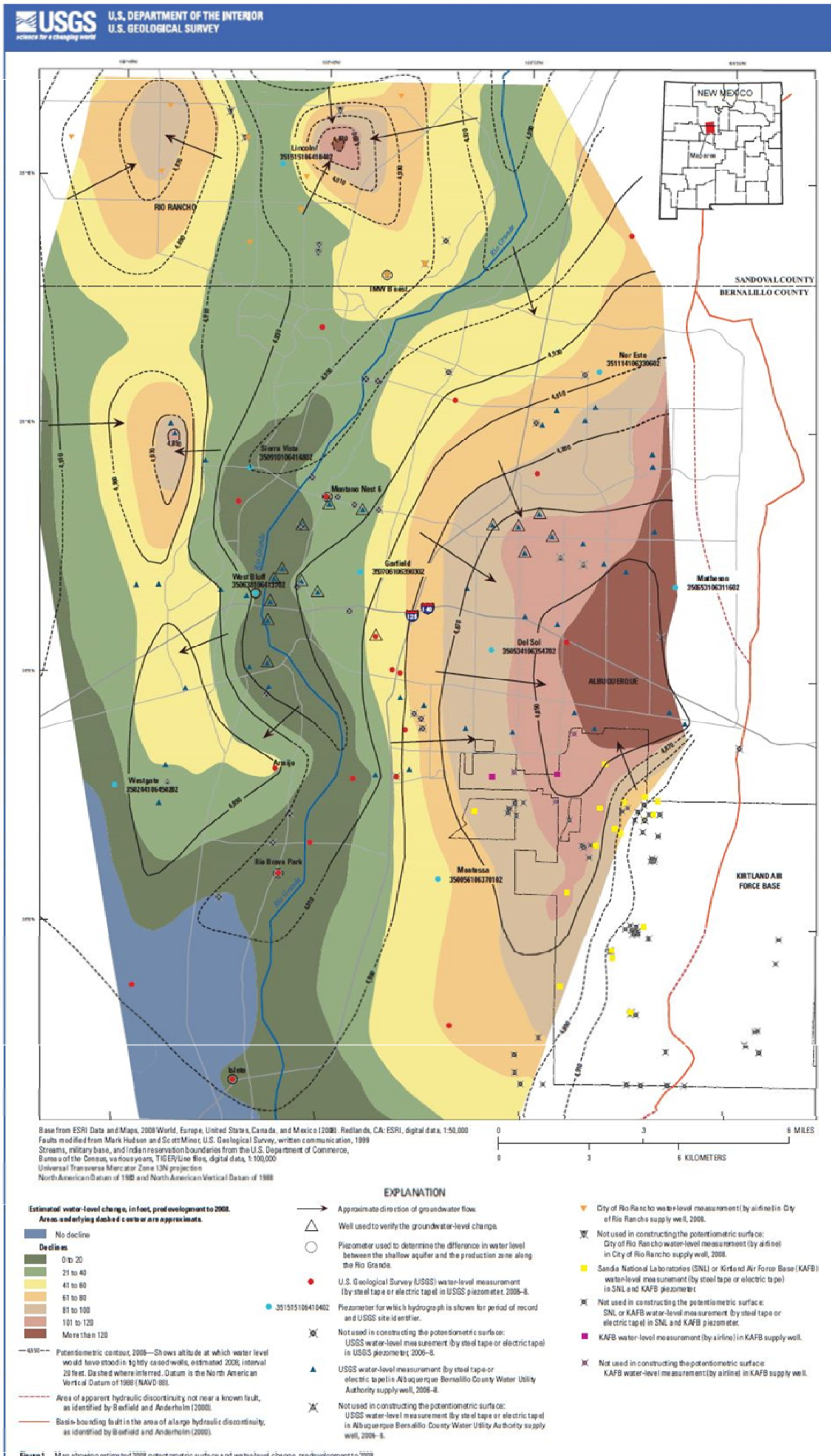


Figure 1. Map showing estimated 2008 potentiometric surface and water-level change, predevelopment to 2008.

Figure 15. 2012 Water Levels, Water Level Change from Pre-Development, and Hydrographs Showing 2009-12 Water Level Rise (Powell and McKean, 2014)

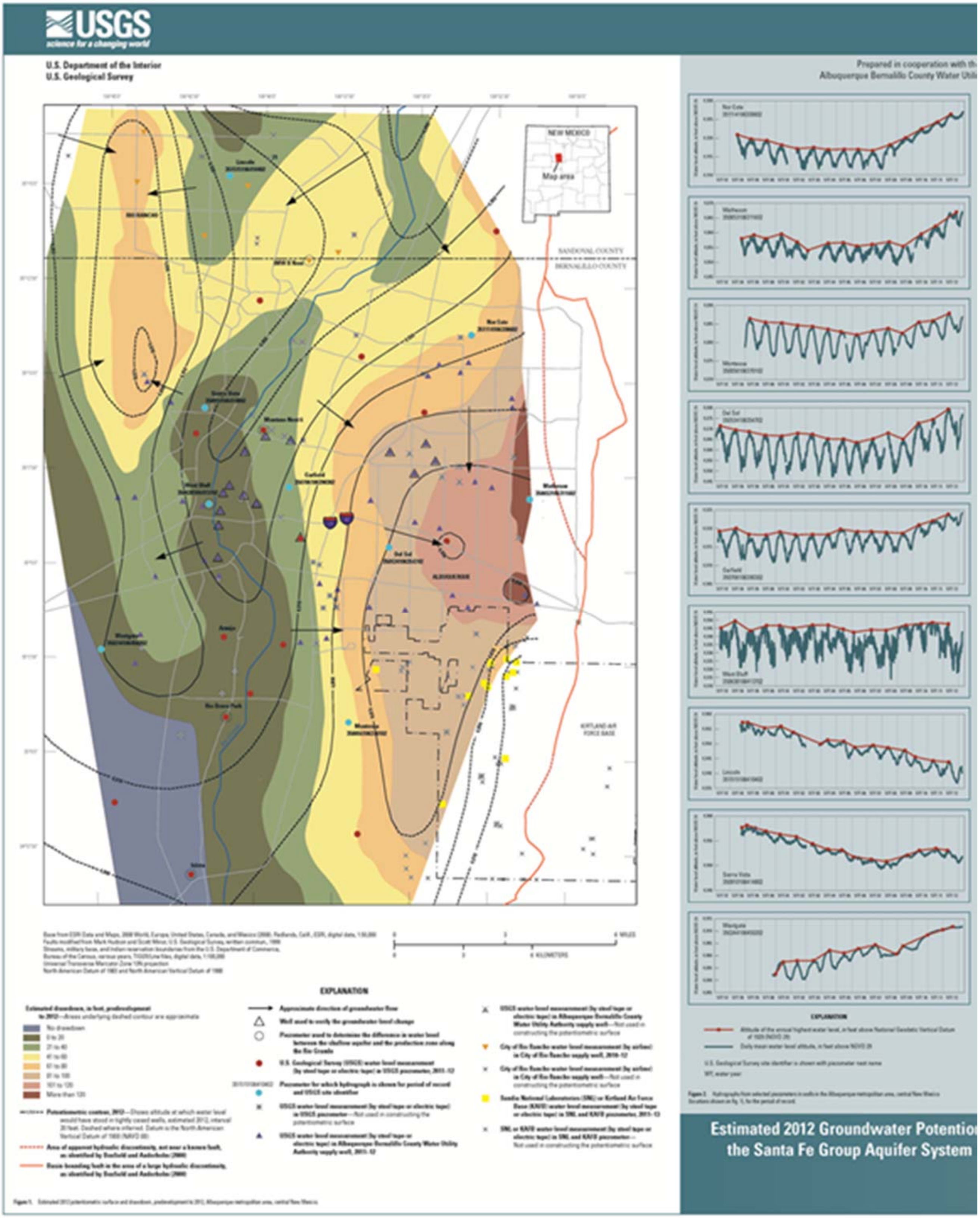


Figure 16. Trumbull Piezometer Nest Water Levels, 6/20/14 (raw data from USGS.gov)

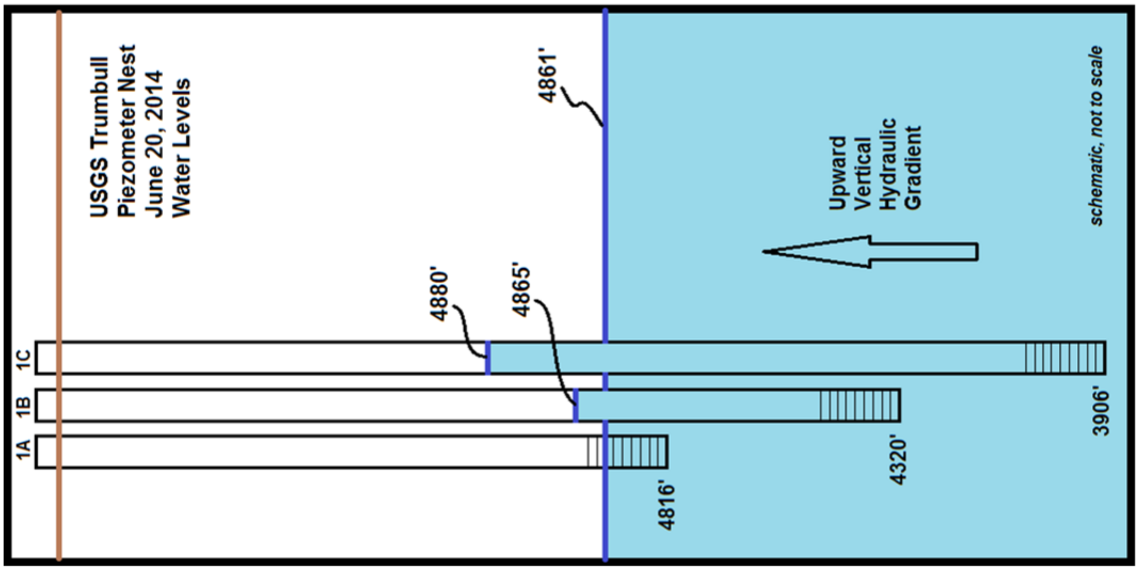


Figure 17. Trumbull Piezometer Nest Hydrographs (raw data from USGS.gov)

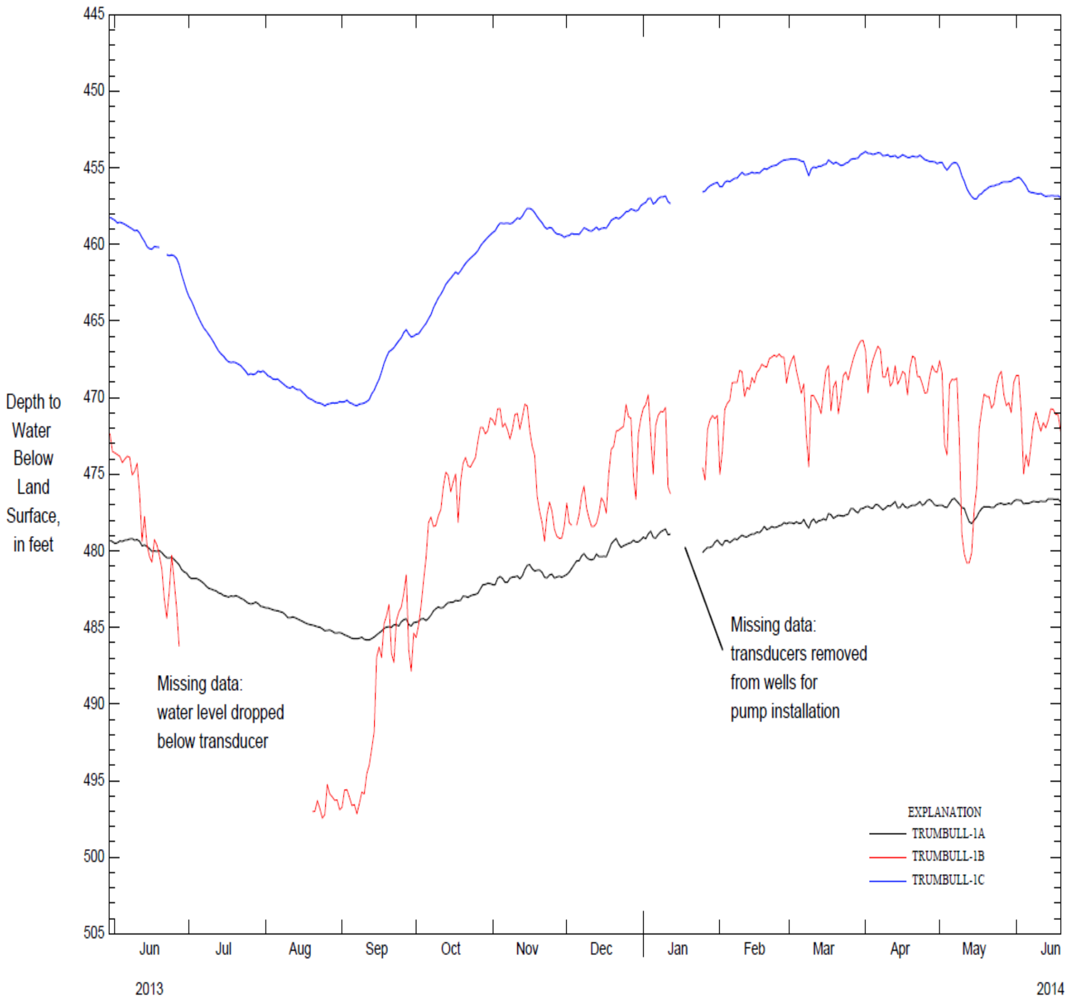
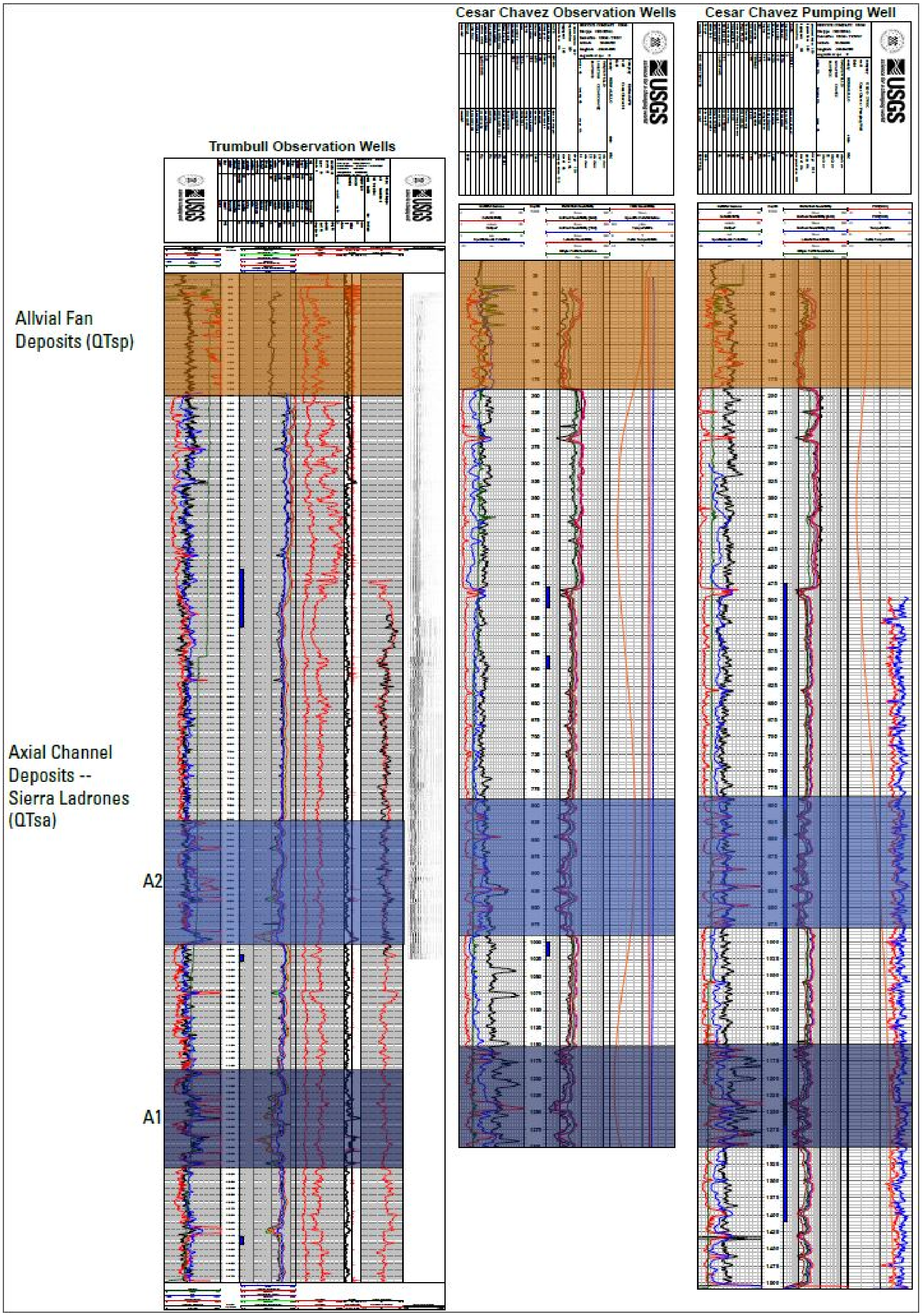


Figure 18. Geophysical Logs for Wells Near the KAFB Fuel Spill Alluvial fan deposits and the A1 and A2 fine-grained sediment sequences in the Sierra Ladrones Formation are shown.



STOP 1 - WATER RESOURCES PORTFOLIO

(Rick Shean, Albuquerque Bernalillo County Water Use Authority [ABCWUA])

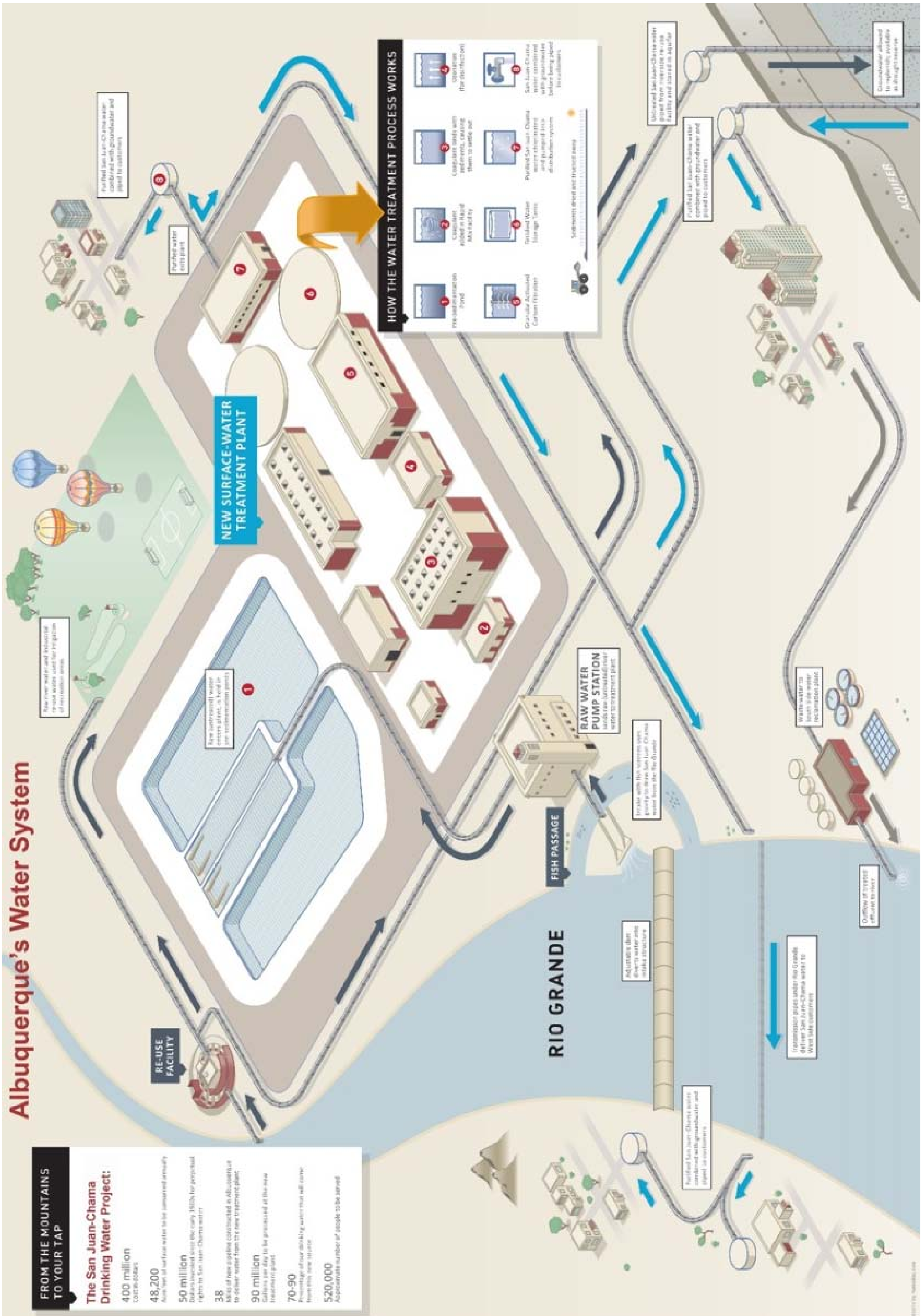
The Albuquerque Bernalillo County Water Utility Authority (Water Authority) provides both drinking and wastewater reclamation services, has over 200,000 customer accounts, serves over 600,000 people and employs 621 people. The Water Authority is considered a large utility, as many other larger cities have several smaller utilities serving their residents. Albuquerque residents have reduced their per person usage of water from 255 gallons per day in the mid-1990s to less than 135 gallons per day in 2014.

In fiscal year 2014, the Water Authority produced a total of 30.2 billion gallons of water from its ground and surface water resources, which was almost 10% less than FY 2013. Nearly 20 billion gallons of water were discharged into the Rio Grande from the reclamation plant. In addition, the Water Authority runs two reuse systems and has begun two aquifer storage and recovery projects, which will stretch our water resources build a large drought reserve that can be used during the peak summer seasons for years to come.

Water rights held by the Water Authority include permits to pump 155,000 acre-feet per year from the aquifer, with required offsets to balance river depletions, and approximately 96,200 acre-feet per year of San Juan/Chama Water.

NOTES:

Figure 19. Albuquerque's Water System



STOP 1 - REGIONAL GROUNDWATER GEOCHEMISTRY

(Dennis McQuillan, New Mexico Environment Department [NMED])

Groundwater at the KAFB fuel spill site is in the East Mountain Front hydrochemical zone, characterized as having low specific conductance and total dissolved solids, along with high concentrations of dissolved oxygen (DO) (Plummer et al., 2004 and Bexfield, 2010). The naturally high DO levels are advantageous for the intrinsic biodegradation of petroleum hydrocarbons such as benzene. The natural groundwater also has basic pH values, and a mixed calcium-sodium-bicarbonate composition with variable concentrations of chloride and sulfate (Plummer et al., 2004 and Bexfield, 2010). Background bromide concentrations at the KAFB fuel spill site range from 0.064 to 0.085 mg/L.

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Figure 20. Hydrochemical Zones in the Middle Rio Grande Basin (Bexfield, 2010)

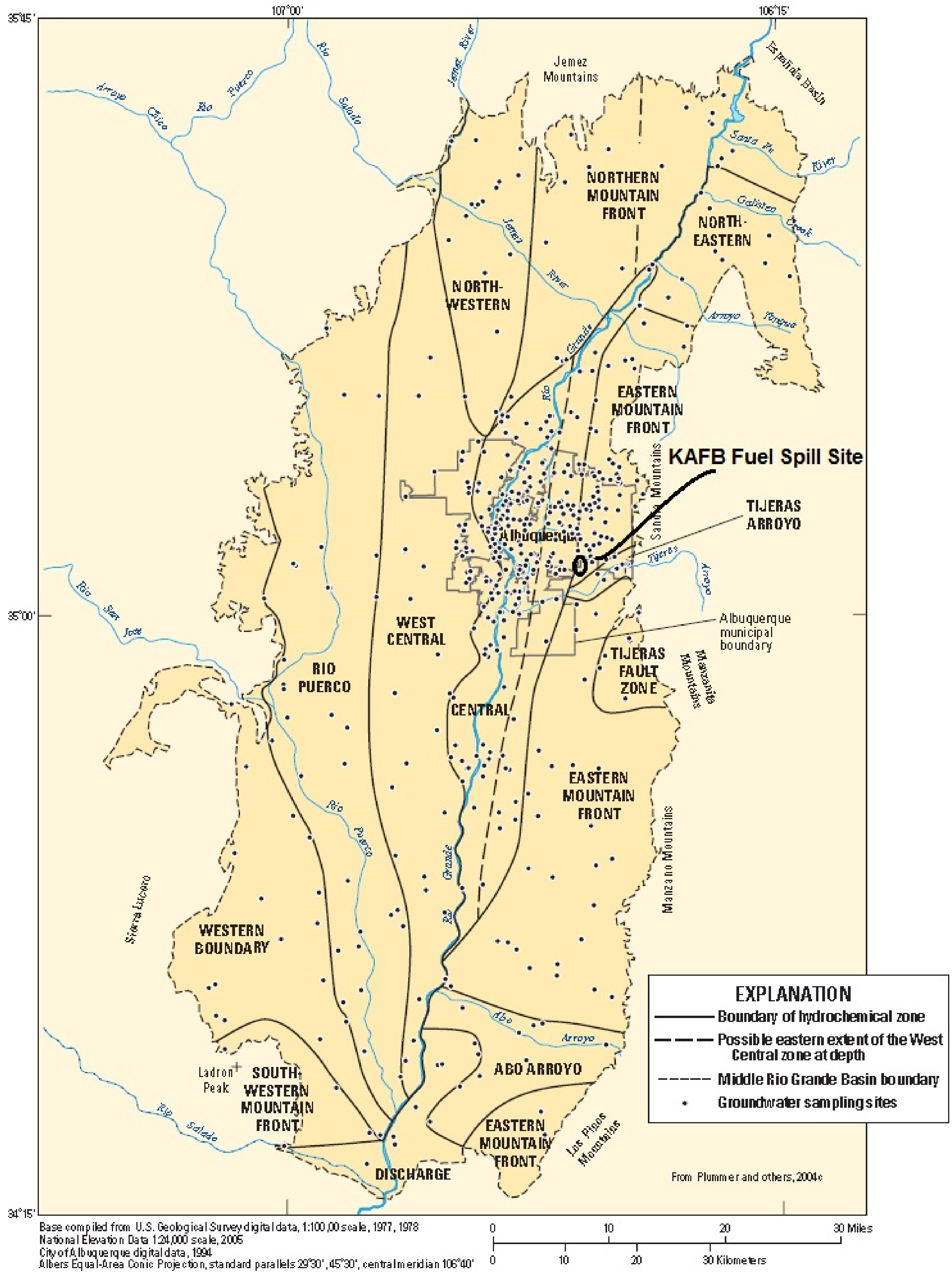


Table 1. Hydrochemical Zone Water Quality Parameters (Bexfield, 2010)

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

[Specific 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)

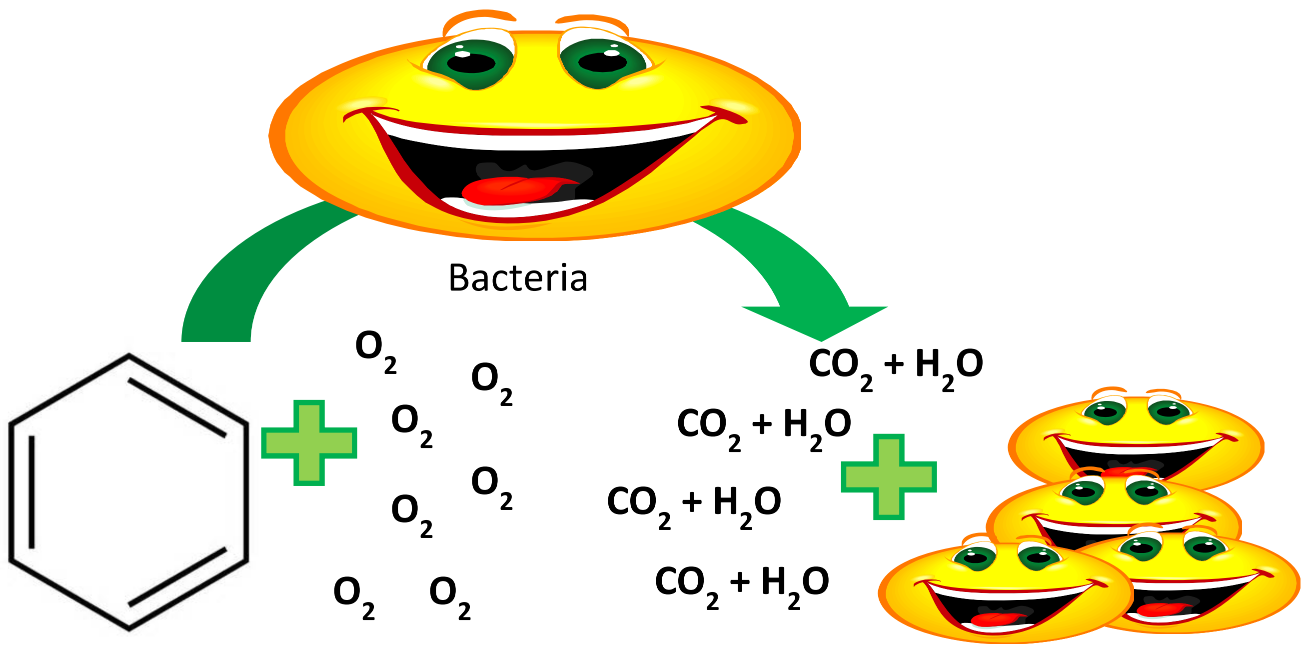
Ridgecrest Well #3, 6/22/96 (Plummer et al., 2004)

STOP 1 – MICROBIOLOGY AND REACTIVE MINERALS

(Dr. Adria Bodour, U.S. Air Force)

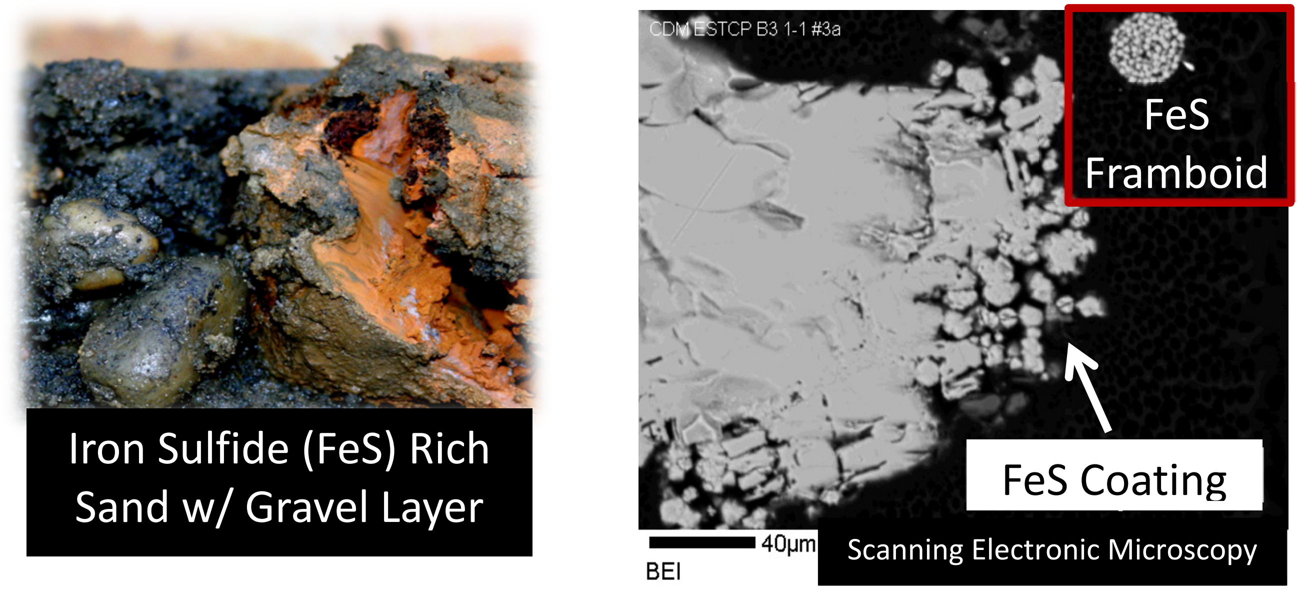
Another important aspect of the geology system is the natural bacteria and minerals that are present at a given site. Indigenous bacteria are abundant and are living in the soil and saturated zone (i.e., aquifer). These bacteria are capable of degrading the fuel constituents under aerobic (with oxygen) and anaerobic (without oxygen) conditions to non-toxic products. The diversity and the abundance of mineral composition are controlled by earth chemistry and the physical and chemical reactions during weathering (i.e., wind, precipitation, freezing, etc.). Some minerals have the capability to be reactive and indiscriminately degrade fuel constituents to non-toxic products.

Figure 21. Example of bacteria degradation under aerobic conditions



C_6H_6 (benzene) + O_2 (oxygen) $\rightarrow$ CO_2 (carbon dioxide) + H_2O (water) + cell mass

Figure 22. Example of the Reactive Mineral Iron Sulfide (FeS)



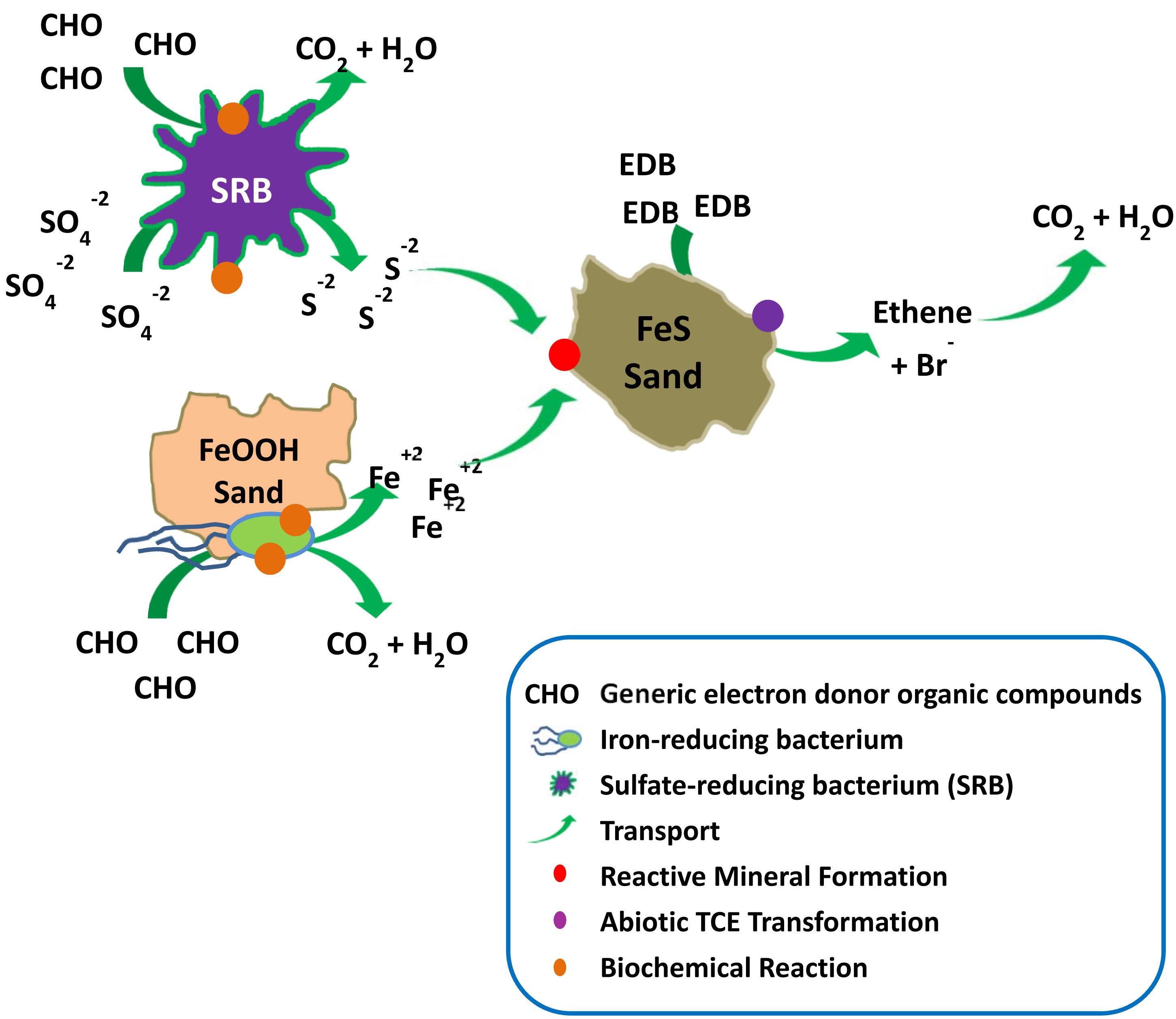
In situ Biogeochemical Transformation (ISBGT) can occur naturally when conditions are conducive for reactive mineral formation such as iron sulfide, pyrite, green rusts, and magnetite. ISBGT can be a technology that can be engineered by providing the necessary substrates to drive the process to completion in situ at a contaminated site. This technology has been demonstrated and validated for cleaning up contaminated sites and has been selected as the remedy at some Air Force sites. ISBGT is a 3-step process:

1. Under anaerobic conditions bacteria activity reduces iron (Fe^{+2}) and sulfate (SO_4^{-2})
2. Reduced iron (Fe^{+2}) and sulfide (S^{-2}) form reactive minerals such as iron sulfide (FeS)
3. Reactive minerals (i.e., FeS) degrades contaminant under abiotic conditions

Table 3. Examples of Reactive Minerals

Mineral	Formula
Iron sulfide	FeS
Pyrite	FeS_2
Green rusts	$Fe^{II}_4 Fe^{III}_2 (OH)_{12} SO_4 . yH_2O$
Magnetite	$Fe_3 O_4$

Figure 23. Cartoon of the 3-Step Process to Form Reactive Minerals Called In-Situ Biogeochemical Transformation



NOTES:

STOP 1 - MOUNTAINVIEW GROUNDWATER NITRATE BIOREMEDIATION

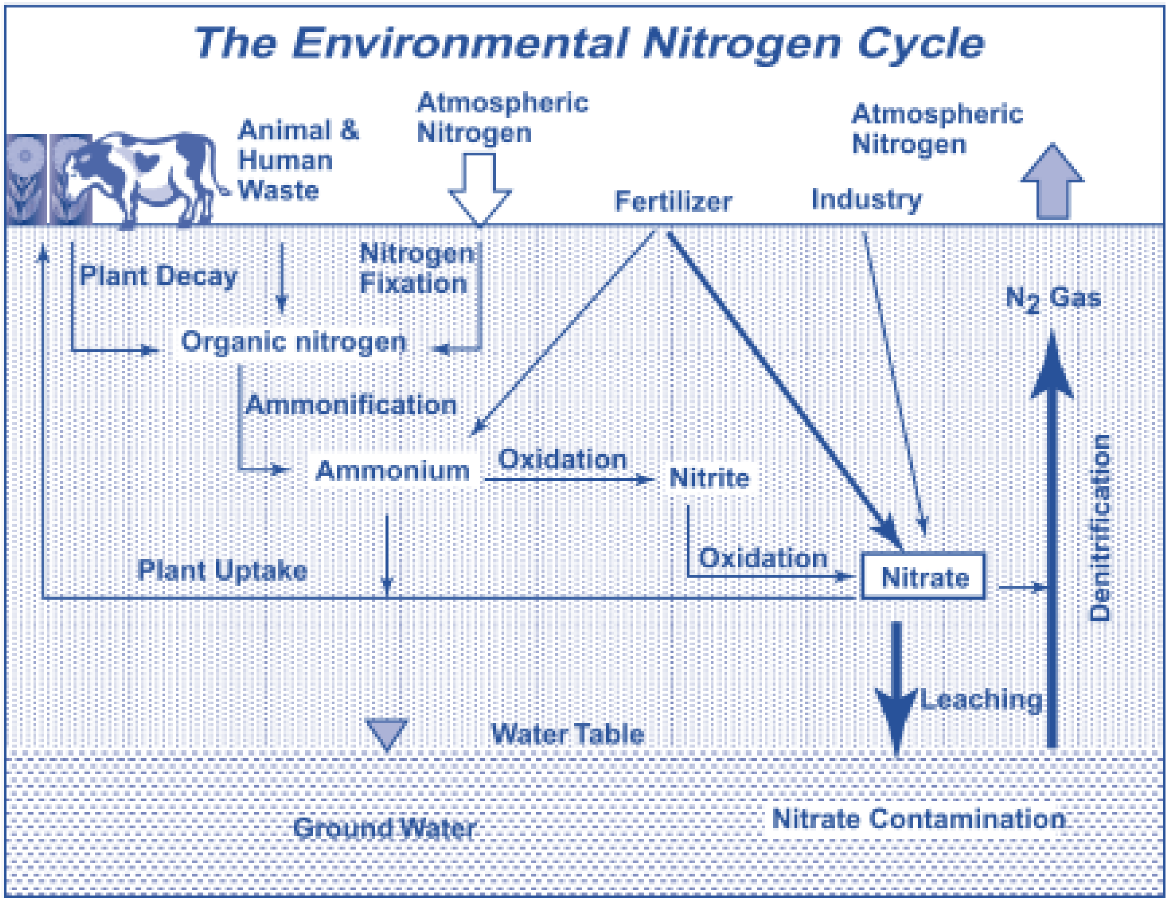
(Dr. Eric Nuttall, UNM Emeritus [nuttall@unm.edu])

The South Valley Mountainview site was the location of a blue baby incident in 1980. This incident initiated an investigation by NMED (see McQuillan, this guidebook). Results showed that a one square mile plume was created in the 1950s and during subsequent decades as the result of a commercial flood irrigated vegetable farm. Nitrogen rich fertilizers were regularly prepared in several unlined lagoons and applied by flood irrigation to many acres of vegetables. The vegetable farm nitrogen contaminated surface water rapidly recharged through the 40-70 ft sandy vadose zone into the underlying groundwater and created at nitrate nitrogen contamination of several hundred ppm. Following closure of the farm in the 1960s, the nitrate groundwater plume grew in the subsequent decades into its present size of about one square mile. The plume became an NM orphan site and NMED has recently initiated remediation of this plume using the EISB technology.

Many remediation remediates were considered with the most viable being enhanced in-situ anaerobic bioremediation (EISB). The University of New Mexico in the 1990s field tested several variations of EISB. Result showed that denitrification occurred rapidly with the addition of various carbon substrates or electron donors. Currently a large scale EISB project is underway and has shown excellent reduction of nitrate by converting this toxic chemical into harmless nitrogen gas which returns immediately back into the atmosphere. The technology is a form of pump->in-situ treat->reinjection. All water is conserved in the process and thousands of pounds of nitrate have been biologically decontaminated.

NOTES:

Figure 24. Nitrogen Cycle



Denitrification Reaction—greatly simplifed

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

Figure 25. Mt. View Field Site at Holcium's

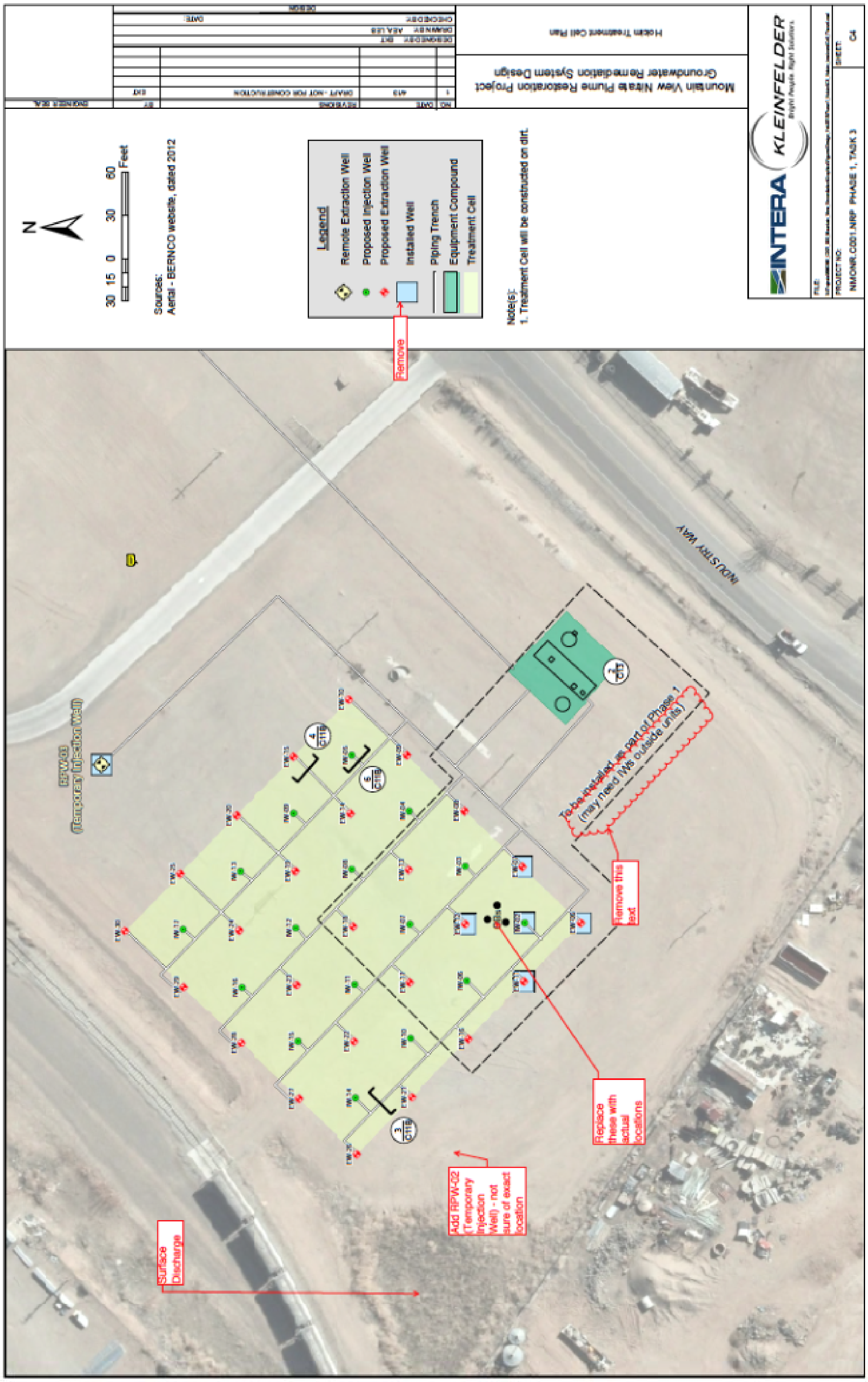


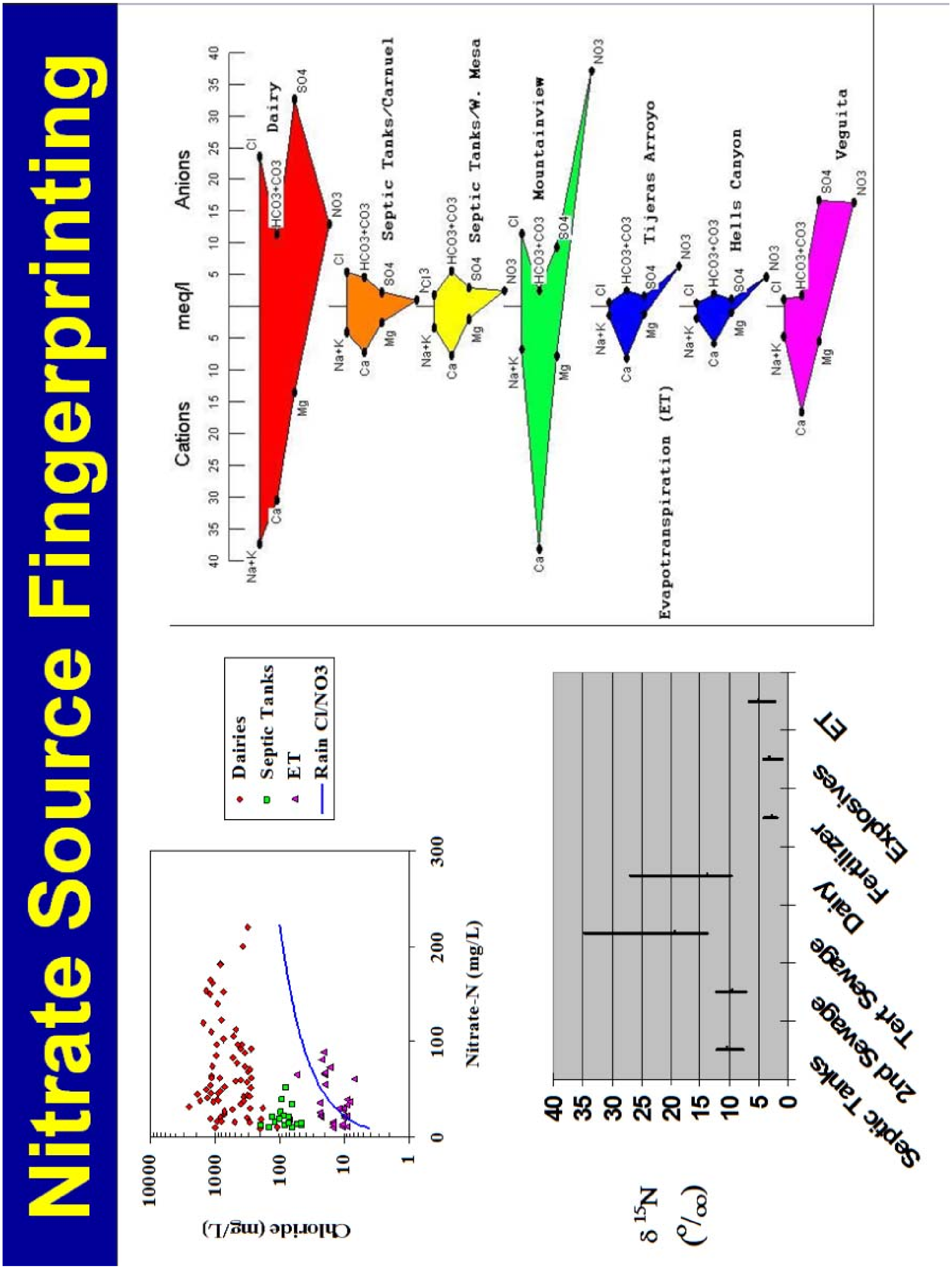
Table 4. Groundwater Nitrate Contamination Geochemistry Examples, Albuquerque Area (NMED unpublished data) ET, evapotranspiration; ND, not detected; NO_3 + NO_2, nitrate plus nitrite; SC, specific conductance; TDS, total dissolved solids.

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
$d^{15}N$ ($^{o}/_{oo}$)	+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 5. 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
$d^{15}N$ ($^{o}/_{oo}$)	+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 26. Nitrate Source Fingerprinting



Kirtland Air Force Base (KAFB)
Bulk Fuels Facility (BFF)
Public Field Trip

STOP 2 - Deciphering the Subsurface of a Complex Site

Understanding hydrogeology on plume and site scale

Speakers:

John Gillespie, U.S. Air Force

Tom Champion, AECOM

Colin Plank, AECOM

Dr. John Sigda, INTERA

STOP 2 – COARSE-GRAINED ALLUVIAL FAN DEPOSITS NEAR WOODEN TRESTLE; LOCAL SEQUENCED STRATIGRAPHY

(John Gillespie (USAF); Tom Champion (AECOM), and Colin Plank (AECOM))

One of many challenges that face environmental professionals at complex sites is transferring their understanding of the regional scale (geology and hydrogeology) to the site or plume scale. The BFF is a good example of this challenge. Depth to water and complexity of the alluvial fan and ancestral Rio Grande fluvial deposits increase uncertainties in predicting plume migration through this material. Cleanup team working groups from the various agencies and organizations are utilizing all data, processes and techniques to understand the structure of the sediments. This understanding will help build more effective cleanup systems.

At stop 2 we show how we incorporate sequence stratigraphy to help understand the structure of the subsurface.

Example of Alluvial Fan Stratigraphy

This stop provides an example of the vertical and lateral distribution of sediment grain sizes typical of alluvial fan deposits. The type of stratigraphy exposed here is also present underneath the bulk fuels storage facility (BFF). The units observed here directly overlie the Ancestral Rio Grande deposits observed at Stop1.

Figure 1 of the stop 2 figures shows the stop 2 and BFF locations on a geologic map. Stop 1 is located off this map, just to the west. The deposits in the exposure here are the piedmont member of the Sierra Ladrones Formation (mapped as "Qtsp" on figure1). These Pliocene to Pleistocene deposits are characterized by a wide range of grain sizes, from clay (<.004mm) to pebble and small cobble size gravel (10cm). Individual sediment particles (clasts) tend to be angular (edges visible) to subrounded (edges rounded off), which is indicative of a relatively close proximity to the sediment source. Deposition of the sediments you see at this site occurred in an alluvial fan, a large fan like body of sediment deposited by fluid and gravity flows, originating from the Sandia uplands just east of the location.

A generalized conceptual drawing of an alluvial fan is shown in Figure 2. Text in the figure caption describes origins of the variety of grain sizes present an alluvial fan deposit. In general, alluvial fans tend to form large, concave-up sediment bodies. The sediment sizes tend to be largest close to the upland sediment source (referred to as "proximal"), and finest at the very outer reaches of the fan (referred to as "distal"). In the central portion of the fan (referred to as "medial"), where stop two is approximately located, a very wide range of grain sizes are present. Coarsest (and most permeable) materials tend to be concentrated in the preserved remnants of distributary channels.

Figure 3 shows the exposure in view at stop 2. Panel 3A shows the outcrop as you see it. Panel 3B highlights two zones of coarse sediments (High permeability zones 1 &2) and two zones of generally finer sediments (Low permeability zones 1 and 2). As viewed here, you are looking roughly down the axis of a series of distributary channels (the high permeability zones) which are separated by interdistributary deposits (Low permeability zones).

Figure 27. Geologic Map and Location of Stop #2- Example of Alluvial Fan Stratigraphy

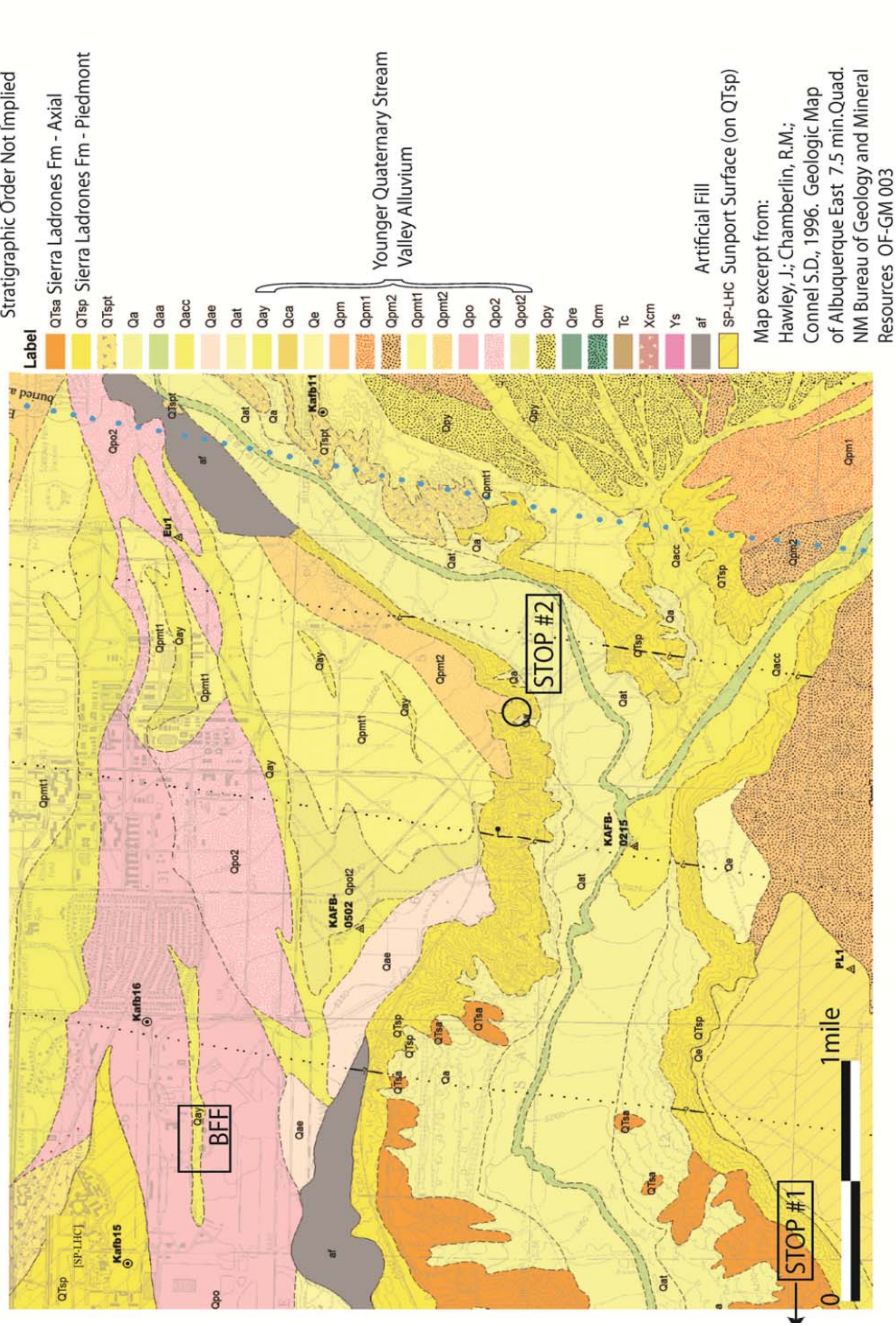
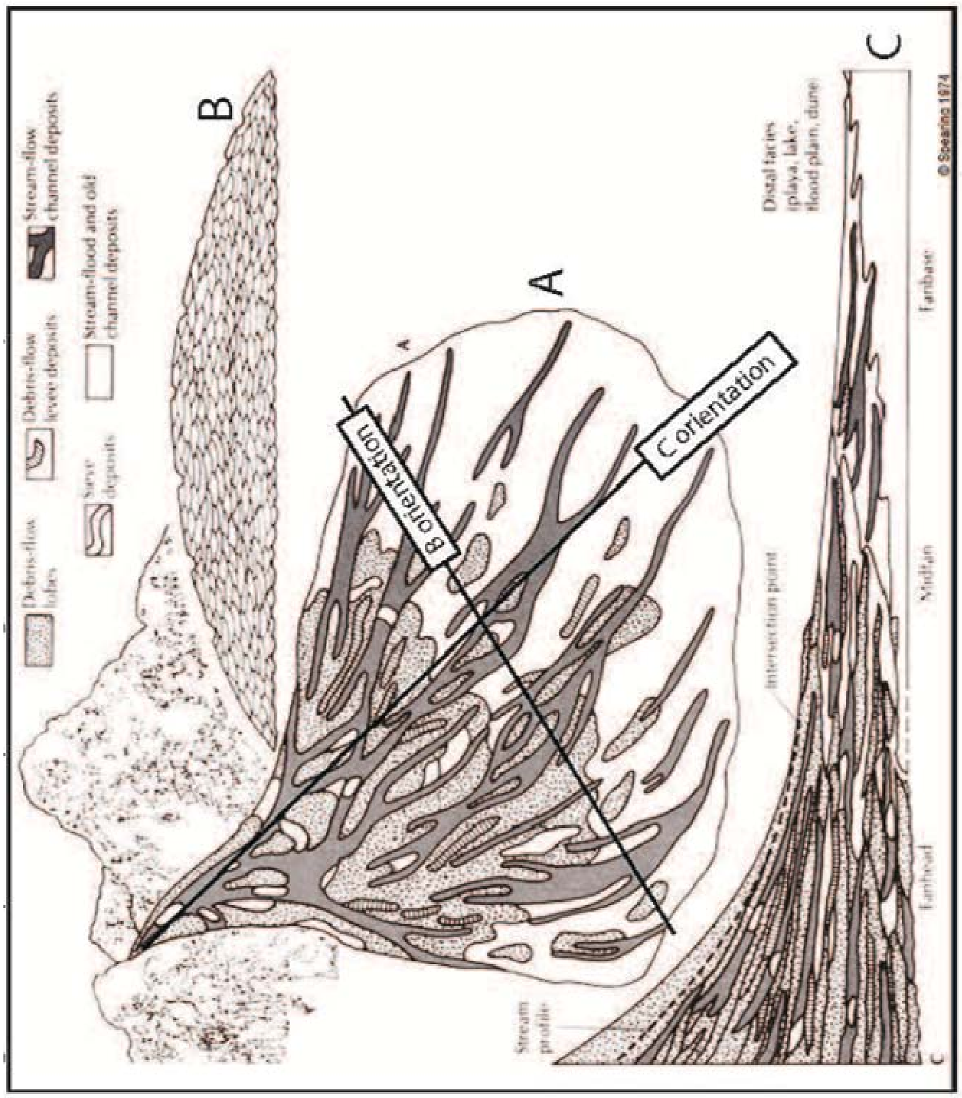


Figure 28. Conceptual Diagram of Alluvial Fan System



Generalized Conceptual Drawing of the Alluvial Fan Depositional System in Plan View (A) and Cross sectional views (B and C), after Spearing 1974.

Plan View, A, shows the variety of grainsizes and their spatial distribution within the fan. Channelized flow, characterized by coarse sediment occurs through out fan because distributary channels fill and migrate. Coarser and more heterogeneous debris flows may interfinger with and/or be cross-cut by distributary channels. Sheet like overbank flood deposits and interdistributary sedimentation, occurs between channels and consists of silty sands, silts, and some clays.

Note in Section B that as a whole, the fan system forms a concave upward "mound" of sediment that is constructed of stacked lensoidal bodies of a variety of grainsizes.

Section C shows a conceptual rendering of the internal distribution of grainsizes that results from the lateral and vertical building of the fan, referred to as progradation and aggradation respectfully. Internal variations in grainsize are important because they control groundwater flow.

This is the "Plumbing" of the subsurface.

Figure 29. Sierra Ladrones Formation, piedmont member (QTsp); Alluvial Fan Stratigraphy

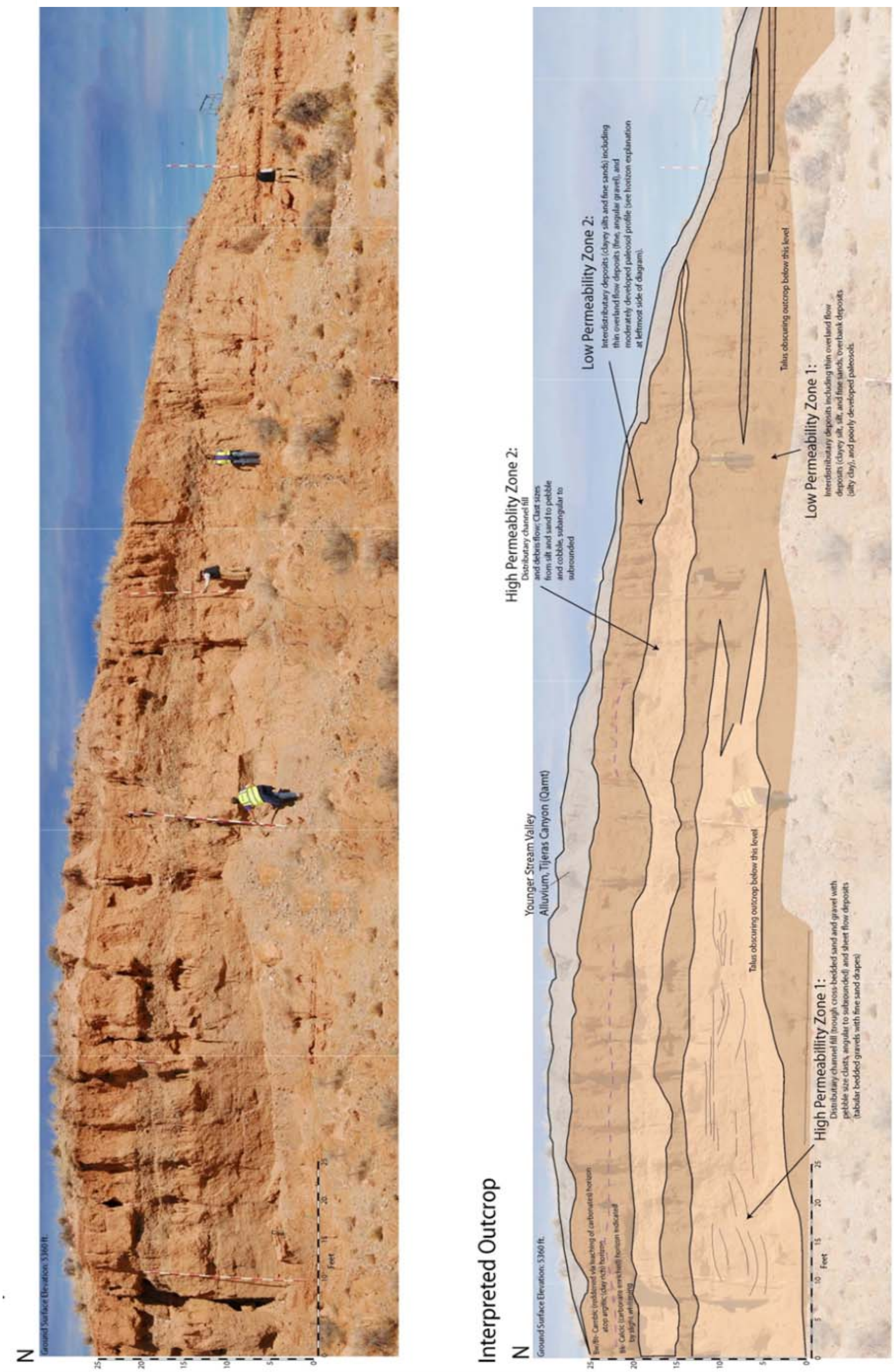


Figure 30. Cross Section T1, Extending Northeast from the Bulk Fuels Facility

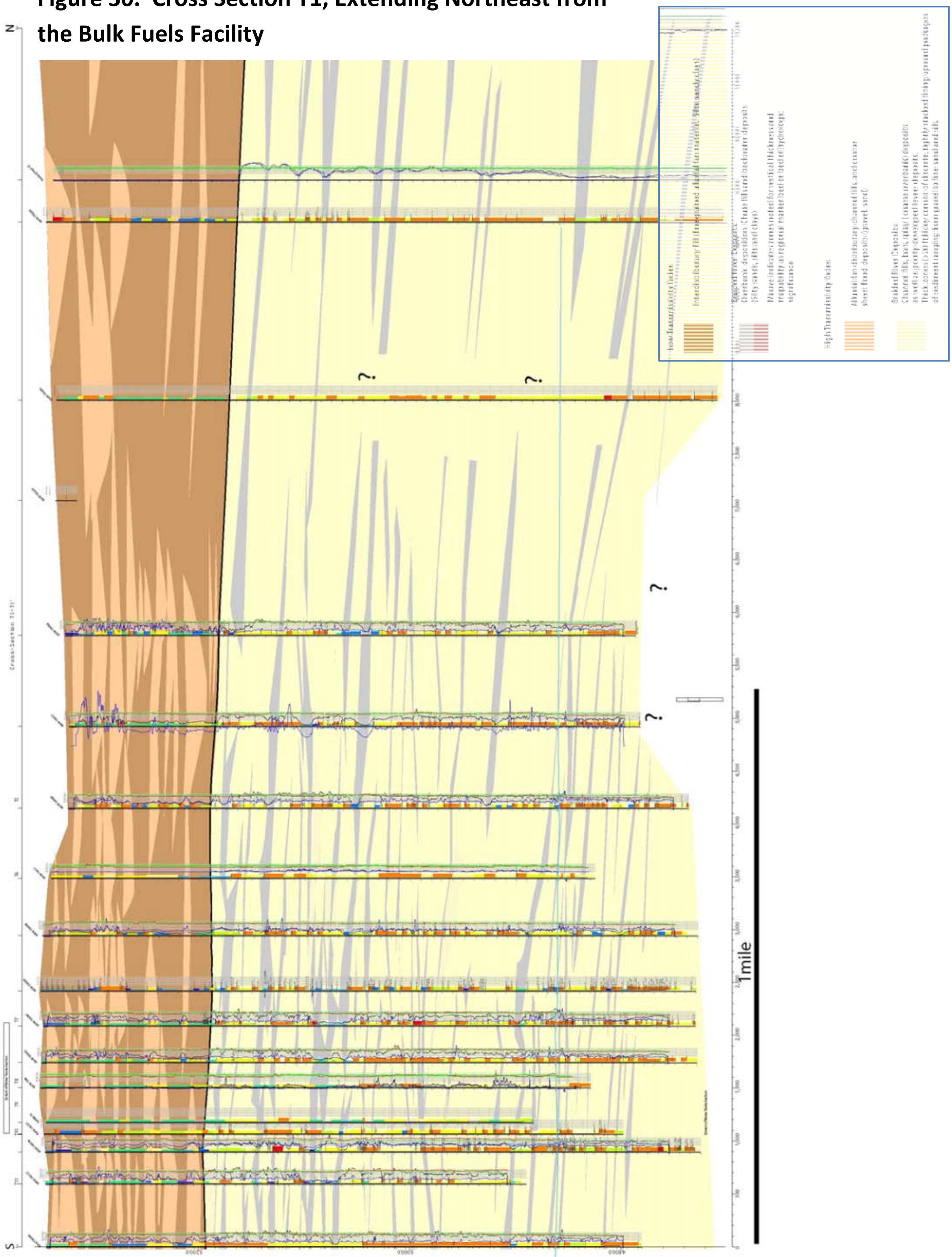
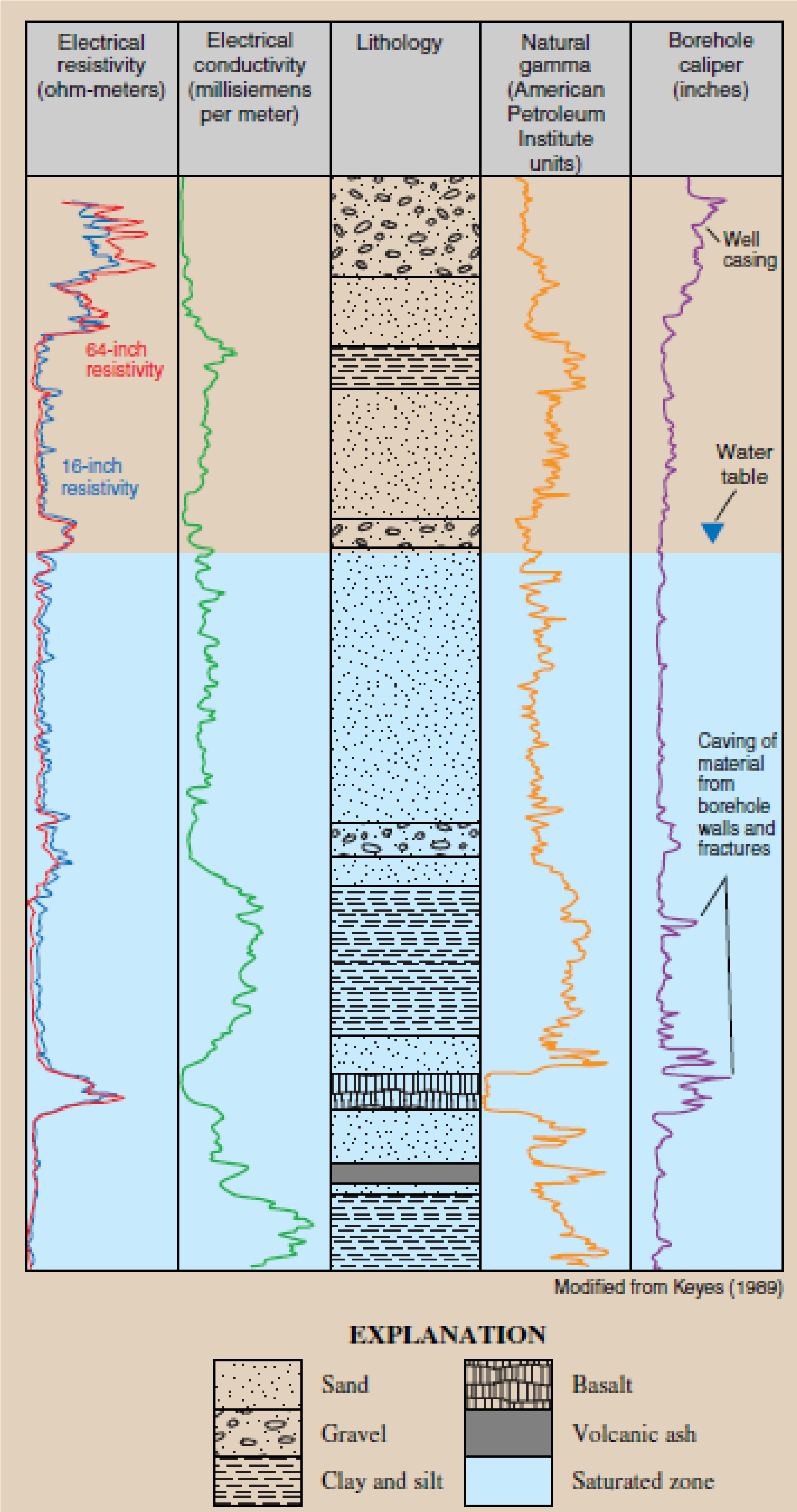


Figure 31. Hypothetical Responses of Various Borehole Geophysical Tools to Alluvial Deposits of Contrasting Texture and Saturation and to Volcanic Rock Units



STOP 2 – LOCAL HYDROGEOLOGY

(Dr. John Sigda, INTERA)

Identifying and designing appropriate corrective measures for the contamination from the BFF release requires understanding the aquifer properties and stresses at the appropriate scales. The most important aquifer properties include hydraulic conductivity (also referred to as permeability), specific yield, and porosity. We need to understand how these properties vary at the spatial scales that are important for plume migration, plume collapse, and source removal. Aquifer stresses, which can be considered as driving forces, include seepage from the Rio Grande, mountain front recharge, and pumping. We need to understand how the stresses are changing over time so that the interim and final measures are correctly selected and designed.

Each remediation problem should be solved by using the physical scale that is appropriate to that problem. Choosing an appropriate physical scale means choosing the right size box to encompass the problem and choosing the right amount of detail to describe what is happening within that box. Figure 5 shows the new lithologic cross-section along the EDB groundwater plume, with the source area to the right and the downgradient areas to the left. Well screens are depicted as colored cylinders for which the cylinder length matches the screen length. The water table is shown as a light blue line. Sediments dominated by sand and gravel are shown as lighter colors whereas sediments dominated by silt or clay are shown as darker colors. The physical scale appropriate for understanding the dissolved EDB groundwater plume is not necessarily the same physical scale that should be used to design the capture wells (left red box in Figure 5) or to deal with the source area (right red box in Figure 5).

The EDB plume moves easily through the lighter-color areas, and less so through the darker areas, below the water table. Understanding the direction and rate of EDB migration will depend on the locations and horizontal extent of the more permeable parts of the sandy aquifer sediments along and beyond the known plume extent.

Designing source control or removal in the BFF source area (Figure 6) needs a matching physical scale. Here, the fuel, which is less dense than water, is smeared in pores below the rising water table. Effectively removing the trapped fuel requires understanding the importance of differences in hydraulic conductivity, pore sizes, and extents between the sandy sediments and the thin gray silty sediment lenses located in the top 15 to 30 feet below the water. The extents and differences in properties for the sandy sediments and dark brown clay-rich sediments above the water table could be important to understanding the likelihood of future contamination of the aquifer from downward fuel migration and designing corrective measures for fuel remaining in the vadose zone.

Designing sets of wells to capture or collapse the EDB groundwater plume likely requires a larger scale than that for the source area. At the site of extraction well KAFB-106228, which will be installed in the next several months, the dissolved EDB is vertically distributed across the upper 60 to 80 feet of the aquifer and horizontally across roughly 1,400 feet at the water table. The screen of the new extraction well extends roughly 80 feet below the water table and 20 feet above (purple cylinder in Figure 7). The extents and properties of the dark brown clay-rich sediments and gray silt-rich sediments below the water table compared to the sandy sediments at this location will be important to understanding the trade-offs between screen length, pumping rate, and well spacing within the plume.

The rising water table and the changing head gradient are some of the important stresses to be considered for designing effective corrective measures. Groundwater head is a measure of the energy driving flow and is essentially the groundwater level within a well. As noted earlier, the BFF contamination is contained within the vadose zone and the shallowest of the three aquifers in this part of the Albuquerque Basin. USGS well clusters provide long-term pictures of head changes in the three aquifers (Figures 8, 9, and 10). Heads in the deepest aquifer (light blue lines in Figures 8, 9, and 10) appear to be increasing at a faster rate than in the unconfined plume aquifer (black lines). The head increases also differ depending on location. Heads in the unconfined and deepest aquifers appear to be occurring at rates of 2.7 feet/year and 4.6 feet/year, respectively, over the 6.5-year period between mid-2008 and end 2014 at the Del Sol Divider cluster, which is near Constitution and Washington NE. At the Jerry Cline cluster, which is very near to a large water supply well located by Louisiana and I-40, heads in the unconfined and deepest aquifers appear to be increasing at slightly higher rates than at the more distant Del Sol Divider cluster: 3.1 feet/year and 6.6 feet/year, respectively, over the same time period. Head data for the Trumbull cluster, located near Ridgecrest 3, are only available for 1.5 years. The average rates of head increase in the unconfined plume aquifer and the deepest aquifer at the Trumbull cluster are 7 feet/year and 13 feet/year, respectively. The rate of head increase appears to be changing with time as the average rate at the Del Sol Divider and Jerry Cline clusters is larger during the 1.5-year period from mid-2013 to end of 2014 than during the mid-2008 to end of 2014 period. Heads at the Trumbull well cluster are increasing at faster average rates over this shorter time period than heads at the other two clusters.

Understanding how the rates of head increases vary over time and with location is important. Changes in the groundwater heads can affect the direction and velocity of the EEDB plume. Selecting and designing interim and final corrective measures will be influenced by the current and future changes in groundwater heads.

Figure 32. T1 Lithologic Cross-Section Looking to East-Southeast

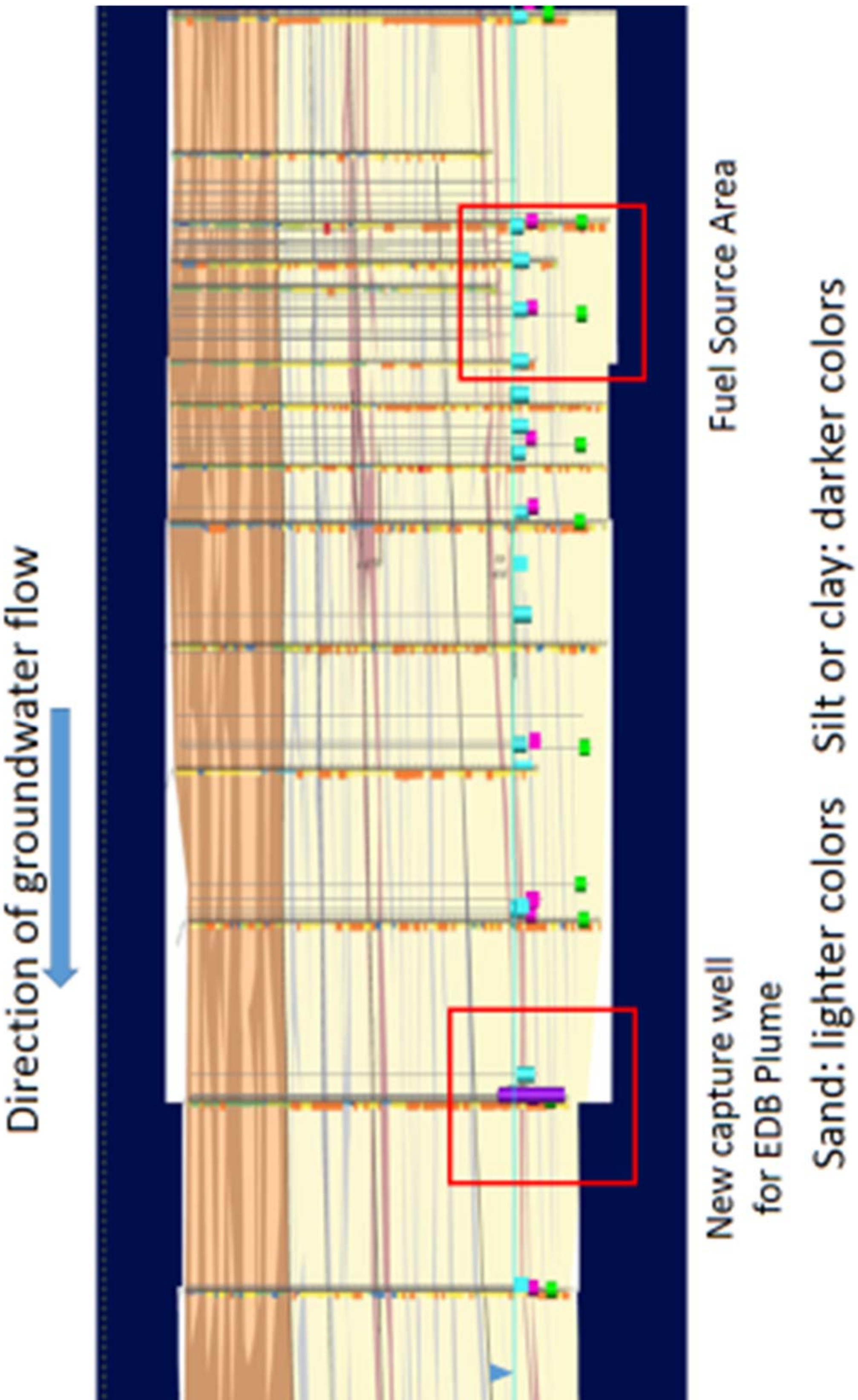


Figure 33. BFF Source Area Looking to East-Southeast

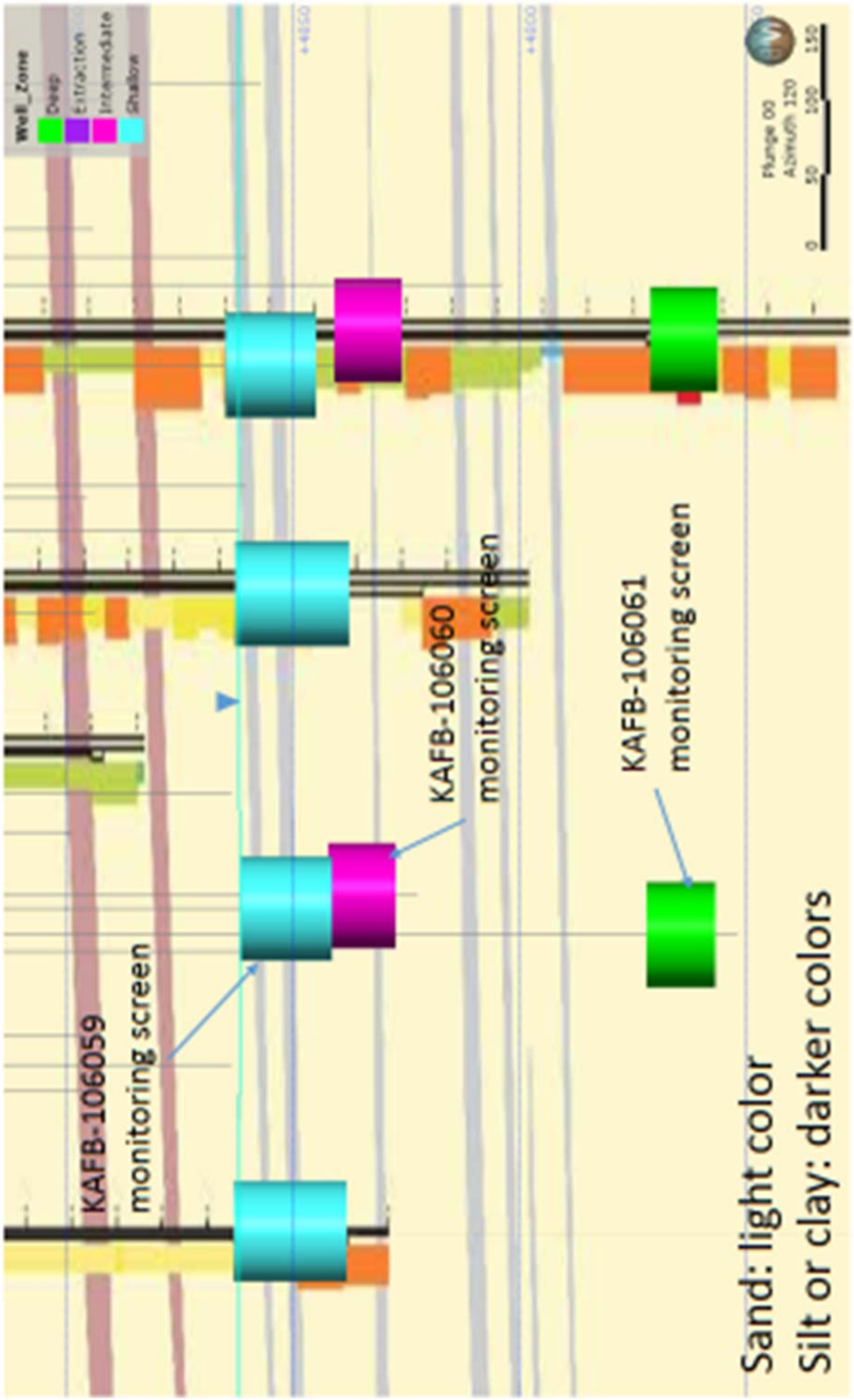


Figure 34. New Extraction Well for EDB Plume Looking to East-Southeast

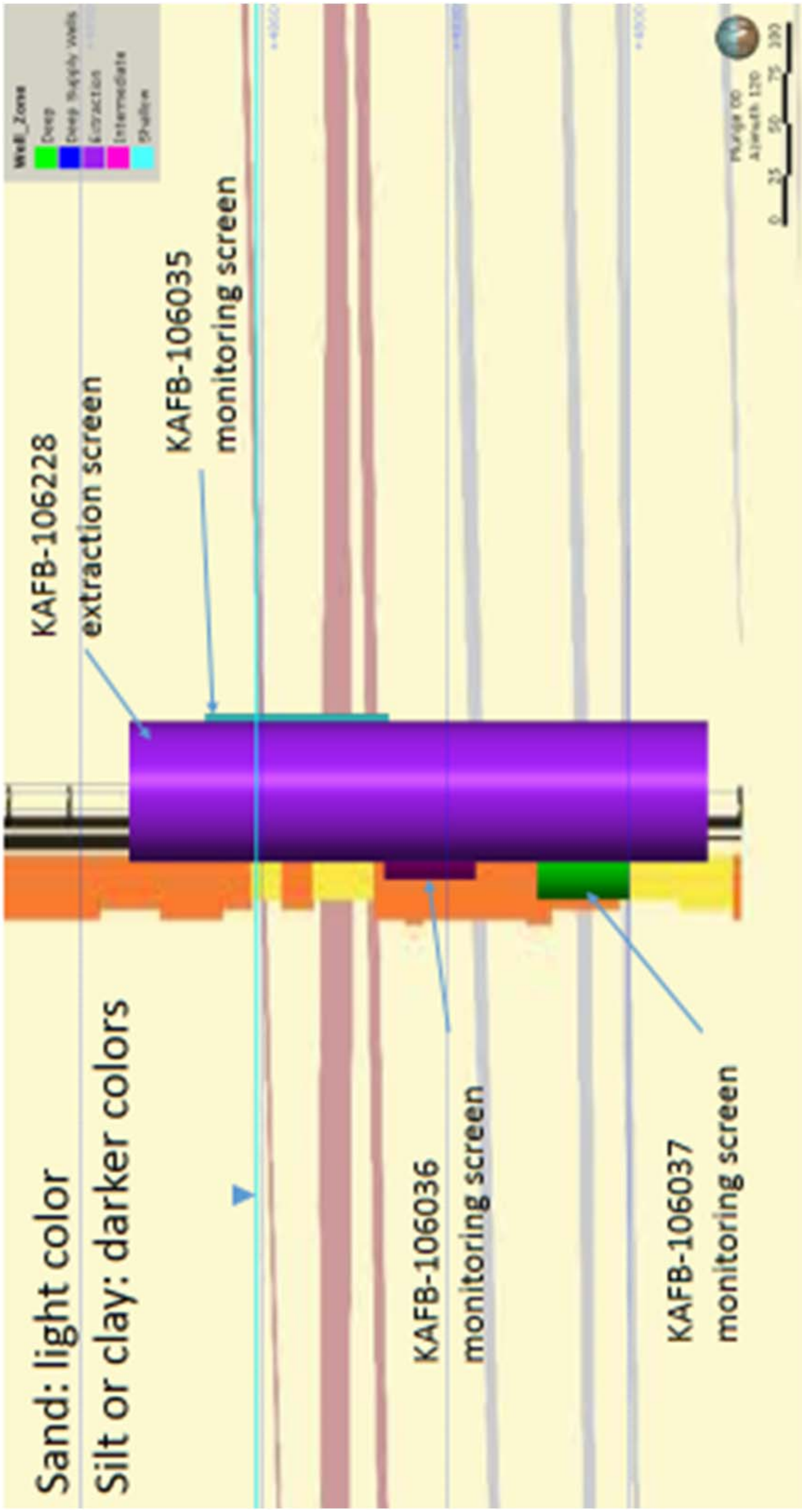


Figure 35. Groundwater Head Changes at Del Sol Divider Cluster

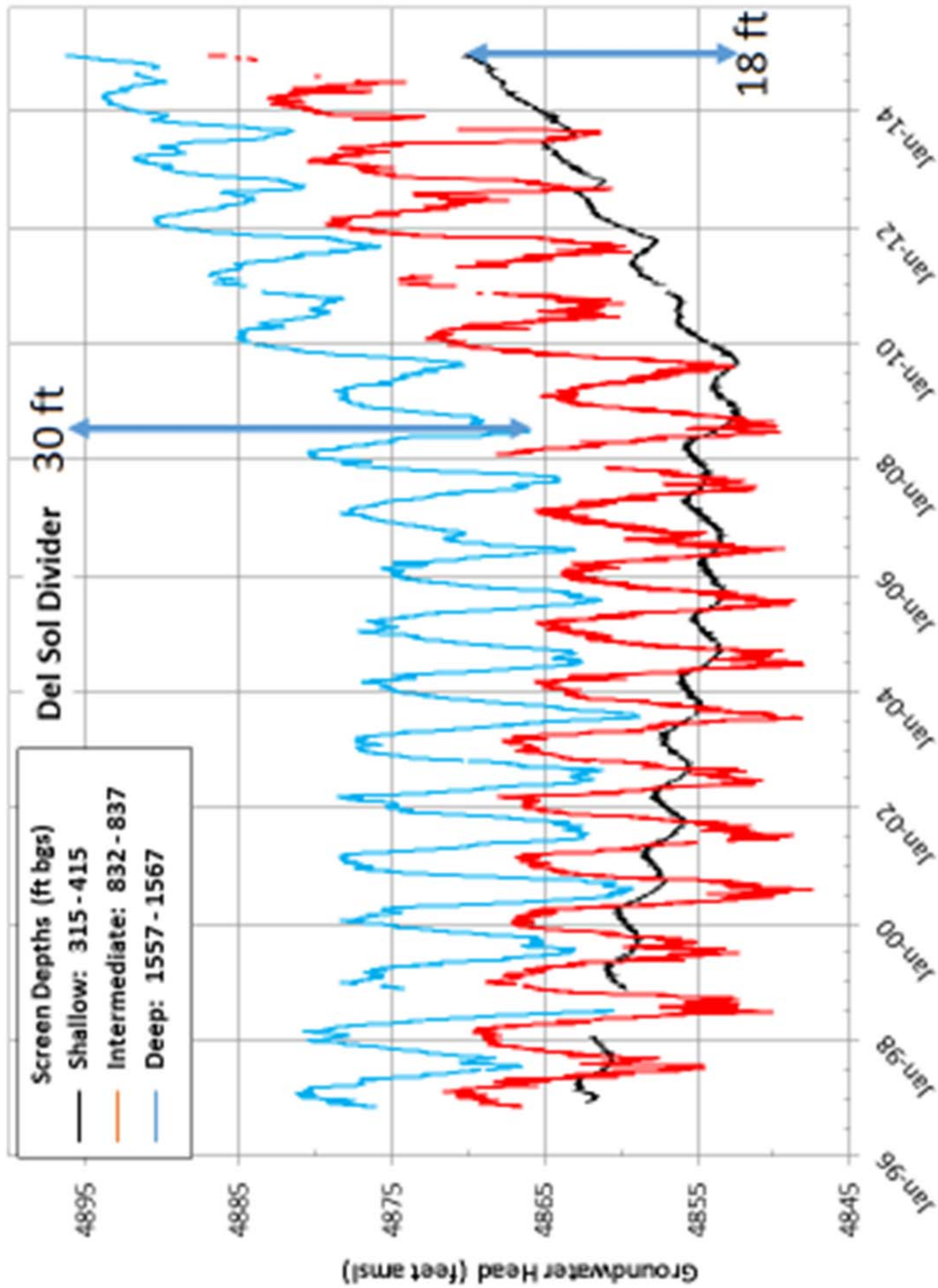


Figure 36. Groundwater Head Changes at Jerry Cline Cluster

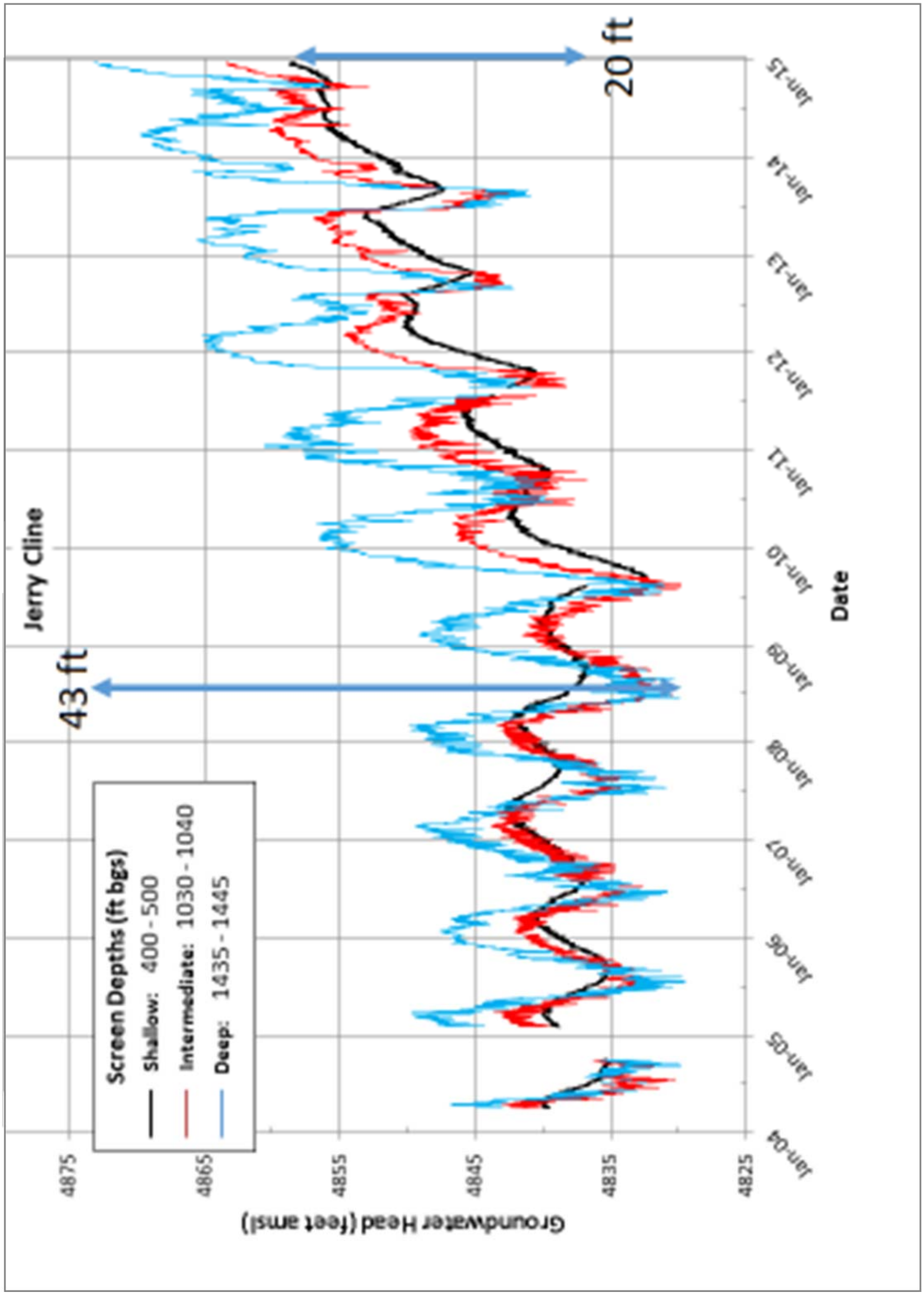
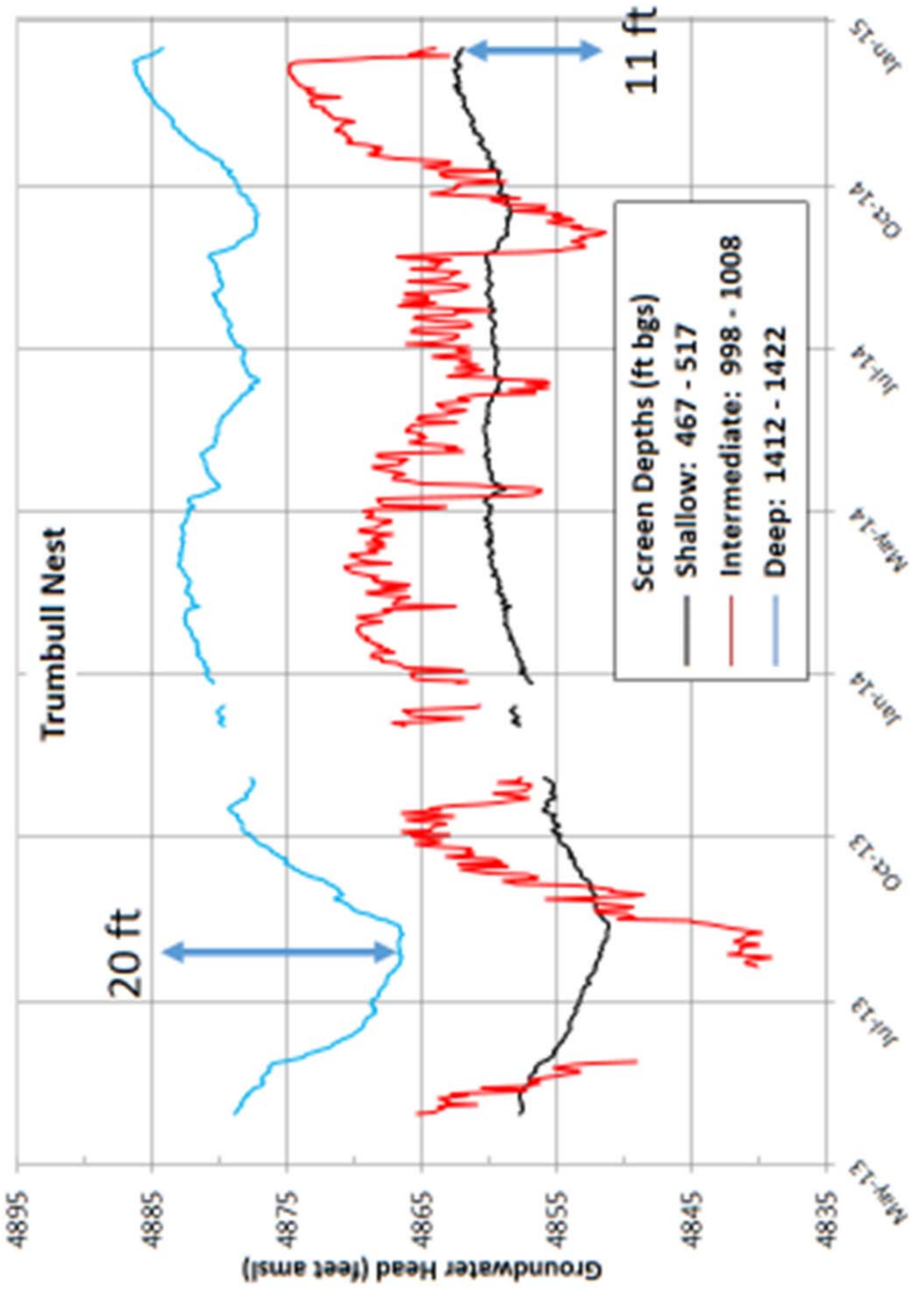


Figure 37. Groundwater Head Changes at Trumbull Cluster



NOTES:

Kirtland Air Force Base (KAFB)
Bulk Fuels Facility (BFF)
Public Field Trip

STOP 3 - Remediation Technologies

Understanding remediation technologies that can be applied in the field

Speakers:

Wayne Bitner, U.S. Air Force

Diane Agnew, CB&I

Dr. Patrick Longmire, Department of Energy Oversight Bureau – New Mexico Environment Department

Dr. Adria Bodour, U.S. Air Force

Jason Tarbert, CB&I

Dennis McQuillan, New Mexico Environment Department

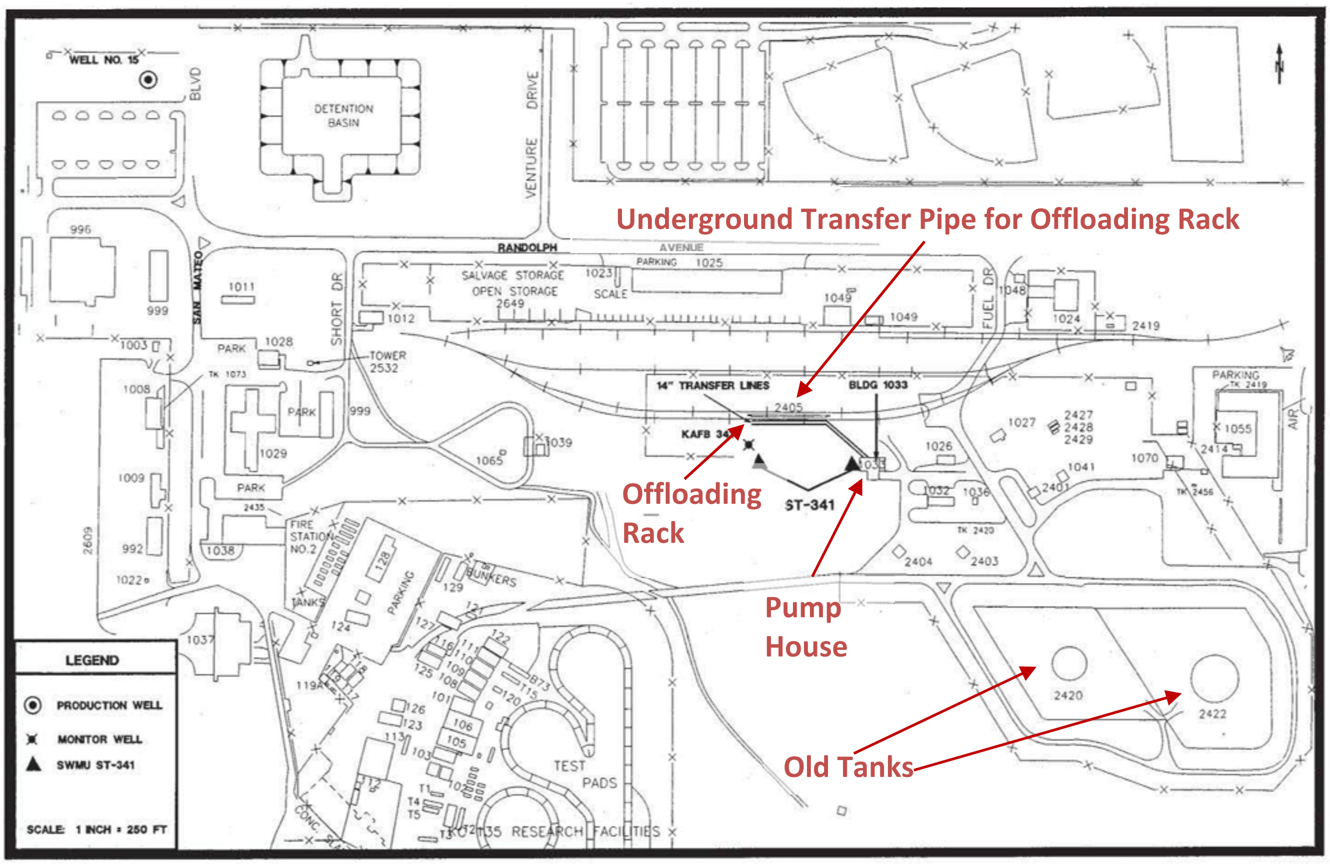
Rick Shean, Albuquerque Bernalillo County Water Utility Authority

STOP 3 – KAFB BFF AND HISTORY OF SPILL

(Wayne Bitner, U.S. Air Force)

The BFF first operated in 1953 and was serviced by a railway delivery system that transported fuel from several sources. Fuel was offloaded through an aboveground offloading rack and transferred through a pump house that moved the fuel to two storage tanks. In 1999, fuel was discovered at the surface, pooling above the underground transfer pipe near the offloading rack. Remediation efforts began in 2000.

Figure 38. Historical configuration of KAFB BFF



NOTES:

In 2011, a new state of the art fuel facility was built. All piping is above ground, double-hulled, with sensors and alarms, with concrete catchment basins, and meters to account for all fuel transferred and distributed.

Figure 39. Current state-of-the-art bulk fuels facility

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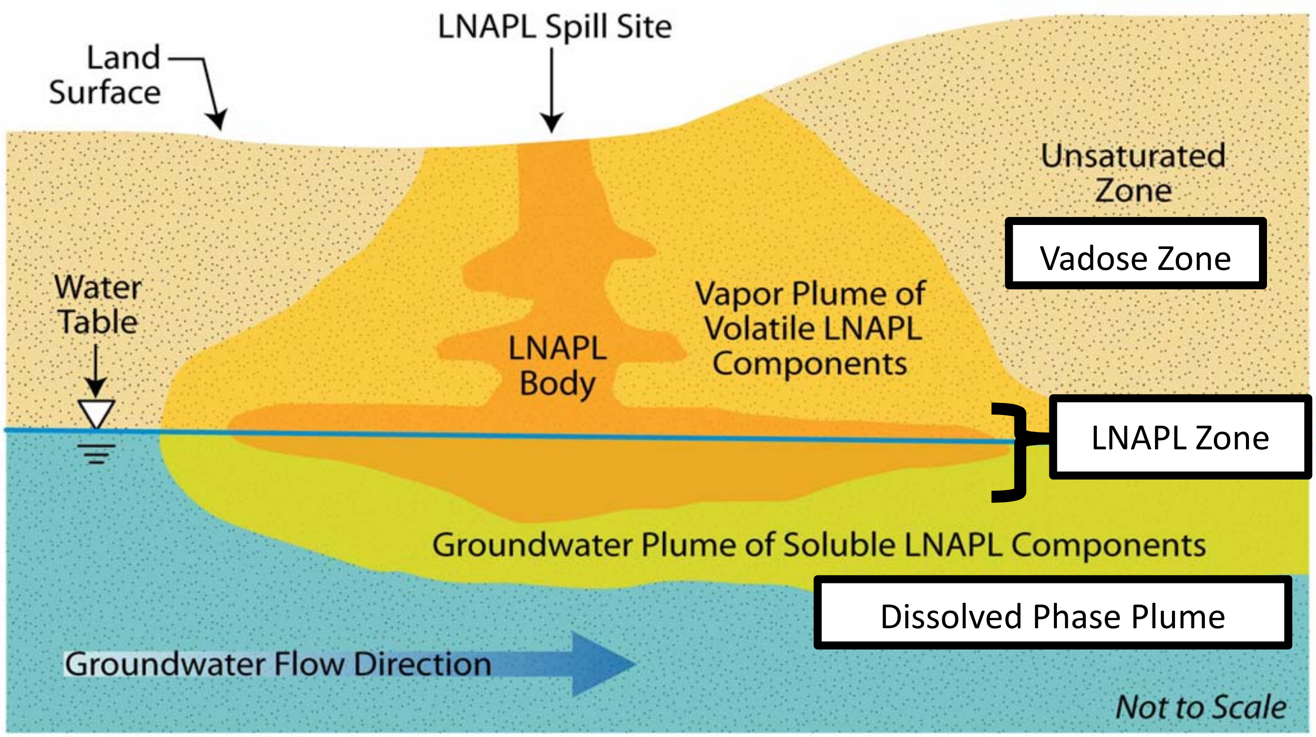
Figure 40. Anatomy of a fuel spill



Adapted from Delin et al., 1998, USGS Fact Sheet FS-084-98

NOTES:

STOP 3 –SOIL VAPOR EXTRACTION (SVE)

(Diane Agnew, CB&I)

The first clean up technology applied at the BFF in 2003 was a soil vapor extraction (SVE) unit using an internal combustion engine (ICE) unit that was connected to nine SVE wells at varying depths. Starting in 2008-09, three more SVE ICE units were put into service expanding the footprint effectiveness for extracting fuel vapor constituents. In 2012, two new SVE wells were installed (KAFB-106160 and KAFB-106161); while the four SVE ICE units were pilot tested on various wells including the newly installed SVE wells. Starting in 2013, all SVE ICE units were replaced by a catalytic oxidation (CATOX) system and only KAFB-106160 and KAFB-106161 were extracted from, until 2014. In March 2014, three soil monitoring clusters were added to the CATOX system; thus increasing the footprint of extracted vapor. This SVE extraction and configuration was in service until the pilot in-situ respiration and rebound testing began on April 6, 2015.

Figure 41. SVE ICE unit attached to nine SVE wells at various depths from 2003 to 2007

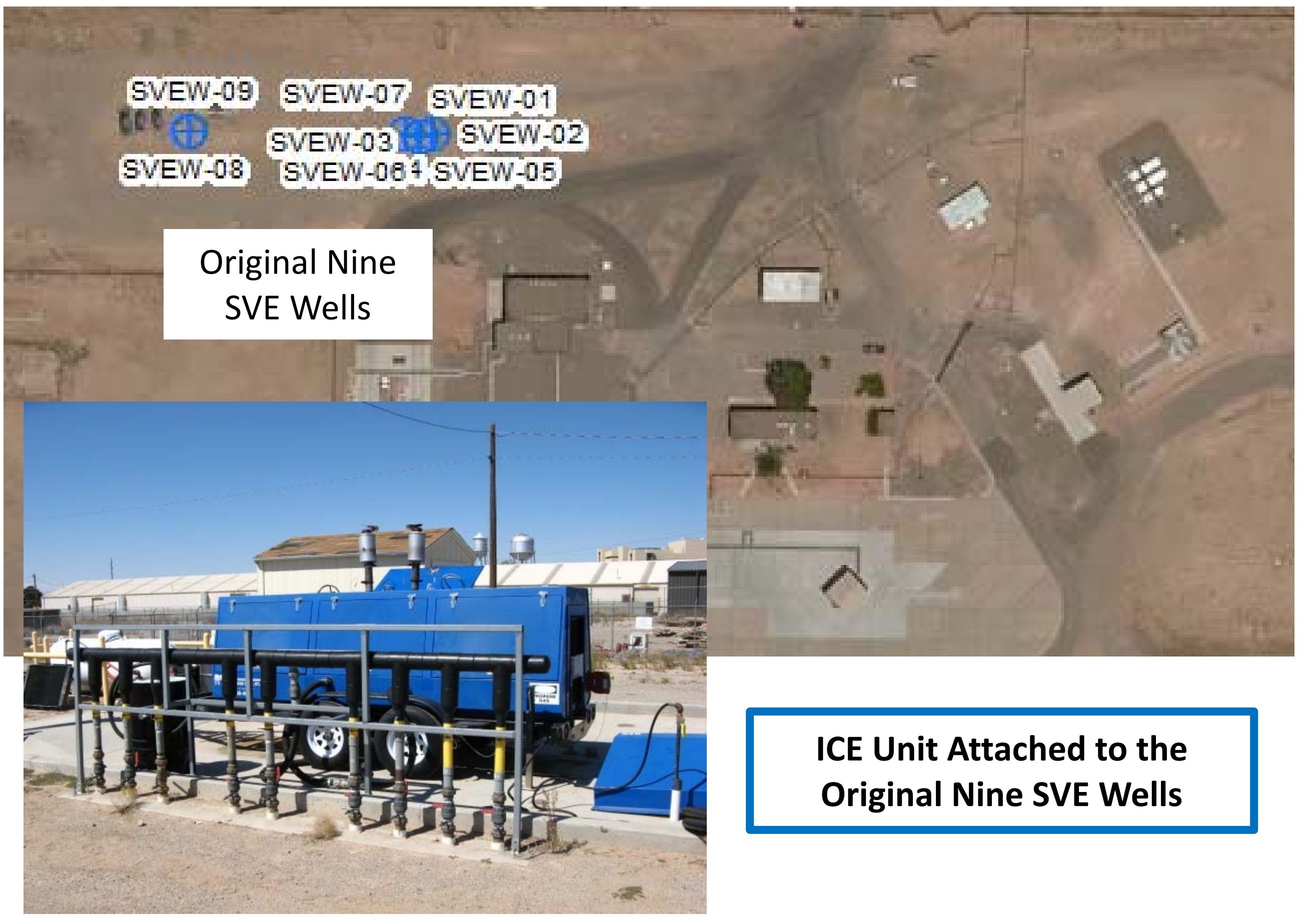
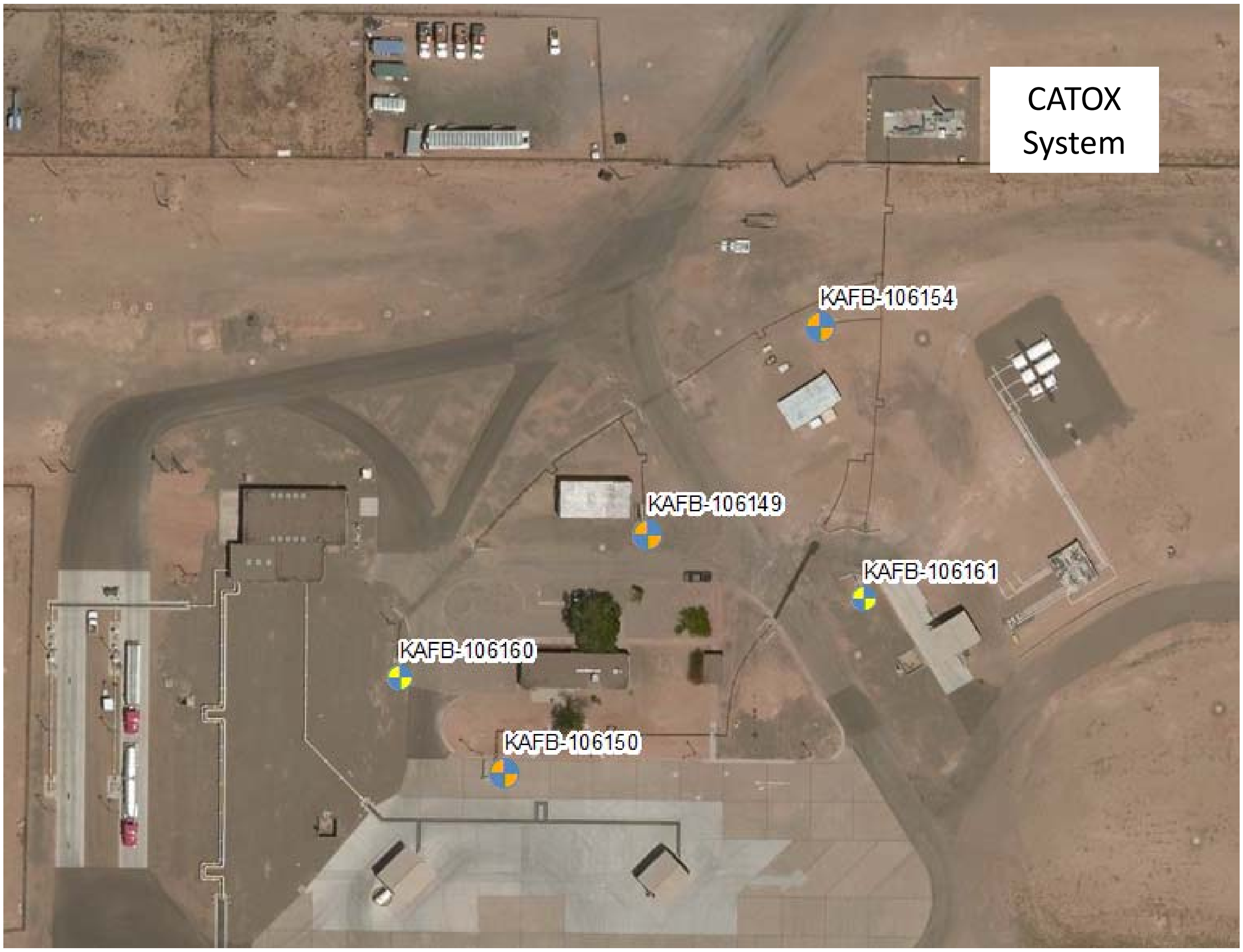


Figure 42. SVE ICE unit locations increasing vapor destruction in 2008-2009

Figure 43. Pilot testing different SVE locations using the four SVE ICE units in 2012

Figure 44. SVE locations using the CATOX system in 2013; KAFB-106160 and KAFB-106161 operated, and in March 2014 KAFB-160149, KAFB-106150, and KAFB-106154 were added to the system, and operated until April 2015



After 12 years of SVE operation, more than 600,000 gallons of fuel have been removed and soil vapor concentrations have dramatically decreased. On April 6, 2015, operation of the soil vapor extraction system was temporarily suspended in order to monitor any increases in vapor concentrations. The next step will be to conduct in-situ respiration and rebound testing by measuring oxygen, carbon dioxide, and hydrocarbon vapor. The oxygen and carbon dioxide measurements will be used to calculate the biodegradation rate of soil bacteria degrading the fuel constituents. Additionally, the rebound evaluation of the hydrocarbon vapor concentrations will identify:

1. Areas for continued SVE due to high residual fuel mass being present
2. Areas where treatment should switch from SVE to bioventing (adding ambient air into the subsurface to increase oxygen concentrations)
3. Areas that need no further treatment

Figure 45. Cumulative mass removed by the SVE from July 2003 to January 2015, totaling ~3.9M pounds (~600,000 gallons) removed

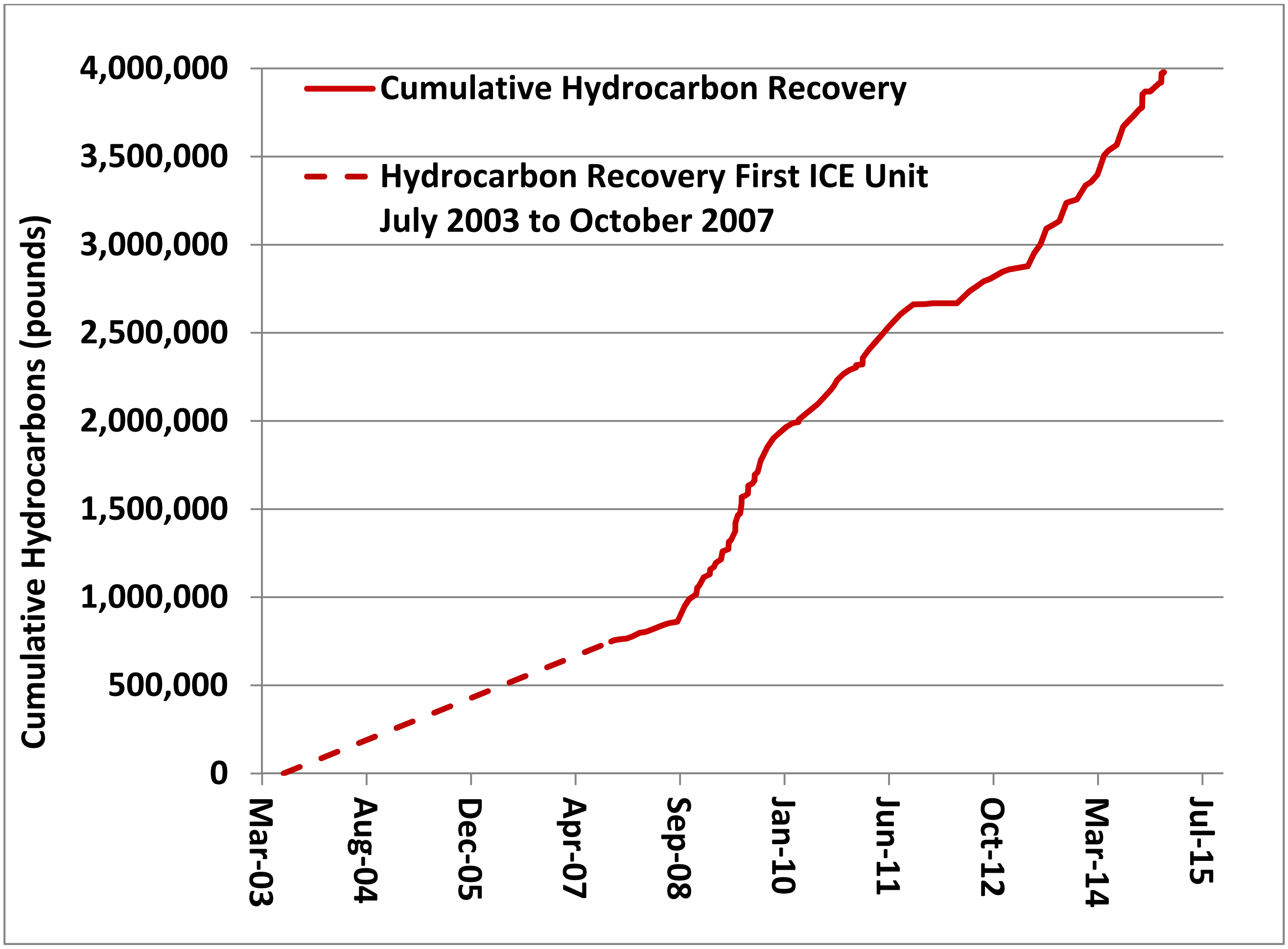
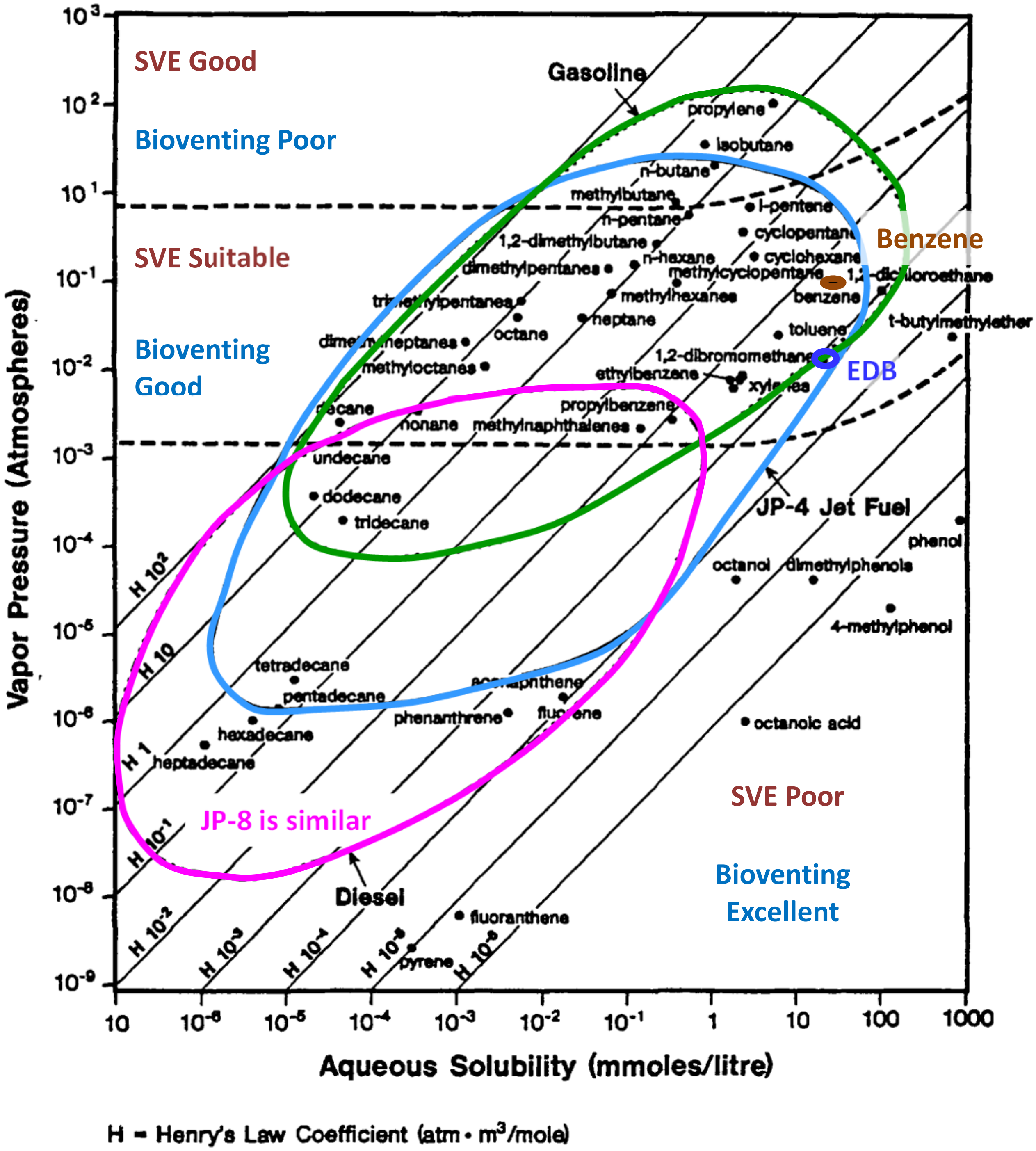


Figure 46. Soil vapor sampling apparatus

Figure 47. Suitability ranges for SVE and bioventing graphic from U.S. EPA Bioventing Manual 1995



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STOP 3 – INTRINSIC BIODEGRADATION OF HYDROCARBONS AND EDB

(Dr. Patrick Longmire, Department of Energy Oversight Bureau – New Mexico Environment Department [NMED])

1,2-Dibromoethane, also called ethylene dibromide (EDB - $CBrH_2CBrH_2$), is a component of aviation gasoline present in the subsurface at Kirtland Air Force Base (KAFB). This toxic chemical is mobile in groundwater under aerobic conditions (dissolved oxygen concentrations greater than 0.1 mg/L) and is the main focus of groundwater remediation downgradient of the light non-aqueous phase liquid (LNAPL) (jet fuel and aviation gasoline). 1,2-Dibromoethane undergoes biodegradation forming ethene and bromide under anaerobic conditions (no dissolved oxygen present). Excess concentrations of dissolved bromide in the regional aquifer suggest that EDB is biodegrading within localized areas in contact with LNAPL. Biodegradation of EDB is most likely occurring under sulfate-reducing conditions, which is limited in aerial extent. Most of the dissolved EDB; however, has become mobilized under aerobic conditions extending approximately 7,000 feet downgradient of the LNAPL zone. Biodegraded concentrations of EDB are estimated between 1 and 3 mg/L, which may represent the effective solubility of EDB in LNAPL consisting of aviation gasoline and jet fuel. Microcosm studies are being conducted to further define EDB biodegradation within the regional aquifer at the site. Bioremediation is a viable remediation option for destroying EDB under anaerobic conditions in contact with LNAPL.

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Potential Biodegradation of 1,2-Dibromoethane in the Regional Aquifer, Kirtland Air Force Base, Albuquerque, NM

Dr. Patrick Longmire[1], Dennis McQuillan[1], and Dr. Javier Santillan[2]

[1]New Mexico Environment Department and [2]Noblis

April 18, 2015

Acknowledgements: Dr. Paul Hatzinger, Dr. Jonathan Myers, Dr. Mike Amdurer, and Diane Agnew of CB&I; Dr. Adria Bodour and Wayne Bitner of US Air Force

Table 6. 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.

The above table provides a partial list of important physicochemical properties of 1,2-dibromoethane (EDB), 1,2-dichloroethane (1,2-DCA), and benzene relevant to environmental investigations. The aqueous solubility of an organic compound strongly influences its ability to adsorb or partition onto aquifer solids and volatilized from soil/sediment moisture and groundwater. Benzene volatilizes to a greater extent than EDB during air sparging and soil vapor extraction, whereas EDB tends to remain in groundwater due to its higher aqueous solubility (4,321 mg/L).

Reduction of 1,2 Dibromoethane to Ethene in Aqueous Solution

$C_2H_4Br_2 + 2e^- \rightarrow C_2H_4 + 2Br^-$

Eh = +325 mV at 25^{o}C, Br^- = $10^{-4.61}$ M (2 mg/L)

EDB reduces to ethene in the presence of *Dehalococcoides* bacteria and this thermodynamic reaction is shown above. Bromide is released to solution during EDB reduction under anaerobic conditions (sulfate reduction).

Figure 48. EDB plume in the regional aquifer (CB&I, 2014)

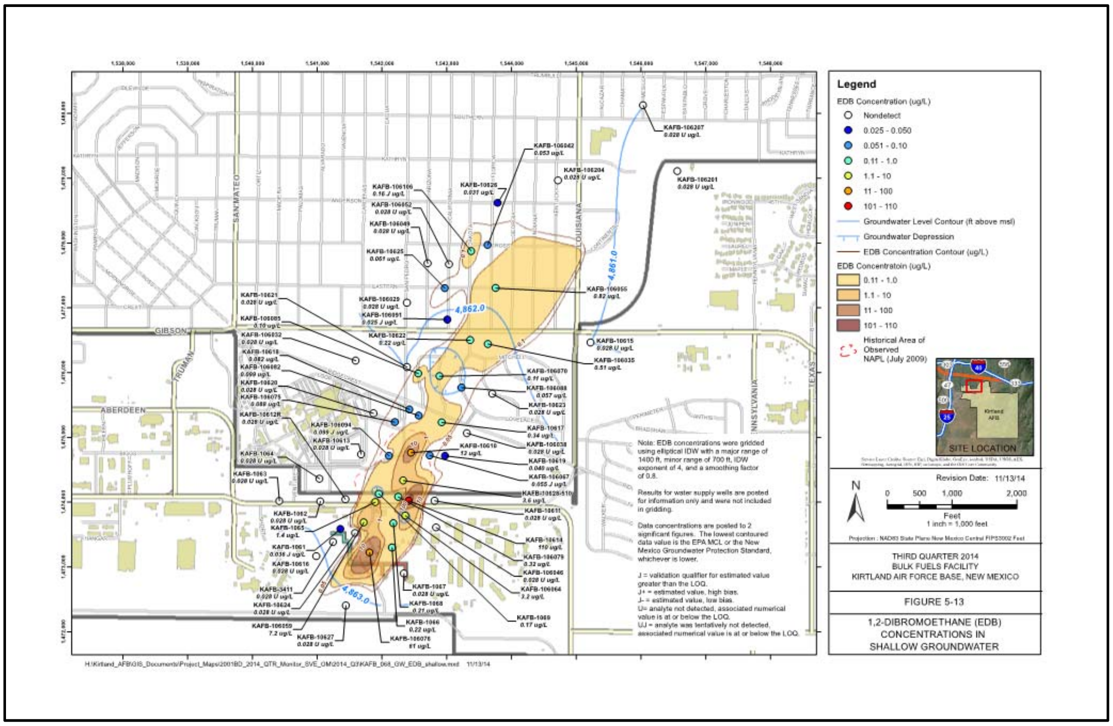
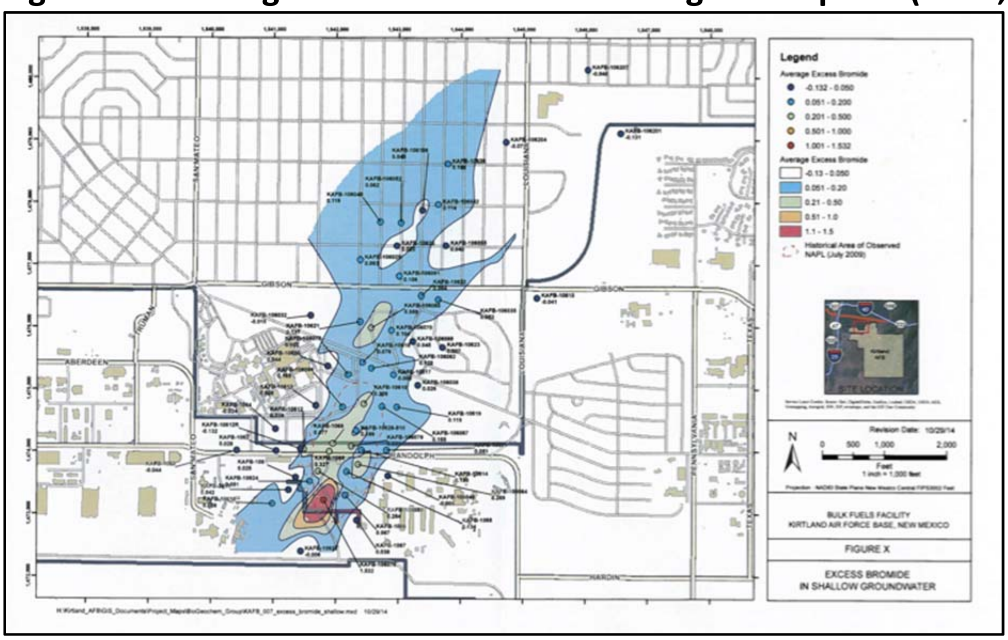


Figure 49. Average excess bromide in the regional aquifer (CB&I, 2014)



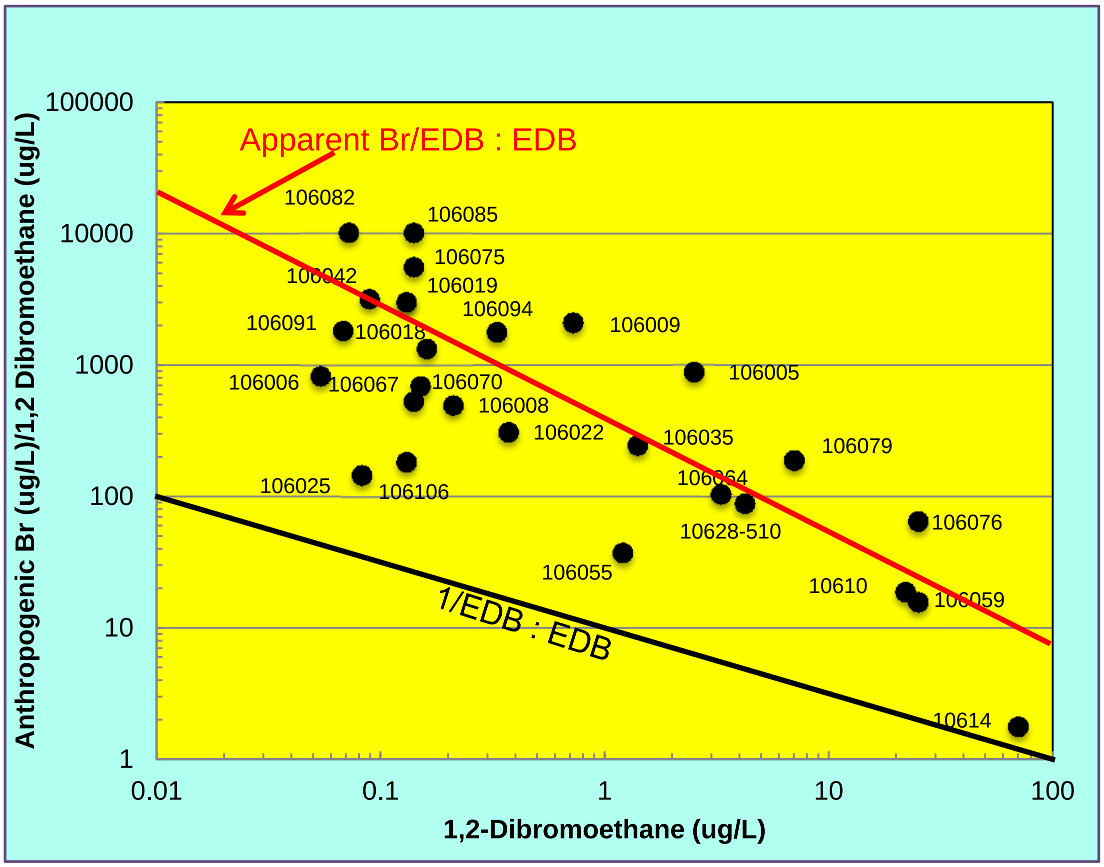
The above figure shows the distribution and range of average excess bromide measured in the shallow zone of the regional aquifer. Average concentrations of excess bromide range from -0.132 to 1.532 mg/L. Average excess concentrations of bromide range from 0.21 to 1.5 mg/L within the LNAPL zone, characterized by iron(III) and sulfate reducing conditions. Mean and median concentrations of background bromide are 0.40 and 0.25 mg/L (32 samples), respectively, in the shallow regional aquifer. Source of map: CB&I, 2014.

Groundwater chemistry data strongly suggest that EDB is biodegrading at specific locations within the LNAPL zone in the regional aquifer.

- Benzene, toluene, ethylbenzene, and xylene isomers (BTEX) and EDB are undergoing localized biodegradation in groundwater at the site.
- Oxidation of BTEX is most likely the carbon source coupled with reductive debromination of EDB in the anaerobic section of the plume below the known light non-aqueous phase liquid (LNAPL) at the site. This debromination process results in an increase in bromide concentration in groundwater.

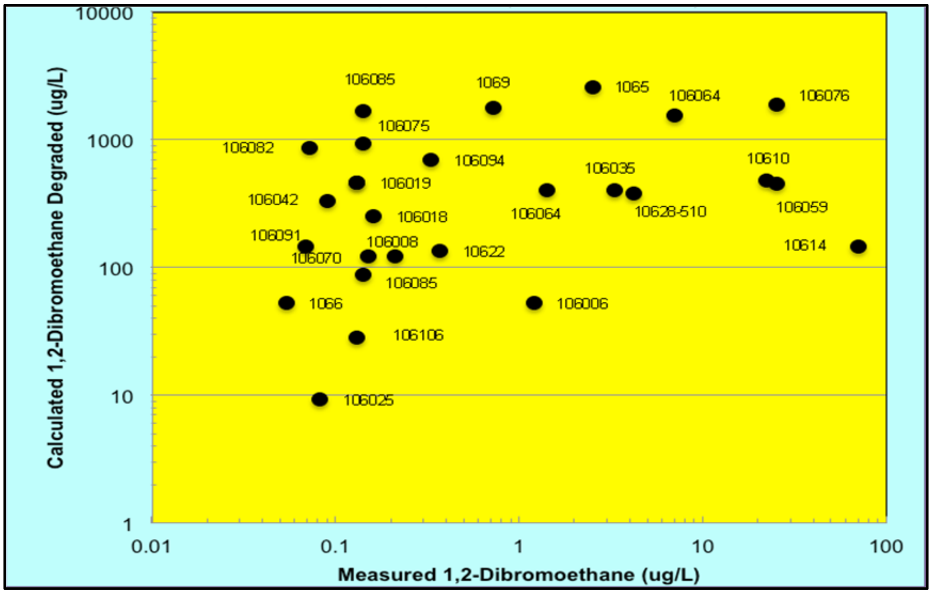
Reduction of EDB to ethene is likely occurring at variable rates of attenuation in the anaerobic groundwater experiencing sulfate reduction. Non-biodegraded EDB is mobilized in aerobic groundwater downgradient of the LNAPL source at KAFB.

Figure 50. EDB vs. anthropogenic bromide/EDB using Q1 2014 groundwater concentrations



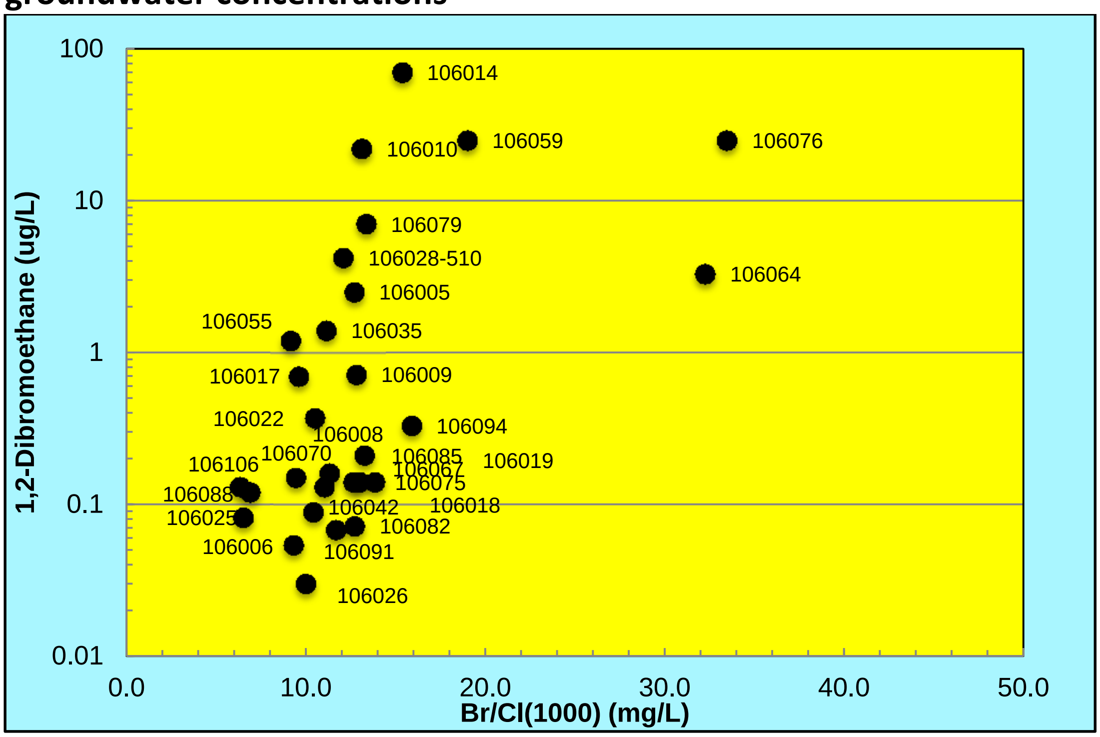
The above figure shows concentrations of EDB versus the ratio of anthropogenic bromide/EDB analyzed in regional aquifer groundwater samples. Groundwater samples collected from monitoring wells showing variable biodegradation (debromination) of EDB plot in the upper left of the figure. Those groundwater samples showing little or no biodegradation of EDB plot in the lower right of the figure. Source of data: CB&I, 2014.

Figure 51. Measured EDB vs calculated EDB using Q1 2014 groundwater concentrations



The above figure shows results of bromide mass balance calculations to quantify biodegradation of EDB. Empirical evidence supporting this process is provided by elevated above background-baseline concentrations of bromide. Estimating EDB biodegradation was calculated by initially subtracting an average background bromide concentration of 0.075 mg/L. Variable rates of EDB biodegradation are likely to occur within the different anaerobic redox zones established at the site. Source of data: CB&I, 2014.

Figure 52. Bromide/chloride vs. EDB in the regional aquifer using Q1 2014 groundwater concentrations



This figure shows ratios of bromide/chloride (1000) versus EDB concentrations analyzed in regional aquifer samples collected during the first quarter of 2014. Most of the groundwater samples collected from monitoring wells have ratios of Br/Cl (1000) ranging from 6 to 19 with two monitoring wells having ratios greater than 32. Groundwater mixing results in variations in Br/Cl (1000) ratios along flow paths within the regional aquifer. Less than one-half of the values shown in this figure represent monitoring wells located in or near the LNAPL zone. Lower concentrations of EDB are associated with monitoring wells located downgradient or crossgradient from the LNAPL zone. Source of data: CB&I, 2014.

Summary and Conclusions

Excess concentrations of dissolved bromide in the regional aquifer suggest that EDB is biodegrading within localized areas in contact with LNAPL. EDB biodegradation is most likely occurring under sulfate-reducing conditions, which is limited in aerial extent.

Most of the dissolved EDB, however, has become mobilized under aerobic conditions extending approximately 7000 feet downgradient of the LNAPL zone.

Biodegraded concentrations of EDB are estimated or calculated between 1 and 3 mg/L, which may represent the effective solubility of EDB in LNAPL consisting of aviation gasoline and jet fuel.

Microcosm studies are being conducted to further define EDB biodegradation within the regional aquifer at the site. Bioremediation is a viable remediation option for destroying EDB under anaerobic conditions in contact with LNAPL.

STOP 3 - COLLAPSING THE EDB PLUME

(Dr. Adria Bodour, U.S. Air Force and Jason Tarbert, CB&I)

We have a three phase approach to collapsing the EDB plume. Phase 1 – Interim measure pump and treat of the EDB plume with one extraction well (diamond symbol in figures) in the vicinity of well KAFB-106035 and additional characterization of the lateral and vertical extent (star symbols in figures). Eleven of the 16 data gap groundwater monitoring wells have been installed. Currently, the last 5 data gap groundwater monitoring wells, and one extraction well, are being installed, which should be done by the end of May 2015. The initial extraction well will pump and treat approximately 100 gallons per minute (gpm) and will begin treating EDB contaminated groundwater on June 30, 2015. Phase 2 – Design and construct an expanded pump and treat system to collapse the EDB plume. This includes the installation of up to 7 additional extraction wells, with a total pumping rate of 600-800 gpm. Phase 3 – System operation and maintenance, along with optimization, to stop potential migration and continue collapsing the EDB plume.

Figure 53. Filling data gaps by installing new groundwater monitoring wells (star symbols)

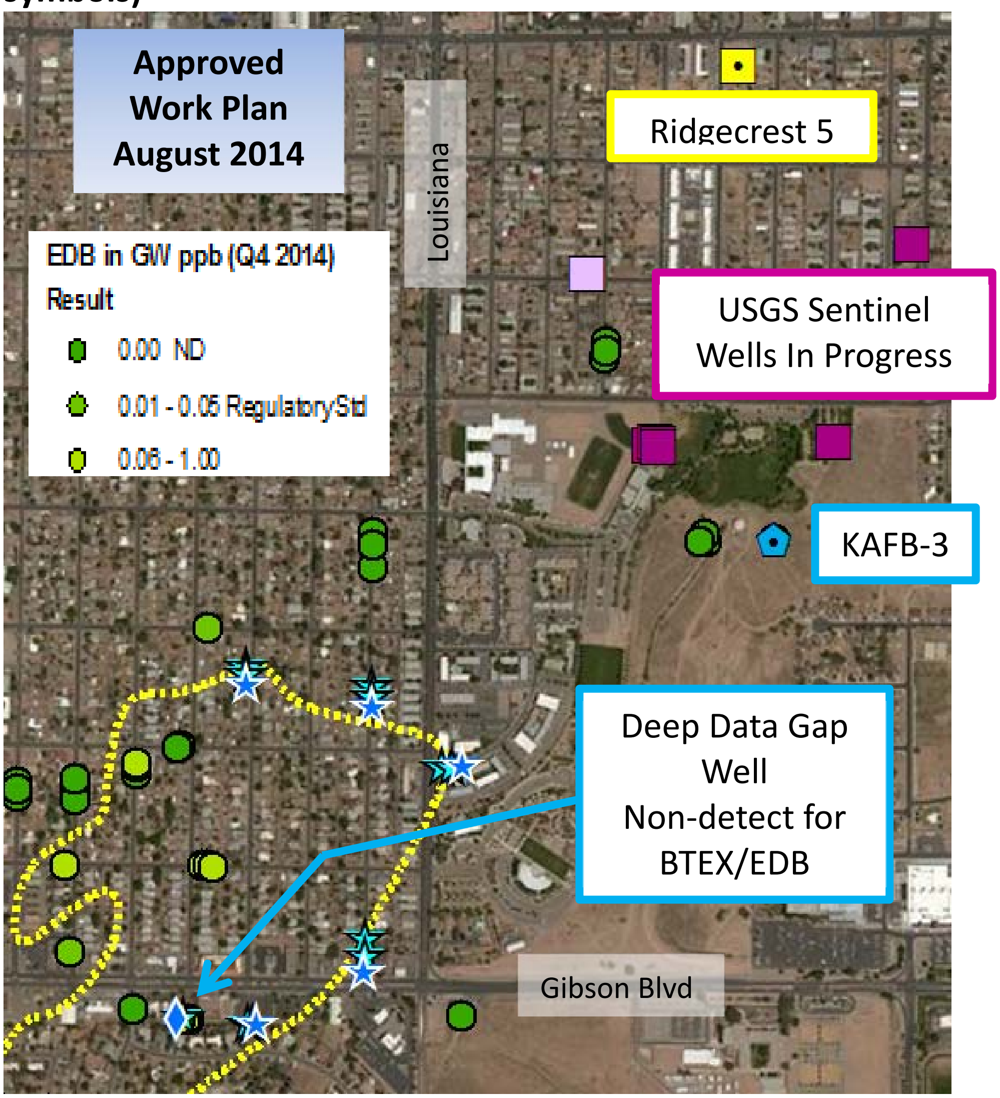


Figure 54. Collapsing the dissolved EDB Phase 1 and 2 for calendar year (CY) 2015

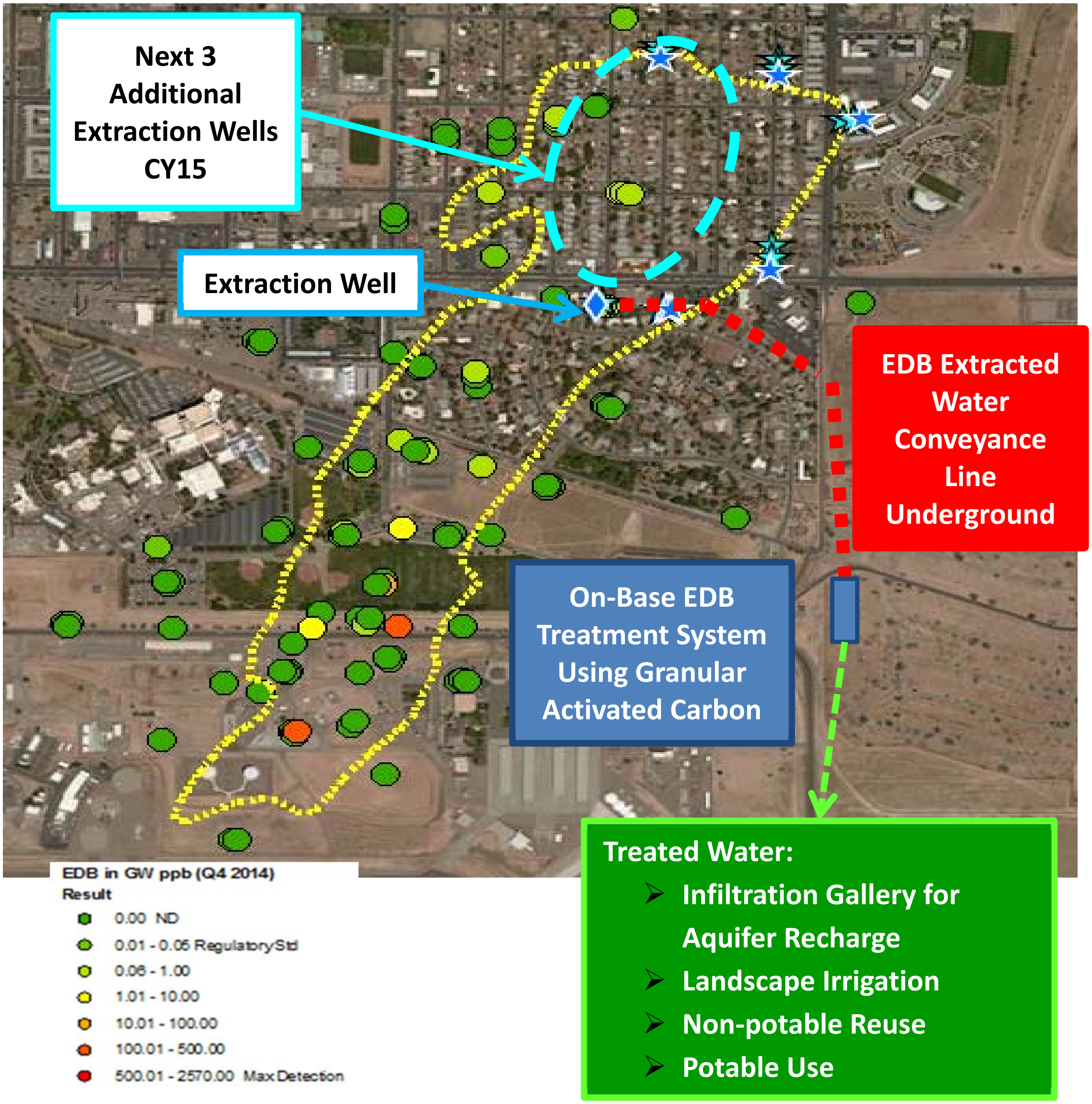


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Figure 55. Dissolved benzene plume maps from Q4 2011 to Q4 2014

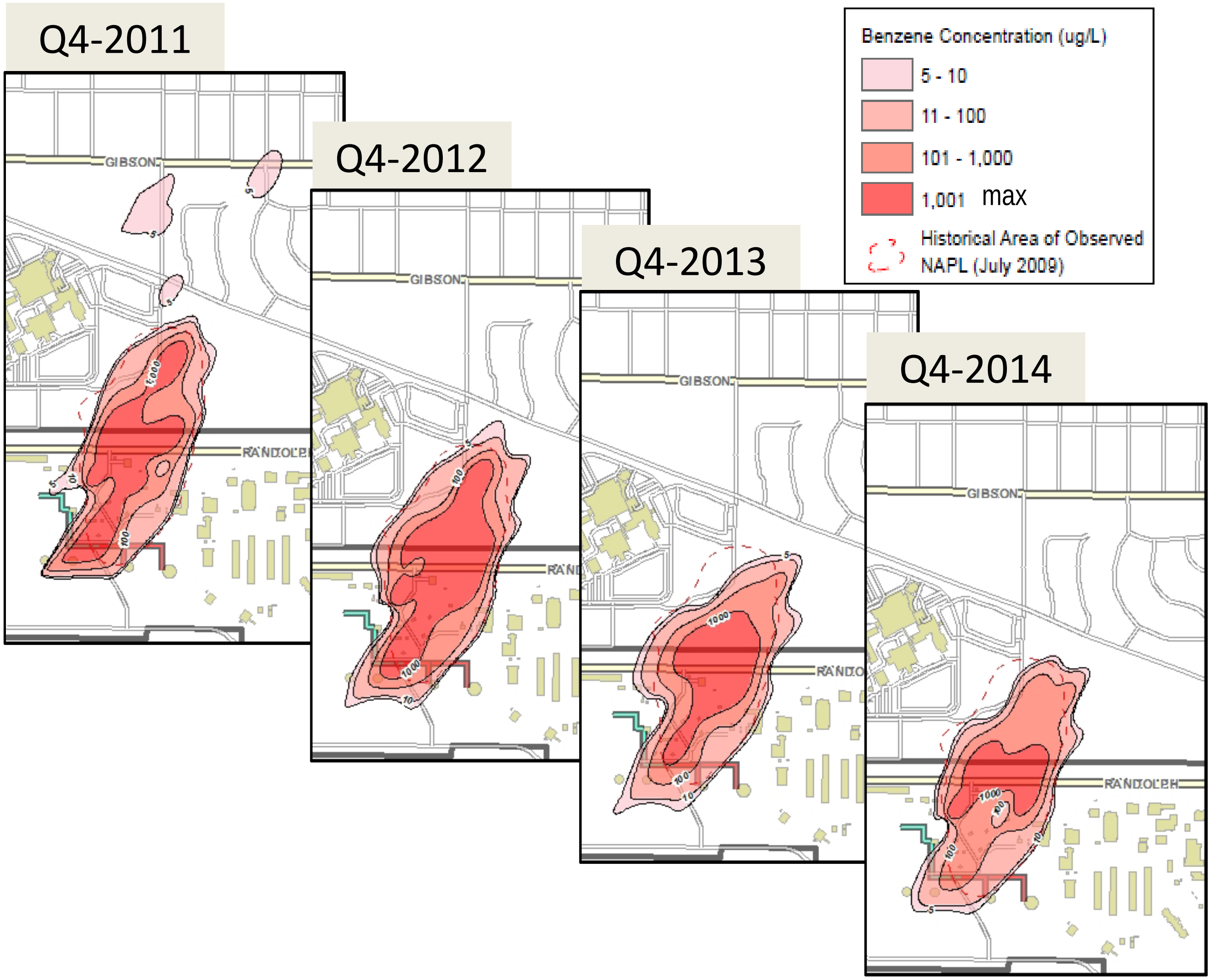

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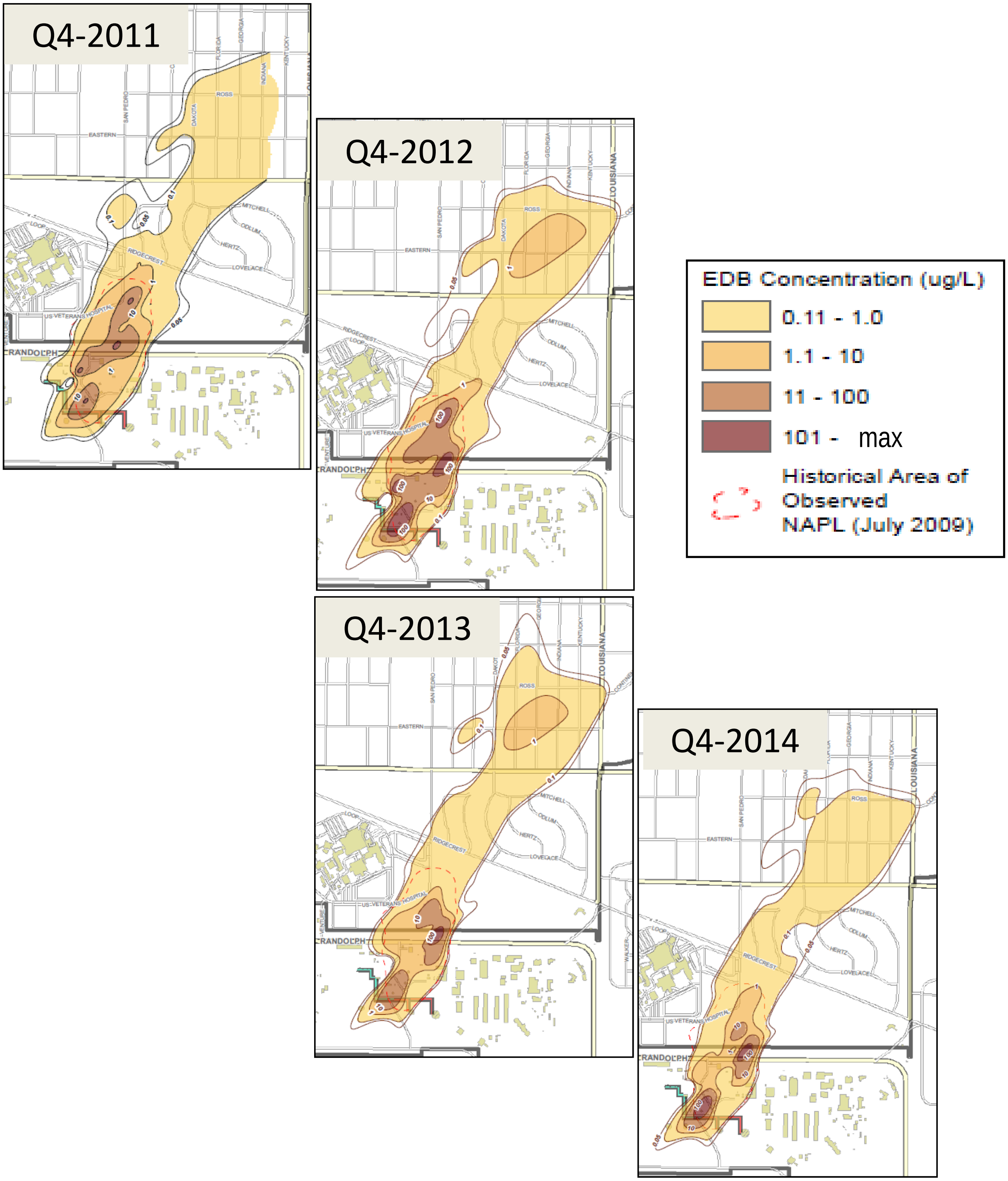
Figure 56. Dissolved EDB plume maps from Q4 2011 to Q4 2014



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STOP 3 - PROTECTION OF WATER-SUPPLY WELLS

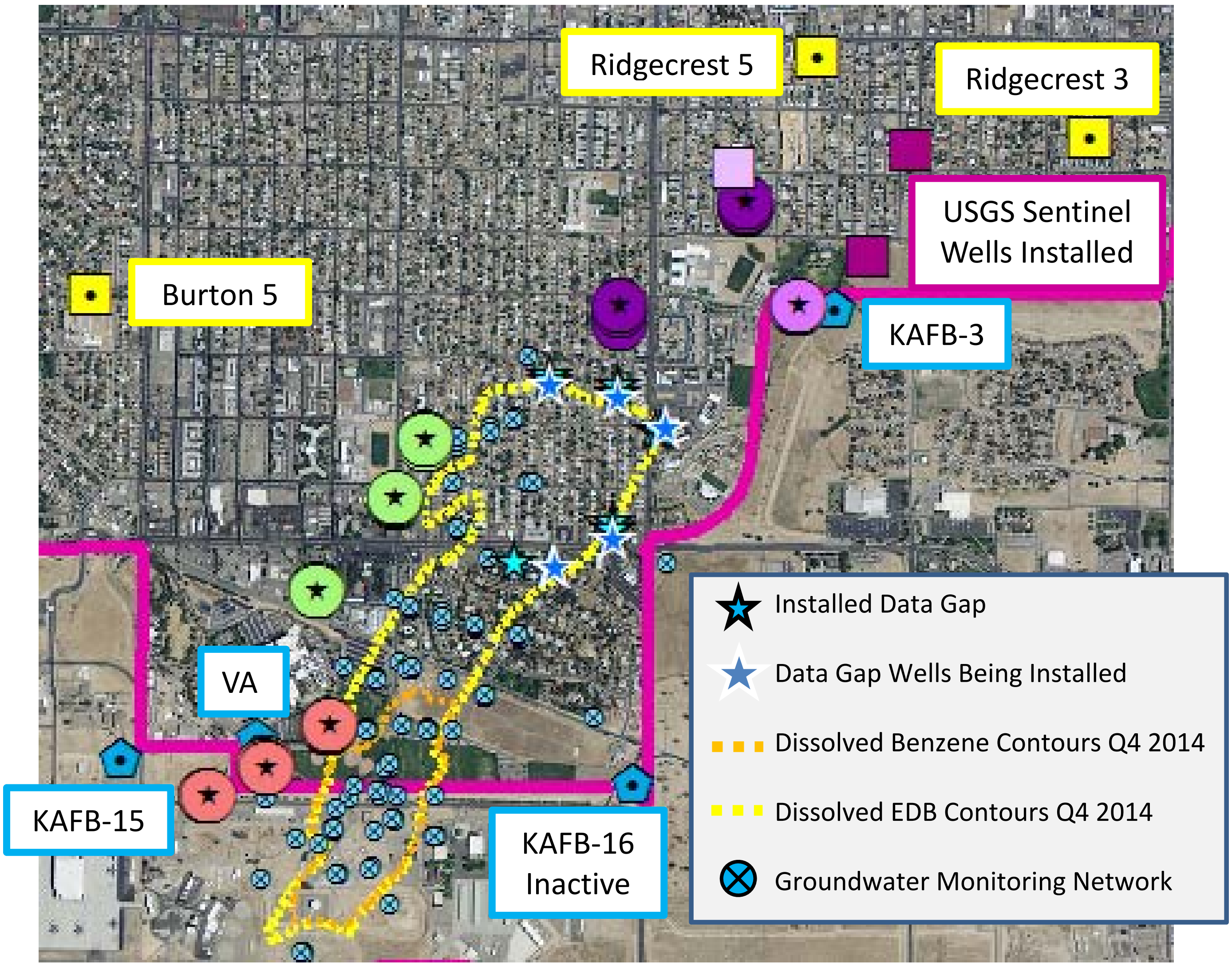
(Dennis McQuillan, New Mexico Environment Department [NMED]) and Rick Shean, Albuquerque Bernalillo County Water Use Authority [ABCWUA])

The NMED has been granted primacy by the U.S. Environmental Protection Agency to administer the provisions of the federal Safe Drinking Water Act (SDWA). One of the requirements of the SDWA program is that public water supply systems deliver water to consumers that complies with the maximum contaminant levels (MCLs) for EDB, benzene and other constituents of the hydrocarbon fuels that were spilled at the KAFB BFF site.

There are several active public water supply wells that are located in the immediate vicinity of the KAFB dissolved benzene and EDB plumes. Each month, both Air Force and Water Authority test the drinking water production wells near the KAFB BFF spill. To date, none of these drinking water production wells have had detections of fuel constituents. Additionally, the sampling frequency exceeds the law requirement to sample the drinking water supply wells, which is once every three years. NMED, Water Authority, and the Air Force are committed to keep Albuquerque's citizens from drinking contaminated groundwater and to protect their health.

Furthermore, deep sentinel wells have been installed by the USGS at locations between the dissolved EDB plume and the drinking water supply wells, Ridgecrest 3 and 5. In addition, there are several proximal sentinel wells that are tested on a quarterly basis and no fuel constituents have been detected in any of these wells.

Figure 57. Early detection sentinel wells (enlarged colored circle and square symbols) for the active public water supply wells (yellow square symbols and blue pentagon symbols) in the immediate vicinity of the dissolved benzene and EDB plumes



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