Kirtland Air Force Base
Fuel Leak Cleanup

Note: These slides were not given as a presentation.

Individual slides were used as needed to help answer participant's questions. Many of these slides were not used at this event, but were used at various other speaking engagements and public meetings. Some of them are quite technical and were brought to provide a more detailed explanation about different aspects of the project, as needed.

As a general reminder, we are available to meet with you or your community group to discuss the project and answer any questions you may have. Please feel free to contact any of us using the phone numbers and emails provided on the last slide at the end of this document.

Technical Backup Slides

Community Conversation about the Kirtland Air Force Base Jet Fuel Spill

August 13, 2016

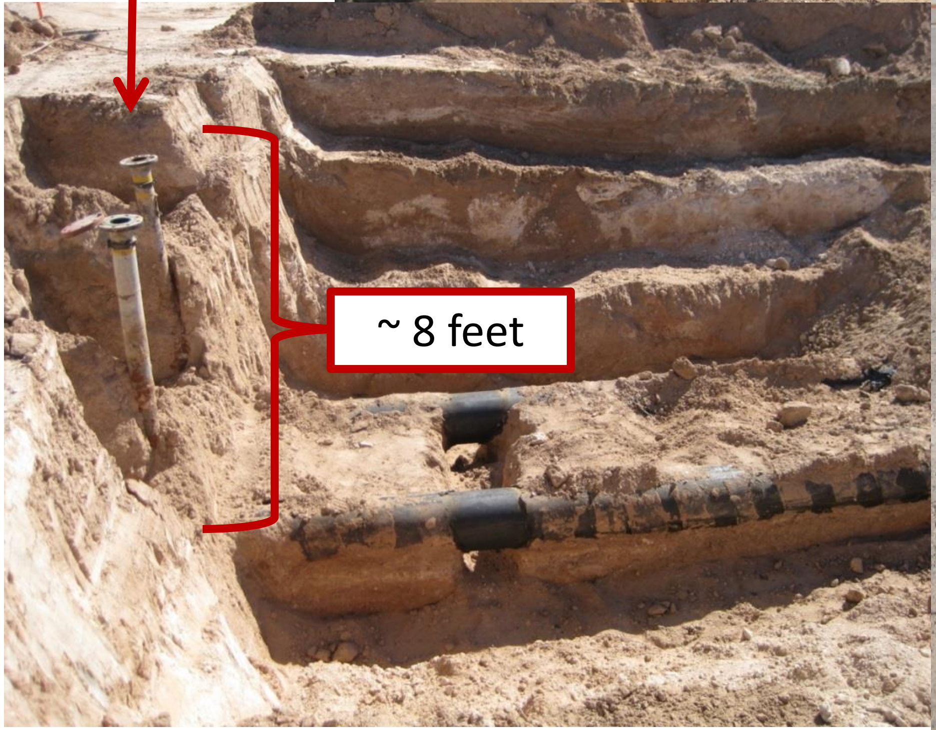
Site History

- The Kirtland Air Force Base (KAFB) Bulk Fuels Facility (BFF) is located in the northwestern portion of the base and began operation in 1953
- BFF was the fueling area for the installation and received bulk shipments of fuel from railcars and trucks
- An underground pipeline extending from the fuel off-loading area to the fuel pump house leaked jet fuel into the ground
- The leak was discovered in 1999 and KAFB sealed off the underground pipe and removed it from service
- The KAFB fuels facility was replaced in 2011 with all above-ground piping and tanks along with state-of-the-art leak detection technology

1999 Leak Photos at BFF

Metal Stair Step

Removal of Piping 2010 Photos



Regulatory Framework

- The New Mexico Environment Department (NMED) governs the fuel leak site through the administration of two federal acts:
  - Safe Drinking Water Act (SDWA)
  - Resource Conservation and Recovery Act (RCRA)
- Site activities are being completed under the Corrective Action provision of RCRA and KAFB's permit
  - Site investigation
  - Interim Measures (IMs)
  - Corrective Measures Evaluation (CME)
  - Corrective Measures Implementation (CMI)

Evaluating Potential Risk

- Current monitoring data and historical project records are used to determine human exposure and risk
- Potential risk is determined by identifying and evaluating possible contaminant pathways to people and the environment
- A risk assessment evaluates site data against possible pathways
- 2015 update to the NMED Risk Assessment Guidance provides a conservative road map for the Air Force to evaluate potential risk
- If necessary, risk is re-evaluated as site conditions change
- RFI Report will include the risk assessment and will be submitted in Winter 2016

Exposure Pathways

Potential risk occurs when a human or ecological receptor is exposed to contamination.

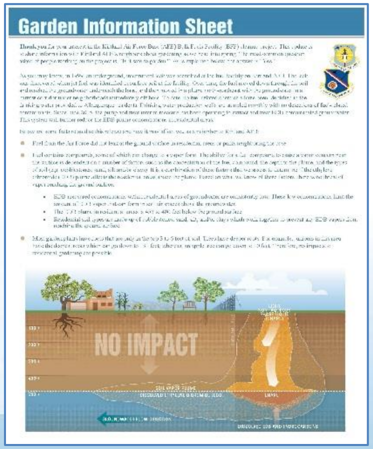
No exposure pathways or risks from BFF fuel contamination are present

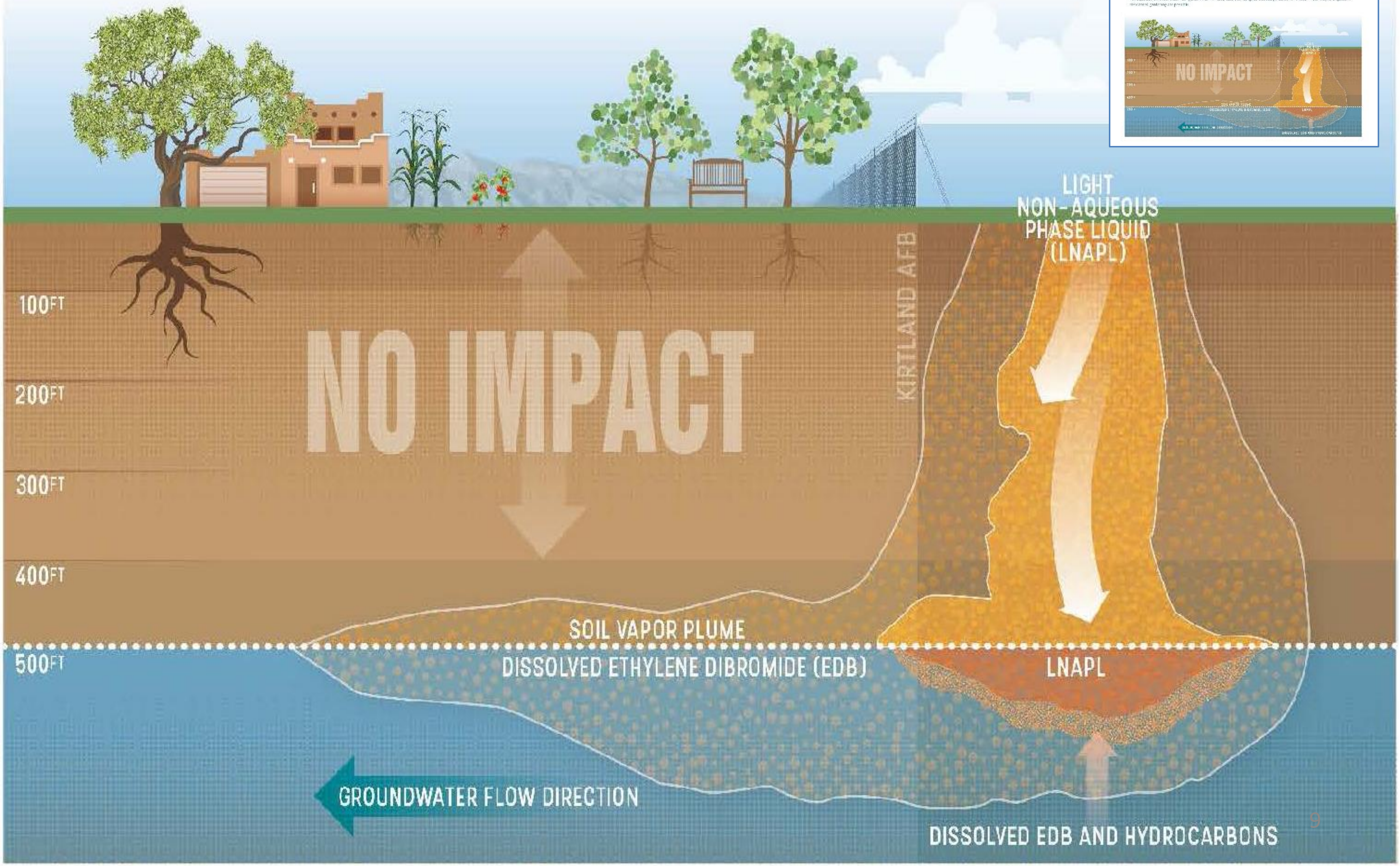
Potential Exposure Pathway	Risk Level	Explanation
Drinking Water		**Drinking water provided by the Albuquerque Bernalillo County Water Utility Authority (ABCWUA) continues to be free of any detectable fuel contamination and is safe for all uses.** Public drinking water wells near the groundwater contamination plume are tested monthly, and show no detections of any fuel compounds. Sentinel wells, which are monitoring wells located between the drinking water wells and the contamination plume, are tested quarterly and show no detections.
Surface Soil		**Surface soil contamination never migrated off of Kirtland.** Surface soil contamination has only occurred at the Kirtland Air Force Base Bulk Fuels Facility (BFF) industrial area which is not accessible to the general public. Contaminated soil has been excavated and removed for off-site disposal.
Surface Water		**There is no pathway for contaminants to enter surface water.**
Vapor Intrusion		**Homes and businesses are not at risk for vapor contamination.** There is no off-Base surface or near-surface soil contamination, and groundwater contaminants are too deep, to allow vapors to enter homes and buildings.
Garden Vegetables		**There is no risk of contamination to garden vegetables.** ABCWUA water is safe for irrigation. There is no off-Base surface soil contamination, and vapors from groundwater are too deep, for fuel to contaminate garden vegetables.
Recreational Activities		**There is no risk of contamination to people enjoying recreational activities in Bullhead Park or in the Dog Park.** Reclaimed ABCWUA water is used to irrigate the parks. There is no off-Base surface soil contamination, and vapors from groundwater are too deep, to pose a risk to people in the park areas.

(June 2016)

Safe	**Use Caution**	**Unsafe**

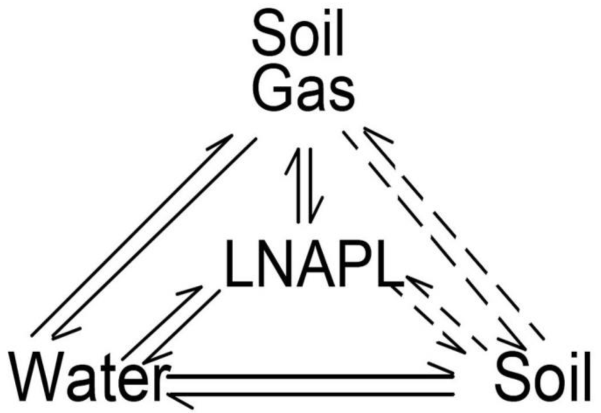
Garden Information Sheet



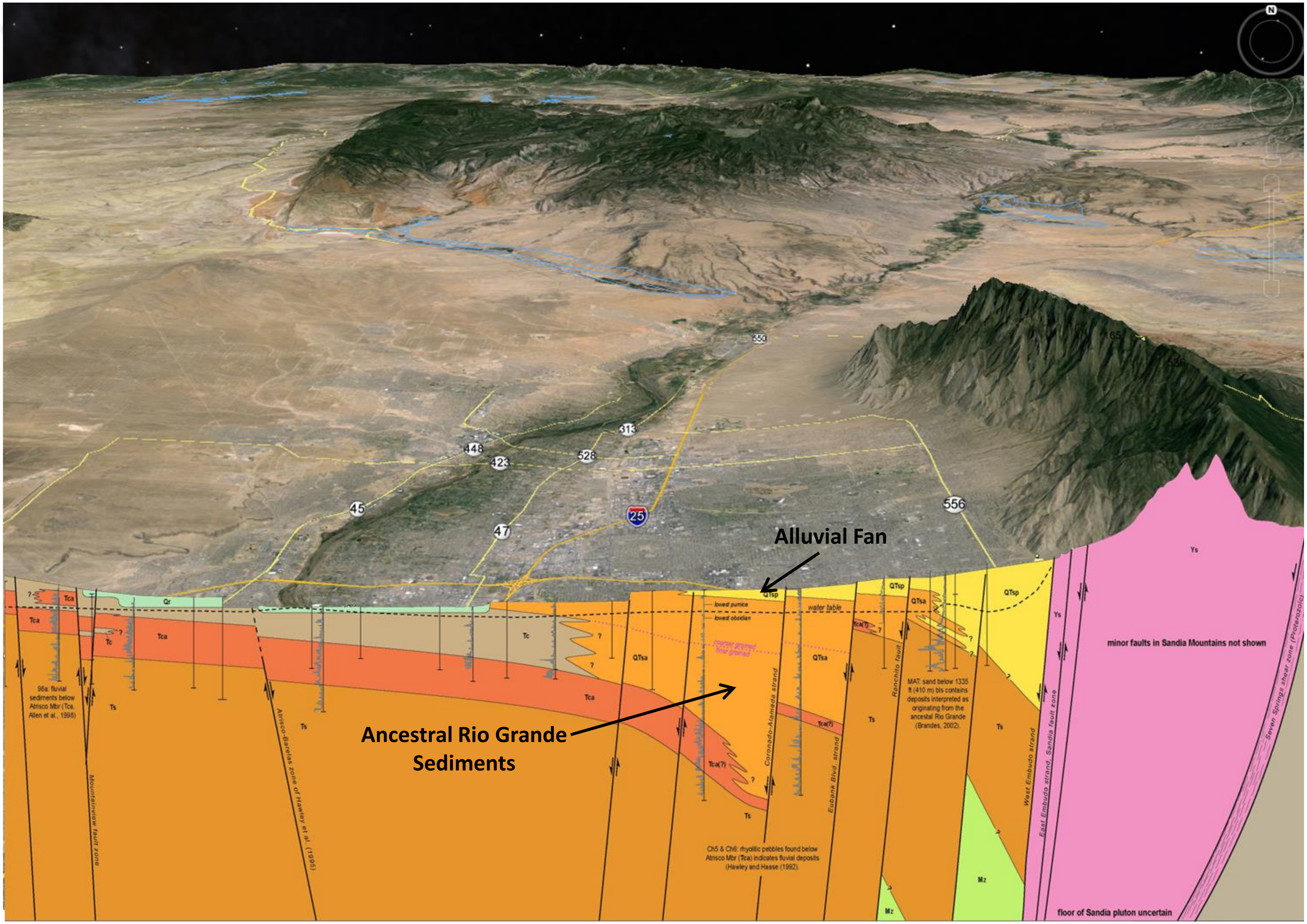


Fuel Plume Basics

- What is a plume?
  - A plume is a measureable discharge of a contaminant from a given point of origin
- When fuel is released into the ground, it migrates through the soil (vadose zone) until it eventually reaches groundwater
- In the case of the BFF, the fuel is found in four phases:
  - Light Non-aqueous Phase Liquid (LNAPL) residual fuel
  - Soil gas (vapor phase)
  - Adsorbed contaminants
  - Dissolved contaminants



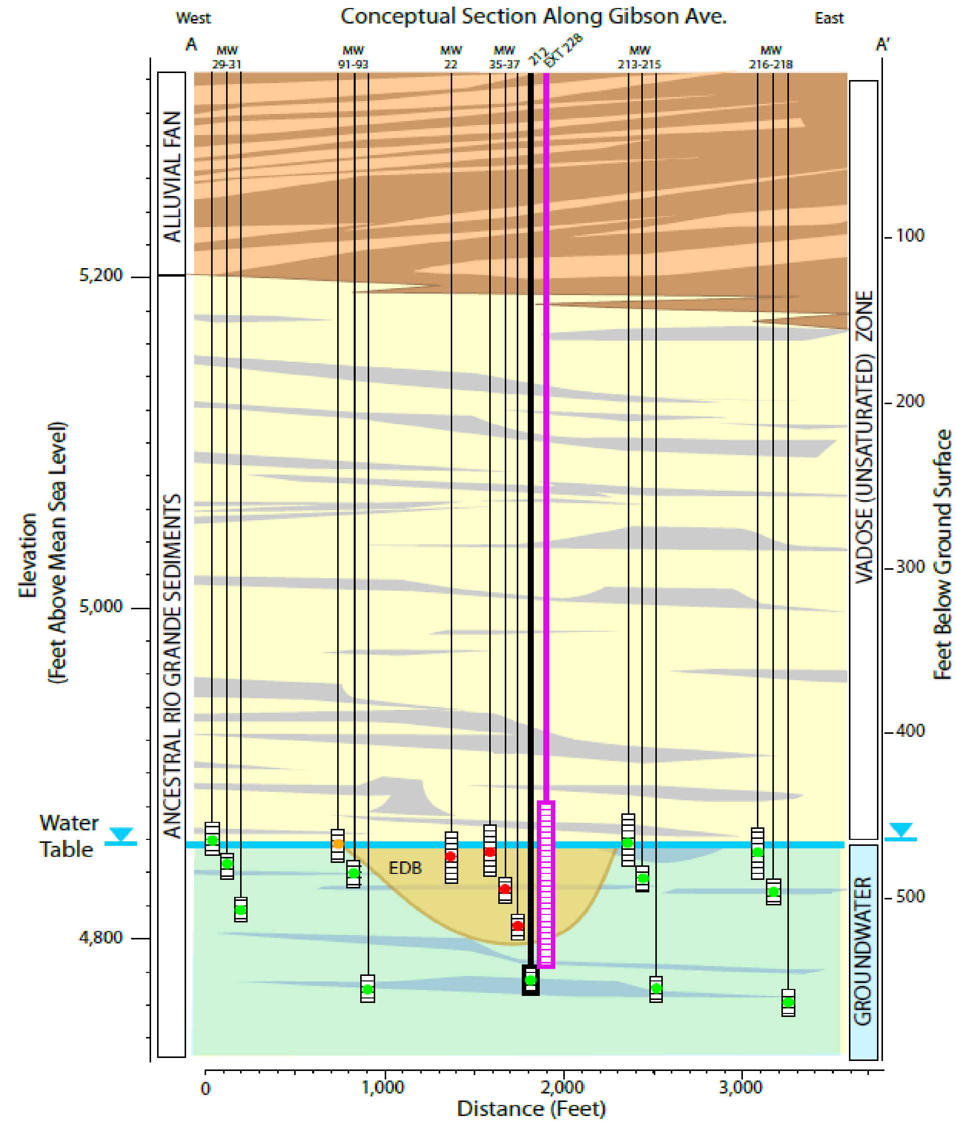
Understanding the Hydrology



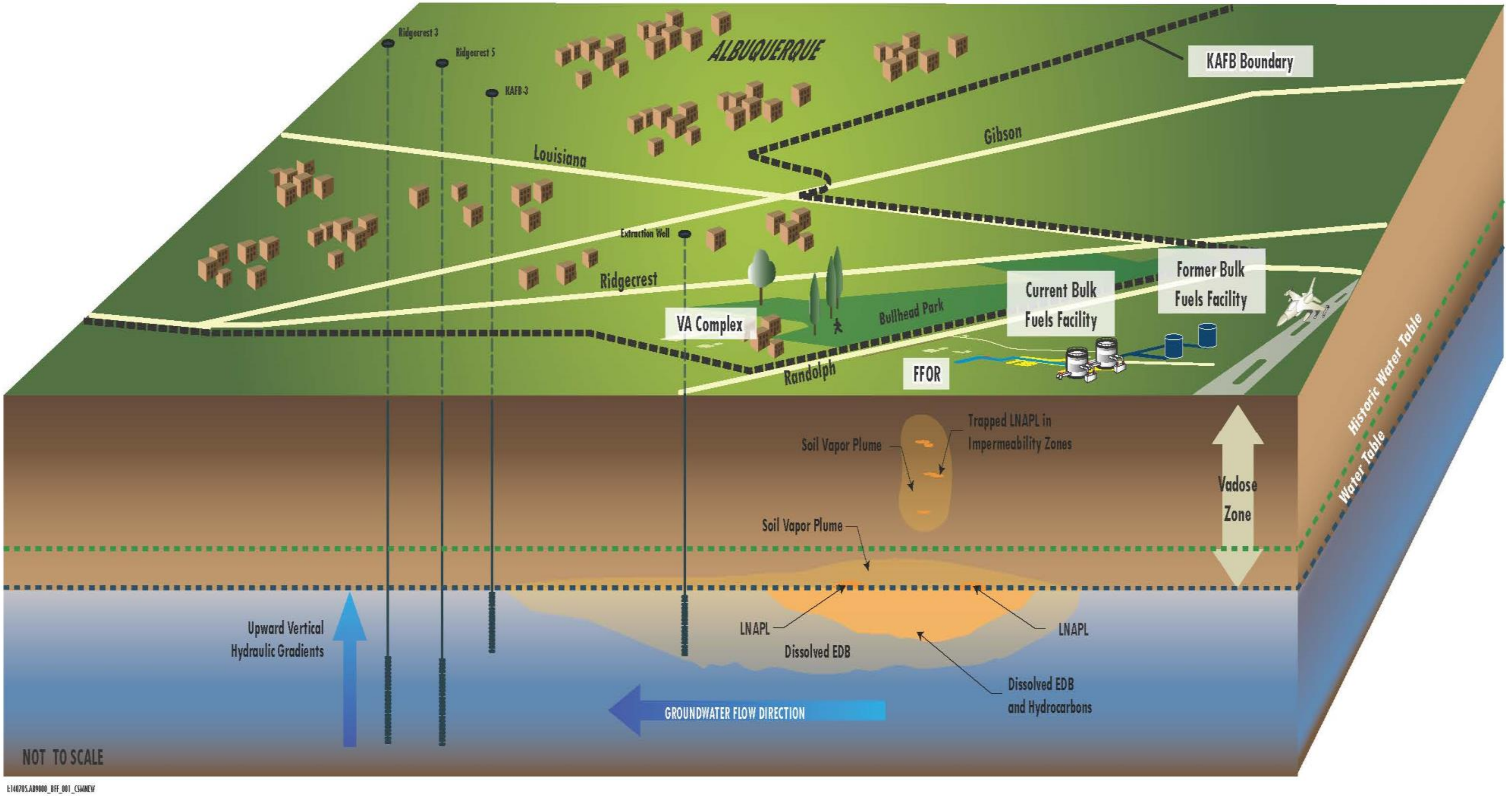
Understanding the Geology

Alluvial Fan Deposits

Ancestral Rio Grande Braided River Deposits

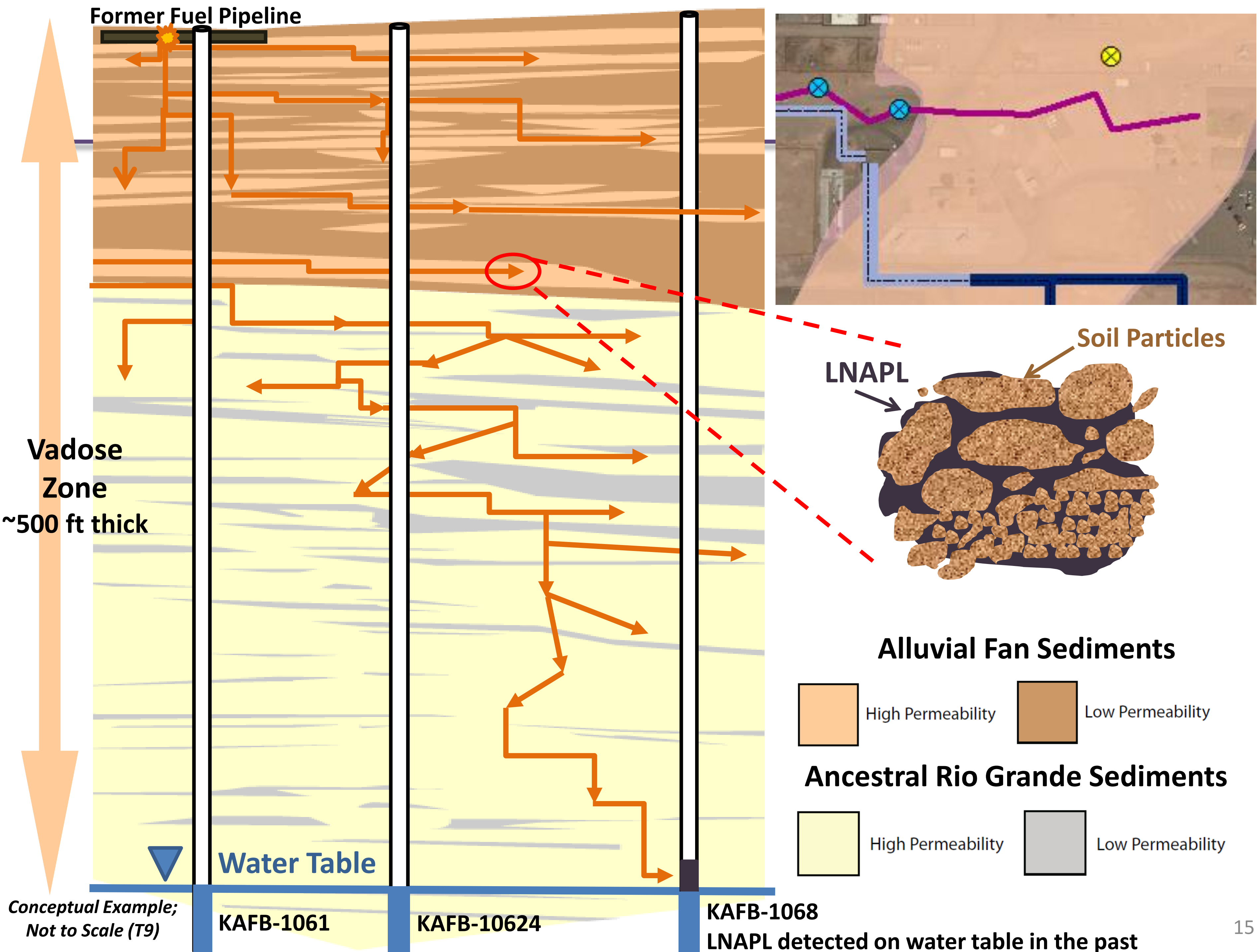


Conceptual Side Model Based on Current Data



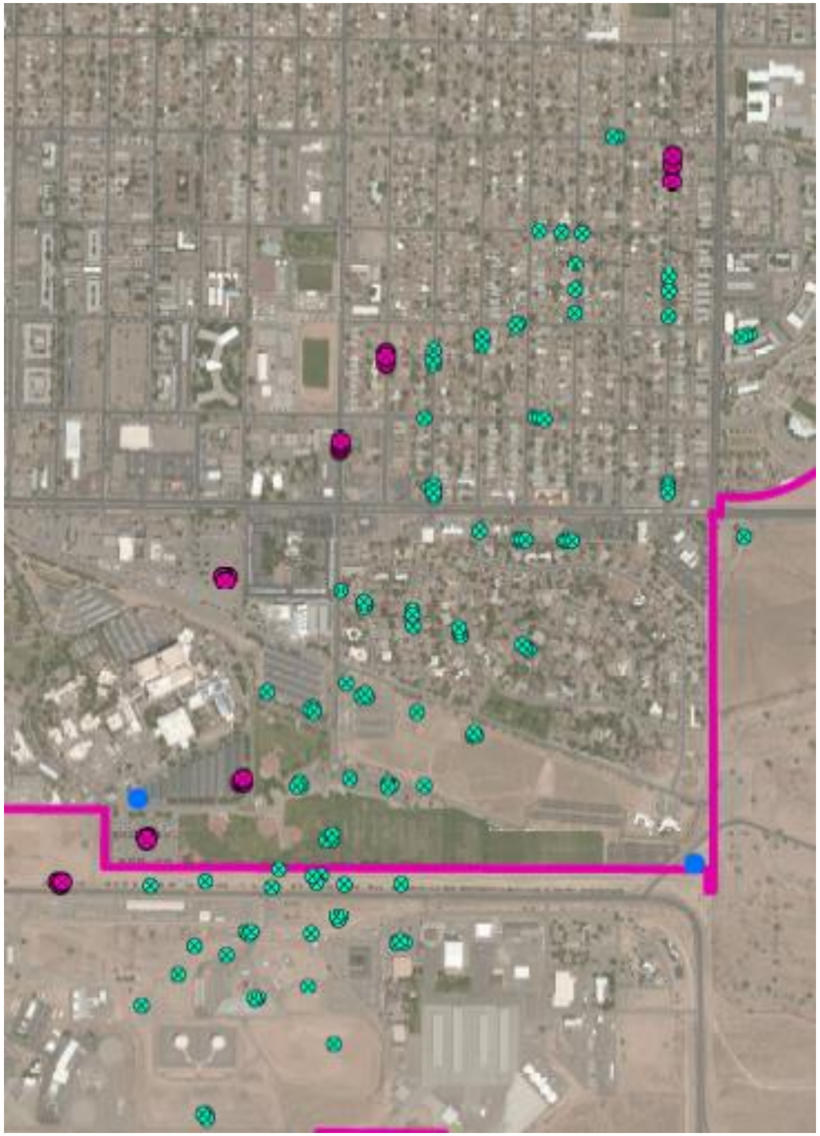
Conceptual Site Model Animation

https://www.env.nm.gov/NMED/Issues/KirtlandFuelPlume/KAFBProjectImages.html


Former Fuel Pipeline
Vadose Zone ~500 ft thick
Water Table
Conceptual Example; Not to Scale (T9)
KAFB-1061
KAFB-10624
KAFB-1068
LNAPL detected on water table in the past
LNAPL
Soil Particles
Alluvial Fan Sediments
High Permeability
Low Permeability
Ancestral Rio Grande Sediments
High Permeability
Low Permeability

Groundwater Network and Sampling

- 134 groundwater monitoring wells
- Quarterly and semi-annual measurements include:
  - Field analysis for temperature, pH, dissolved oxygen (DO), conductivity, & oxidation reduction potential (ORP)
  - Laboratory analysis for volatile organic compounds (VOCs), ethylene dibromide (EDB), metals, anions, ammonia nitrogen, sulfide, and alkalinity
- Data is evaluated to identify concentration trends to define the dissolved phase and evaluate effectiveness of cleanup



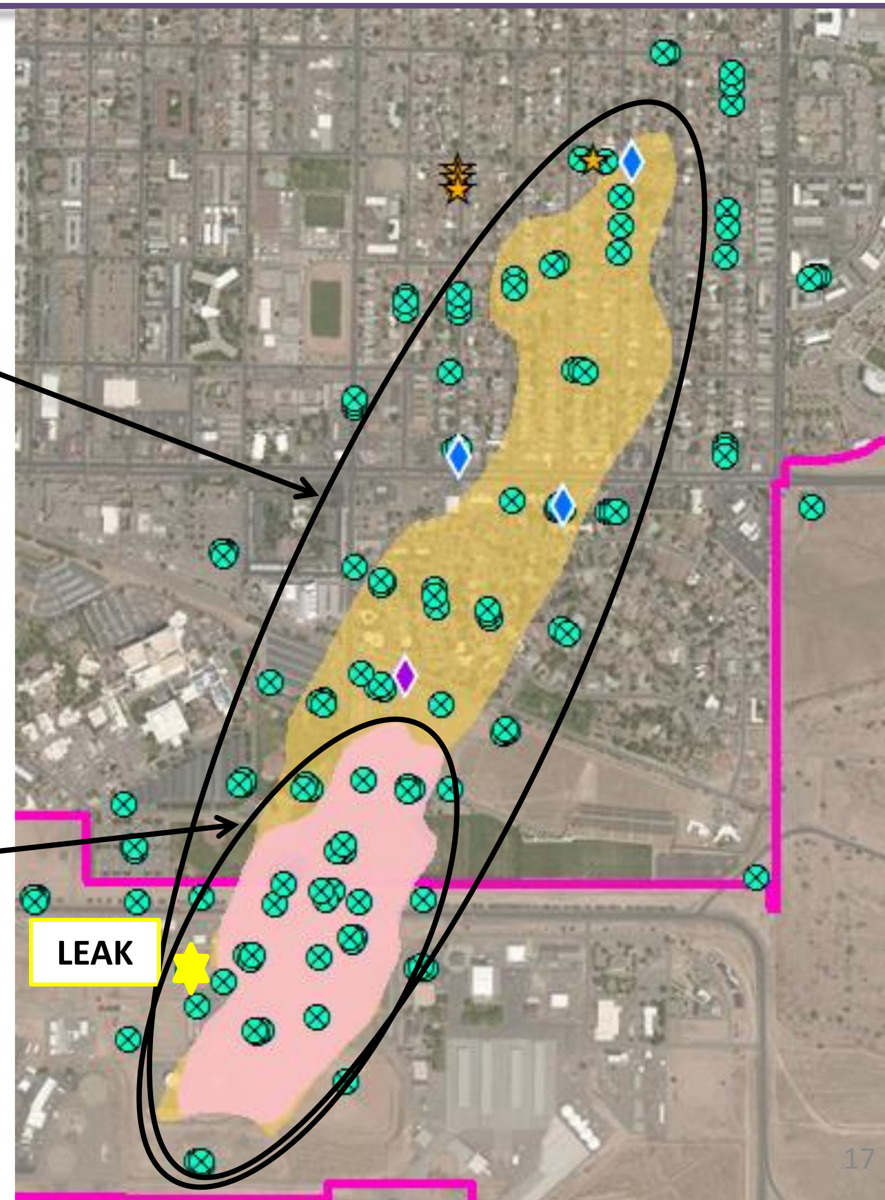
Anatomy of the Fuel Plume

EDB Plume

- Downgradient portion shows evidence of hydrolysis (i.e., breaking chemicals down by reacting with water) through new stable isotope data
- Average downgradient concentrations are low, less than 0.1 part per billion (ppb) or micrograms per liter (µg/L)
- EDB is being anaerobically degraded by natural bacteria in source area

Source Area

- Highest fuel concentrations
- Residual LNAPL
- Dissolved EDB and hydrocarbons
- High biodegradation



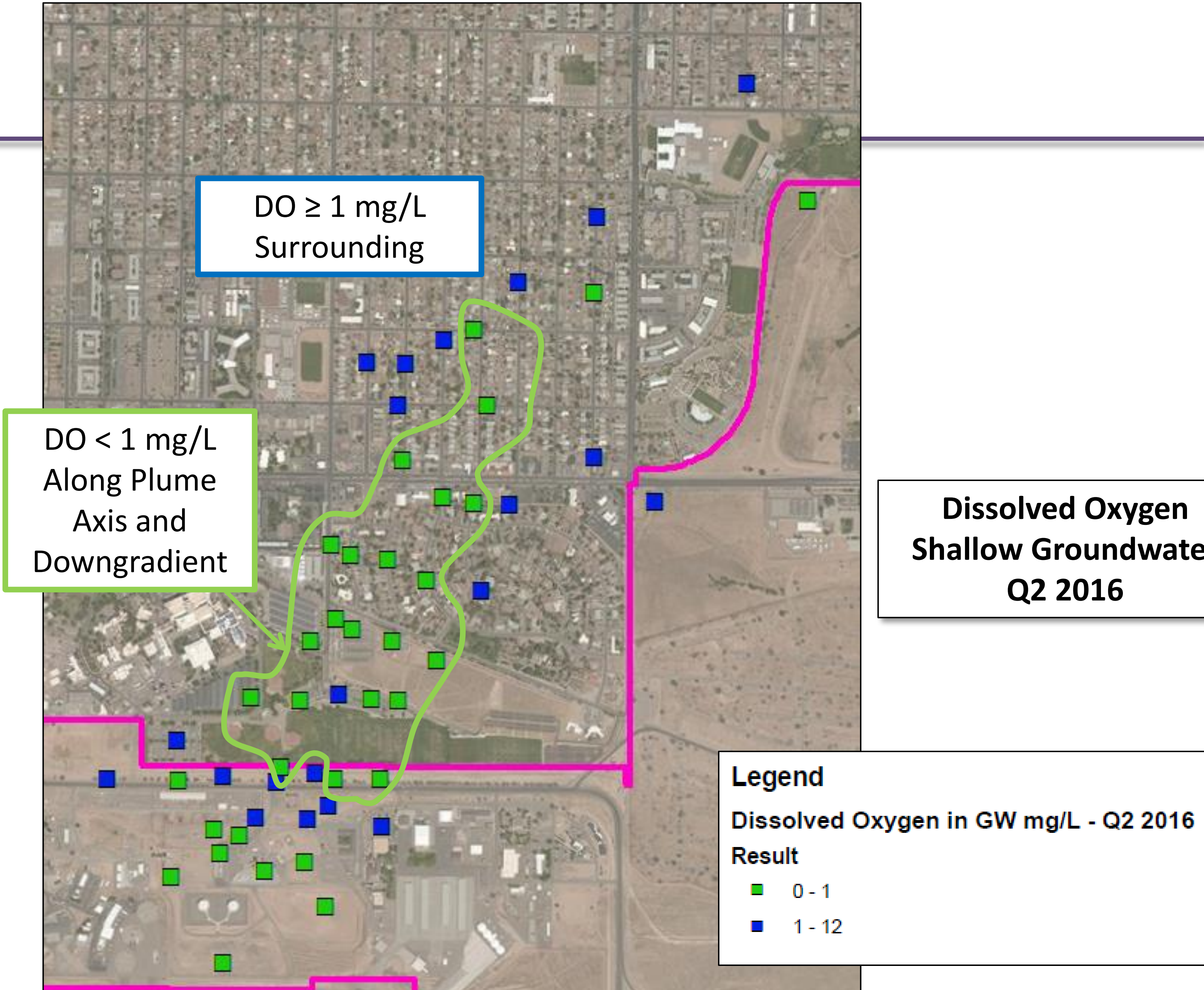
Plume Geochemistry

Redox Conditions

- Lines of evidence for redox conditions:
  - Dissolved oxygen < 1 mg/L → anaerobic
  - Dissolved oxygen ≥ 1 mg/L → aerobic
  - Anaerobic redox conditions require further definition through evaluation of nitrate, manganese, iron, sulfate, and carbon dioxide

Redox Take-Away:

Understanding redox conditions is crucial for understanding the occurrence and degradation of plume constituents.



Dissolved Oxygen Shallow Groundwater Q2 2016

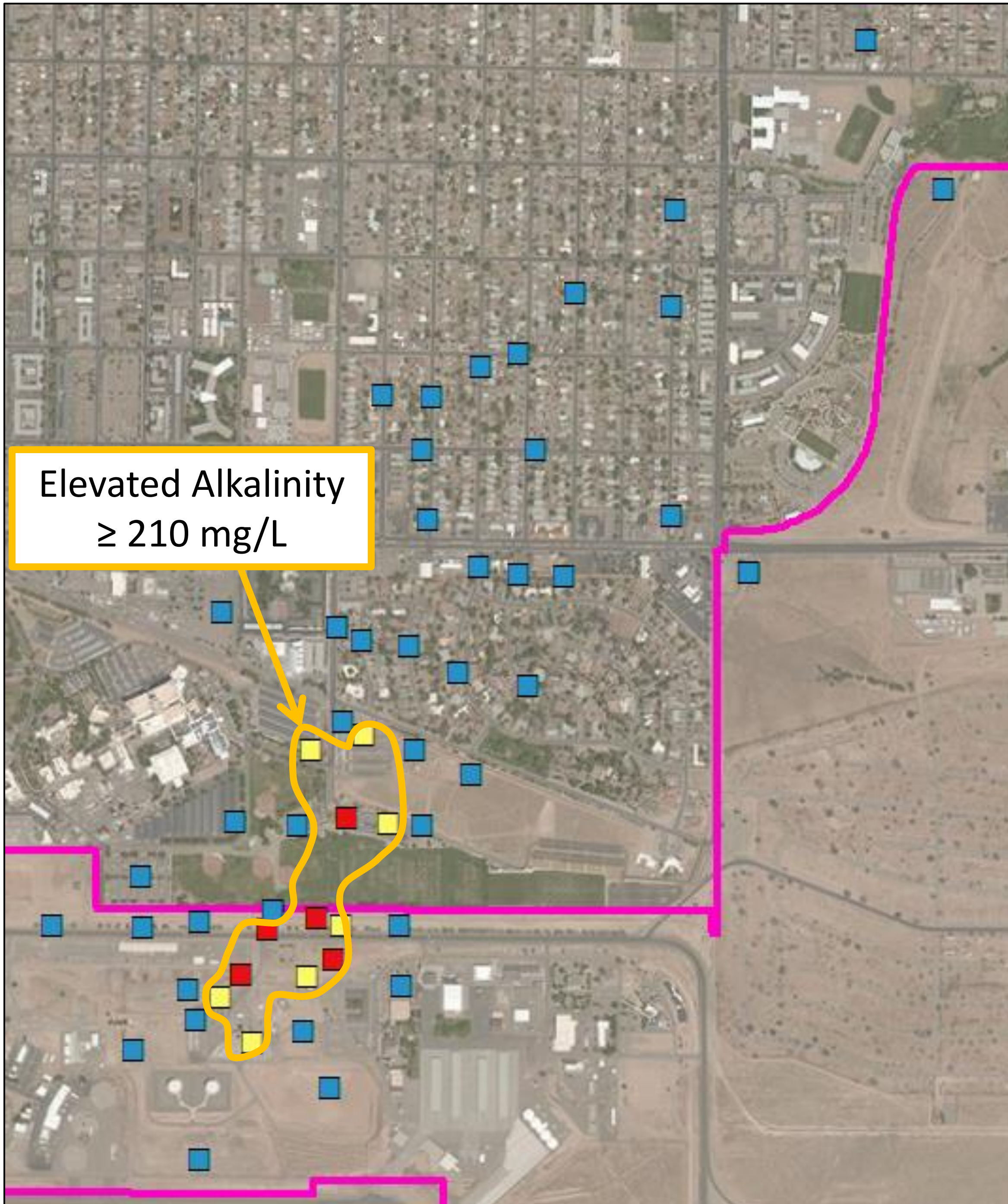
Plume Geochemistry

Degradation

- Hydrocarbons can undergo biological degradation
- Lines of evidence for biodegradation
  - Elevated alkalinity (> 250 mg/L)
  - Elevated bromide
  - Redox conditions
  - Decreased O_2 and hydrocarbon concentration

Degradation Take-Away

Multiple biodegradation processes can occur and each process results in different degradation rates for individual hydrocarbon compounds.



Alkalinity
Shallow Groundwater
Q2 2016

Legend

Alkalinity in GW (mg/L) - Q2 2016

Result

- 84.8 - 145
- 145 - 237
- 237 - 346

Plume Geochemistry

Multiple solutes

- Jet fuel and aviation gas have multiple organic compounds
- The solubility of organic compounds is dependent on the mixture of solutes present

Multiple Solutes Take-Away

- The concentration of a solute is less than it would be in water alone.
- Over time, the fraction of LNAPL constituents with lower solubility increases → increased equilibrium concentration in groundwater. ???

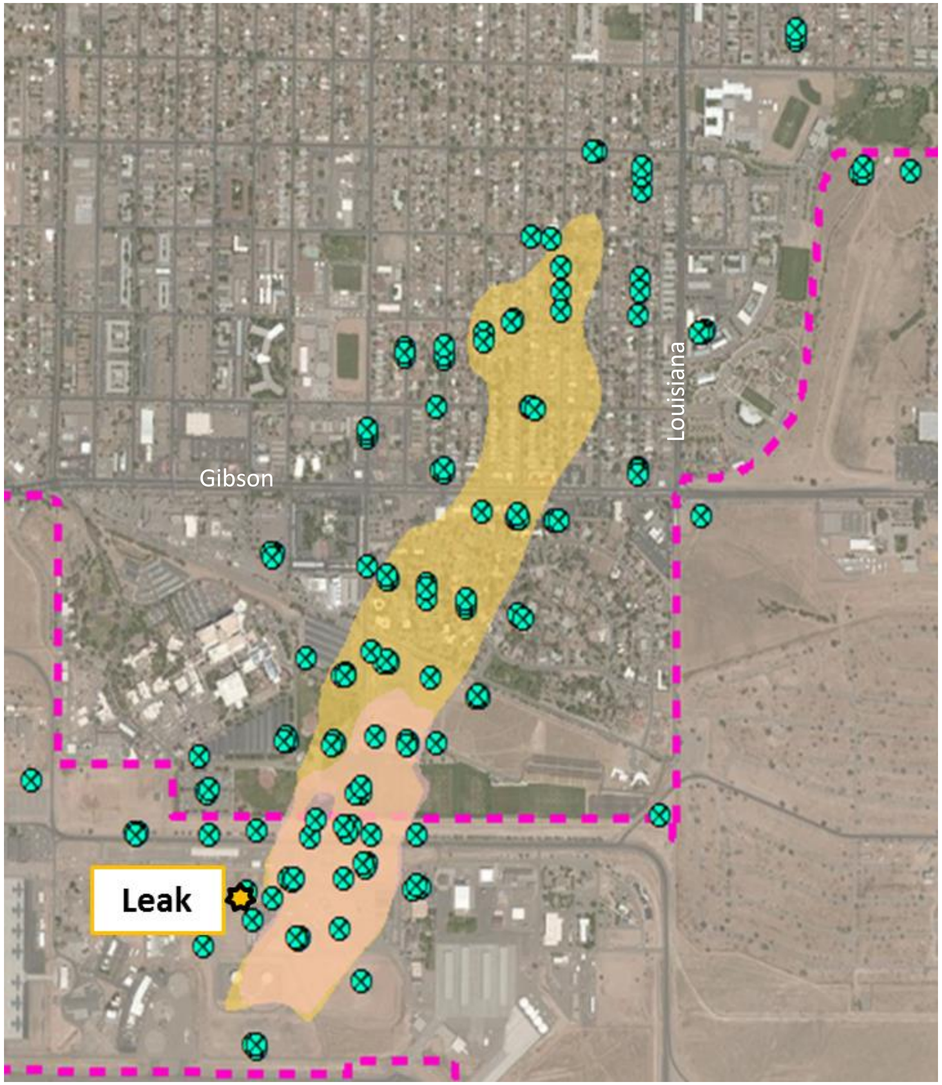
Interim Measure Strategies at BFF

<u>Source Removal</u>

- Soil excavation down to 20 feet below ground surface at leak location (primary source) removed nearly 5,000 tons of contaminated soil
- 12 years of soil vapor extraction (SVE) in vadose zone (secondary source)

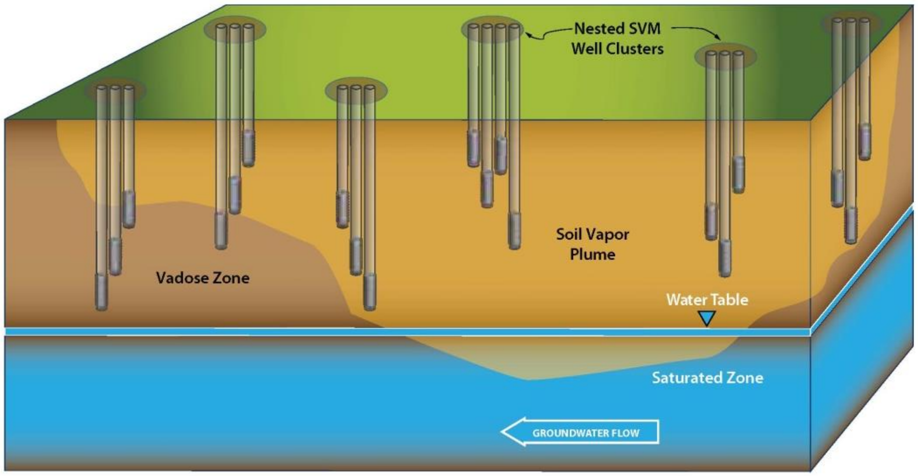
<u>EDB Plume Collapse</u>

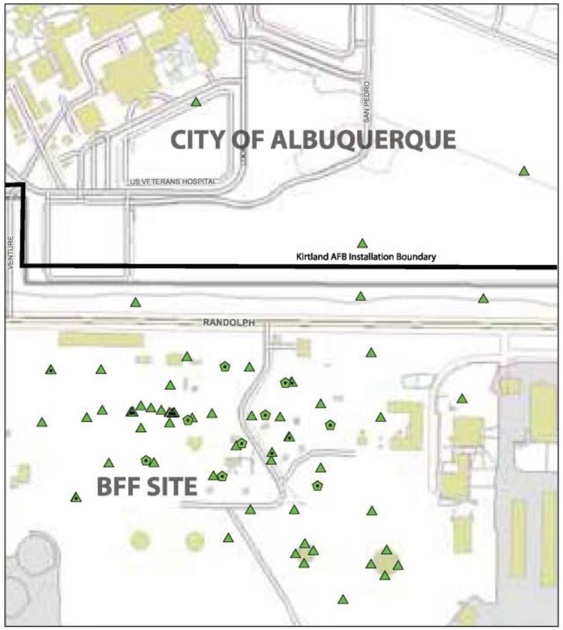
- Contain the dissolved EDB mass (secondary source)
- Prevent EDB from reaching drinking water supply wells near the dissolved plumes



Soil Vapor Network and Sampling

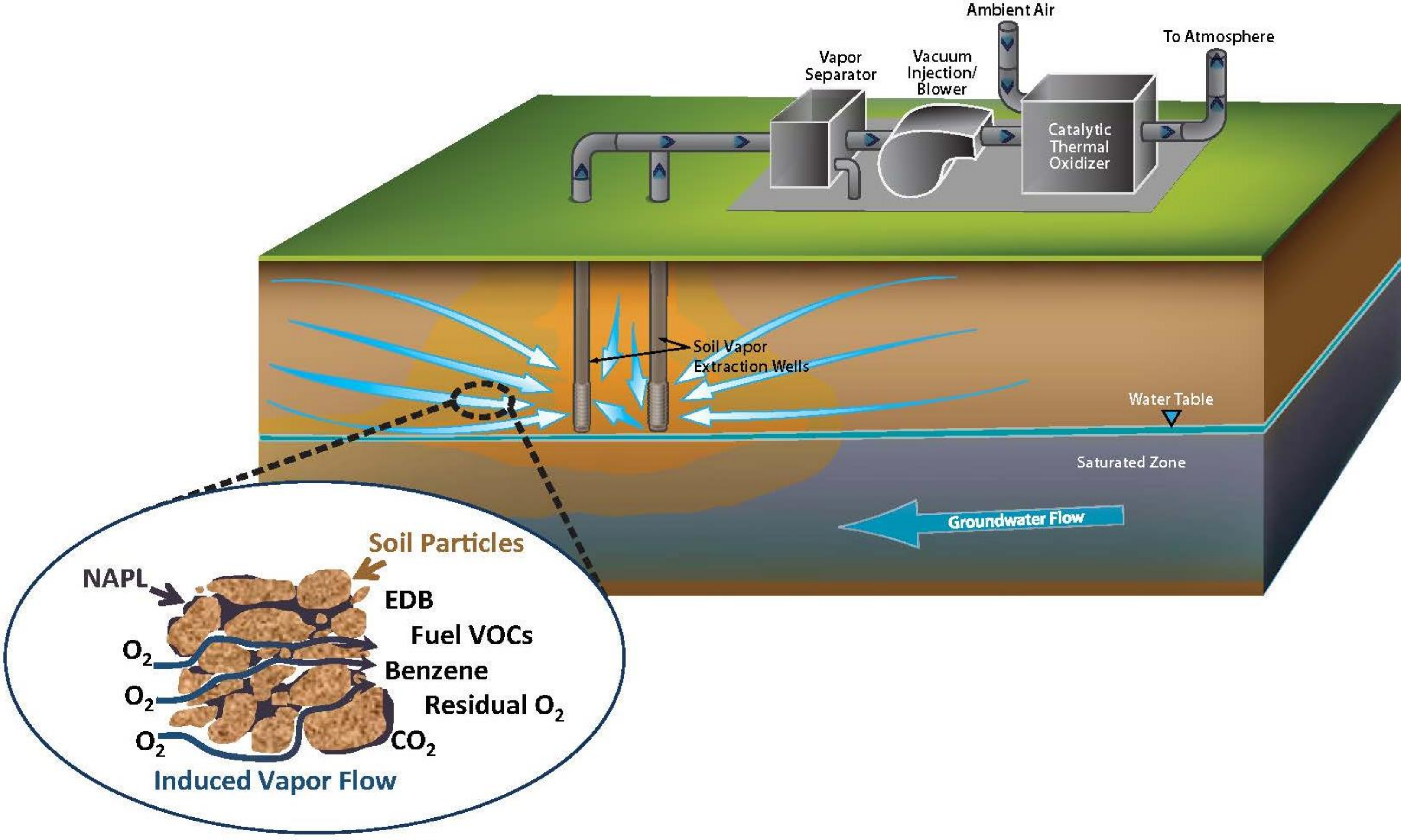
- Soil vapor sampling in source area from a network of 284 soil vapor monitoring points
  - 56 locations with 3 or 6 sampling depths each location
- Quarterly measurements include:
  - Field measurements of O_2, CO_2, and total petroleum hydrocarbons (TPH)
  - Laboratory analysis for volatile organic compounds (VOCs), EDB, and TPH
- Data is evaluated to identify hydrocarbon concentrations and to inform evaluation of remediation methods





Soil Vapor Extraction

SVE is a remediation technology that reduces concentrations of volatile petroleum hydrocarbons by applying a vacuum and treating the vapors



Application of SVE

- The effectiveness of SVE is dependent on soil and contaminant properties
- Must be able to move vapor and effectively reach contaminated soils
  - Soil permeability
  - Soil structure
  - Soil moisture
- The ease of a contaminant to go into the vapor phase is important
  - Henry's Law Constant
  - Vapor pressure
- SVE efficiency decreases over time as mass is removed

History of SVE at BFF

- The original SVE system was installed in 2003
  - One unit connected to a total of 9 SVE wells
- In 2008/2009 SVE was expanded to add in three more units at existing groundwater monitoring wells
- Additional expansion and optimization was done in 2012, 2013, and 2014
  - In 2013 expansion included startup of a larger SVE system (known as the CATOX)
- SVE continued until 2015 when it was shut down to support in situ rebound test to determine where residual source remains in the soil

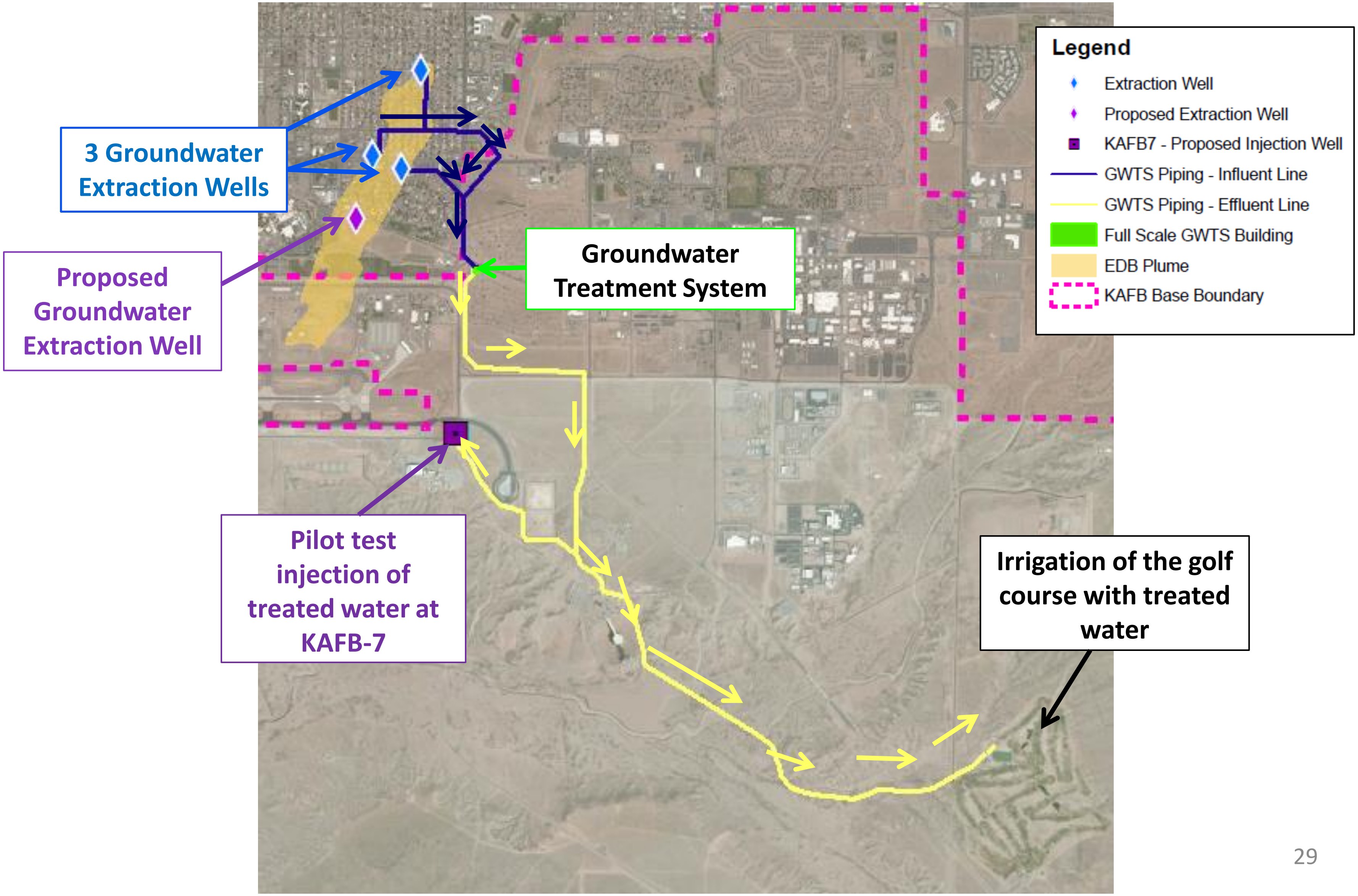
Groundwater Remediation

- Remediation generally addresses two issues:
  - Source control (primary and secondary)
  - Protection of human health and the environment through cleanup to regulatory standards
- Technologies include:
  - Pump and treat
  - Air sparging
  - Permeable reactive barriers
  - Monitored natural attenuation
  - Enhanced bioremediation - recirculation

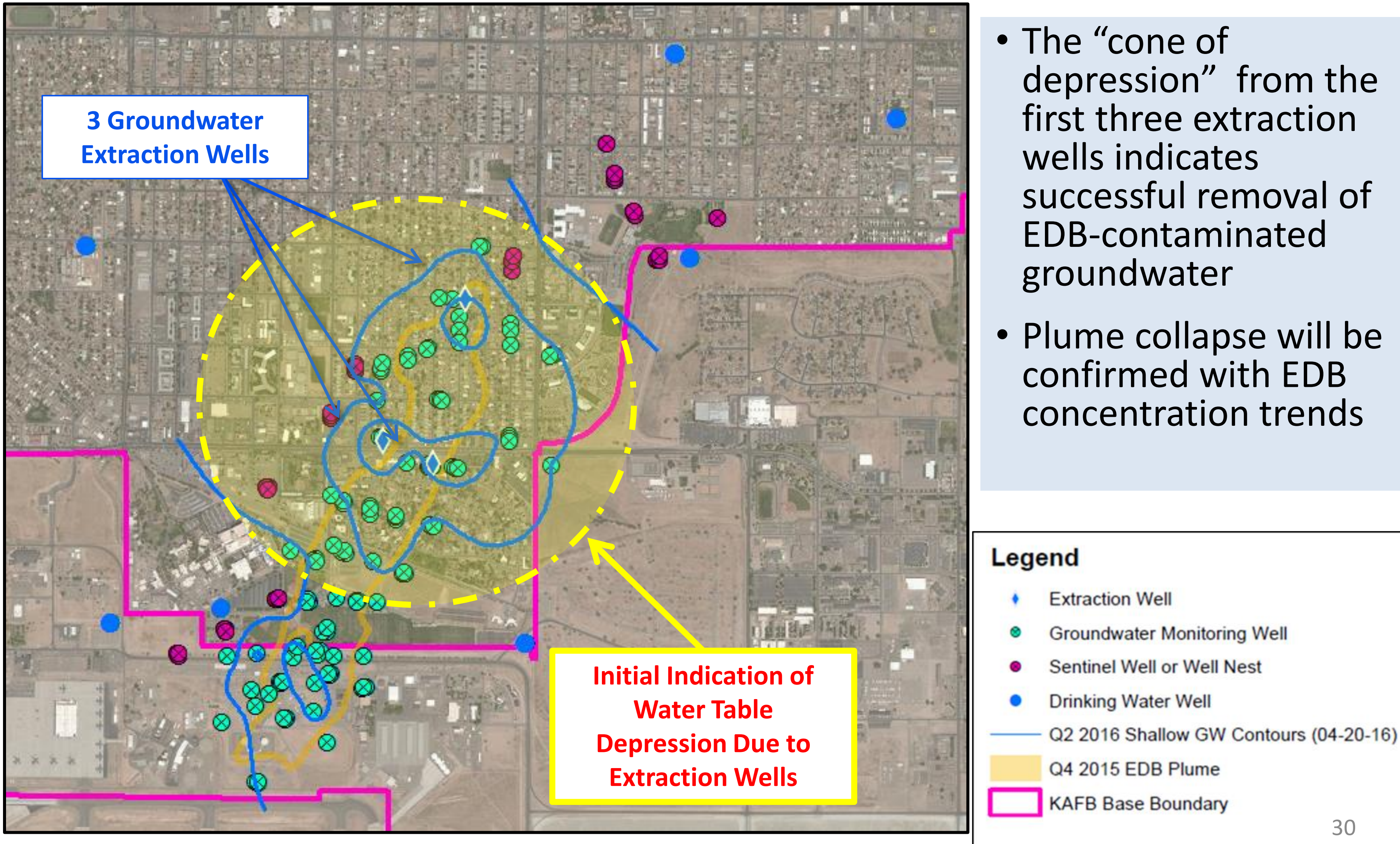
Remediation is **NOT** one-size fits all. Key factors include:

- Site geology and hydrology
- Depth of contamination
- Infrastructure requirements
- Cost

EDB Plume Collapse

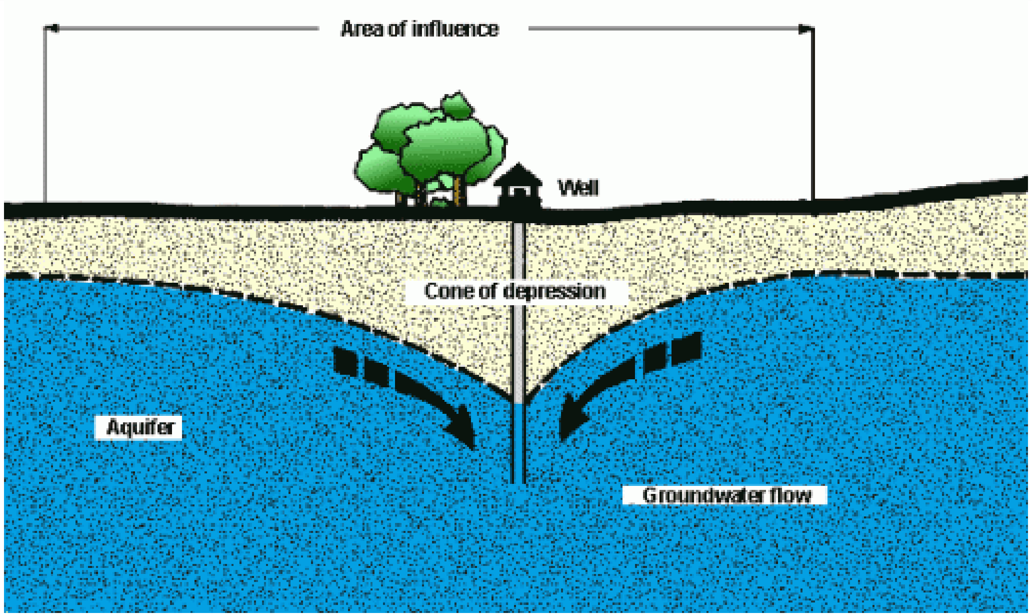


2nd Quarter 2016 Groundwater Levels Evidence of Success



- The "cone of depression" from the first three extraction wells indicates successful removal of EDB-contaminated groundwater
- Plume collapse will be confirmed with EDB concentration trends

What is a “Cone of Depression”?



- Forms in the water table when groundwater is extracted in all directions by a pumping well
- Measured water levels in groundwater monitoring wells near the extraction well define the area of influence and capture zone
- One method used to determine if an extraction well is capturing the EDB plume

GWTS Performance

- System operation dates: 16 Dec 2015 - present
- System operations are still being fine-tuned (i.e., “shake-down”)
- System Maintenance and Repair Activities:
  - Pump replacement at extraction well KAFB-106228 at Christ United Methodist Church on Gibson
  - Redevelopment of extraction well KAFB-106233 on California, north of Gibson
  - Troubleshoot treatment system fouling
- Two of 3 extraction wells operating at a pumping rate of approximately 300 gallons per minute

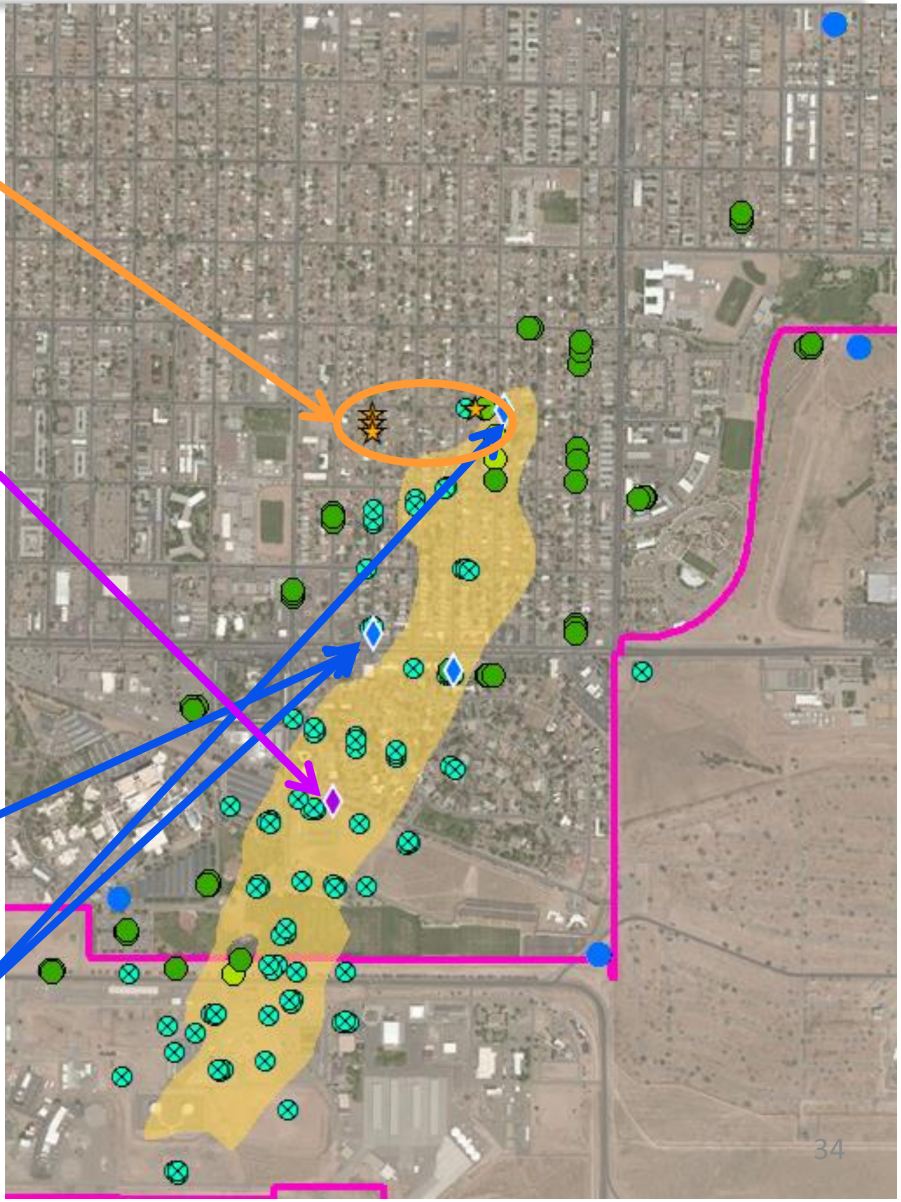
GWTS Performance

Extracted and treated 88.5 million gallons of EDB-contaminated groundwater and removed 29.4 grams of EDB

- Average plume concentration is 0.11 parts per billion (ppb) off-Base
- Drinking water standard for EDB is 0.05 ppb

What's Next for EDB Plume Collapse?

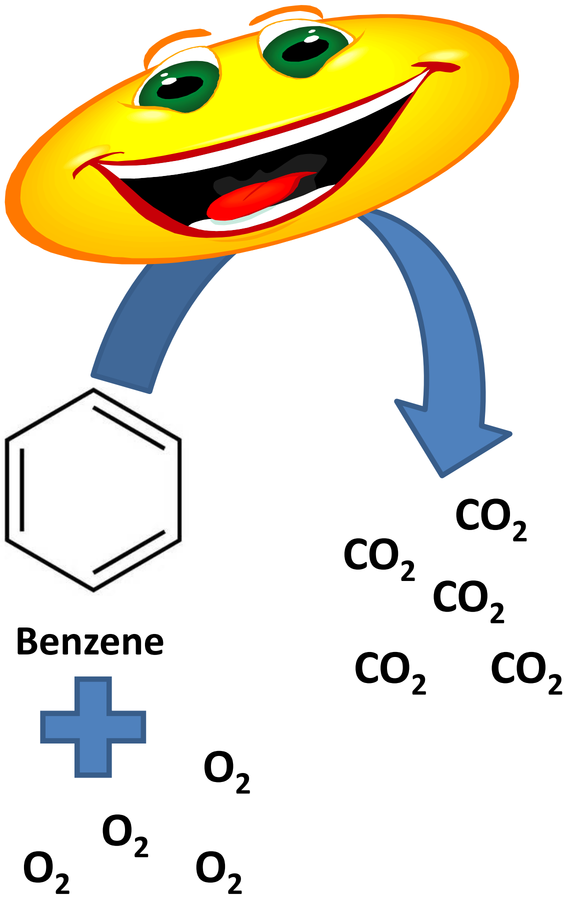
- Drill and install data gap groundwater monitoring wells in late Summer 2016
- Drill and install 4th extraction well south of Ridgecrest in Winter 2016
- Install sand filters to address GWTS fouling
- Redevelop KAFB-106233
- Conduct aquifer testing of extraction wells



Bioremediation

- Biodegradation can happen in both soil and groundwater
- Naturally occurring soil bacteria consume O_2 and produce CO_2 as they biodegrade hydrocarbons

$$C_6 + O_2 \rightarrow \text{biomass} + CO_2 + H_2O$$



Testing for Biodegradation

In Situ Respiration Testing

- Measure concentrations of oxygen, carbon dioxide, and hydrocarbons over time

Laboratory Microcosm Studies

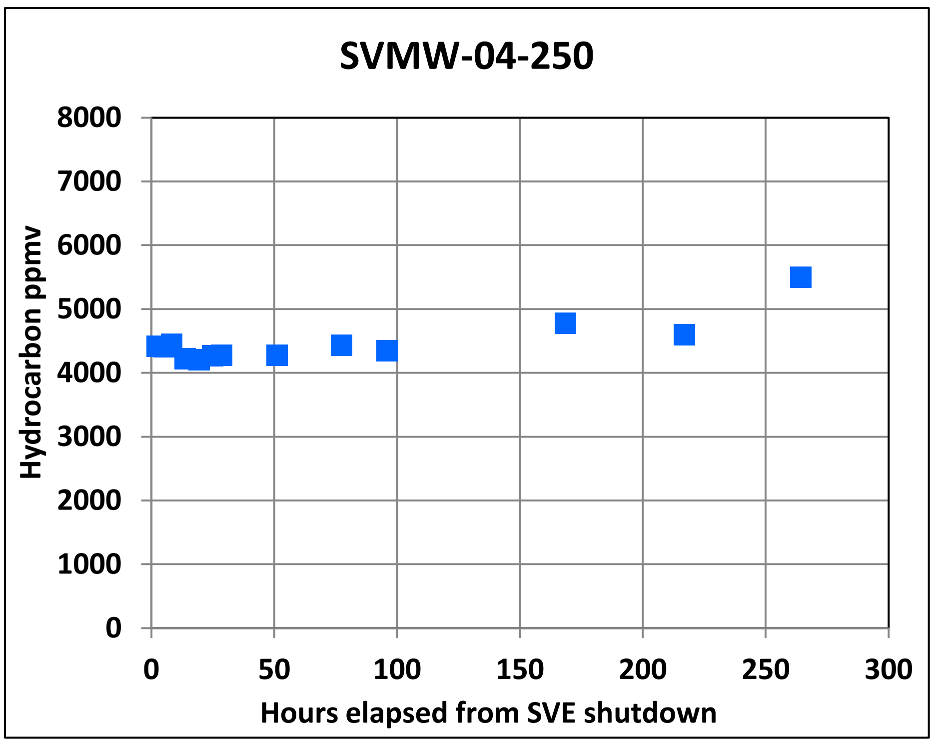
- Experiments run in a laboratory using groundwater and soil from the site
- Identify potential technologies for degradation of hydrocarbons, including EDB

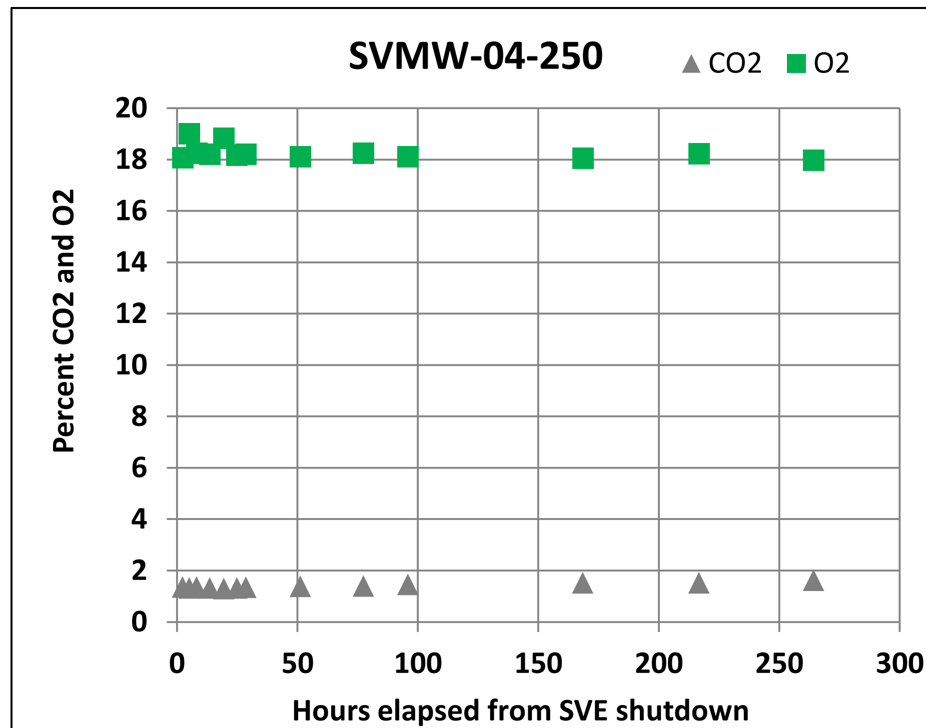
In Situ Respiration Testing

- Short-term monitoring of 61 soil vapor monitoring points (SVMPs)
- Long-term monitoring on a subset of 34 SVMPs
- Field parameters: total hydrocarbon, O_2, CO_2, pre- and post-purge static pressure, and relative humidity
- Laboratory analyses in addition to field measurements

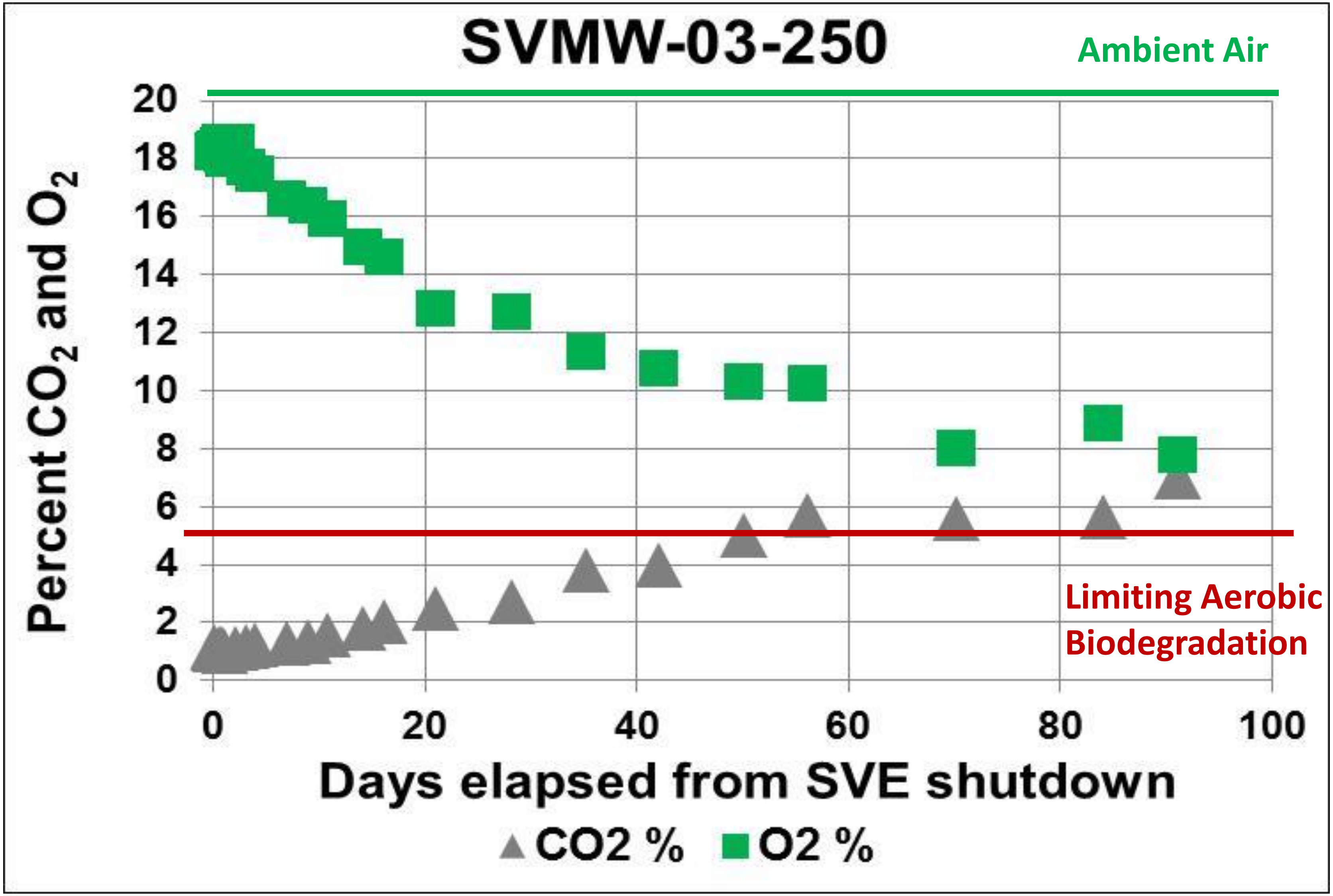
Summary of Results - Respiration

- Changes in O_2 and CO_2 indicates aerobic hydrocarbon degradation
- Some locations indicate microbial activity limited due to relative humidity

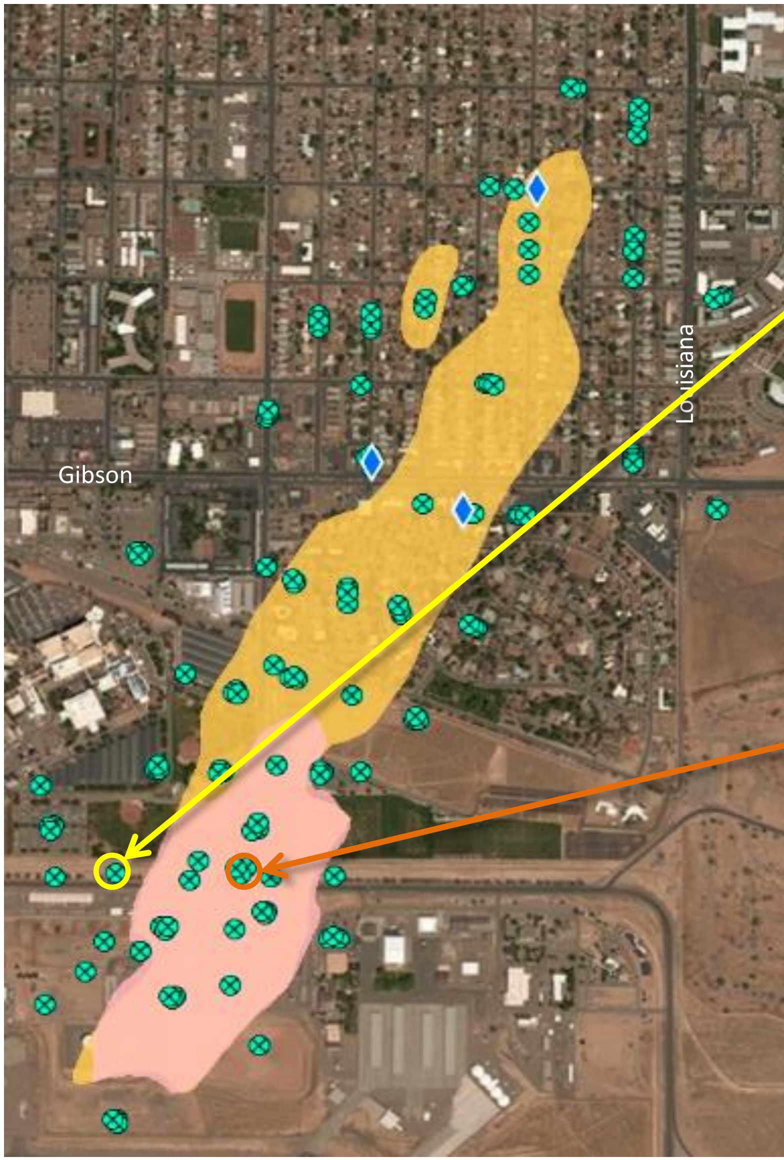




Understanding the Data



Laboratory Microcosm Testing



Two areas were cored and sampled:

Side gradient:

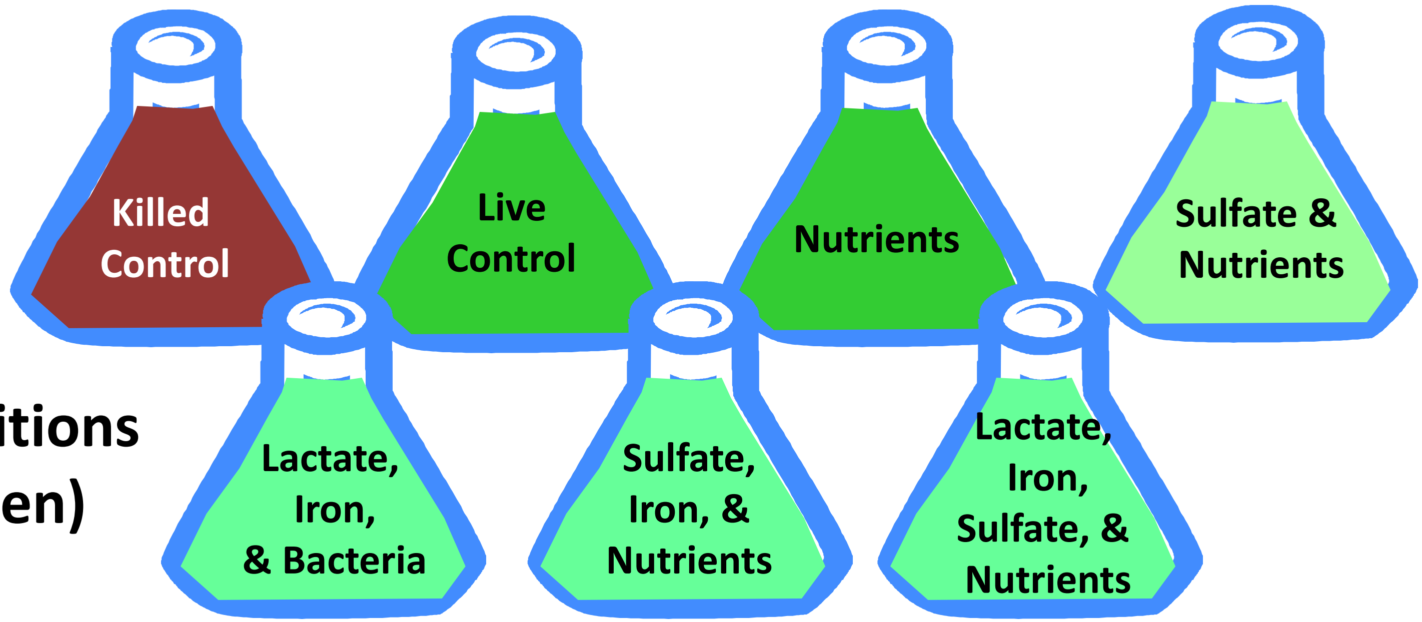
- Collected core during drilling of a groundwater monitoring well KAFB-10612R
- Collected groundwater from the same well

Source Area (LNAPL):

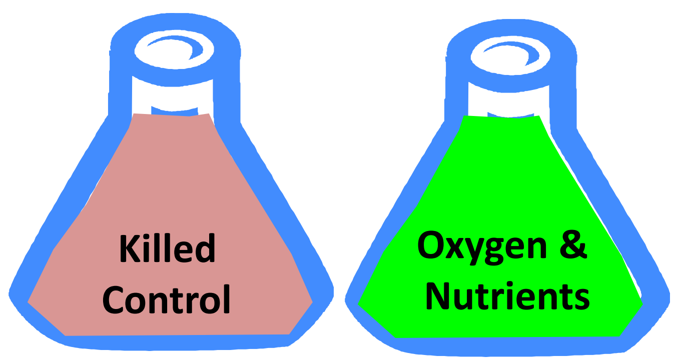
- Collected core during drilling of groundwater monitoring well KAFB-106210
- Collected groundwater from the same well

Laboratory Microcosm Testing

Anaerobic conditions
(without oxygen)



Aerobic conditions
(with oxygen)



Microcosm Summary

Side Gradient

Aerobic

- Complete BTEX and nearly complete EDB degradation

Anaerobic

- Complete EDB degradation when *Dehalococcoides* added
- Minimal EDB degradation with added lactate, sulface, Fe, and/or nutrients

Source Area

Aerobic

- Completed BTEX and partial EDB degradation

Anaerobic

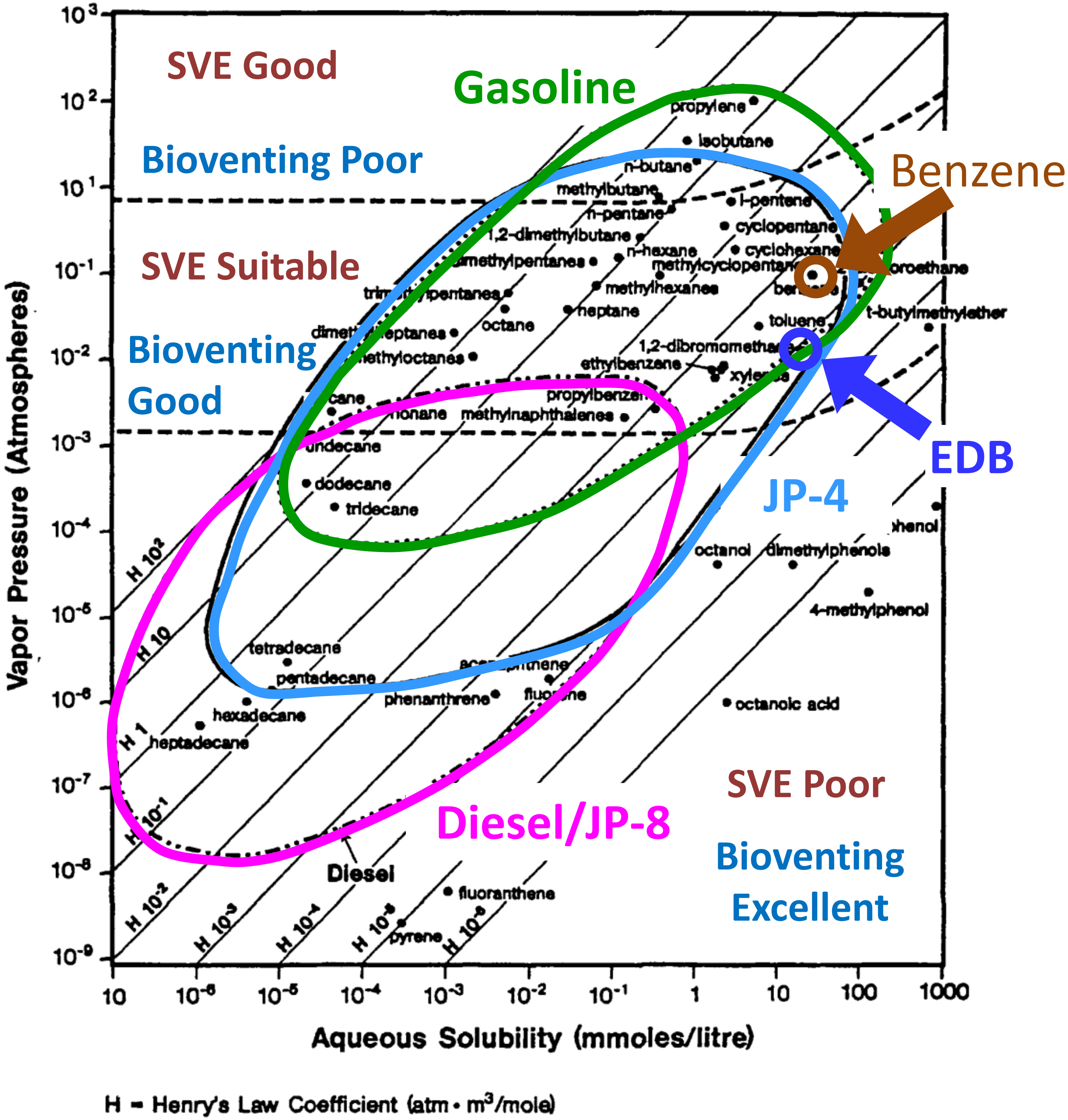
- Completed EDB degradation when *Dehalococcoides* added
- Minimal EDB degradation with added lactate, sulfate, Fe, and/or nutrients

Vadose Zone Remediation

- Remediation generally addresses two issues:
  - Source removal
  - Protect human health and the environment
- Technologies include:
  - Excavation – remove soil
  - SVE – applying a vacuum to draw volatile compounds and destroy them
  - Bioventing – injecting air to stimulate biodegradation
  - Natural attenuation

Remediation is **NOT** one-size fits all and evolves as the contaminant is cleanup overtime. Key factors include:

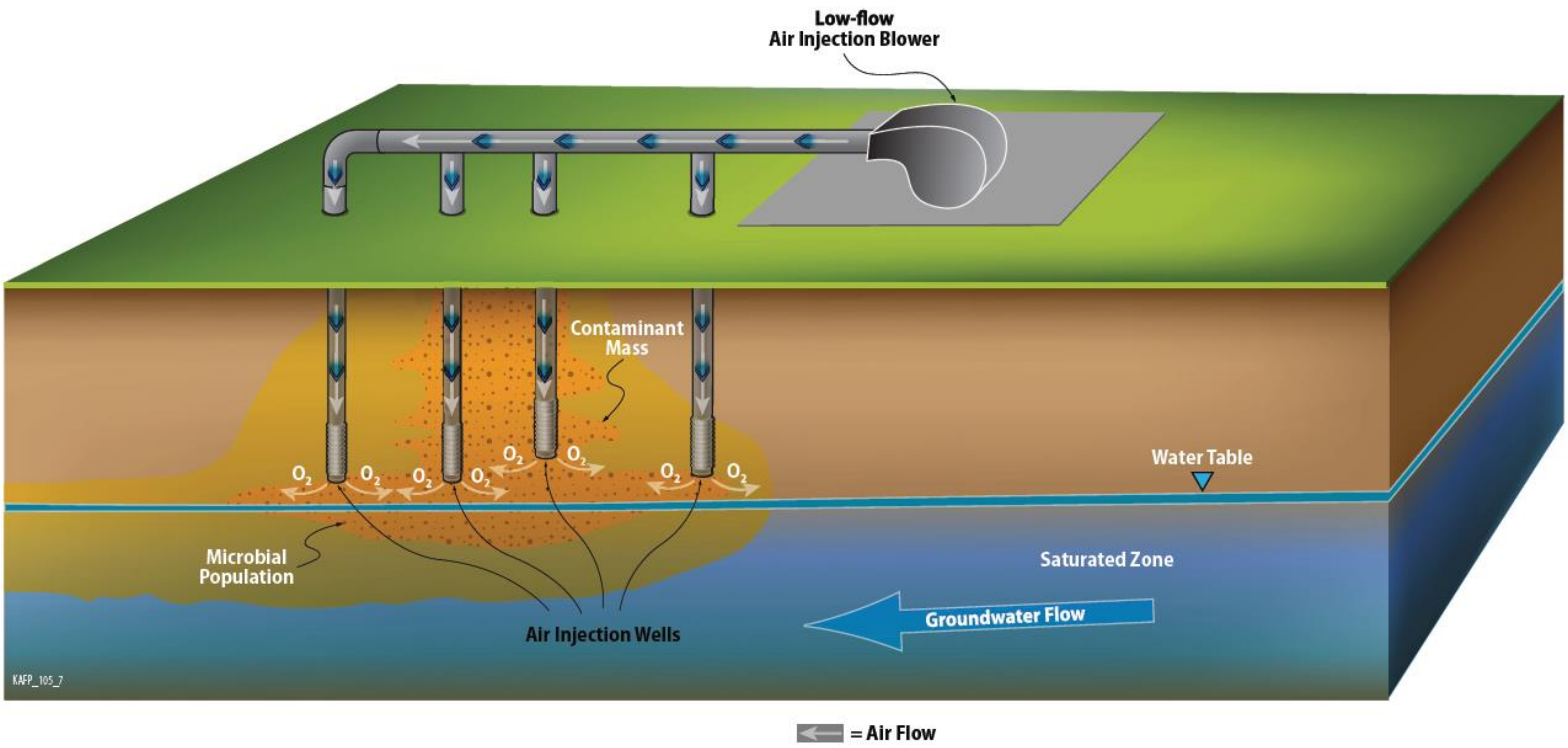
- Natural Conditions (aerobic vs anaerobic)
- Effectiveness and Efficiency
- Sustainability and Cost



SVE Good
Gasoline
Bioventing Poor
Benzene
SVE Suitable
Bioventing Good
EDB
JP-4
Diesel/JP-8
SVE Poor
Bioventing Excellent
Diesel
propylene
isobutane
n-butane
methylbutane
i-pentene
n-pentane
cyclopentane
1,2-dimethylbutane
n-hexane
cyclohexane
methylcyclopentane
dimethylpentanes
methylhexanes
trimethylpentanes
octane
heptane
toluene
t-butylmethylether
dimethylheptanes
1,2-dibromomethane
ethylbenzene
methyloctanes
xylenes
propylbenzene
nonane
methylnaphthalenes
undecane
dodecane
tridecane
octanol
dimethylphenols
4-methylphenol
tetradecane
pentadecane
phenanthrene
hexadecane
heptadecane
octanoic acid
fluoranthene
pyrene
Vapor Pressure (Atmospheres)
Aqueous Solubility (mmoles/litre)
H = Henry's Law Coefficient (atm • m³/mole)

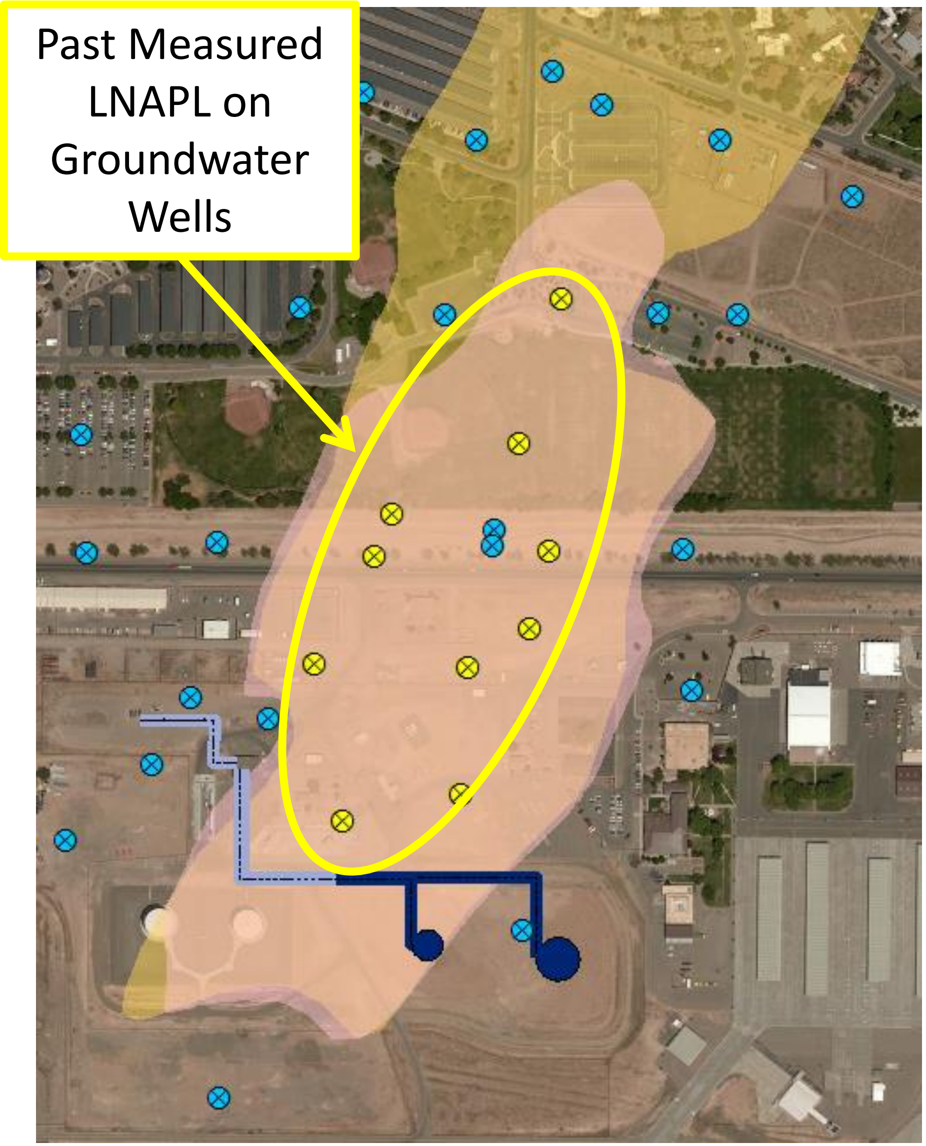
Bioventing

In-situ remediation technology that enhances the activity of indigenous (naturally existing) bacteria to degrade contaminants of concern in the vadose zone by injecting air or adding amendments



LNAPL Remediation

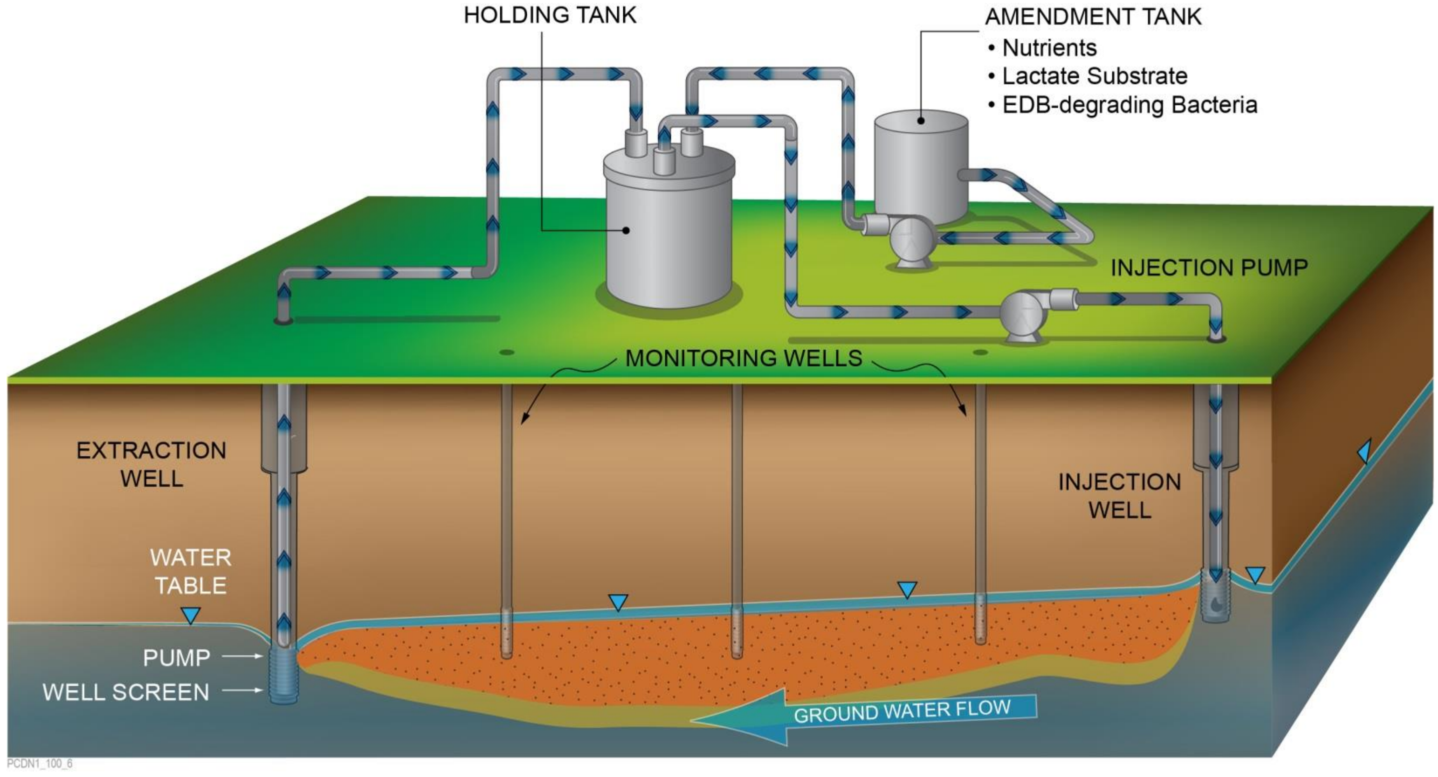
- Technologies include:
  - Skimmer – extracting primary source (i.e., free product/LNAPL)
  - SVE
  - Air sparging – bubbling air into the saturated zone
  - Enhanced in situ bioremediation – may use biostimulation and/or bioaugmentation to speed up degrade
- Past measurable LNAPL floating on the groundwater before skimmer/SVE applied ~ 1 to 1.5 feet thickness
- Currently measurable LNAPL has been small amounts (i.e., 0.1 foot to sheen) to non-measurable



Anaerobic Biodegradation

Groundwater Recirculation

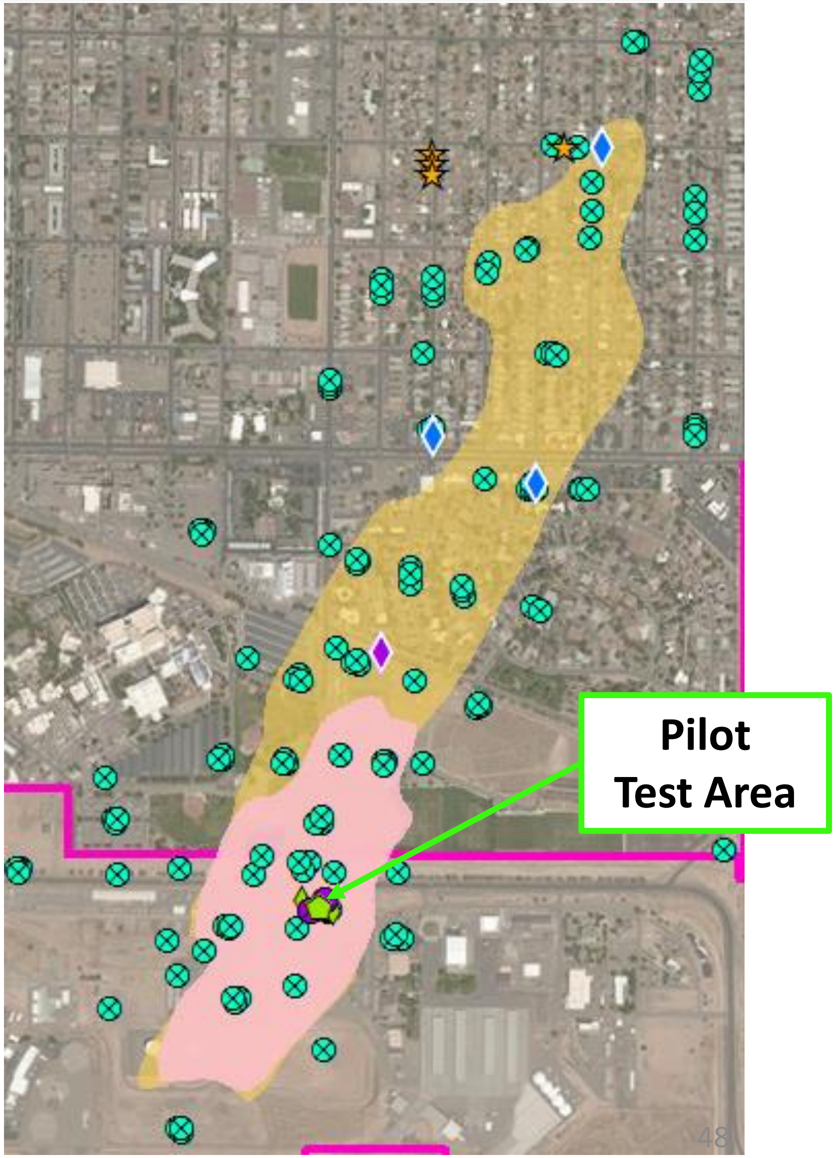
- Pump groundwater and add amendments in phases
- Inject amended water up-gradient to create a recirculation cell
- Supports anaerobic degradation of EDB



In Situ Anaerobic Degradation Pilot Test

Objective: To demonstrate in situ EDB biodegradation under anaerobic conditions using a phased amendment approach

- Reflects laboratory microcosm analysis outcomes
- Located near on-base groundwater well with increasing EDB concentrations
- Work plan will be submitted in July 2016 for NMED review and approval
- Planning to begin work in August 2016

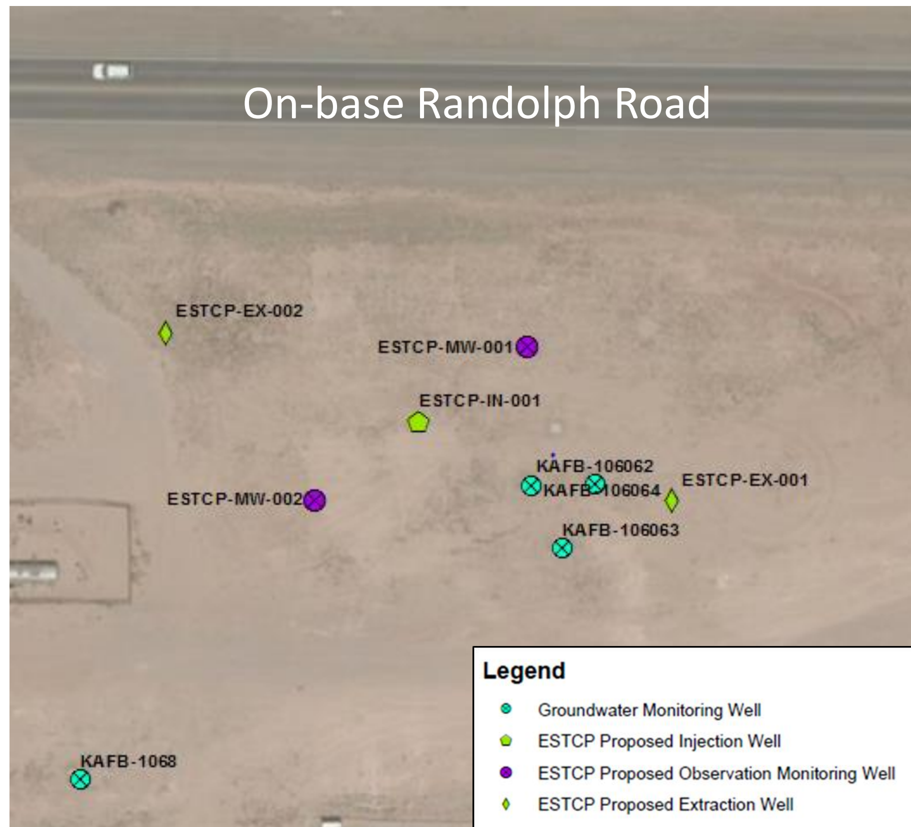


Pilot Test Infrastructure

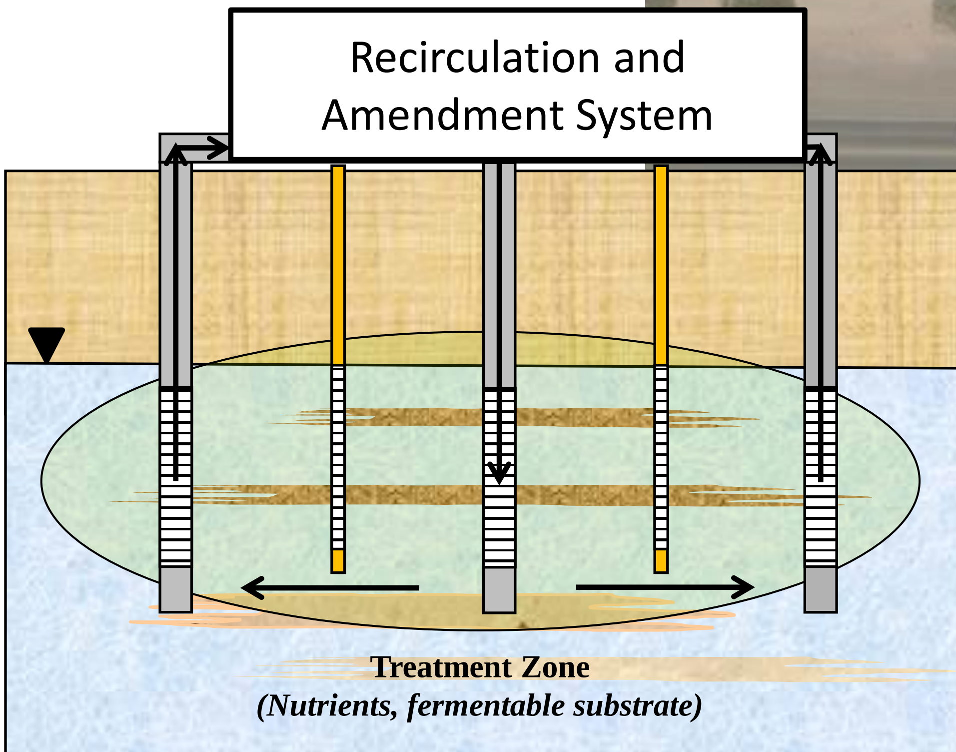
Will use two existing groundwater monitoring wells (i.e., one shallow and one intermediate)

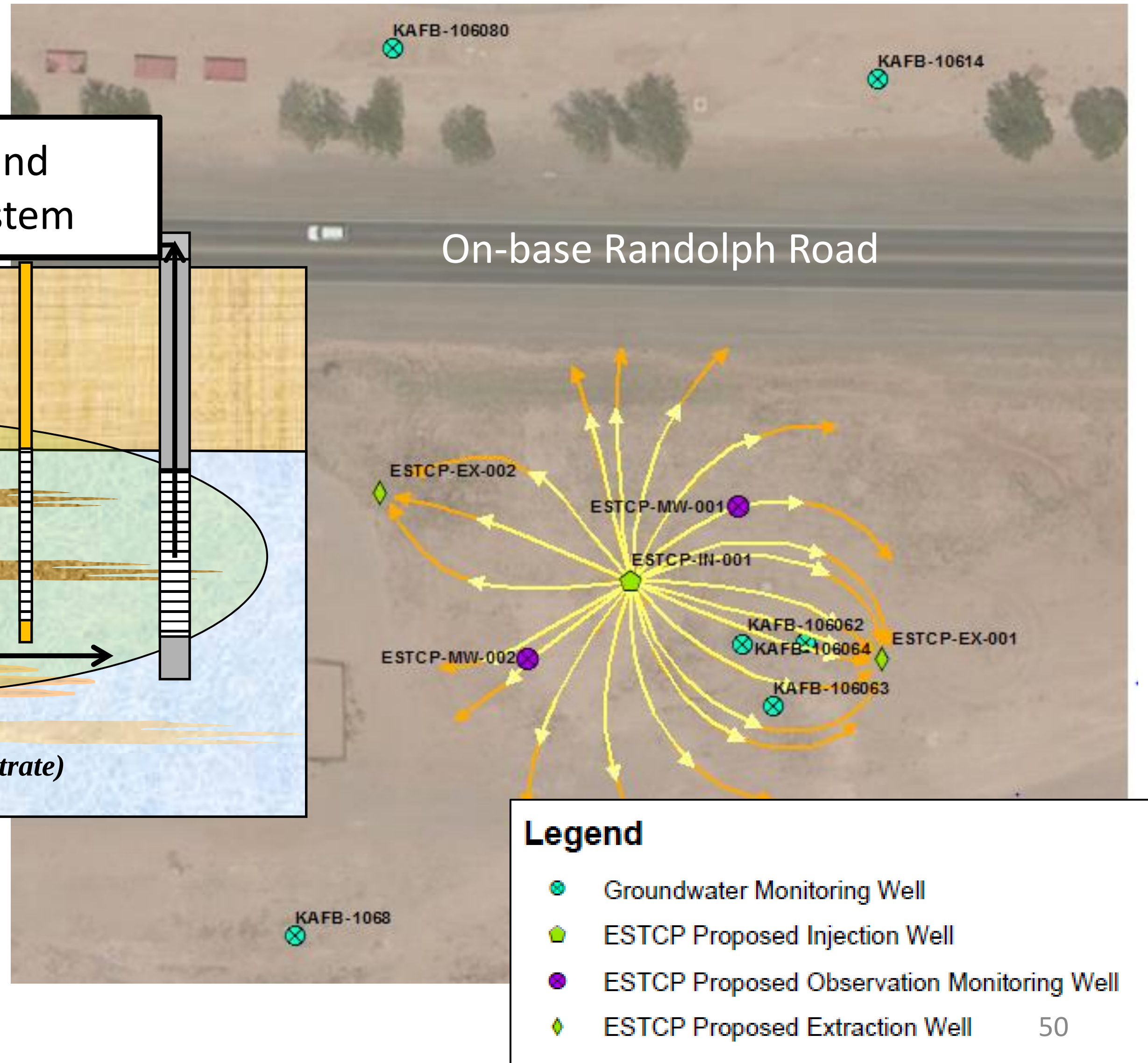
Installing five new wells:

- Two extraction wells
- One injection well with control valve
- Two additional groundwater monitoring wells



How is the Pilot Test Designed?



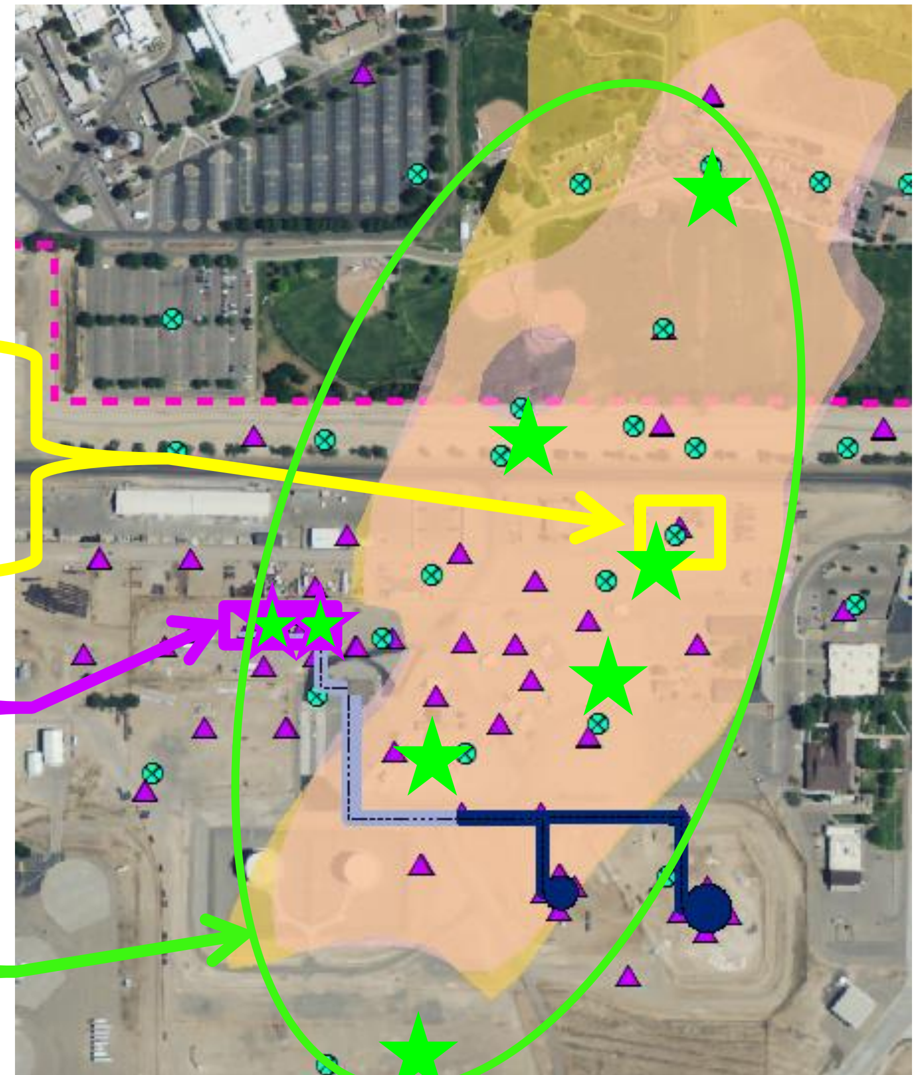


How will Pilot Test be Implemented?

- **Phase 1: Baseline Testing**
  - Approximately 1 month of recirculation
  - 2 months of monitoring
- **Phase 2: Biostimulation**
  - Addition of sodium lactate, diammonium phosphate [DAP] and yeast extract (i.e., inorganic nutrients)
  - Approximately 1 month of recirculation
  - 4 months of monitoring
- **Phase 3: Bioaugmentation**
  - Addition of sodium lactate, DAP, yeast extract, and microorganism culture
  - Approximately 1 month of recirculation
  - 2 months of monitoring

What's Next for the Source Area?

- On-going in situ respiration and rebound data collection and analysis
- Implement in situ biodegradation of EDB pilot test (Fall 2016)
- Bioventing pilot test scoping and work plan (Winter 2016)
- Soil coring in source area scoping and work plan (Winter 2016)



EDB and benzene plumes contoured with 4th Quarter 2015 data

2016 Public Outreach To-Date

Date	Description
Jan 12, 2016	**Kirtland Partnership Committee:** Provided project update
Feb 10, 2016	**District 6 Neighborhood Coalition Meeting:** Provided project update
Feb 24, 2016	**Highland High School Advanced Placement Chemistry and Environmental Science:** Worked with chemistry students to design lab experiments and presented results to April public meeting participates
Apr 8, 2016	**New Mexico Geological Society Spring Meeting:** Presented on site stratigraphy and migration of the EDB plume at the BFF site
Apr 13, 2016	**New Mexico Tech Engineering Club:** Presented undergraduate and graduate engineering students on the BFF site

Date	Description
Apr 19, 2016	**Regular Public Meeting with Poster Session**
Apr 23, 2016	**Public Field Trip:** Toured groundwater treatment facility and discharge points
May 26, 2016	**International District Healthy Communities Coalition Meeting:** Provided project information
June 22, 2016	**Water Utility Authority Governing Board:** Provided project update
July 12, 2016	**New Mexico Legislature, Radioactive and Hazardous Materials Committee:** Provided project update
July 14, 2016	**Regular Public Meeting with Poster Session and Technical Deep Dive**
Aug 3, 2016	**Westside Coalition Presentation:** Provided project update
Aug 13, 2016	**Community Conversation About the Kirtland Air Force Base Jet Fuel Spill**

Currently Scheduled Public Outreach

Date	Description	Location
August 15, 2016	**Rotary Club of Albuquerque** 12:00 – 1:00 p.m.	Hotel Albuquerque, 800 Rio Grande Blvd. NW
August 30, 2016	**Kirtland Partnership Committee** 7:30 a.m.	African American Performing Arts Center 310 San Pedro Dr. NE
September 12, 2016	**American Institute of Petroleum Geologists**	Santa Fe, NM
September 15-16, 2016	**New Mexico Water Law Conference** TBD	Santa Fe, NM
September 24, 2016	**Albuquerque International District Fair** 10:00 – 5:00 p.m.	Veterans Memorial Park 1100 Louisiana Blvd SE
November 10, 2016	**Regular Public Meeting with Poster Session** 5:00 – 8:30 p.m.	African American Performing Arts Center 310 San Pedro Dr. NE
November 2016	**Public Technical Workshop** TBD	Location TBD