Kirtland Fuel Leak Cleanup

Dr. Adria Bodour, AFCEC Environmental Scientist
Diane Agnew, NMED Hydrologist

Highland High School Classroom Presentation
February 24, 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

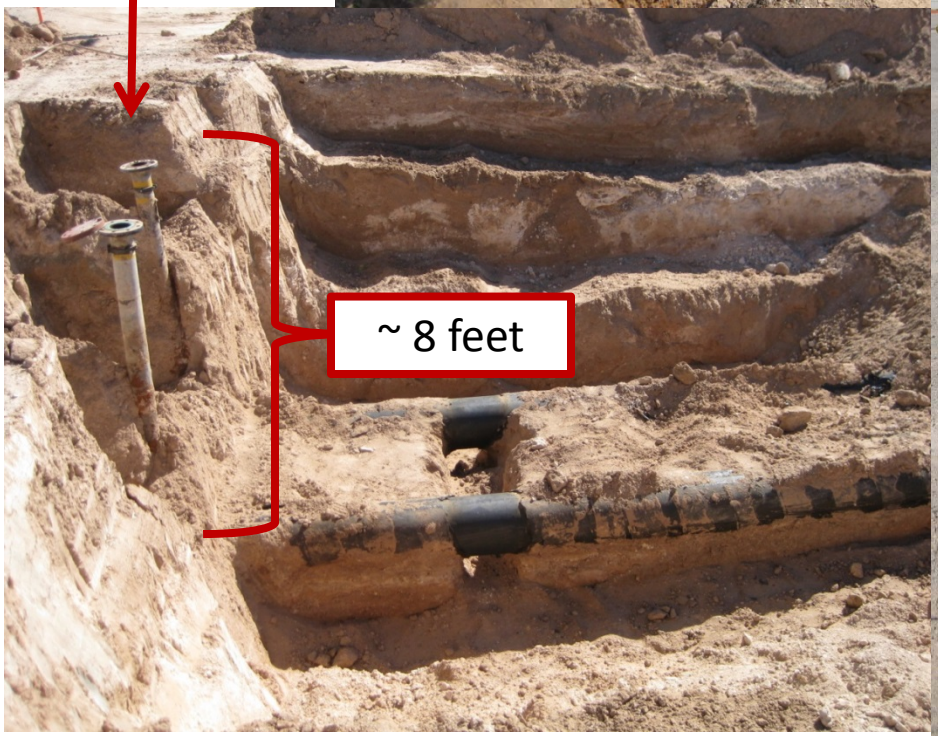
1999 Leak Photos at BFF

Metal Stair Step

Removal of Piping 2010 Photos

Hole in Bottom of Transfer Pipe

Pipe Connect into the Pump House Building



~ 8 feet

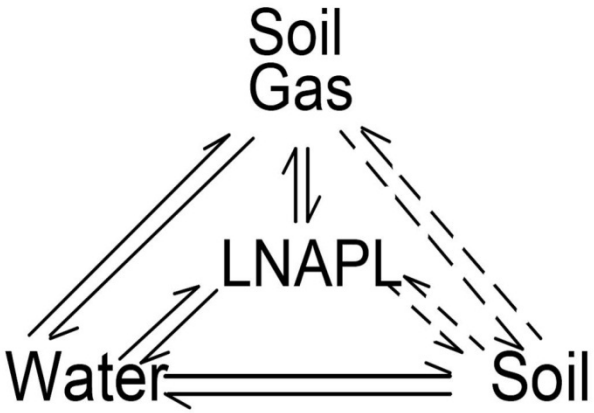
Pipe Bent when Removed from Trench

Regulatory Framework

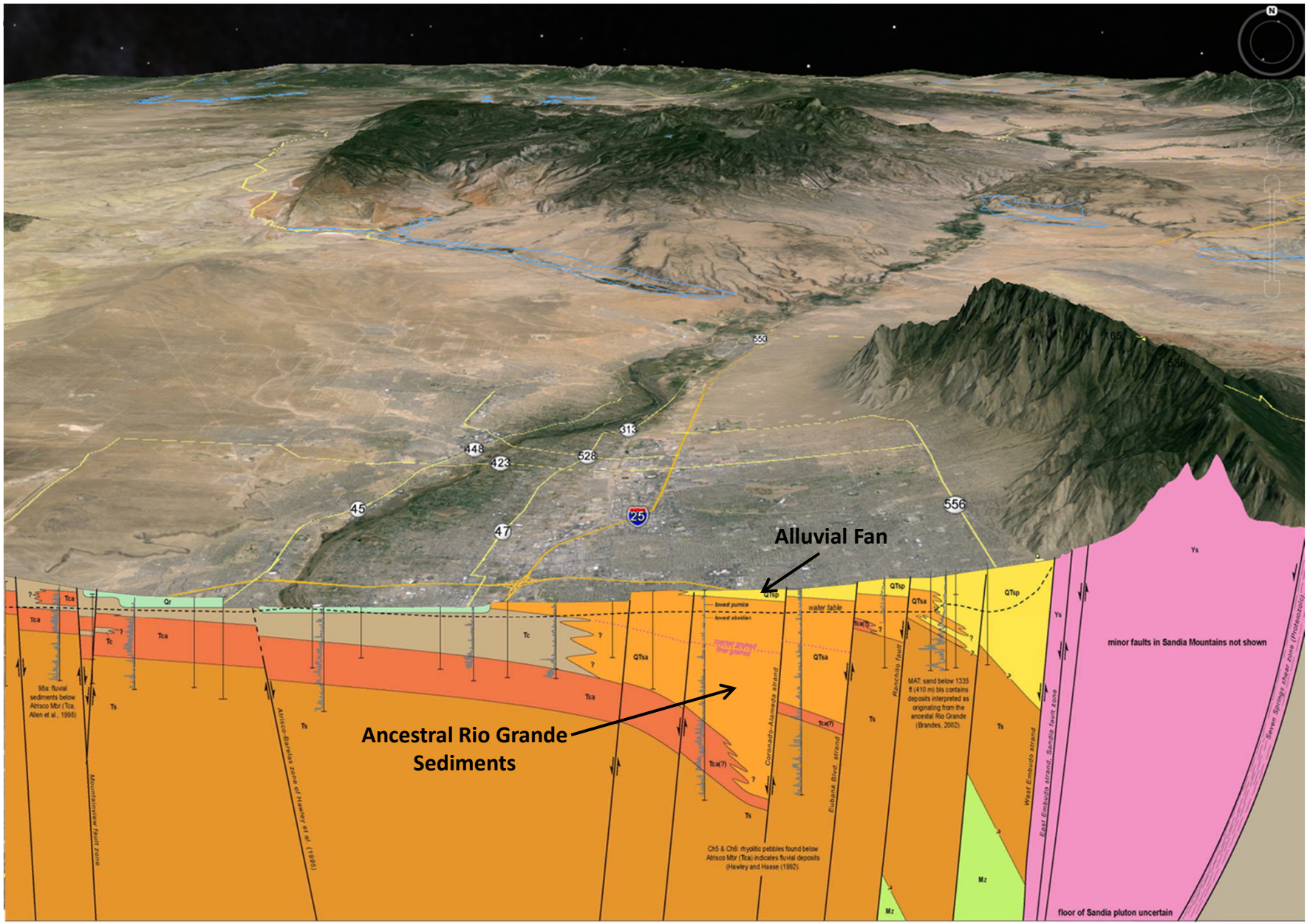
- The New Mexico Environment Department (NMED) governs the fuel leak site through the administration of two federal acts:
  - Safe Drinking Water Act (SDWA)
  - Resource Conservation and Recovery Act (RCRA)
- Site activities are being completed under the Corrective Action provision of RCRA and KAFB's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

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



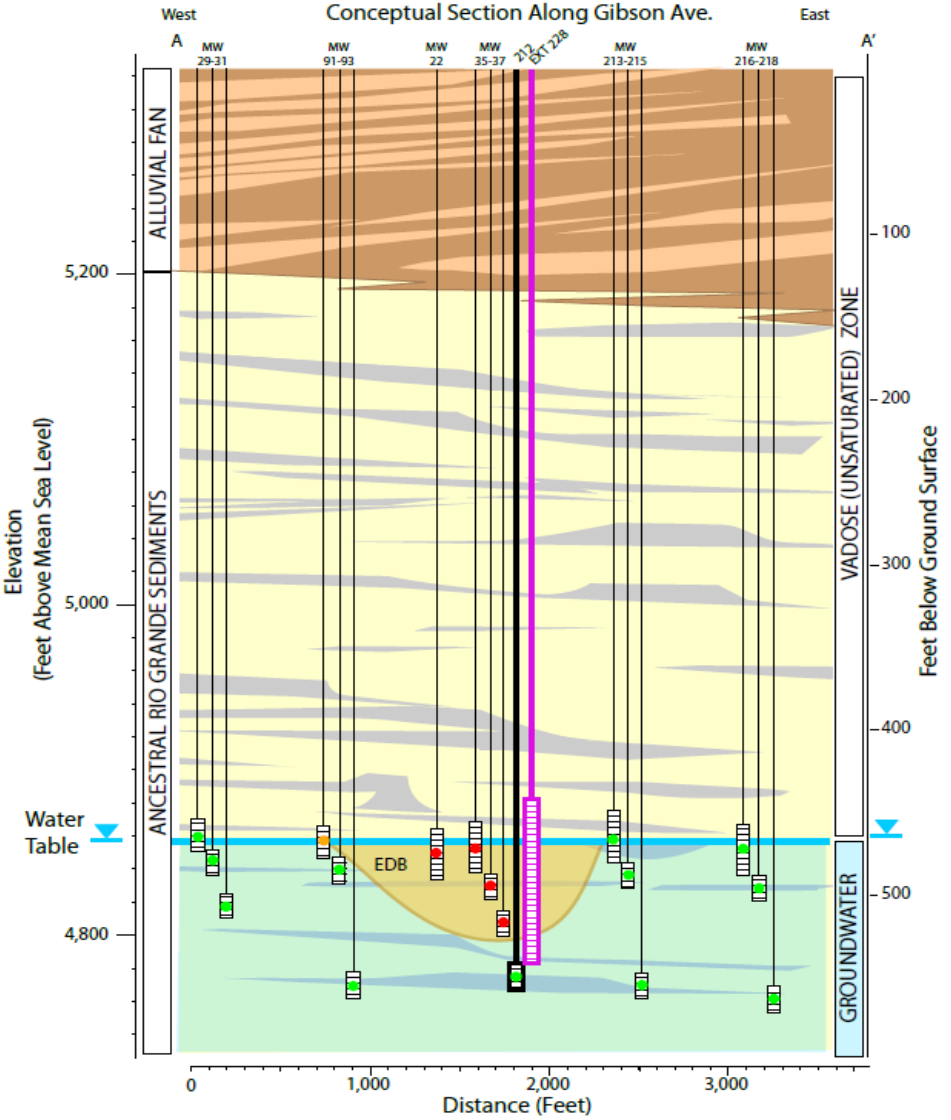
Understanding the Hydrology



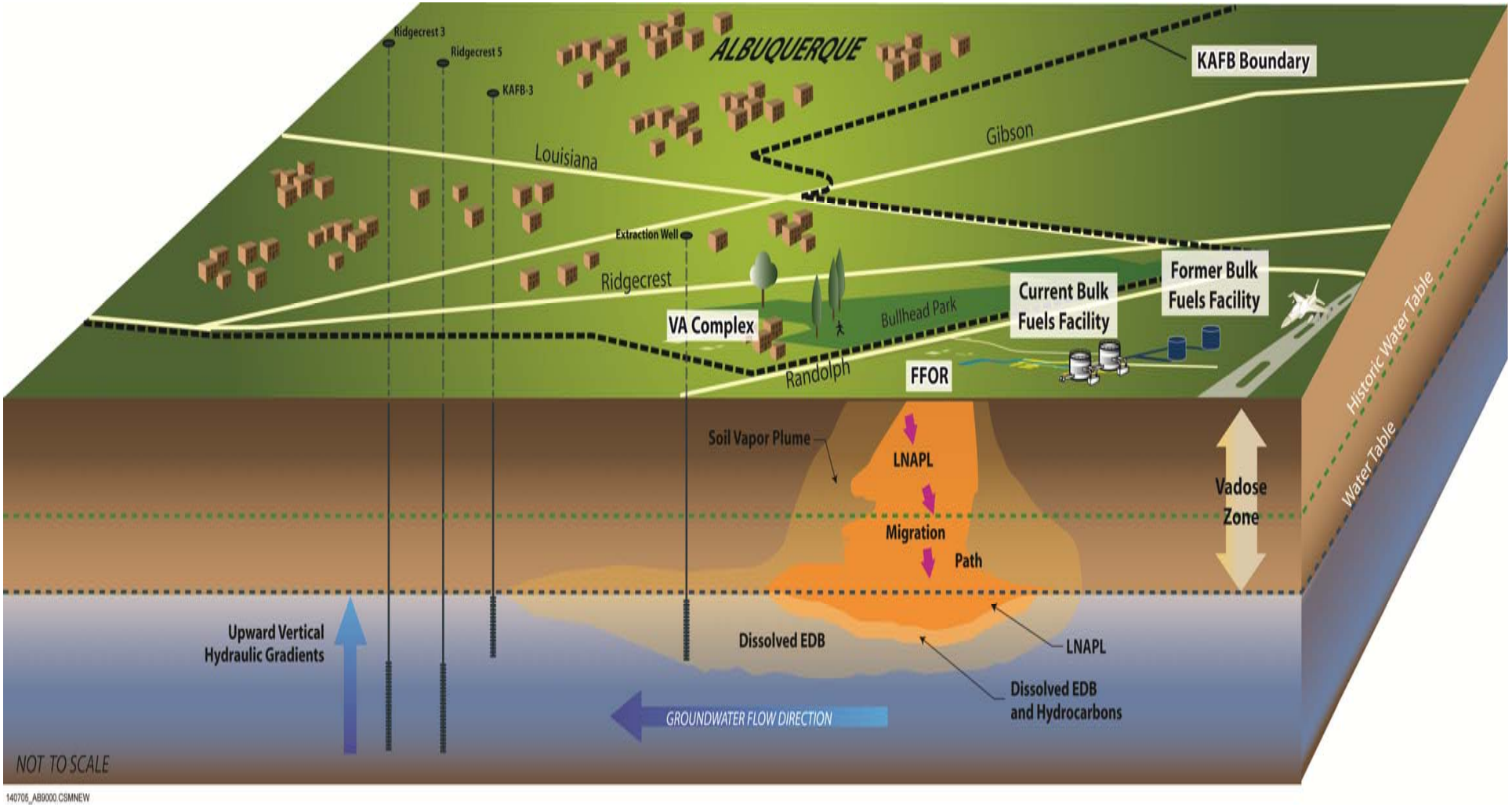
Understanding the Geology

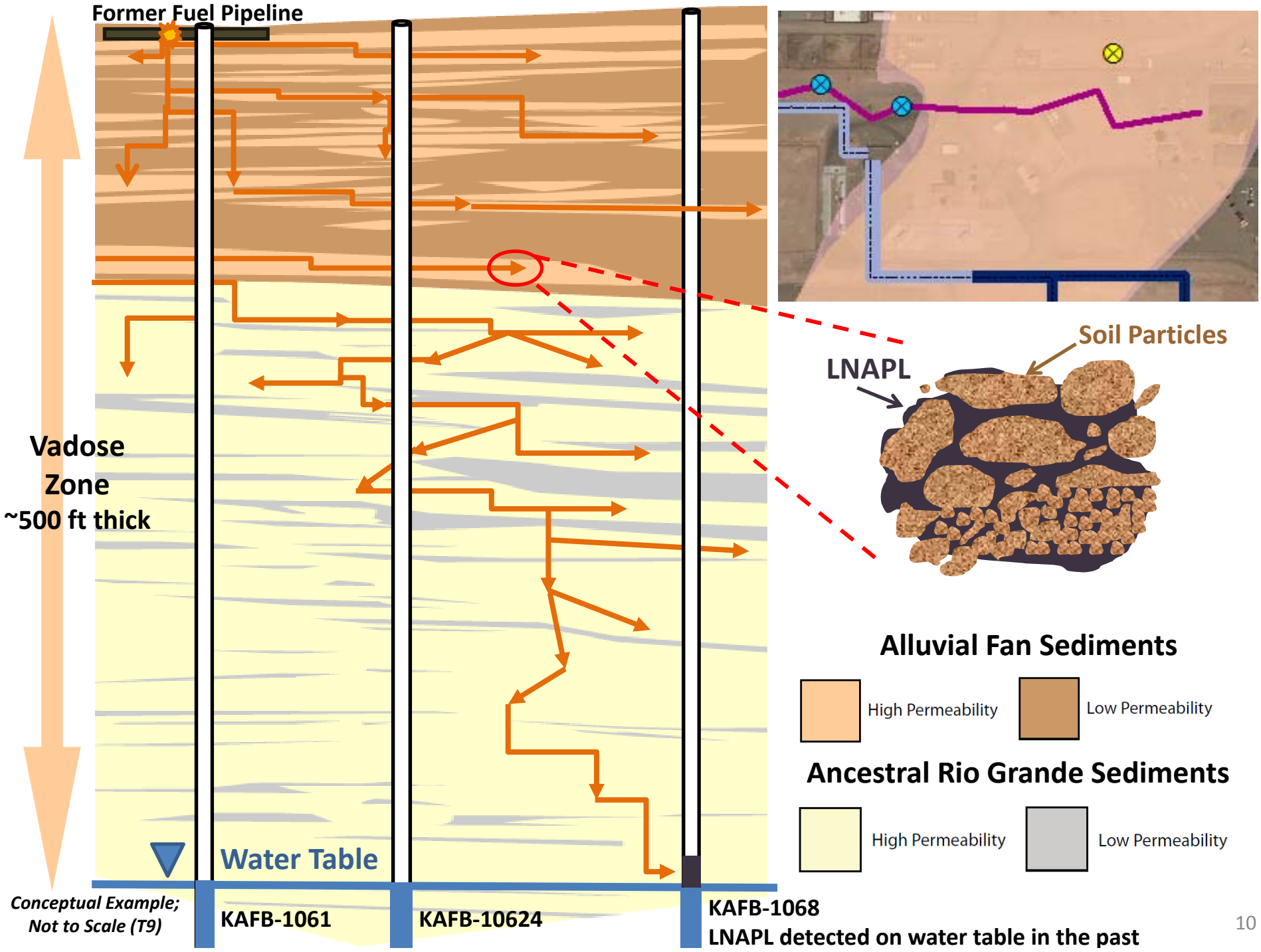
Alluvial Fan Deposits

Ancestral Rio Grande Braided River Deposits



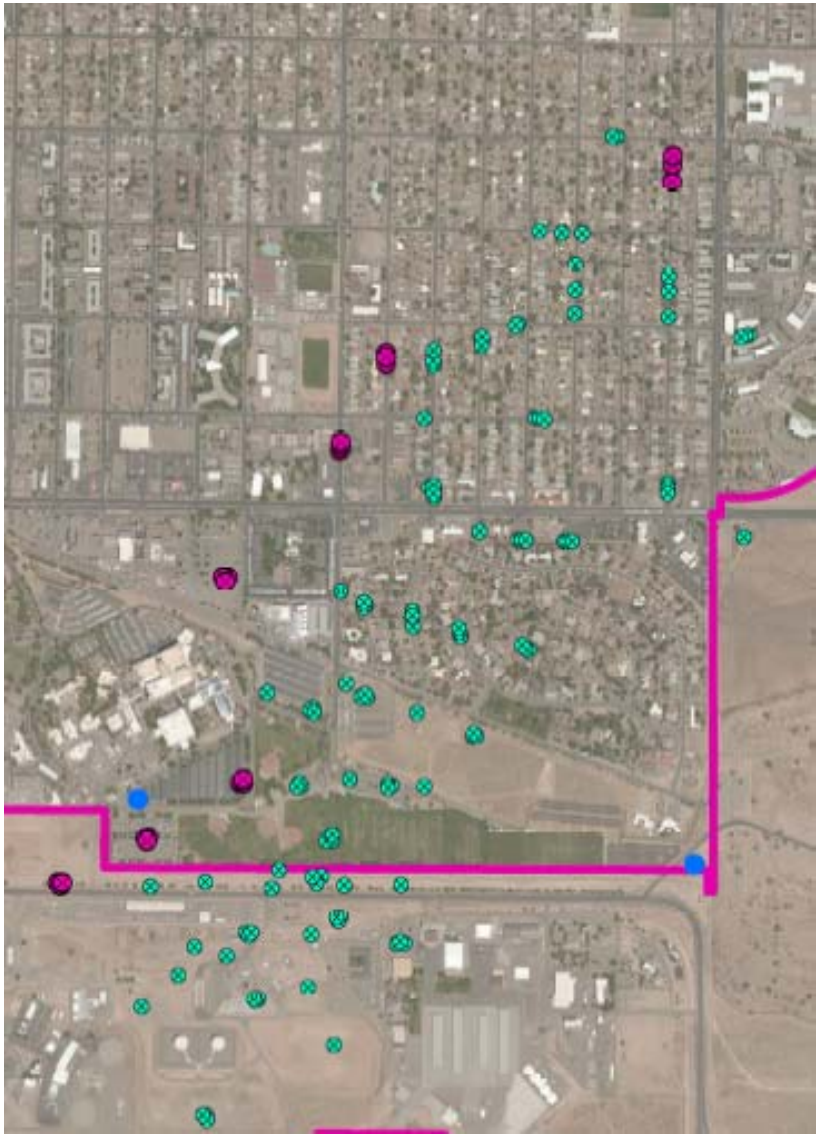
What do we know?




Former Fuel Pipeline
Vadose Zone ~500 ft thick
Water Table
KAFB-1061
KAFB-10624
KAFB-1068
LNAPL detected on water table in the past
Conceptual Example; Not to Scale (T9)
Soil Particles
LNAPL
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



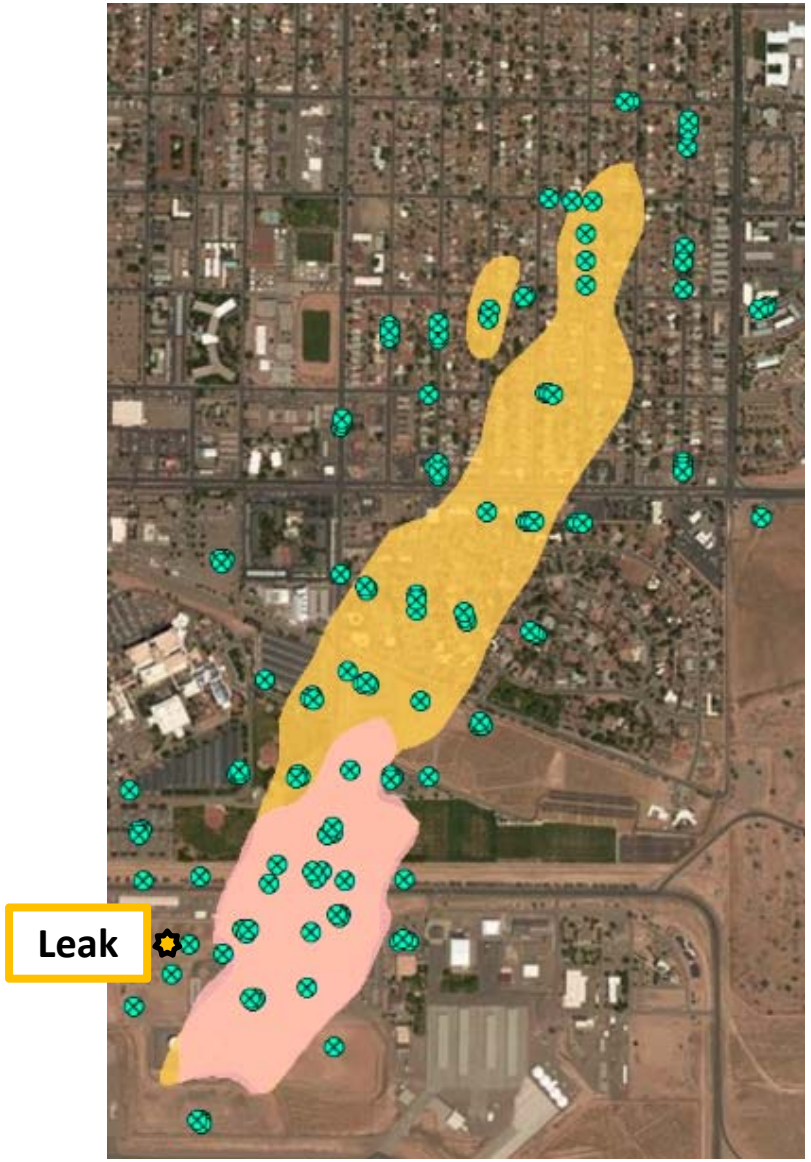
Plume Anatomy

Source Area Definition

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

Distal Plume Definition

- Only dissolved EDB
- No biodegradation



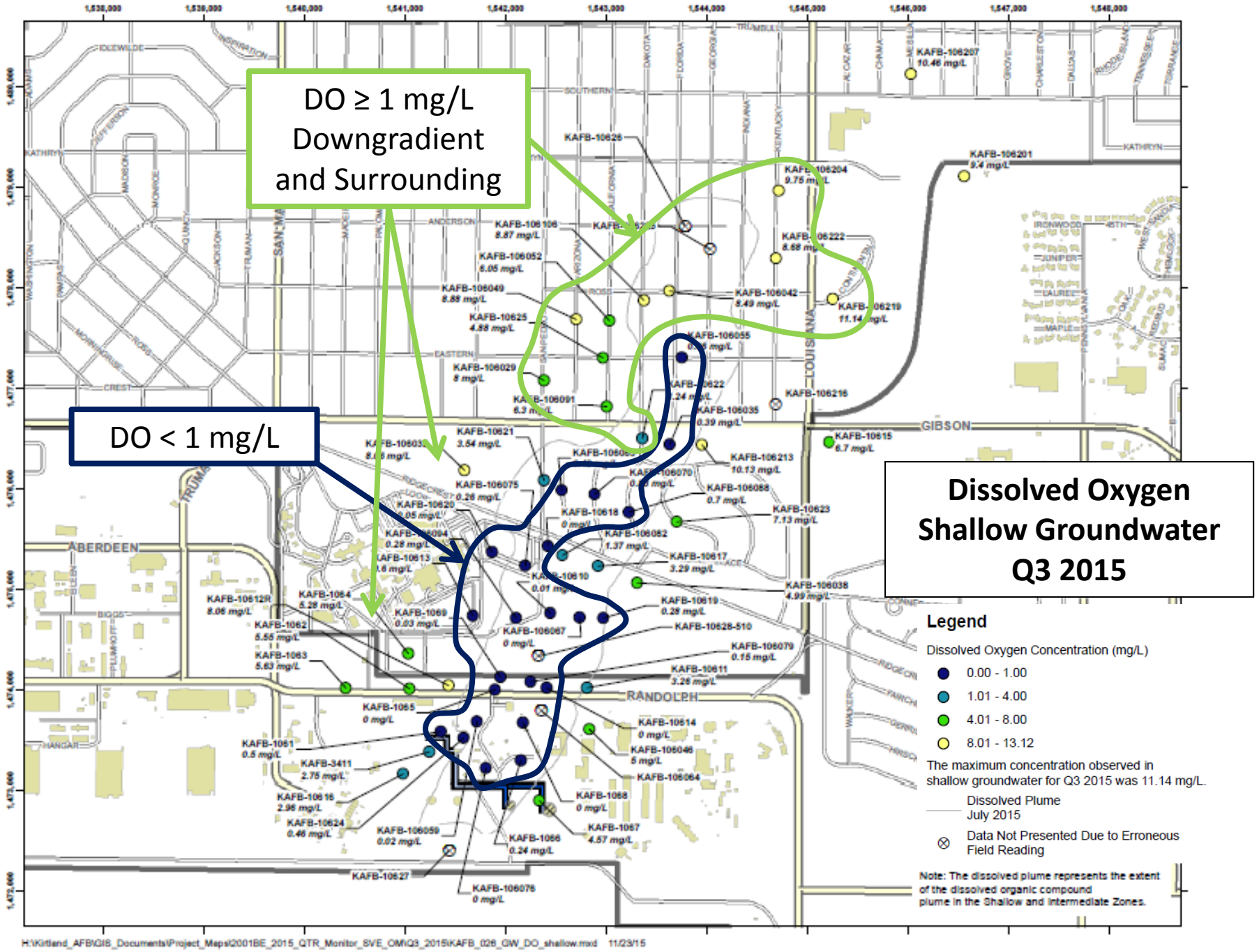
Plume Geochemistry

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.


DO ≥ 1 mg/L
Downgradient
and Surrounding
DO < 1 mg/L
Dissolved Oxygen
Shallow Groundwater
Q3 2015
Legend
Dissolved Oxygen Concentration (mg/L)
0.00 - 1.00
1.01 - 4.00
4.01 - 8.00
8.01 - 13.12
The maximum concentration observed in shallow groundwater for Q3 2015 was 11.14 mg/L.
Dissolved Plume
July 2015
Data Not Presented Due to Erroneous Field Reading
Note: The dissolved plume represents the extent of the dissolved organic compound plume in the Shallow and Intermediate Zones.
ABERDEEN
RANDOLPH
GIBSON
KAFB-106207
10.46 mg/L
KAFB-106201
9.4 mg/L
KAFB-106204
9.75 mg/L
KAFB-106222
8.68 mg/L
KAFB-106219
11.14 mg/L
KAFB-106042
8.49 mg/L
KAFB-106216
KAFB-106213
10.13 mg/L
KAFB-106623
7.13 mg/L
KAFB-106038
4.99 mg/L
KAFB-106615
6.7 mg/L
KAFB-106625
KAFB-106106
8.87 mg/L
KAFB-106052
6.05 mg/L
KAFB-106049
8.88 mg/L
KAFB-10625
4.58 mg/L
KAFB-106029
8 mg/L
KAFB-106091
6.3 mg/L
KAFB-106055
KAFB-106035
0.39 mg/L
KAFB-10621
3.54 mg/L
KAFB-106075
0.26 mg/L
KAFB-106070
KAFB-106088
0.7 mg/L
KAFB-10618
0 mg/L
KAFB-106052
1.37 mg/L
KAFB-10617
3.29 mg/L
KAFB-10619
0.28 mg/L
KAFB-106079
0.15 mg/L
KAFB-10611
3.26 mg/L
KAFB-10614
0 mg/L
KAFB-106046
5 mg/L
KAFB-106064
KAFB-10512R
8.06 mg/L
KAFB-1062
5.55 mg/L
KAFB-1063
5.63 mg/L
KAFB-1064
5.28 mg/L
KAFB-1069
0.03 mg/L
KAFB-106067
0 mg/L
KAFB-1065
0 mg/L
KAFB-1061
0.5 mg/L
KAFB-3411
2.75 mg/L
KAFB-10616
2.95 mg/L
KAFB-10624
0.46 mg/L
KAFB-106059
0.02 mg/L
KAFB-1066
0.24 mg/L
KAFB-1068
0 mg/L
KAFB-1067
4.57 mg/L
KAFB-10627
KAFB-106076
0 mg/L
H:\Kirtland_AFB\GIS_Documents\Project_Maps\2001BE_2015_QTR_Monitor_SVE_OM\Q3_2015\KAFB_026_GW_DO_shallow.mxd 11/23/15

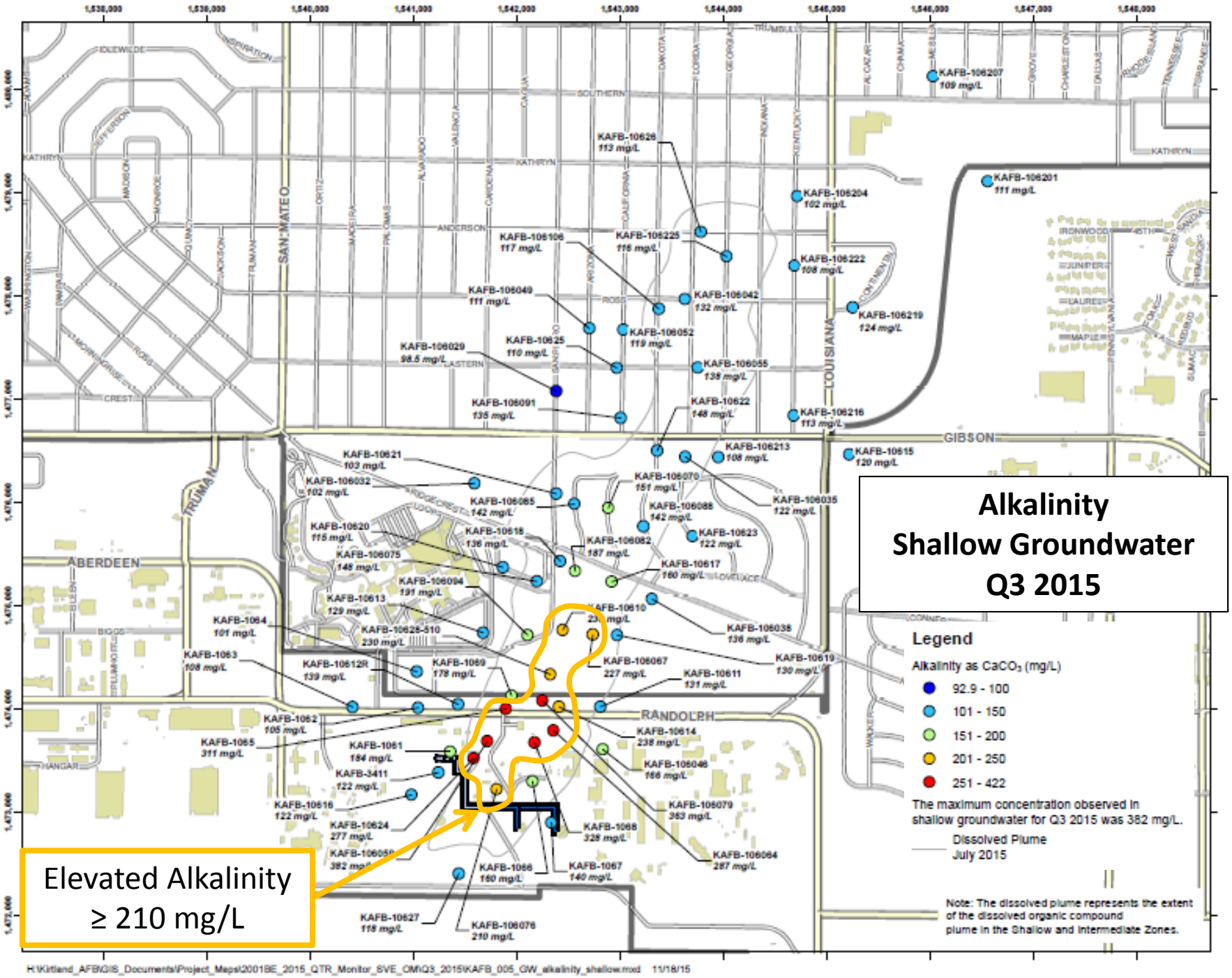
Plume Geochemistry

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
Q3 2015
Legend
Alkalinity as $CaCO_3$ (mg/L)
92.9 - 100
101 - 150
151 - 200
201 - 250
251 - 422
The maximum concentration observed in shallow groundwater for Q3 2015 was 382 mg/L.
Dissolved Plume
July 2015
Note: The dissolved plume represents the extent of the dissolved organic compound plume in the Shallow and Intermediate Zones.
Elevated Alkalinity
≥ 210 mg/L
KAFB-106207 109 mg/L
KAFB-10626 113 mg/L
KAFB-106201 111 mg/L
KAFB-106204 102 mg/L
KAFB-106106 117 mg/L
KAFB-106225 116 mg/L
KAFB-106222 108 mg/L
KAFB-106049 111 mg/L
KAFB-106042 132 mg/L
KAFB-106219 124 mg/L
KAFB-106052 119 mg/L
KAFB-106029 98.5 mg/L
KAFB-10625 110 mg/L
KAFB-106055 138 mg/L
KAFB-106091 135 mg/L
KAFB-10622 148 mg/L
KAFB-106216 113 mg/L
KAFB-10621 103 mg/L
KAFB-106213 108 mg/L
KAFB-10615 120 mg/L
KAFB-106032 102 mg/L
KAFB-106070 151 mg/L
KAFB-106085 142 mg/L
KAFB-106088 142 mg/L
KAFB-106035 122 mg/L
KAFB-10620 115 mg/L
KAFB-10618 136 mg/L
KAFB-106082 187 mg/L
KAFB-10623 122 mg/L
KAFB-106075 148 mg/L
KAFB-10617 160 mg/L
KAFB-106094 191 mg/L
KAFB-10613 129 mg/L
KAFB-10610 23 mg/L
KAFB-1064 101 mg/L
KAFB-10628-510 230 mg/L
KAFB-106038 136 mg/L
KAFB-1063 108 mg/L
KAFB-10612R 139 mg/L
KAFB-1069 178 mg/L
KAFB-106067 227 mg/L
KAFB-10619 130 mg/L
KAFB-10611 131 mg/L
KAFB-1062 105 mg/L
KAFB-10614 238 mg/L
KAFB-1065 311 mg/L
KAFB-1061 184 mg/L
KAFB-106046 166 mg/L
KAFB-3411 122 mg/L
KAFB-10616 122 mg/L
KAFB-106079 363 mg/L
KAFB-10624 277 mg/L
KAFB-1068 328 mg/L
KAFB-106064 287 mg/L
KAFB-1066 160 mg/L
KAFB-1067 140 mg/L
KAFB-10627 118 mg/L
KAFB-106076 210 mg/L
ABERDEEN
RANDOLPH
GIBSON
LOUISIANA
SAN MATEO
TRUMAN
H:\Kitland_AFB\GIS_Documents\Project_Maps\2001BE_2015_QTR_Monitor_SVE_OM\Q3_2015\KAFB_005_GW_alkalinity_shallow.mxd 11/18/15

Plume Geochemistry

Multiple solutes

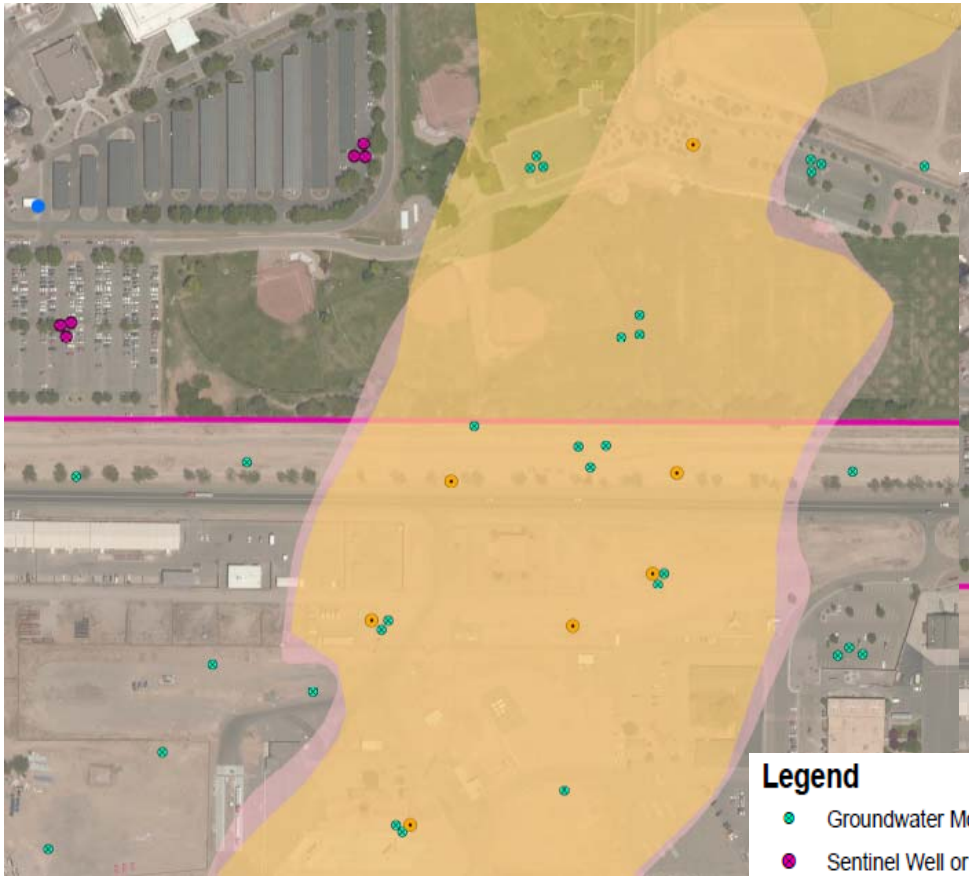
- Jet fuel and aviation gas have multiple organic compounds
- The solubility of organic compounds is dependent on the mixture of solutes present

Multiple Solutes Take-Away

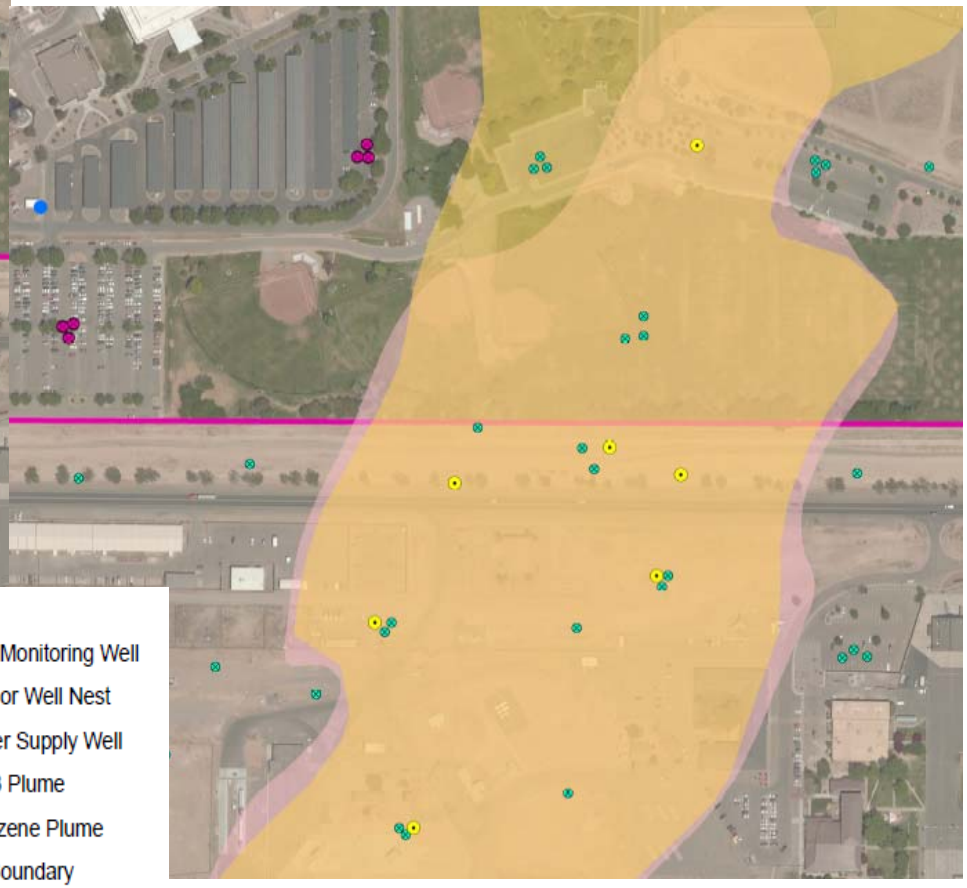
- The concentration of a solute is less than it would be in water alone.
- Over time, the fraction of LNAPL constituents with lower solubility increases → increased equilibrium concentration in groundwater. ???

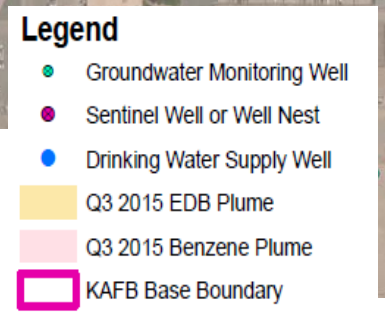
Benzene Footprint - Solubility

Toluene ≥ 750 µg/l NMED standard



Naphthalene
≥ 30 µg/L NMED standard





Interim Measure Strategies at BFF

Source Removal

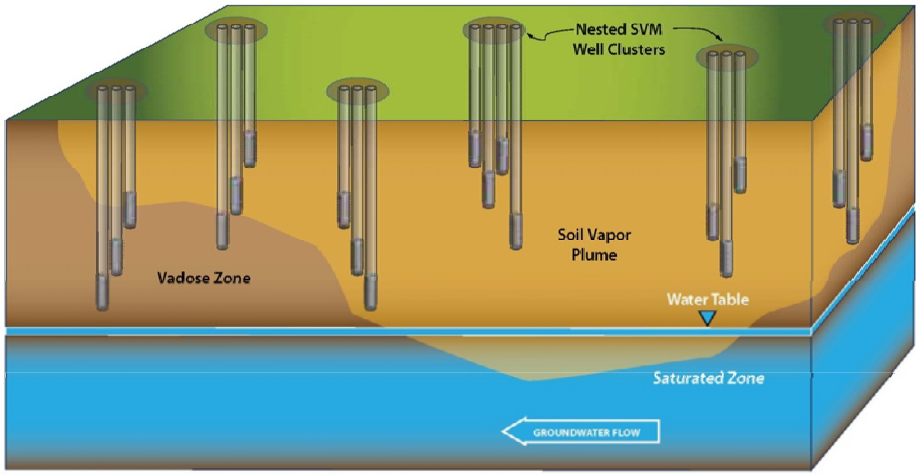
- Soil excavation down to 20 feet below ground surface at leak location (primary source)
- Soil vapor extraction (SVE) in vadose zone (secondary source)

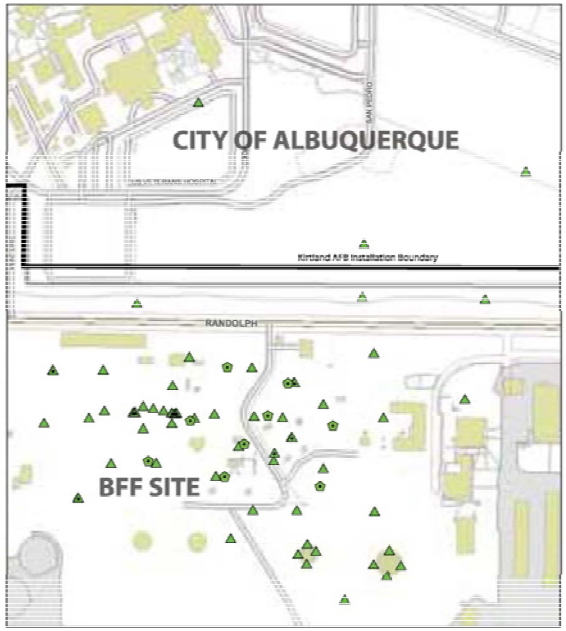
EDB Plume Collapse

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

Soil Vapor Network and Sampling

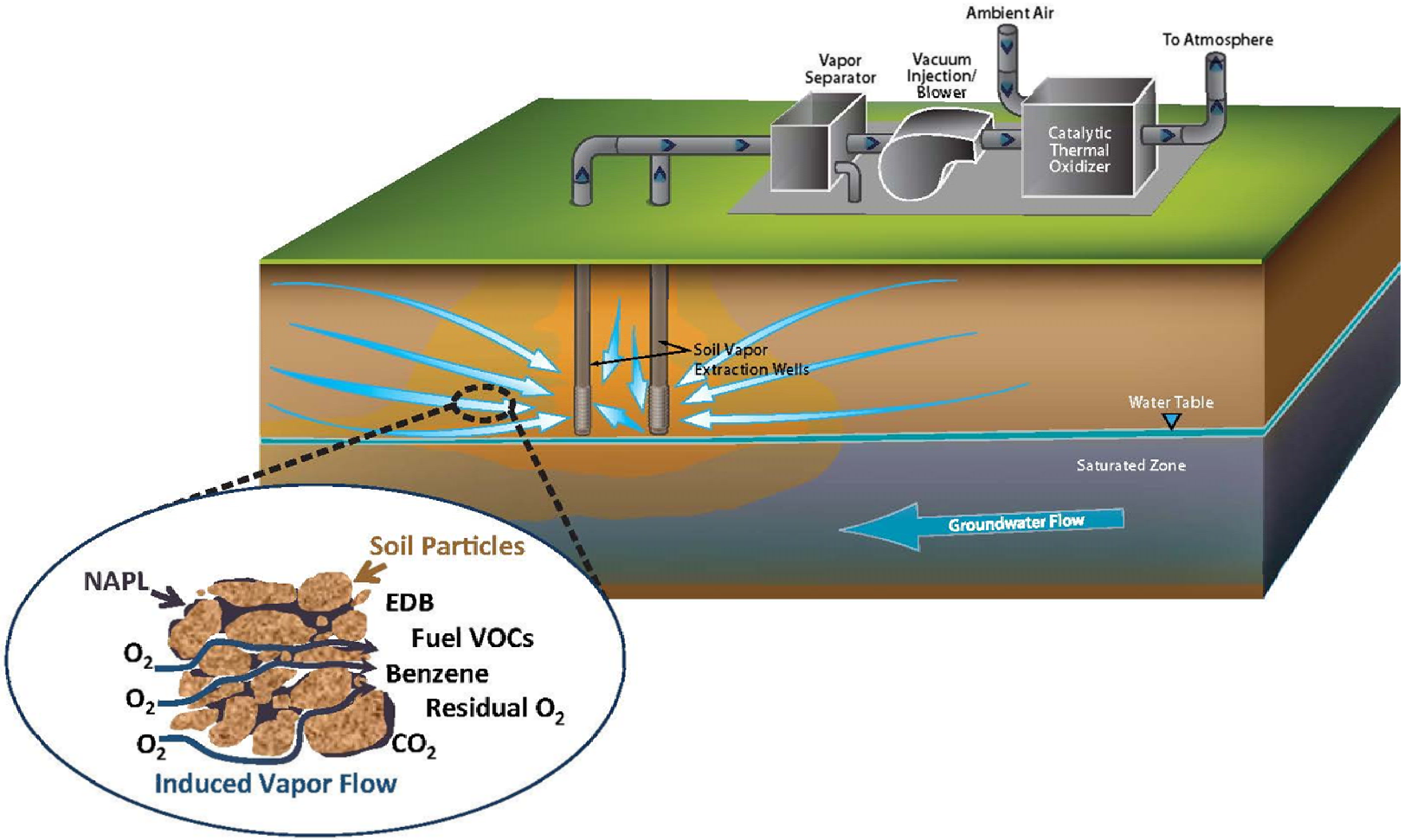
- Soil vapor sampling in source area from a network of 284 soil vapor monitoring points
  - 56 locations with 3 or 6 sampling depths each location
- Quarterly measurements include:
  - Field measurements of O_2, CO_2, and total petroleum hydrocarbons (TPH)
  - Laboratory analysis for volatile organic 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

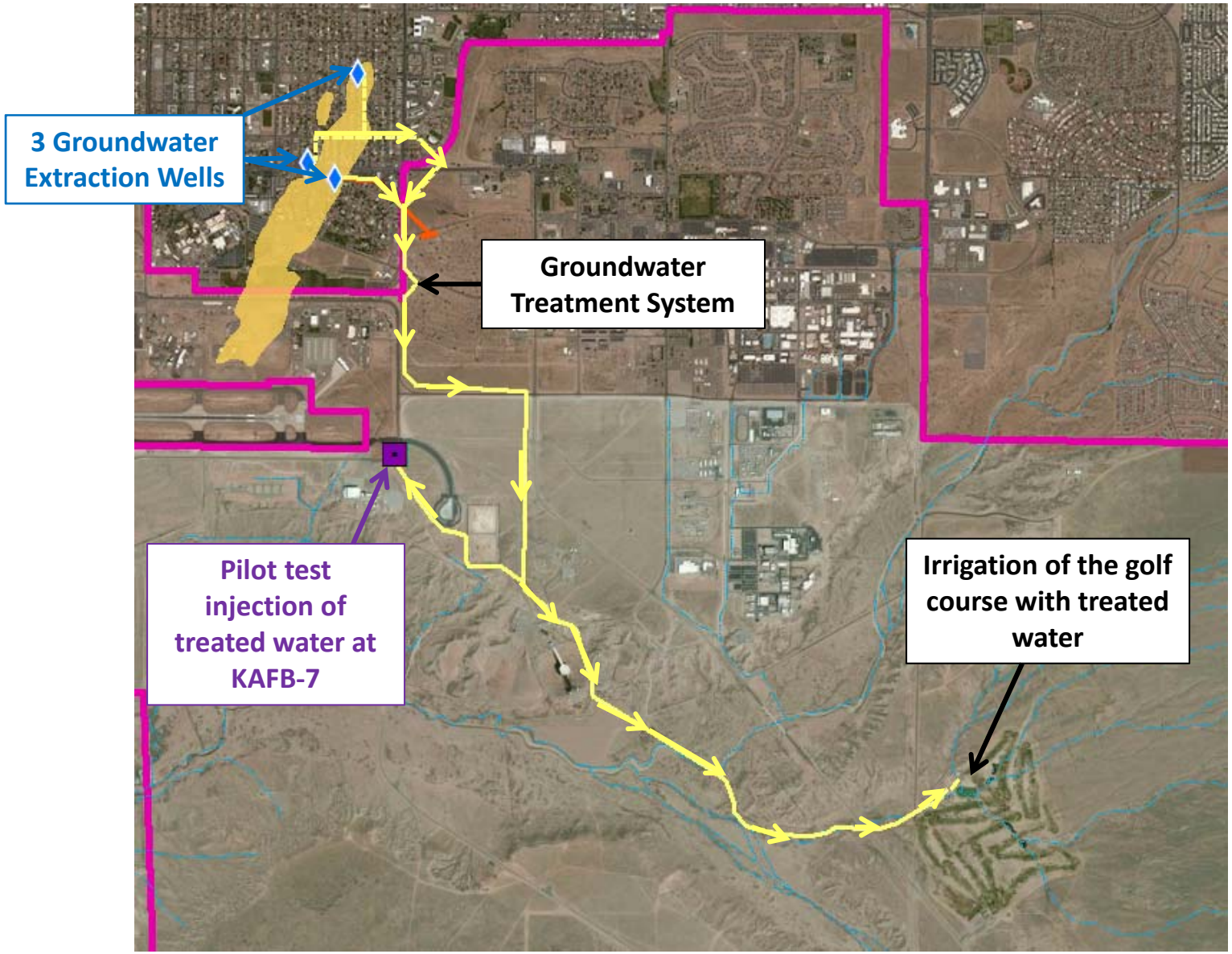
Groundwater Remediation

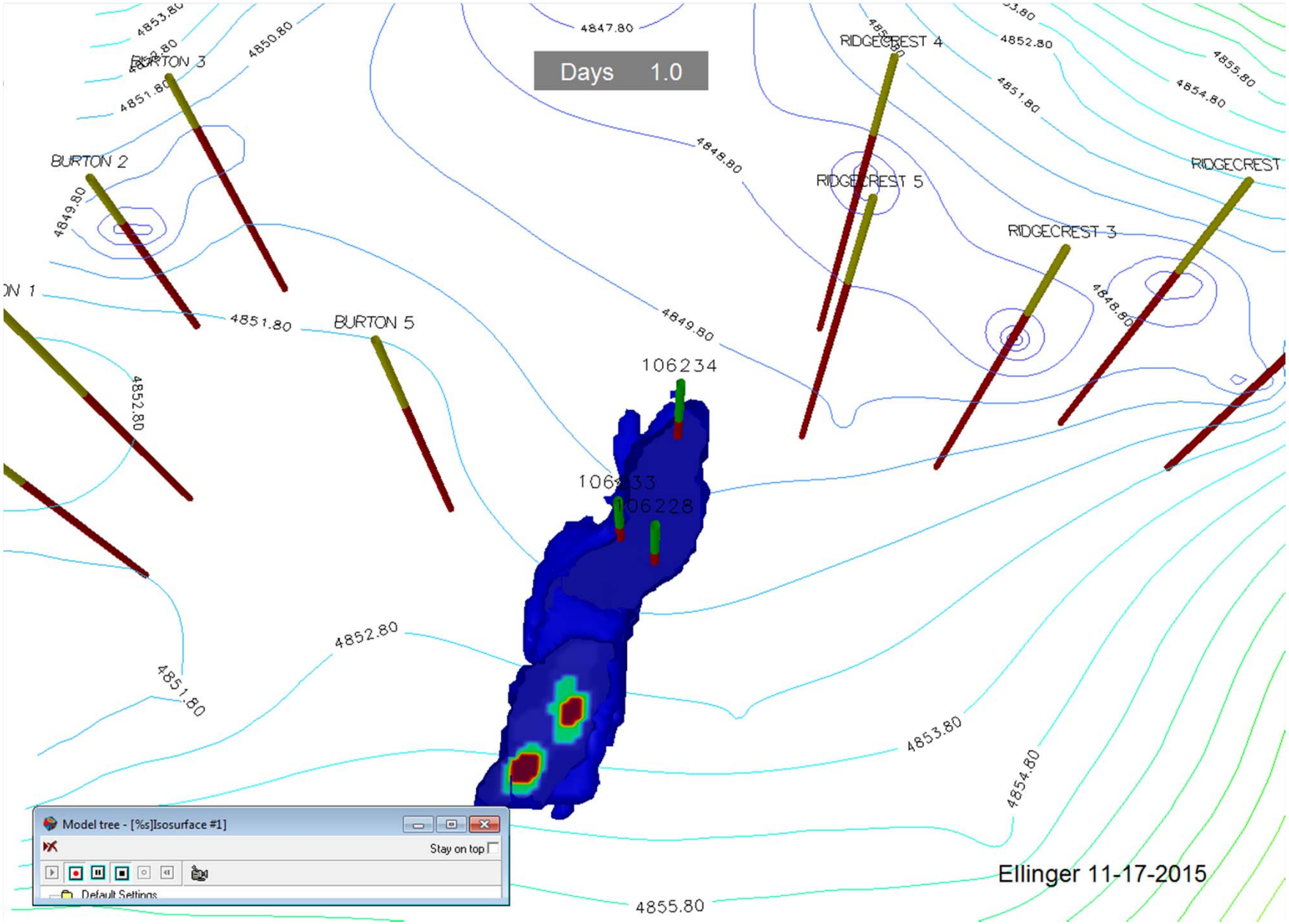
- Remediation generally addresses two issues:
  - Source control (primary and secondary)
  - Protection of human health and the environment through cleanup to regulatory standards
- Technologies include:
  - Pump and treat
  - Air sparging
  - Permeable reactive barriers
  - Monitored natural attenuation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

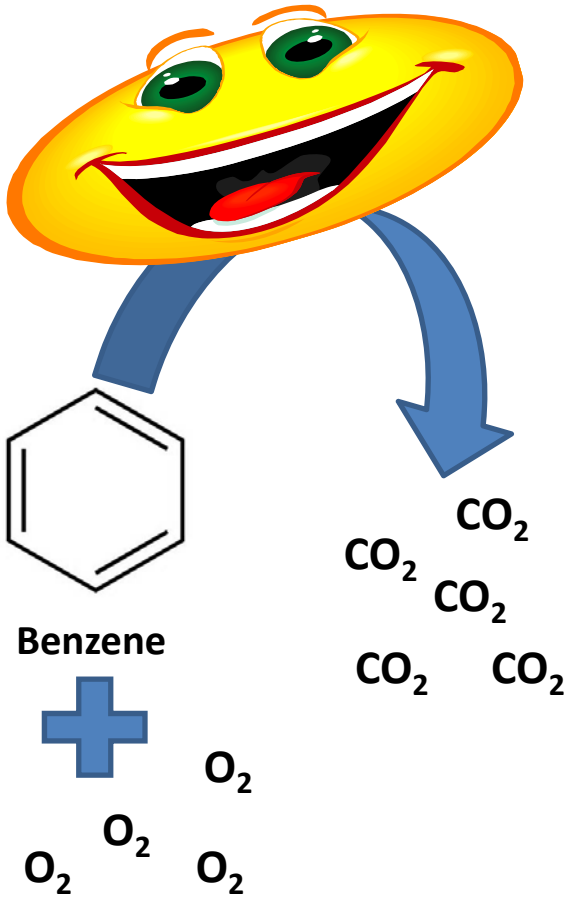



Days 1.0
BURTON 3
BURTON 2
BURTON 5
RIDGECREST 4
RIDGECREST 5
RIDGECREST 3
RIDGECREST
106234
106233
106228
4847.80
4848.80
4849.80
4850.80
4851.80
4852.80
4853.80
4854.80
4855.80
Model tree - [%s]Isosurface #1
Stay on top
Default Settings
Ellinger 11-17-2015

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

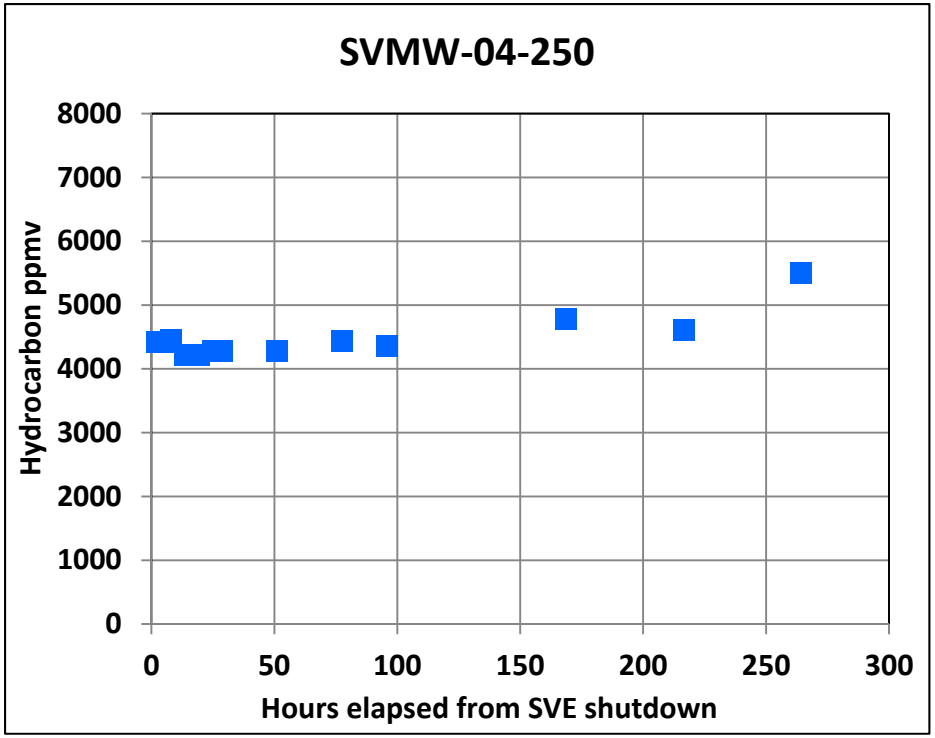
- Experiments run in a laboratory using groundwater and soil from the site
- Identify potential technologies for degradation of hydrocarbons, including EDB

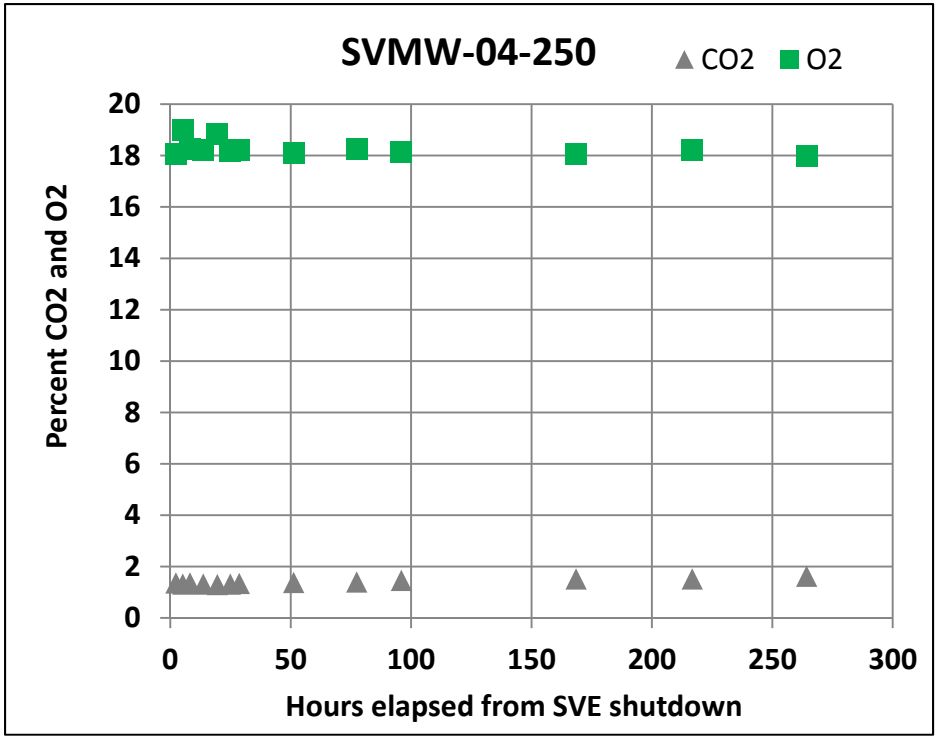
In Situ Respiration Testing

- 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

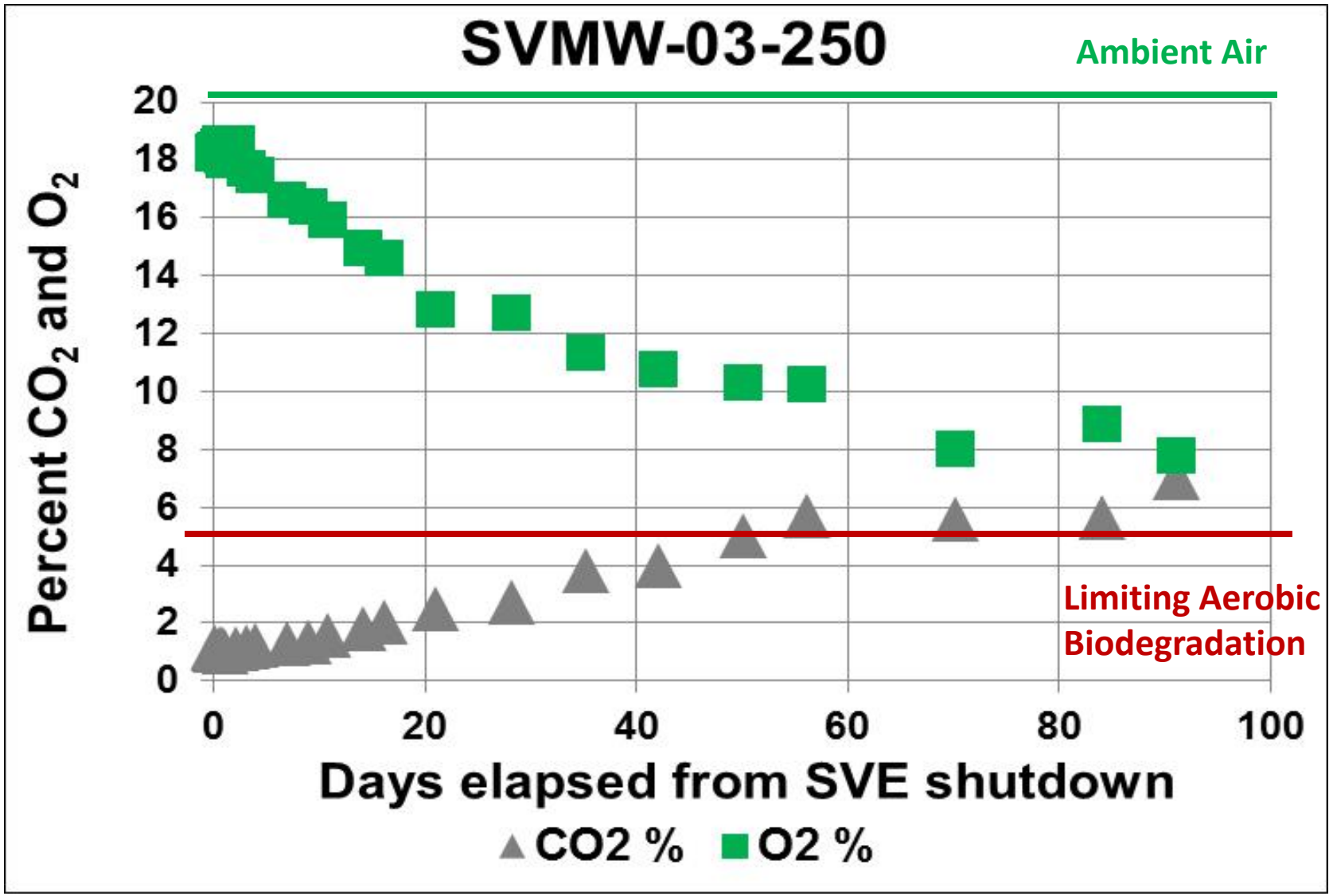
Summary of Results - Respiration

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

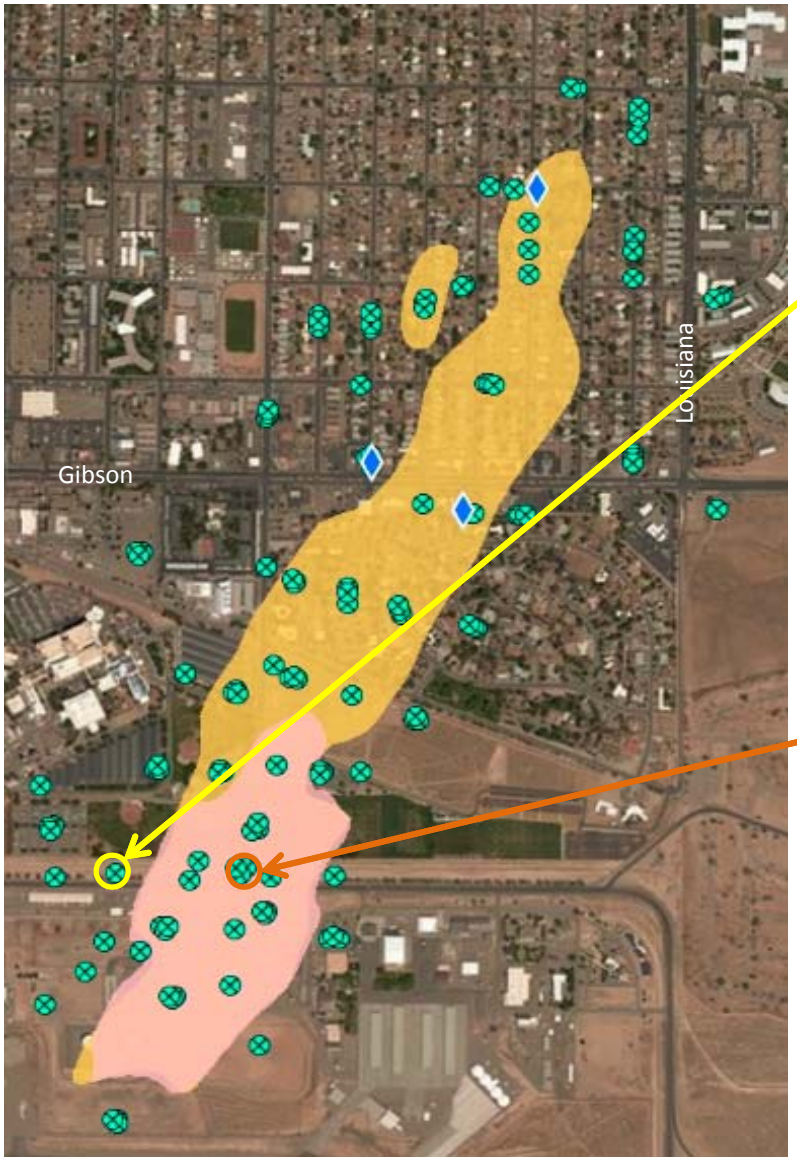




Understanding the Data



Laboratory Microcosm Testing



Two areas were cored and sampled:

<u>Side gradient</u>:

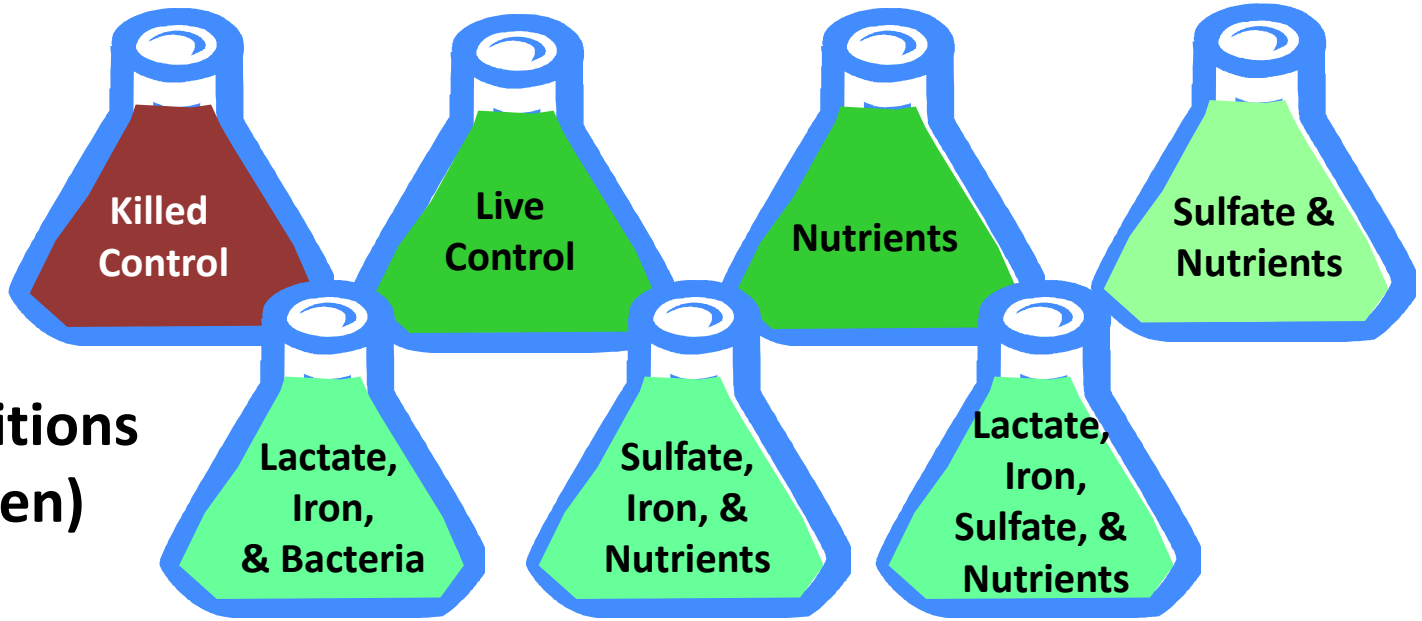
- Collected core during drilling of a groundwater monitoring well KAFB-10612R
- Collected groundwater from the same well

<u>Source Area (LNAPL):</u>

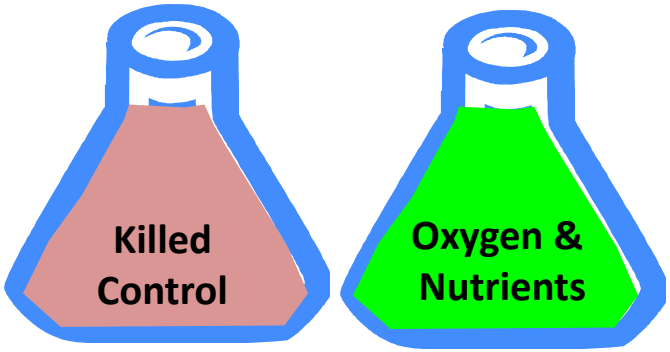
- Collected core during drilling of groundwater monitoring well KAFB-106210
- Collected groundwater from the same well

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

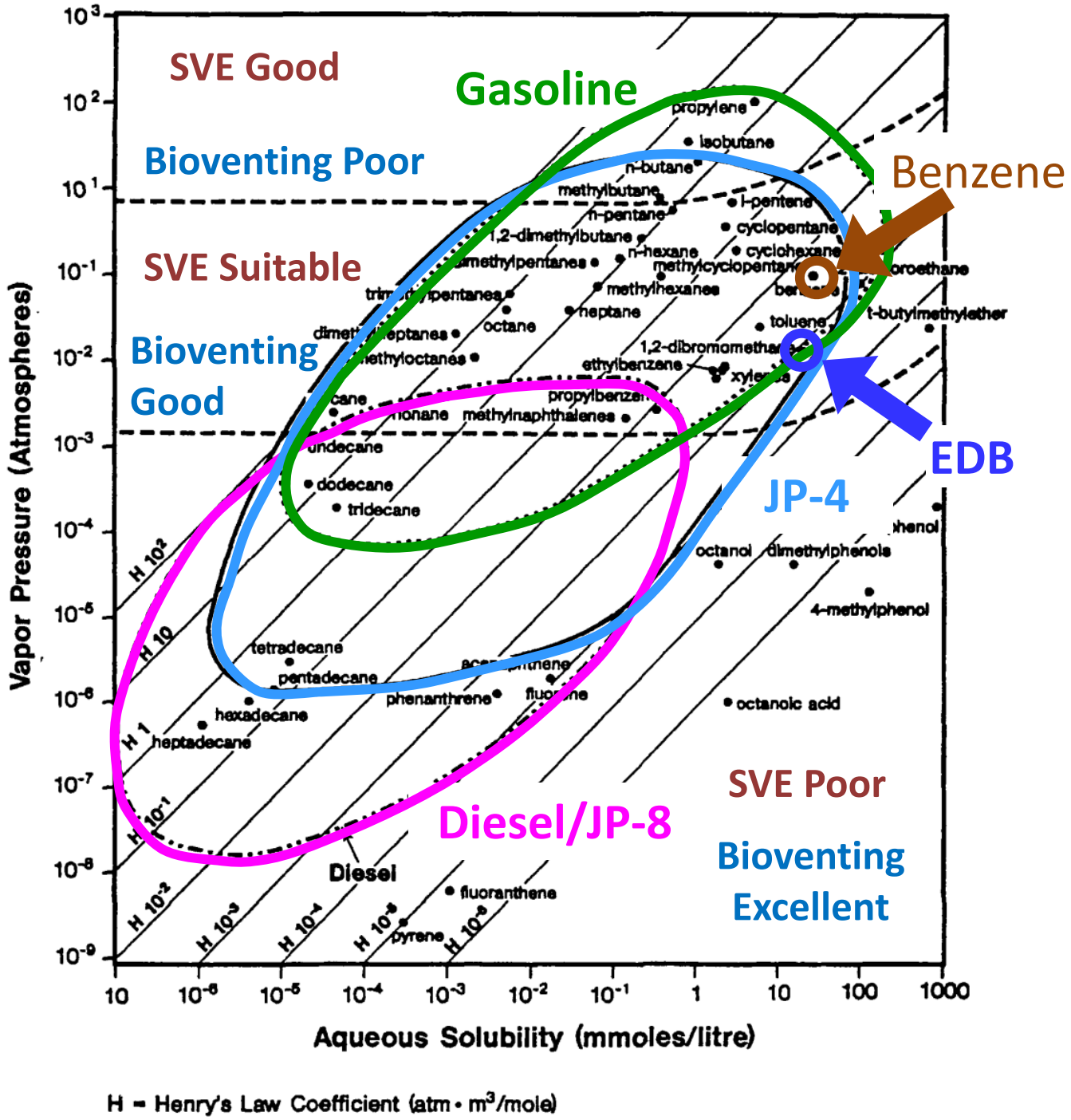
- Completed EDB degradation when *Dehalococcoides* added
- Minimal EDB degradation with added lactate, sulfate, Fe, and/or nutrients

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

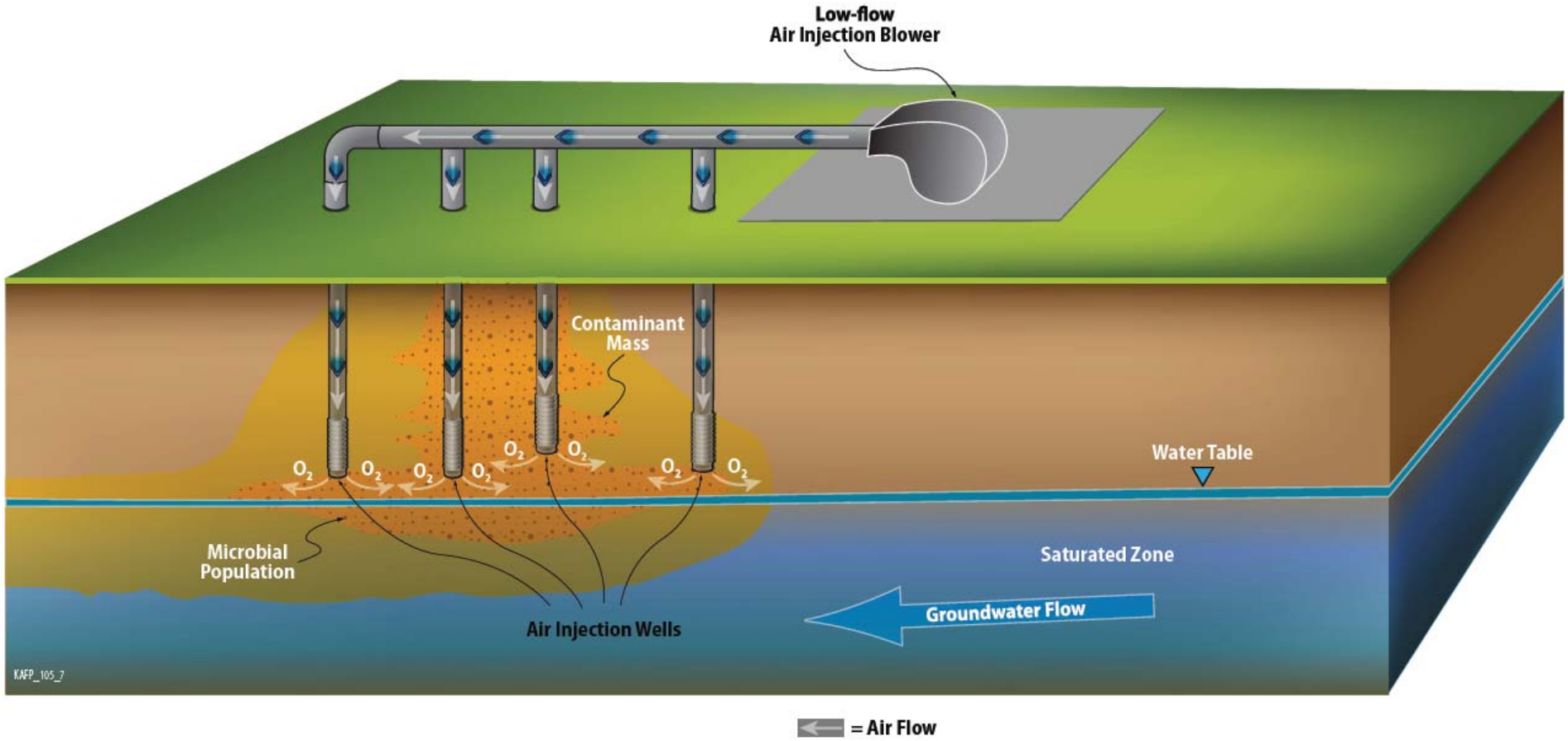
Remediation is **NOT** one-size fits all and evolves as the contaminant is cleanup overtime. Key factors include:

- 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
Vapor Pressure (Atmospheres)
Aqueous Solubility (mmoles/litre)
H = Henry's Law Coefficient (atm • m³/mole)
propylene
isobutane
n-butane
methylbutane
1-pentene
n-pentane
cyclopentane
1,2-dimethylbutane
n-hexane
cyclohexane
methylcyclopentane
methylhexanes
heptane
toluene
t-butylmethylether
octane
ethylbenzene
propylbenzene
methylnaphthalenes
undecane
dodecane
tridecane
octanol
dimethylphenols
4-methylphenol
tetradecane
pentadecane
phenanthrene
hexadecane
heptadecane
octanoic acid
fluoranthene
pyrene
H 10⁻²
H 10⁻¹
H 1
H 10
H 10²

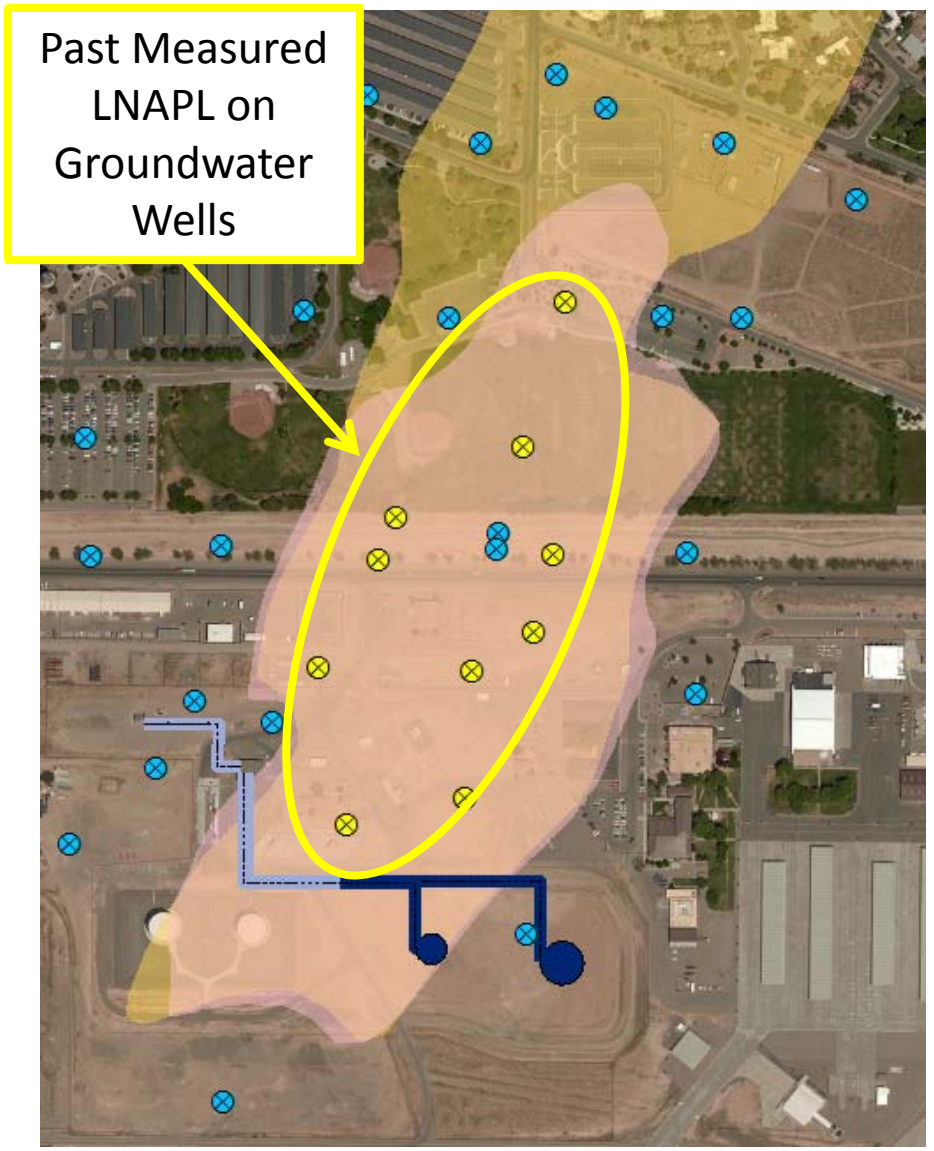
Bioventing

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

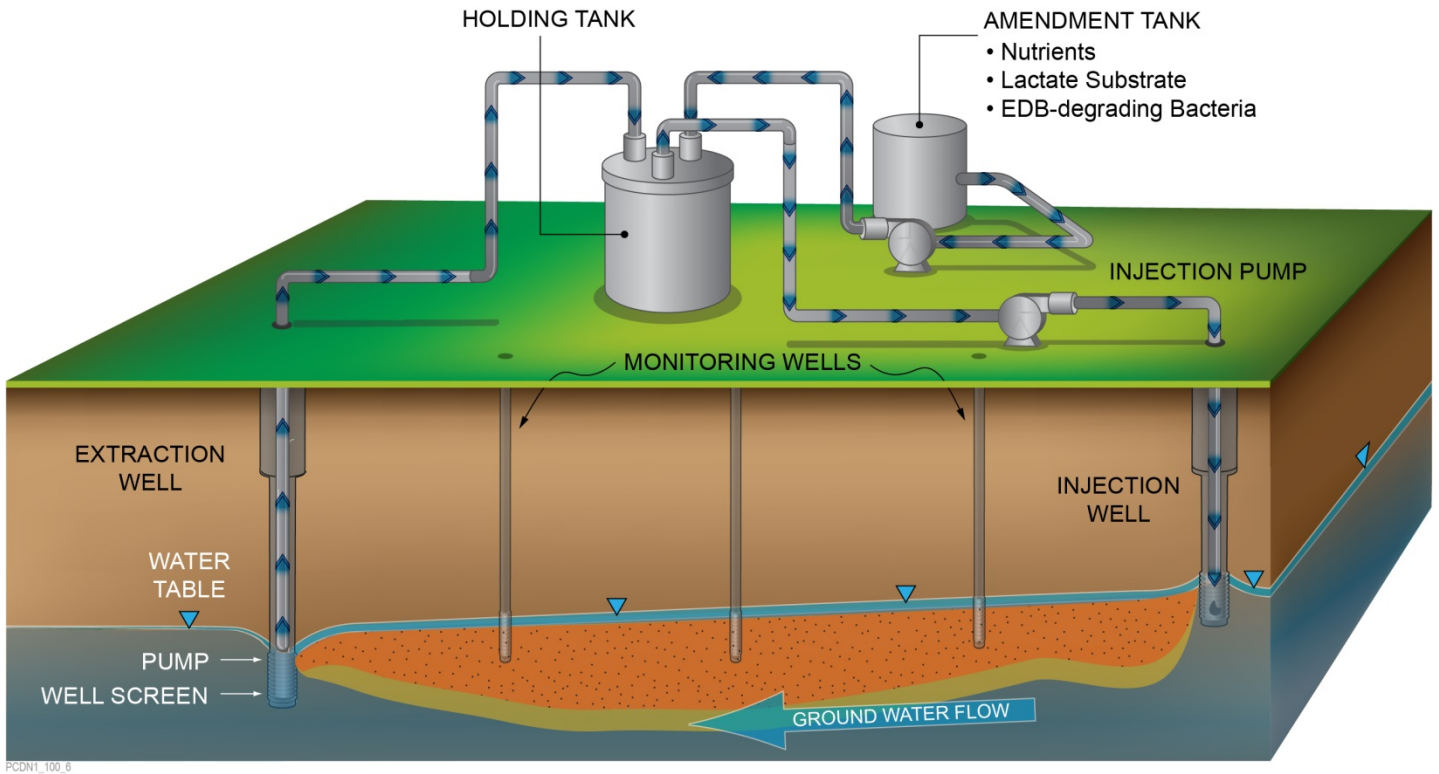
- Technologies include:
  - Skimmer – extracting primary source (i.e., free product/LNAPL)
  - SVE
  - Air sparging – bubbling air into the saturated zone
  - Enhanced in situ bioremediation – may use biostimulation and/or bioaugmentation to speed up degrade
- Past measurable LNAPL floating on the groundwater 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



Discussion