# Chemical Attenuation in a Fractured Bedrock Aquifer Impacted by Landfill Leachate

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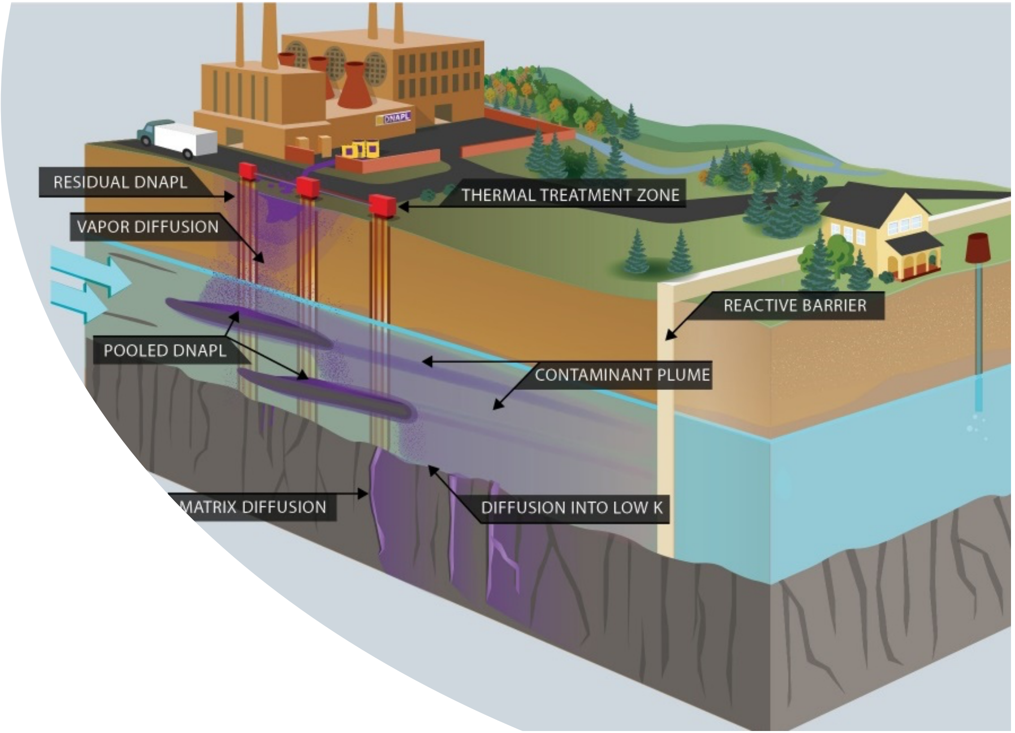
*September 11, 2019*

CDM Smith

CLU-IN

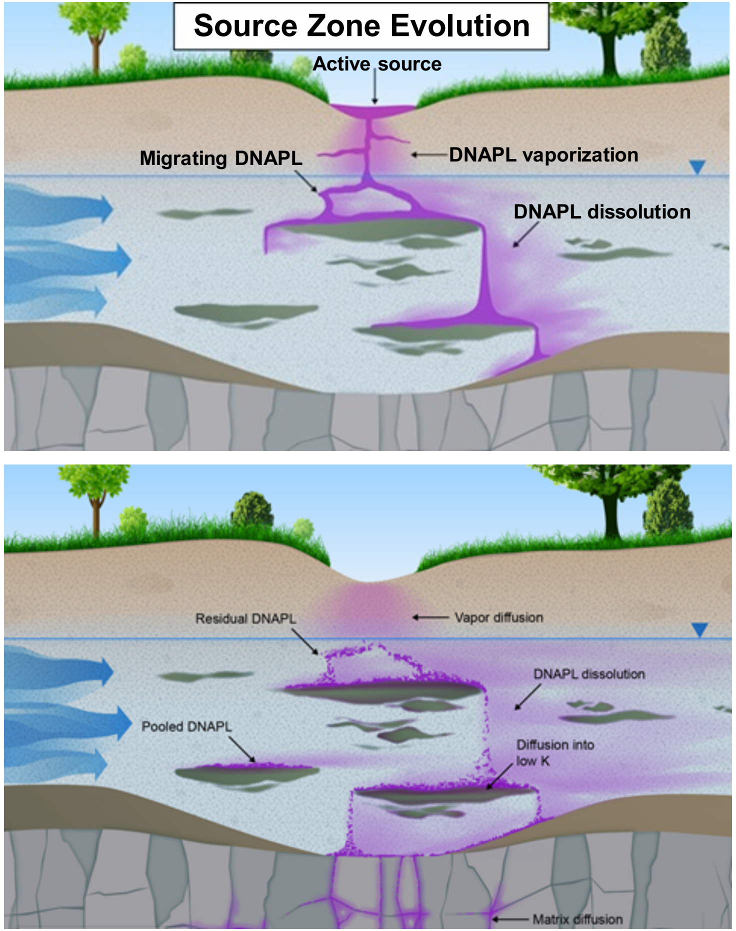
# The Chlorinated Solvent Problem

- Chlorinated solvents plumes can impact large volumes in aerobic aquifers
- Impacts to receptors can be significant and can last for decades to centuries
- Long-term management strategies must account for nature and persistence



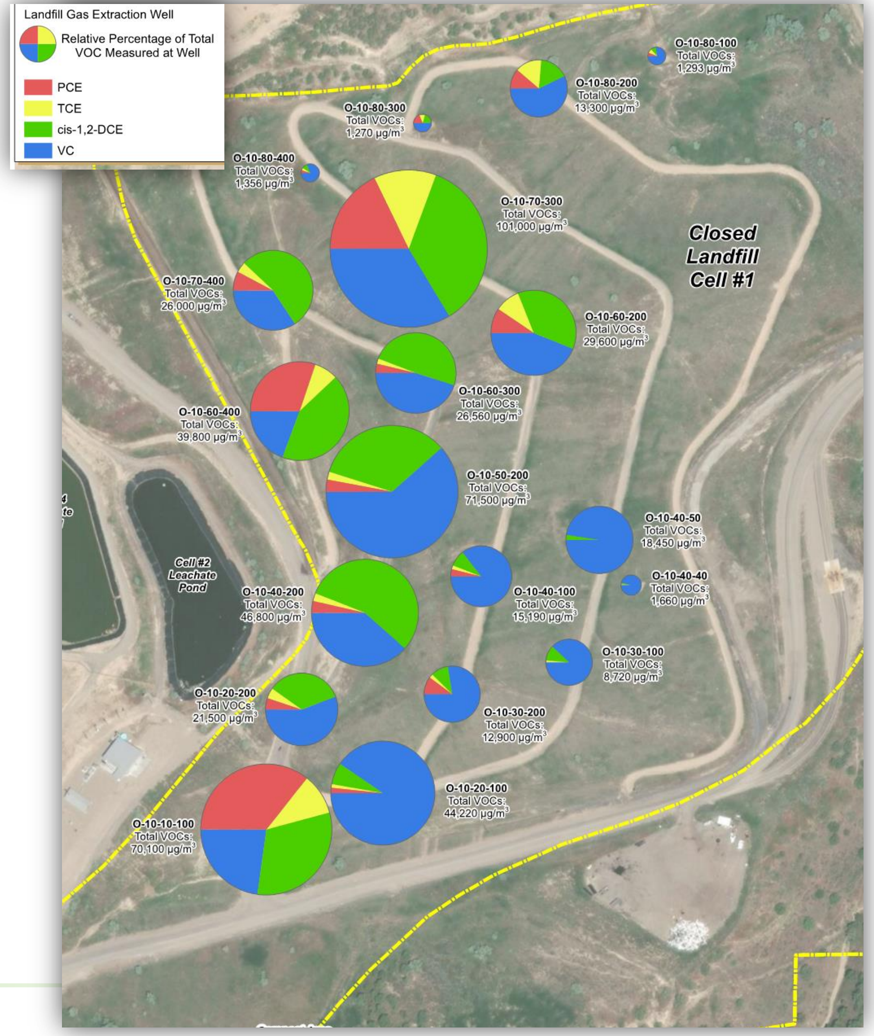
# DNAPL Characteristics

- Density greater than water and so “sink” below groundwater table
- Low solubility, e.g. “oil in water”
- Recalcitrant in aerobic aquifers (including the aquifer in this case study)
- Sorb and diffuse in soil/sediment

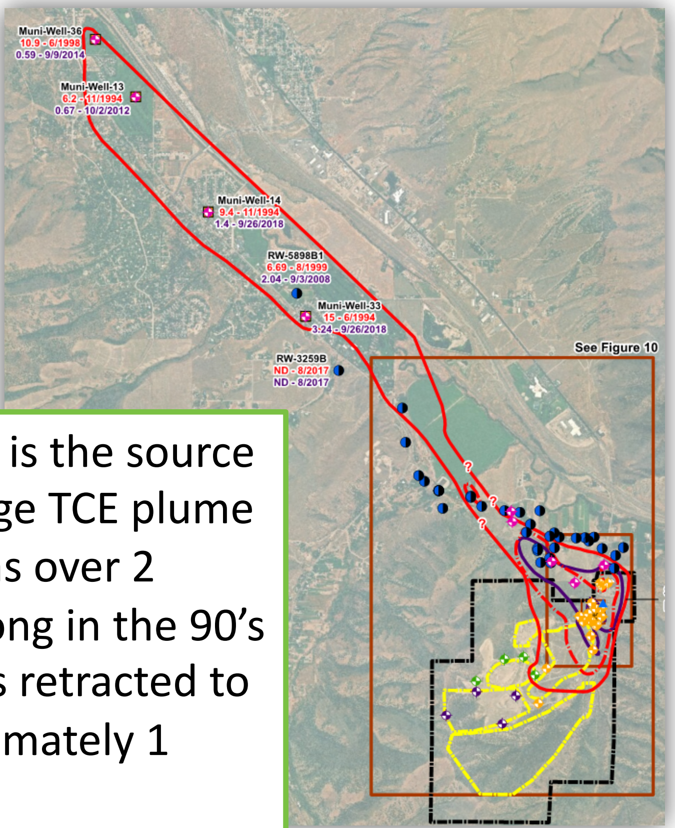


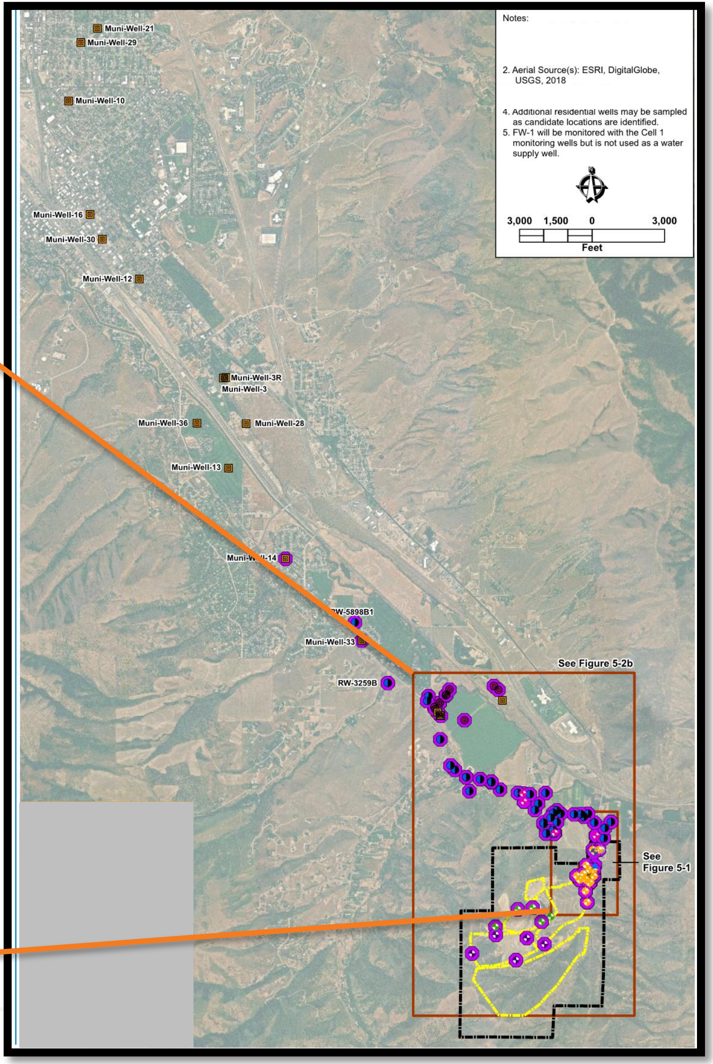
# Landfill Source Area

- 1942-1992- 1,500,000 tons of waste were disposed in Cell 1
- Cell 1 is approximately 69 acres and 3-4,000,000 cubic yards
- Thickness of waste up to 85 feet
- Cell 1 closed with a 30-inch barrier to effectively eliminate approximately 90 percent of precipitation falling on the cover



# Chemical Plume




Landfill is the source of a large TCE plume that was over 2 miles long in the 90’s and has retracted to approximately 1 mile.

# Hydrogeology

- Water Table- 40-80 feet bgs
- Alluvium- 0-100 feet bgs- discontinuous units of sand, gravel, silt, and clay with K of 2-10 feet/day.
- Starlight Formation- 100-200 feet bgs–weathered and fractured middle to Late Tertiary basin-filling sediments with K of 0.1-1 feet/day.
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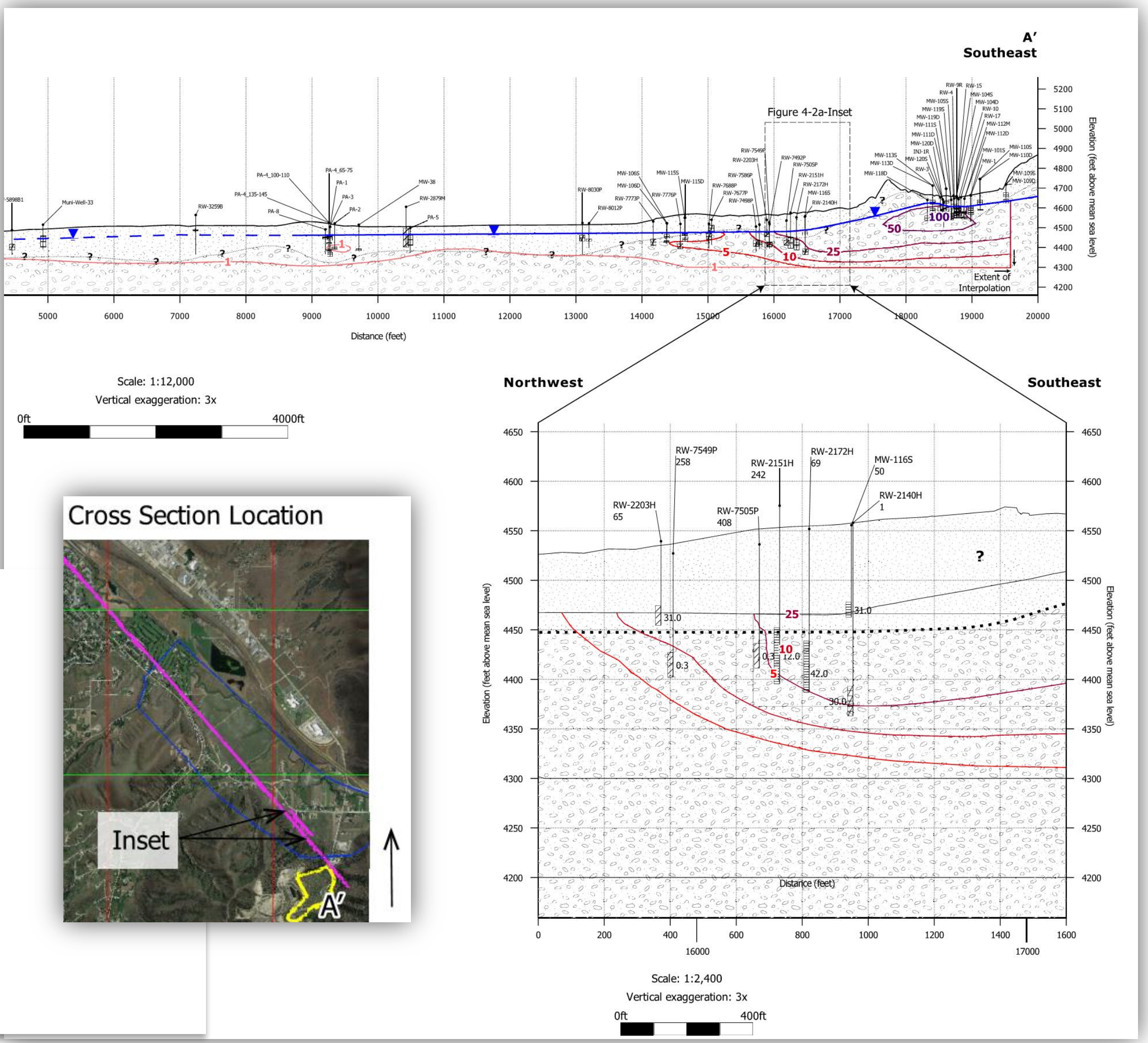


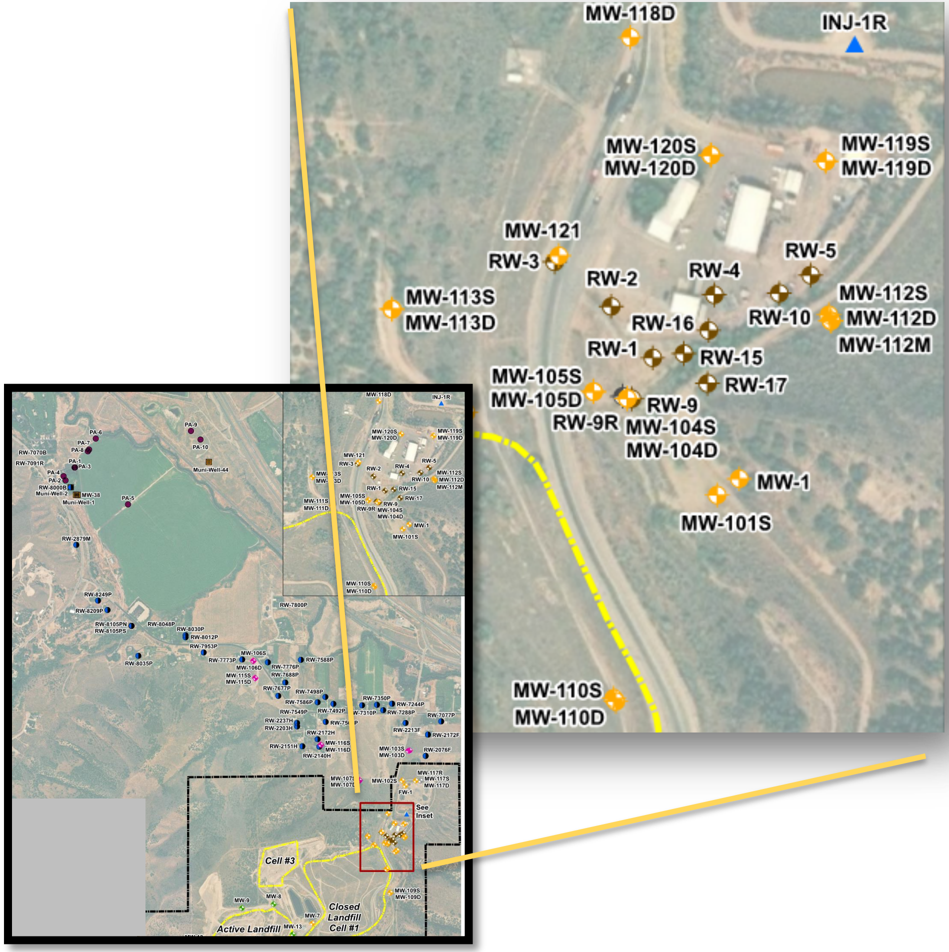
# Remediation System

The groundwater remediation system installed in 2002 and expanded in 2009-2012:

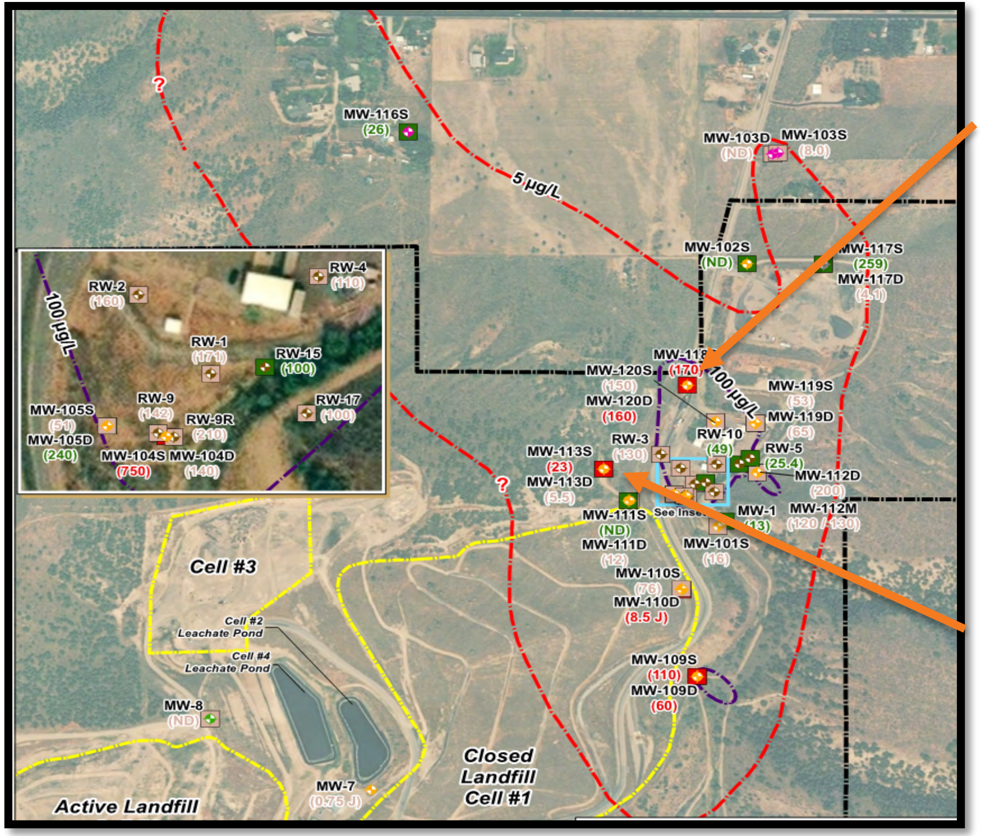
- Extracts groundwater near the landfill entrance
  - Extraction wells (dark brown circles)
  - 30 gpm average (approx. seasonal variation: ~15 to 40 gpm)
  - Average TCE influent : ~90 ug/L

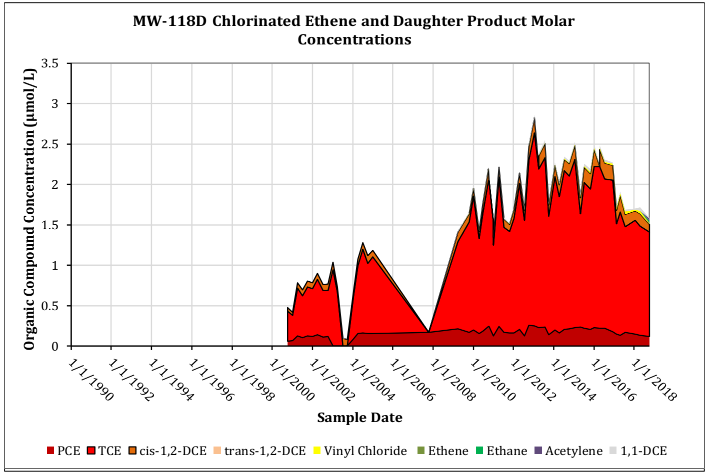
◎ **TCE Removal: 11 to 12 lbs/yr**

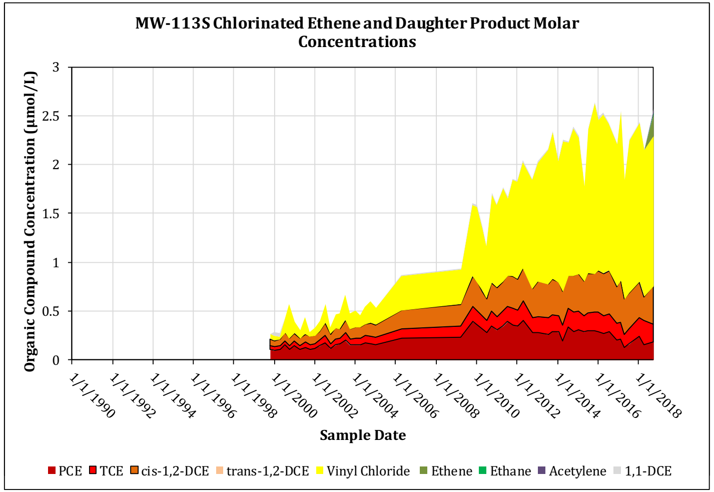
- Treats the water using an air stripper
  - Removes all VOCs
- Reinjects treated groundwater
  - Injection well (blue triangle)



# Chemical Trends Near Landfill

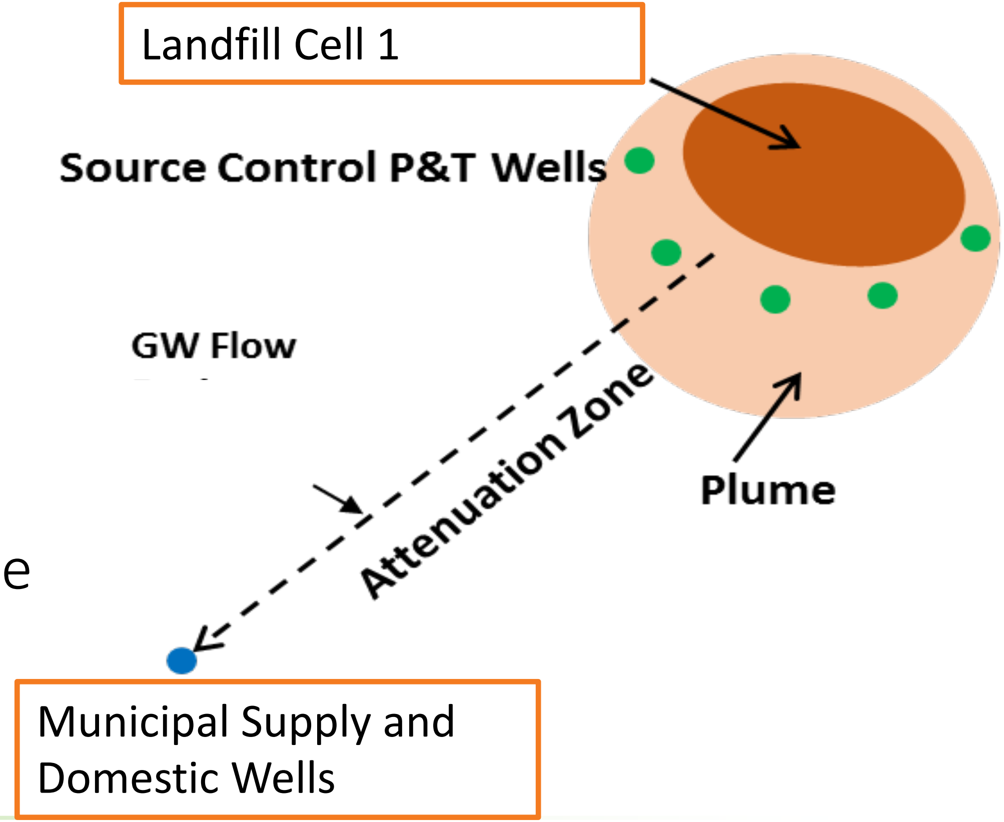


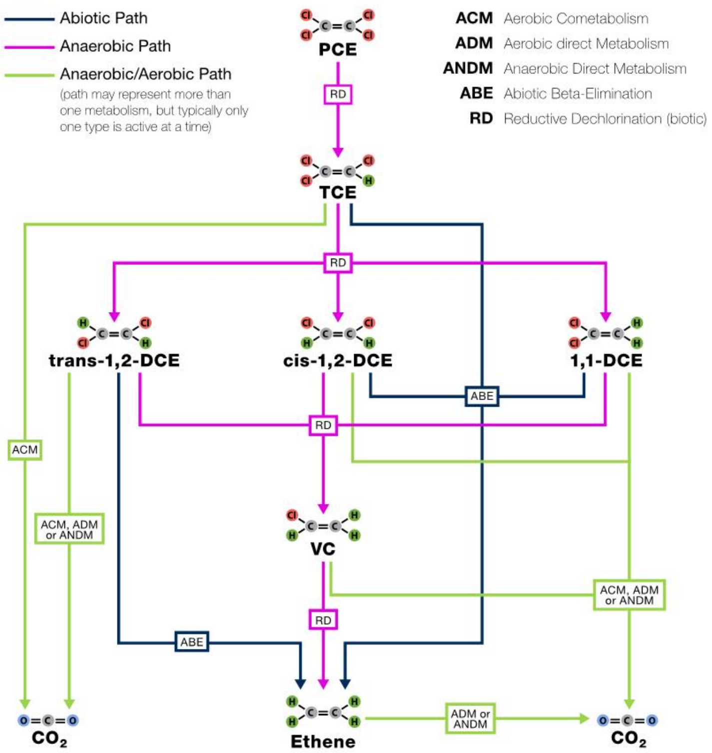
# Building a Model for Attenuation Capacity

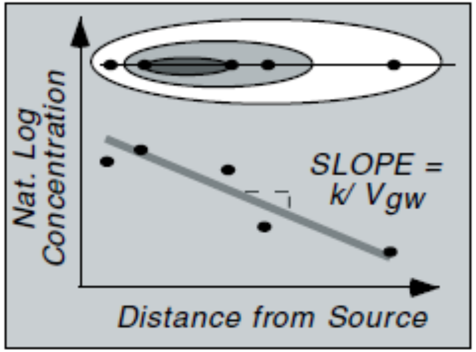
- Numerical modeling approach
- Evaluate the aquifer attenuation capacity between the source and supply well
- Evaluate additional reduction in mass discharge required to protect the supply well

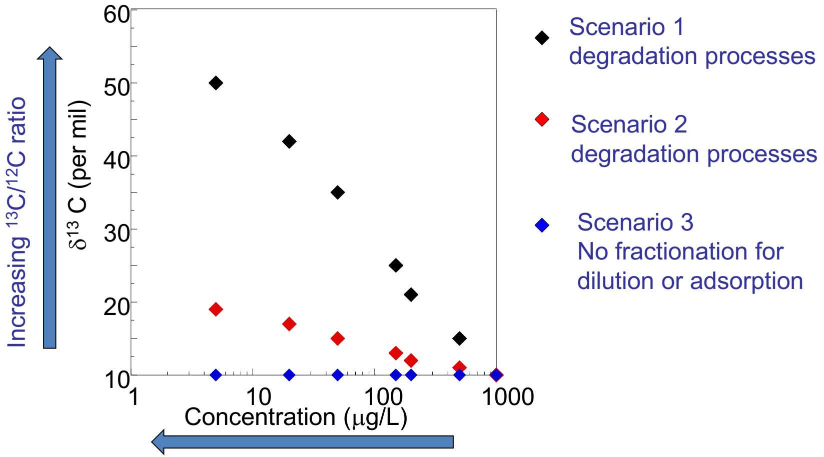


# Evaluating the Potential for Biodegradation

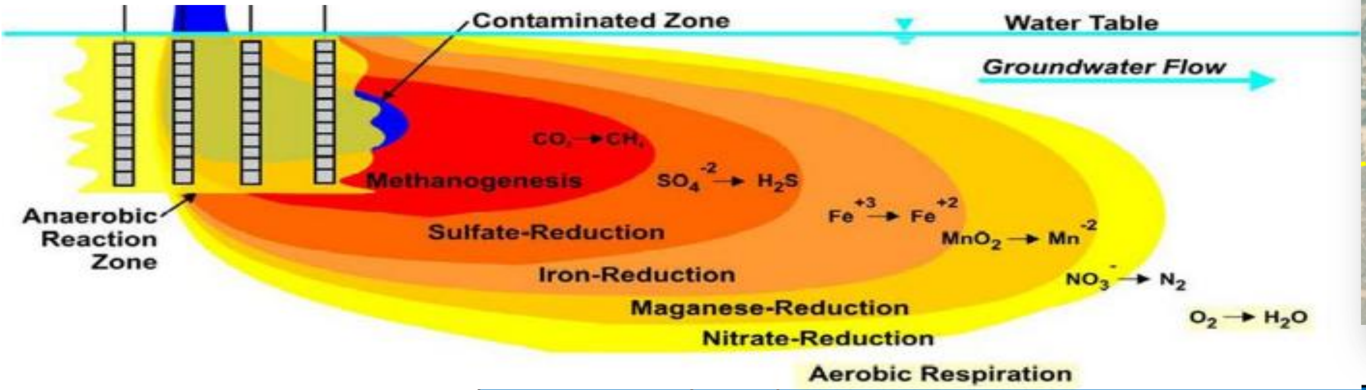
## Anaerobic and Aerobic Degradation Pathways

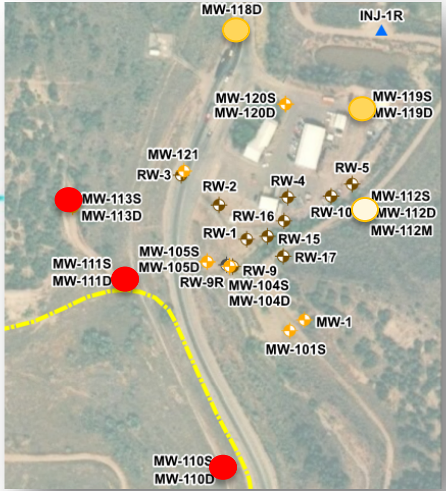


# Cell 1 Results: Chemical Degradation

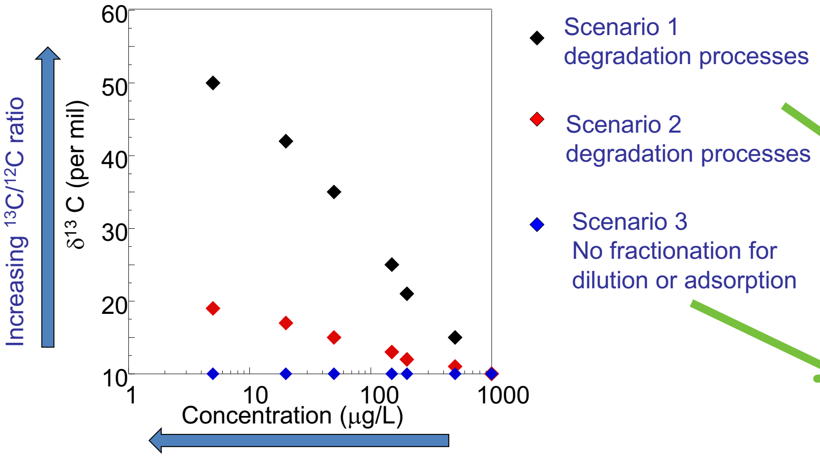


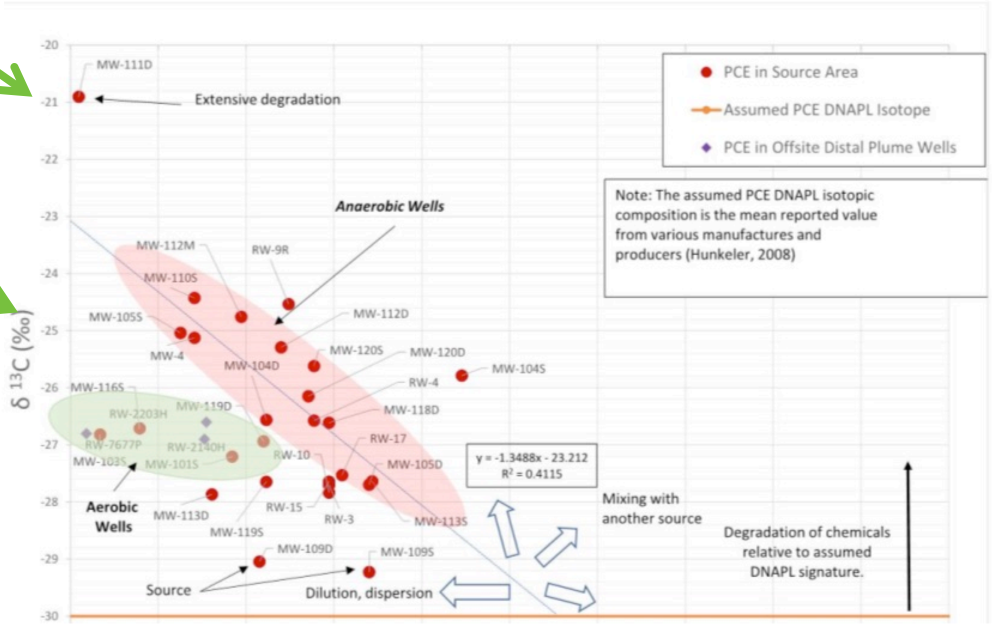




Anaerobic Near Cell 1 Discharge Point

| | Area | Cell 1 | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Well ID | MW-110S | | MW-111D | | MW-111S | | MW-112D | | MW-112M | | MW-113D | | MW-113S | | MW-118D | | MW-119D | | MW-119S | |
| | Sample Name | MW-110S-20181006 | | MW-111D-20181004 | | MW-111S-20181004 | | MW-112D-20181005 | | MW-112M-20181005 | | MW-113D-20181004 | | MW-113S-20181004 | | MW-118D-20181003 | | MW-119D-20181003 | | MW-119S-20181003 | |
| | Sample Date | 10/6/2018 | | 10/4/2018 | | 10/4/2018 | | 10/5/2018 | | 10/5/2018 | | 10/4/2018 | | 10/4/2018 | | 10/3/2018 | | 10/3/2018 | | 10/3/2018 | |
| Analyte | Unit | Result | Q | Result | Q | Result | Q | Result | Q | Result | Q | Result | Q | Result | Q | Result | Q | Result | Q | Result | Q |
| **Geochemistry** | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity, Total (As $CaCO_3$) | mg/L | 420 | | 1300 | | 1700 | | 260 | | 340 | | 350 | | 720 | | 560 | | 310 | | 300 | |
| Total Organic Carbon | mg/L | 3.8 | | 140 | | 180 | | 1.2 | | 0.74 | J | 3.7 | J+ | 11 | | 6.1 | | 1.2 | | 1.6 | |
| Chloride (As Cl) | mg/L | 230 | | 1900 | | 2000 | | 82 | | 78 | | 190 | | 400 | | 400 | | 110 | | 110 | |
| Cyanide | mg/L | 0.002 | U | 0.0094 | J | 0.011 | J | 0.002 | U | 0.002 | U | 0.002 | U | 0.002 | U | 0.002 | U | 0.0048 | J | 0.0053 | J |
| Nitrogen, Nitrate-Nitrite | mg/L | 0.019 | U | 0.019 | U | 0.019 | U | 1.1 | | 0.77 | | 0.41 | | 0.19 | | 12 | | 1.2 | | 4.2 | |
| Sulfate (As $SO_4$) | mg/L | 96 | | 51 | | 44 | | 81 | | 67 | | 36 | | 66 | | 86 | | 100 | | 110 | |
| Sulfide | mg/L | | | | | | | | | | | | | | | | | | | | |
| Ferrous Iron | mg/L | 0.03 | | 3.3 | | 2.16 | | 0 | | 0.02 | | 0.19 | | 0.05 | | 0 | | 0.02 | | 0.02 | |
| **Dissolved Gases** | | | | | | | | | | | | | | | | | | | | | |
| Methane | ug/L | 85 | | 3500 | | 3500 | | 0.64 | U | 0.64 | U | 930 | | 3700 | | 2.9 | J | 0.64 | U | 0.64 | U |
| Ethane | ug/L | 0.57 | U | 3.4 | J | 0.57 | U | 0.57 | U | 0.57 | U | 0.57 | U | 0.57 | U | 0.57 | U | 0.57 | U | 0.57 | U |
| Ethene | ug/L | 0.4 | U | 0.4 | U | 0.4 | U | 0.4 | U | 0.4 | U | 0.76 | J | 6.2 | | 0.4 | U | 0.4 | U | 0.4 | U |
| Propane | ug/L | 0.56 | U | 0.56 | U | 0.56 | U | 0.56 | U | 0.56 | U | 0.56 | U | 2 | J | 0.56 | U | 0.56 | U | 0.56 | U |
| **Field Parameters** | | | | | | | | | | | | | | | | | | | | | |
| Specific Conductance | mS/cm | 1.43 | | 0.01 | | 7.44 | | 0.691 | | 0.756 | | 0.912 | | 2.2 | | 2.2 | | 0.793 | | 0.827 | |
| pH | su | 6.5 | | 6.78 | | 6.96 | | 7.42 | | 6.98 | | 6.84 | | 6.43 | | 6.85 | | 6.79 | | 6.71 | |
| Temperature | °C | 13.05 | | 15.38 | | 14.82 | | 12.49 | | 13.69 | | 13.81 | | 13.78 | | 13.54 | | 16.51 | | 13.36 | |
| Turbidity | NTU | 0 | | 1 | | 2.55 | | 13.3 | | 35.7 | | 41.1 | | 3.1 | | 0 | | 0 | | 0 | |
| Dissolved Oxygen | mg/L | 0.25 | | 0.88 | | 2.04 | | 6.16 | | 5.82 | | 0.67 | | 0 | | 1.16 | | 3.86 | | 2.72 | |
| Oxidation-Reduction Potential | mV | 156 | | -65 | | -80 | | 134 | | 136 | | 95 | | 64 | | 165 | | 152 | | 143 | |

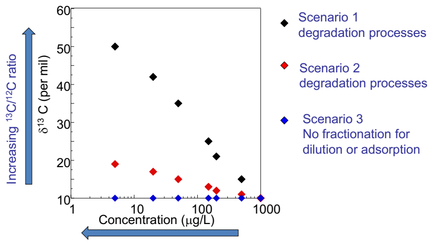
# CSIA: Results / What Happens During Degradation?



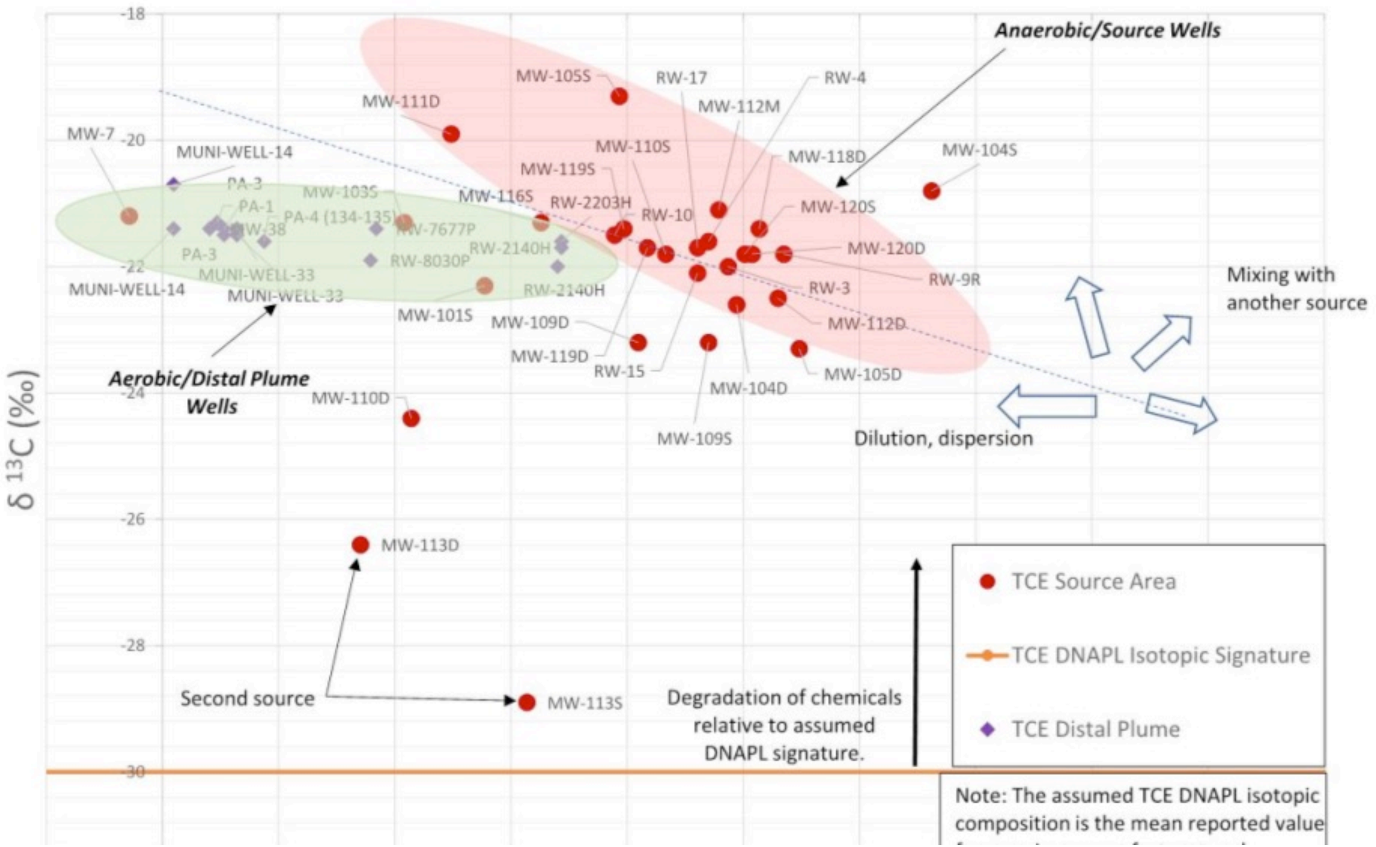




Data indicate biodegradation is actively occurring

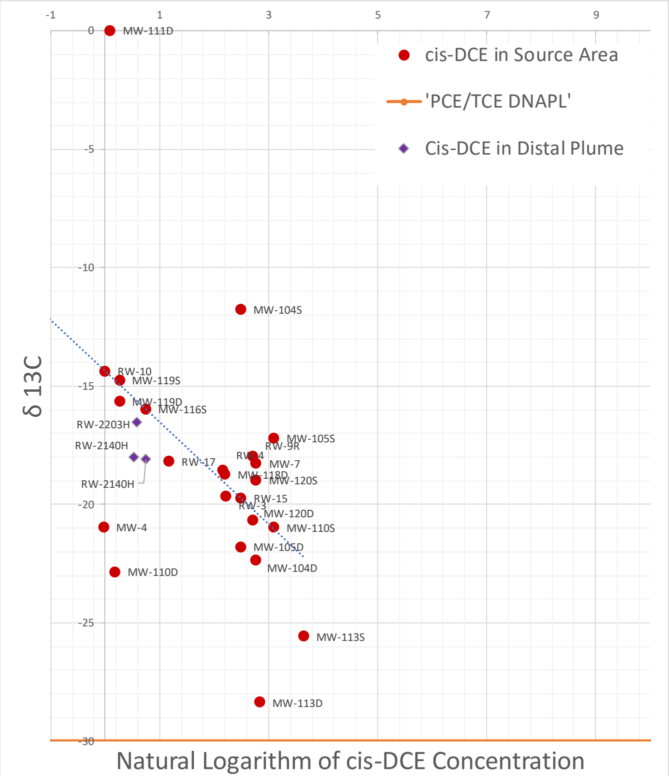
# CSIA: TCE Results

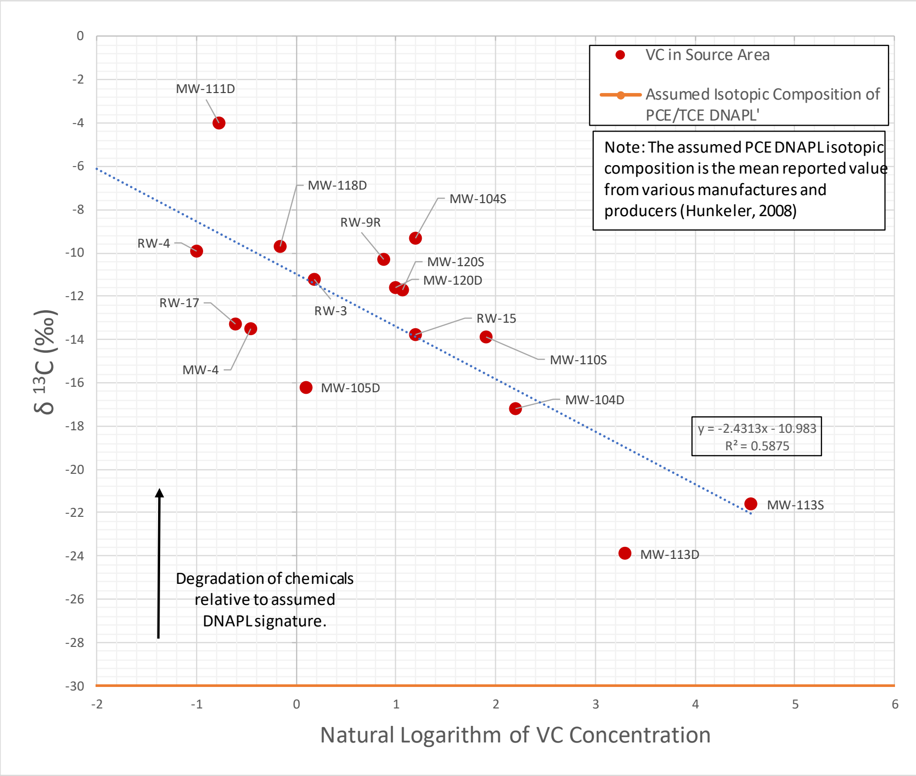



Data indicate biodegradation is actively occurring in the source area.



# Degradation Products



# Estimating Biodegradation Rates

| Location 1 Along Flow Path | Location 2 Along Flow Path | Degradation Mechanism Assumption | Distance in Flow Path (feet) | Hydraulic Condition | Gradient (feet/feet) | Horizontal Hydraulic Conductivity (feet/day) | Seepage Velocity (feet/day) | Travel Time (days) | Maximum Half Life (days) | Minimum Half Life (days) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Tetrachloroethene** | | | | | | | | | | |
| MW-109S | MW-101S | Anaerobic Reductive Dechlorination | 798 | Alluvium | 0.0794 | 10 | 4.2 | 189 | 555 | 26 |
| MW-109S | MW-104D | Anaerobic Reductive Dechlorination | 951 | Alluvium | 0.0687 | 10 | 3.6 | 261 | 580 | 28 |
| MW-109S | MW-112M | Anaerobic Reductive Dechlorination | 1136 | Alluvium | 0.0771 | 10 | 4.1 | 278 | 369 | 18 |
| MW-105D | MW-120D | Anaerobic Reductive Dechlorination | 429 | Alluvium | 0.0876 | 6 | 2.9 | 146 | 560 | 27 |
| MW-105D | MW-118D | Anaerobic Reductive Dechlorination | 580 | Starlight | 0.0806 | 6 | 2.7 | 214 | 1175 | 56 |
| MW-105D | MW-119D | Anaerobic Reductive Dechlorination | 531 | Alluvium | 0.0617 | 6 | 2.1 | 257 | 2008 | 96 |
| MW-113S | MW-120S | Anaerobic Reductive Dechlorination | 174/400 | Starlight and Alluvium | 0.539/0.0626 | 0.07/8 | 0.21/2.8 | 968 | 2850 | 136 |
| MW-113S | MW-118D | Anaerobic Reductive Dechlorination | 174/400 | Starlight and Alluvium | 0.539/0.0626 | 0.07/8 | 0.21/2.8 | 968 | 5603 | 267 |
| MW-119S | MW-103S | Anaerobic Reductive Dechlorination | 840/596 | Starlight and Alluvium | 0.132/0.00886 | 40/170 | 29/8.4 | 99 | 714 | 34 |
| **Trichloroethene** | | | | | | | | | | |
| MW-109S | MW-101S | Aerobic Cometabolism | 798 | Alluvium | 0.0794 | 10 | 4.2 | 189 | 2595 | 157 |
| MW-109S | MW-112M | Aerobic Cometabolism | 1136 | Alluvium | 0.0716 | 10 | 3.8 | 299 | 1755 | 106 |
| MW-105D | MW-120D | Aerobic Cometabolism | 429 | Alluvium | 0.0876 | 6 | 2.9 | 146 | 1202 | 73 |
| MW-105D | MW-118D | Aerobic Cometabolism | 580 | Starlight | 0.0806 | 6 | 2.7 | 214 | 1392 | 84 |
| MW-105D | MW-119D | Aerobic Cometabolism | 531 | Alluvium | 0.0617 | 6 | 2.1 | 257 | 2490 | 272 |
| **cis-1,2-dichloroethene** | | | | | | | | | | |
| MW-105D | MW-118D | Aerobic Cometabolism | 580 | Starlight | 0.0806 | 6 | 2.7 | 214 | 470 | 19 |
| MW-113S | MW-120S | Aerobic Cometabolism | 174/400 | Starlight and Alluvium | 0.539/0.0626 | 0.07/8 | 0.21/2.8 | 968 | 974 | 40 |
| MW-113S | MW-118D | Anaerobic Reductive Dechlorination | 174/400 | Starlight and Alluvium | 0.539/0.0626 | 0.07/8 | 0.21/2.8 | 968 | 941 | 38 |

Notes:

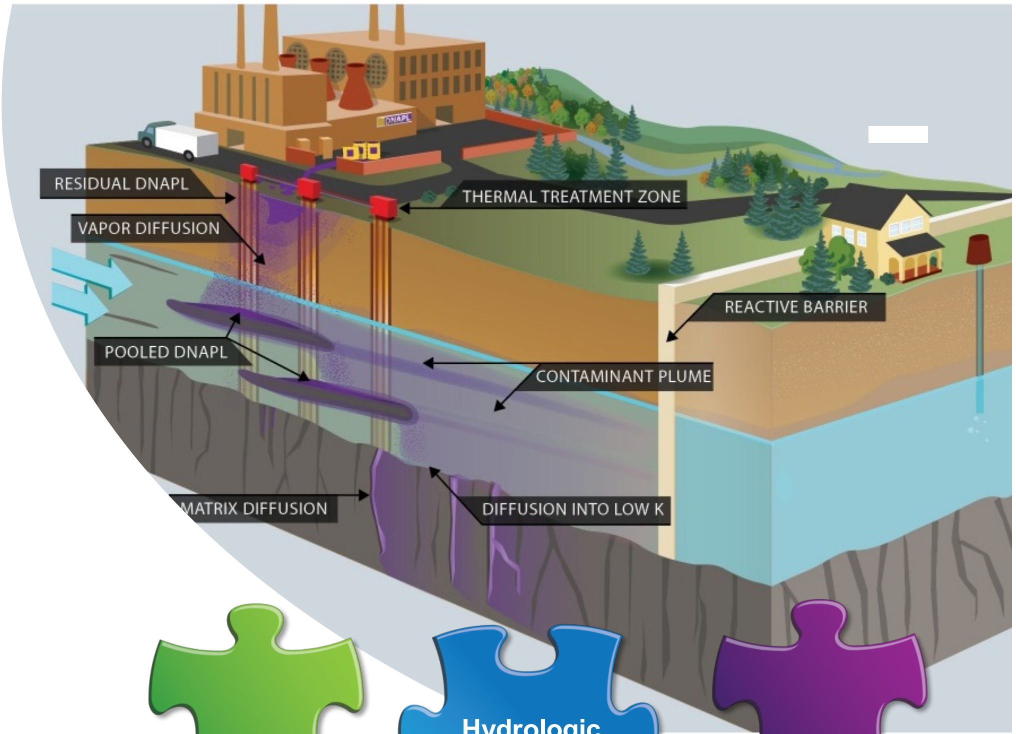
‰ = per mil

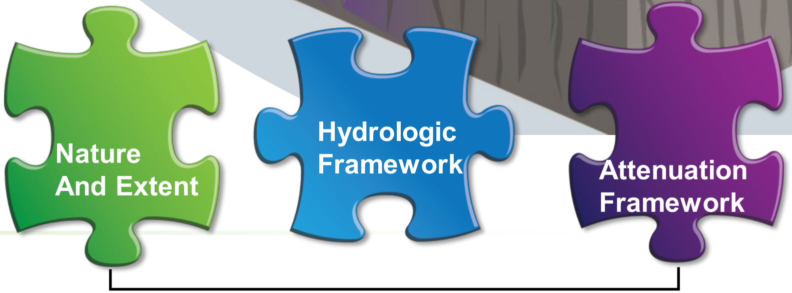
[1] Maximum and minimum Isotopic enrichment factor reported in Hunkeler et al. (2008). Maximum isotopic enrichment factor for aerobic cometabolism for cis-1,2-dichloroethene (-9.8 ‰) reported by Tiehm et al. (2008).

# 2019-2020 Site Characterization

# Building a ***ROBUST*** DNAPL Conceptual Site Model

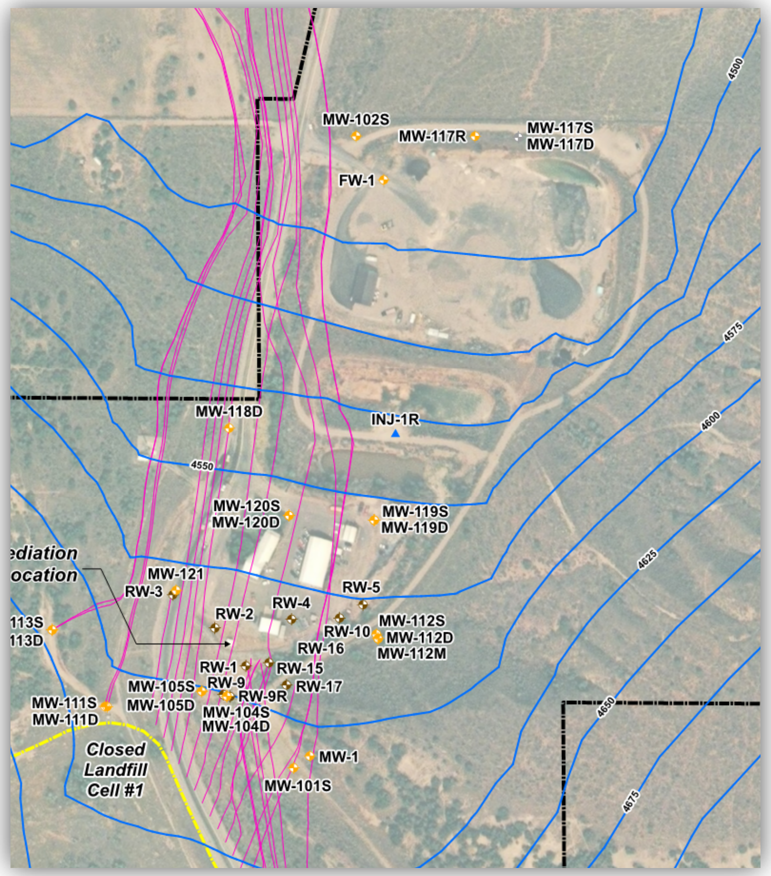
- Multiple source from Cell 1
  - Leaching from Cell 1 waste
  - DNAPL migration into deeper fractures
- Contamination deeper than current monitoring or remediation system
- Chemical distribution, fate and transport in bedrock unknown
- Properties of bedrock highly uncertain



# Understand How Chemicals Migrate from Cell 1

- Remediation System and Hydraulic CSM
- Distribution and migration of chemicals through bedrock
- A detailed characterization program will be implemented in step-wise fashion to evaluate site conditions which includes:
  - Surface geophysical investigation
  - Exploratory borehole program
  - Boreholes/wells completion
  - Mass discharge assessment
  - Aquifer testing



# Surface Geophysics

- Geophysical methods
  - Seismic refraction tomography (SRT) - depth to groundwater
  - Seismic surface wave - depth to bedrock
  - Electrical resistance tomography (ERT) - Estimate the alluvium thickness

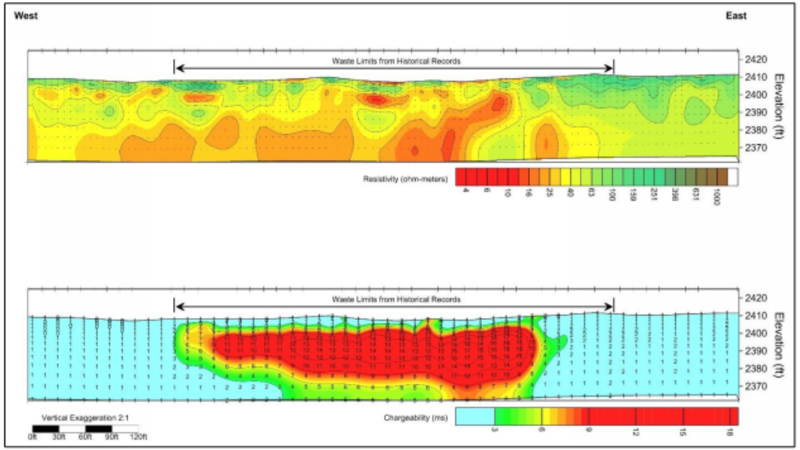
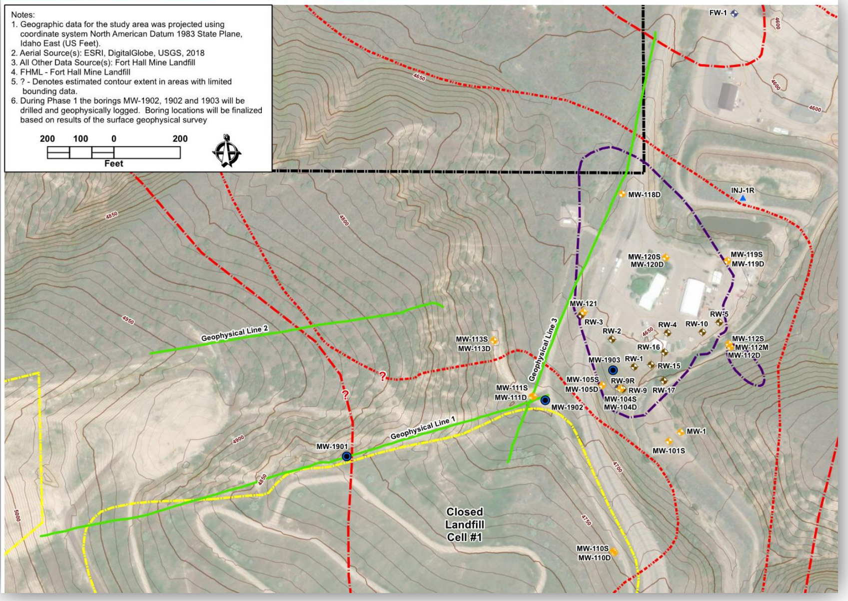
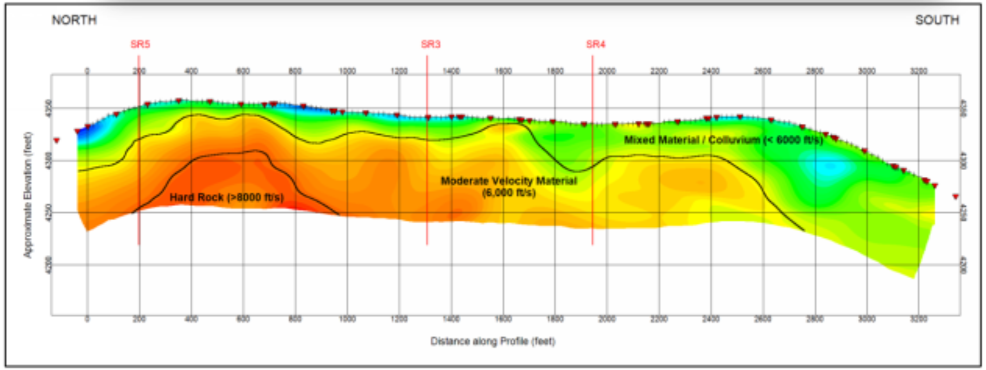


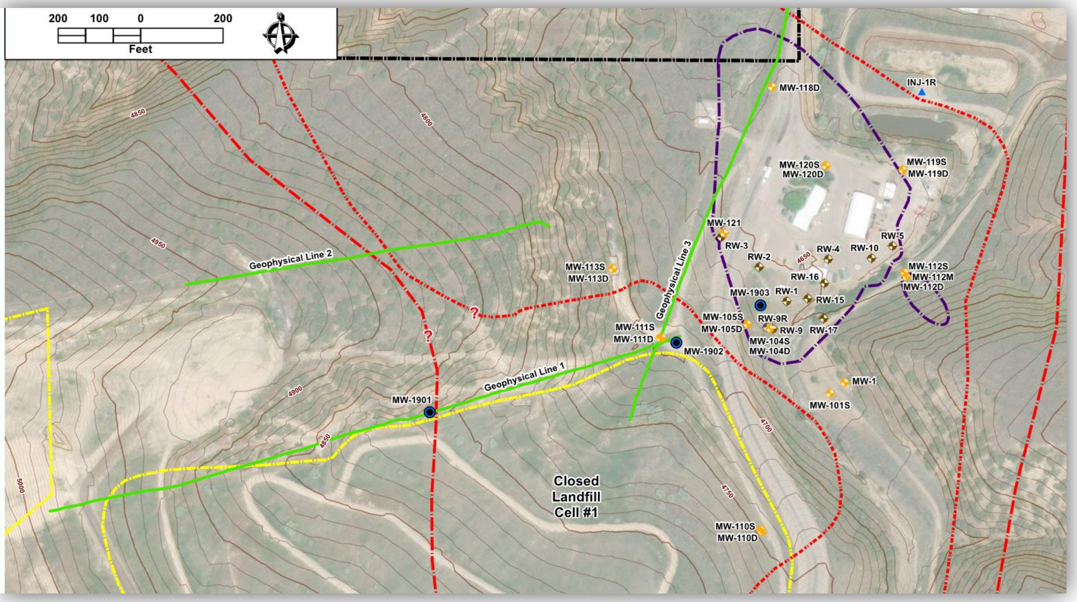

Figure 8-11 – Example 2D ERT survey over landfill materials. Fill materials showed no significant contrast against native materials, but there was a clear IP signature of the fill materials.



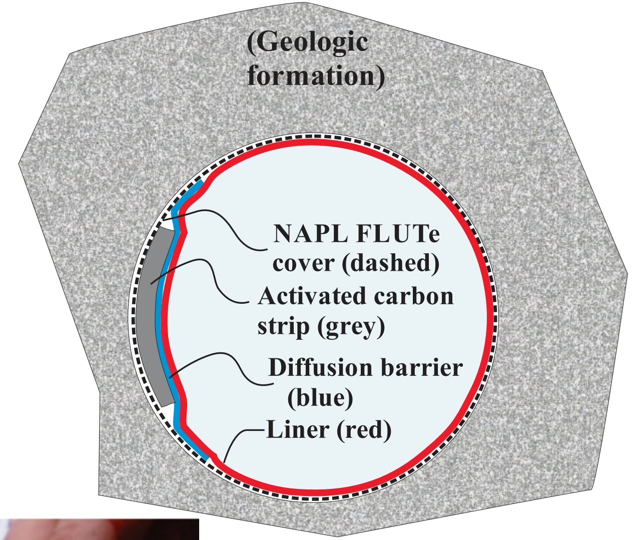
# Phase 1:Exploratory Borings

- Drill boreholes 200 to 300 feet deep
- Obtain rock core for lithologic logging
- High-resolution contaminant/waste profiling
- Borehole geophysical and soil logging
- Data analysis



# Borehole Investigation: High Resolution Chemical Distribution

- <u>Chemicals sorb to a continuous activated carbon felt strip</u>
- The FACT is usually left in place for up to two weeks
- The FACT provides a <u>continuous</u> replica of chemicals in pores <u>**and**</u> fractures
- Usually as combined with the NAPL FLUTe, the NAPL <u>and</u> the dissolved phase are both mapped throughout the entire borehole at the same time

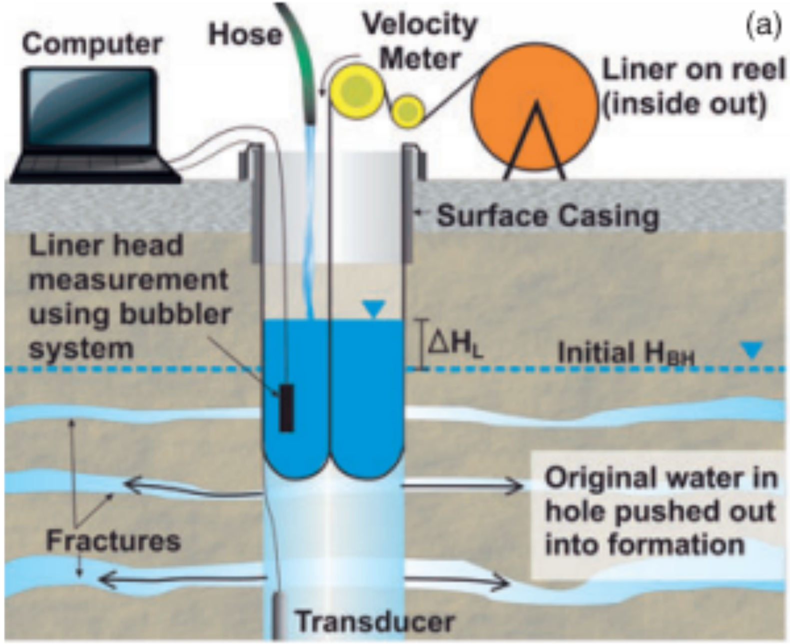



Carbon felt attached Inside NAPL cover

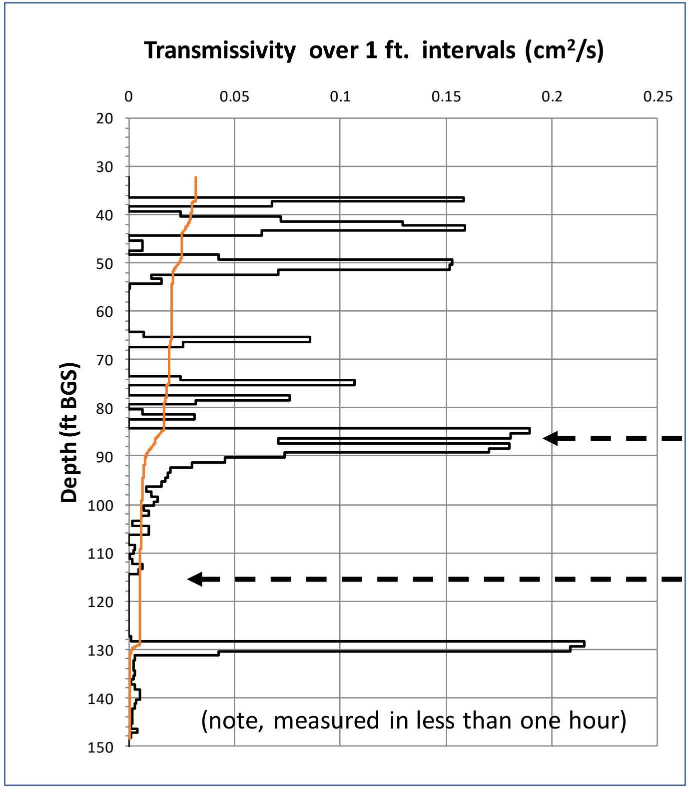
Dye stripped NAPL cover on a liner

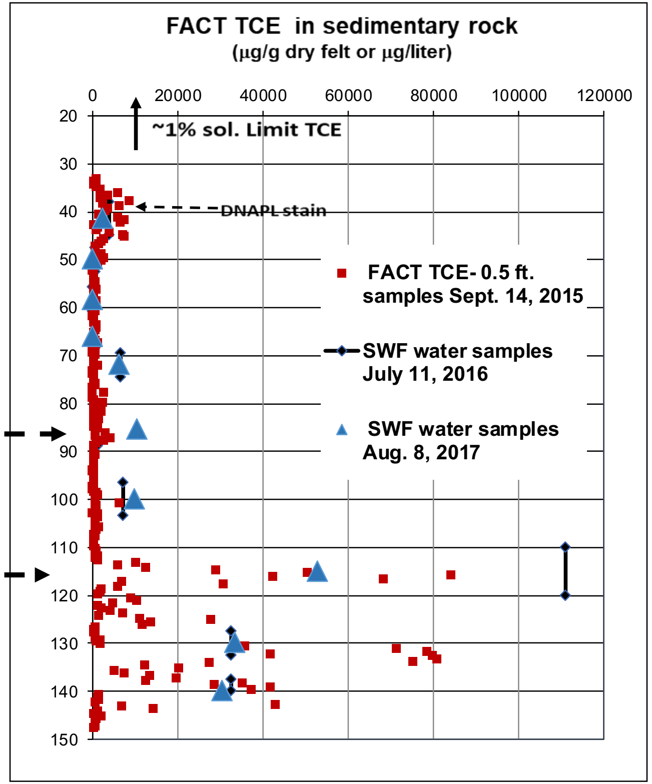
# Borehole Investigation: Map of Bedrock Fractures

- Liner deployed
- Constant head maintained between inside liner
- Decent rate is measured as the head below the liner is measured



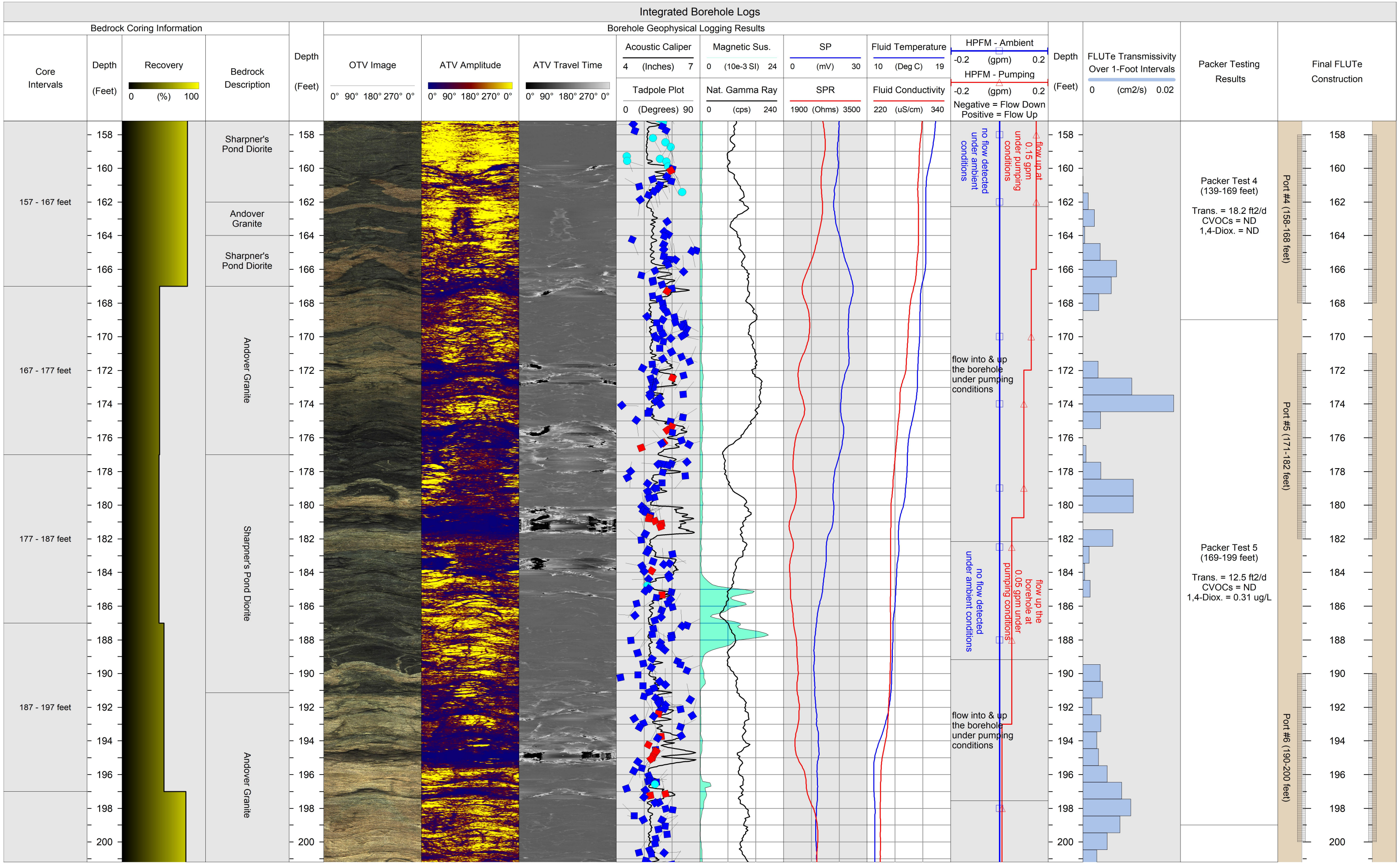

# FLUTe NAPL/FACT and Transmissivity
# High resolution profile of fracture zones and chemicals



# Downhole Geophysics

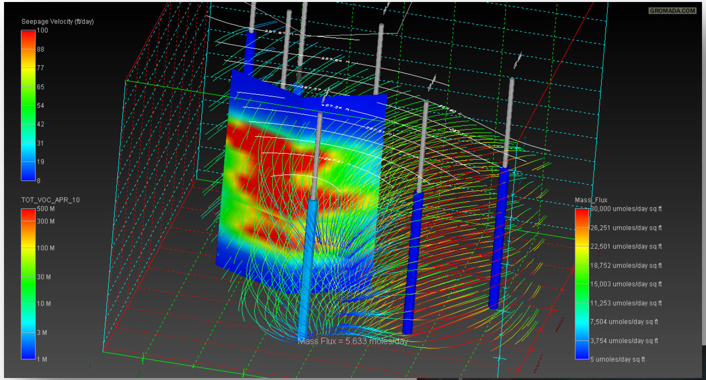
- Fluid temperature and conductivity
  - These logs are run in the portion borehole below the water level in the borehole. Changes in temperature and conductivity may, along with other data, identify where water is entering the borehole.
- Optical televiewer (OTV)
  - This log produces a digital image of the borehole wall in visible light and is run both above and below the water level in the borehole.
  - This log will be run second because it works best in optically clear water.
- Acoustic televiewer (ATV)
  - This log produces an image of the borehole wall using acoustic energy and is run below the water level in the borehole. It can be run in water with high turbidity or in drilling mud.
  - Date from this log will be used to create a 360-degree acoustic caliper log, which shows the smoothness of the borehole wall, and to calculate borehole deviation from vertical.
- Mechanical caliper
  - This log shows smoothness of the borehole wall and is used to help identify fractures. It will be run if the data from ATV is not sufficient to prepare an acoustic caliper log.
- Natural gamma
  - This log provides data on lithology, is used to correlate logs between boreholes, and may be run in combination with another tool.
- Electrical logs: normal resistivity, spontaneous Potential (SP), and single point resistance (SPR)
- The electrical logging suite log provides data on lithology. Normal resistivity will be run if at least 50 to 80 feet of open borehole is available which, due to the nature of the hardware, is the minimum required to produce a useful log.

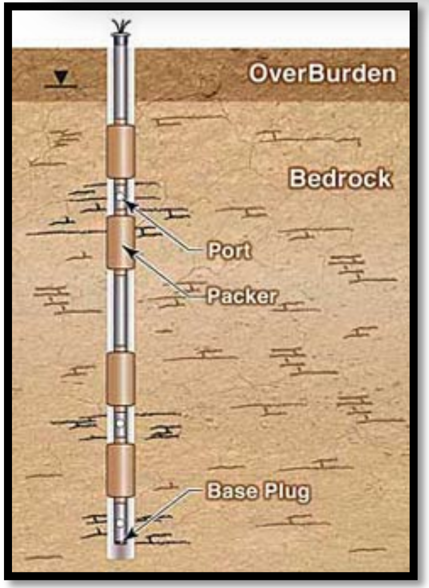

Integrated Borehole Logs
Bedrock Coring Information
Core Intervals
Depth (Feet)
Recovery
0 (%) 100
Bedrock Description
Borehole Geophysical Logging Results
OTV Image
0° 90° 180° 270° 0°
ATV Amplitude
0° 90° 180° 270° 0°
ATV Travel Time
0° 90° 180° 270° 0°
Acoustic Caliper
4 (Inches) 7
Tadpole Plot
0 (Degrees) 90
Magnetic Sus.
0 (10e-3 SI) 24
Nat. Gamma Ray
0 (cps) 240
SP
0 (mV) 30
SPR
1900 (Ohms) 3500
Fluid Temperature
10 (Deg C) 19
Fluid Conductivity
220 (uS/cm) 340
HPFM - Ambient
-0.2 (gpm) 0.2
HPFM - Pumping
-0.2 (gpm) 0.2
Negative = Flow Down
Positive = Flow Up
FLUTe Transmissivity Over 1-Foot Intervals
0 (cm2/s) 0.02
Packer Testing Results
Final FLUTe Construction
157 - 167 feet
167 - 177 feet
177 - 187 feet
187 - 197 feet
158
160
162
164
166
168
170
172
174
176
178
180
182
184
186
188
190
192
194
196
198
200
Sharpner's Pond Diorite
Andover Granite
Sharpner's Pond Diorite
Andover Granite
Sharpner's Pond Diorite
Andover Granite
no flow detected under ambient conditions
flow up at 0.15 gpm under pumping conditions
flow into & up the borehole under pumping conditions
no flow detected under ambient conditions
flow up the borehole at 0.05 gpm under pumping conditions
flow into & up the borehole under pumping conditions
Packer Test 4
(139-169 feet)
Trans. = 18.2 ft2/d
CVOCs = ND
1,4-Diox. = ND
Packer Test 5
(169-199 feet)
Trans. = 12.5 ft2/d
CVOCs = ND
1,4-Diox. = 0.31 ug/L
Port #4 (158-168 feet)
Port #5 (171-182 feet)
Port #6 (190-200 feet)

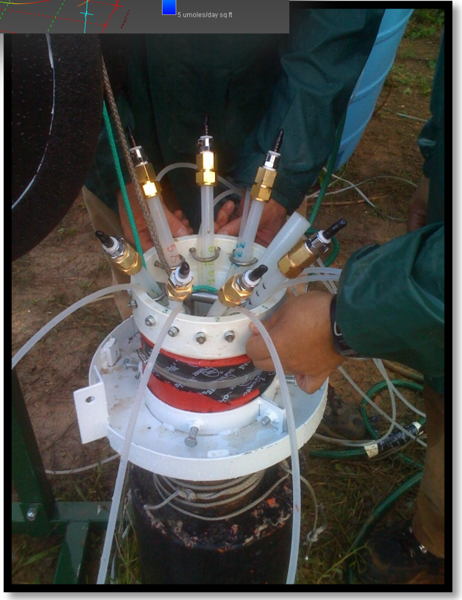
# Monitoring: Locations

Selection of monitoring locations is based on:

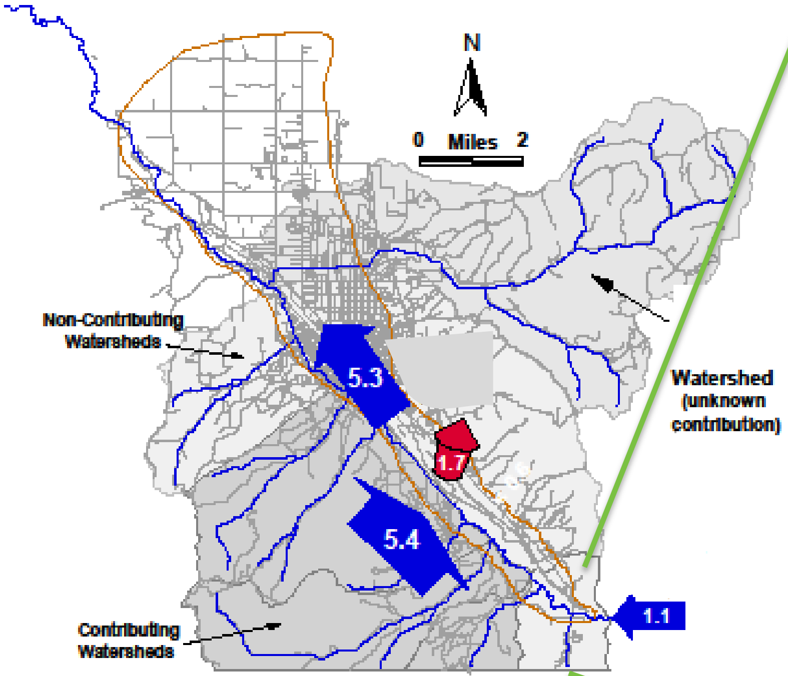
- Fracture network
  - Where are the most transmissive features and what is there orientation?
- Groundwater gradient and flow direction
  - Where is groundwater, and hence contaminants, flowing?
- Geochemistry
  - Focus monitoring on fracture zones with site related chemicals

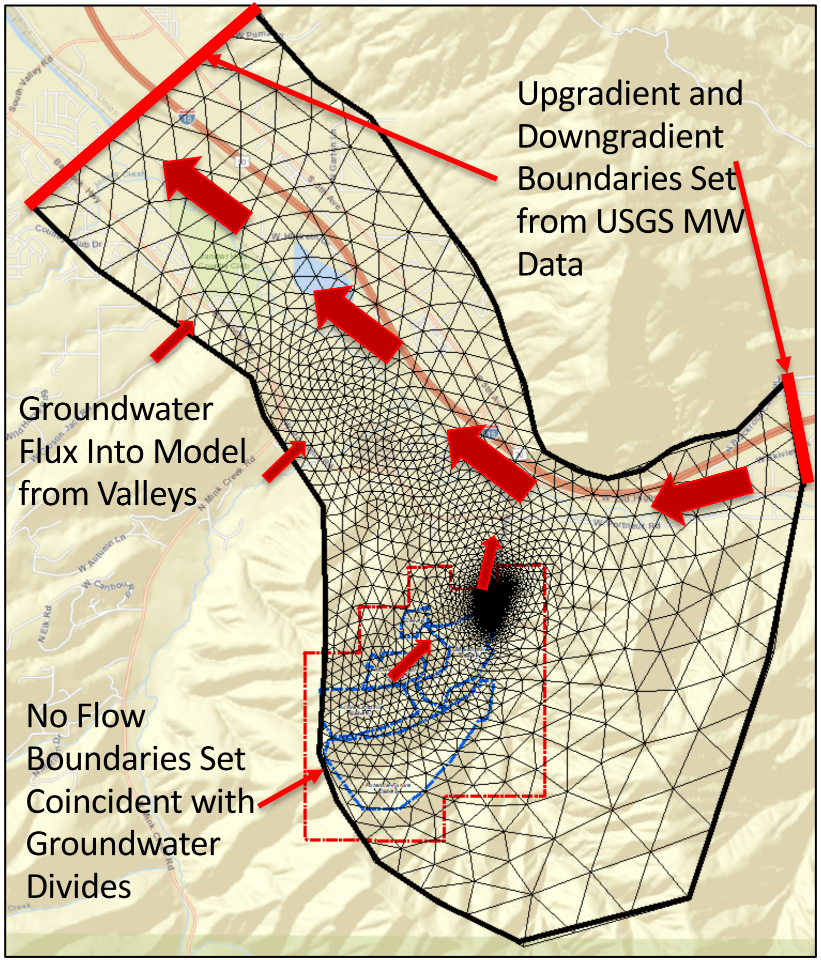


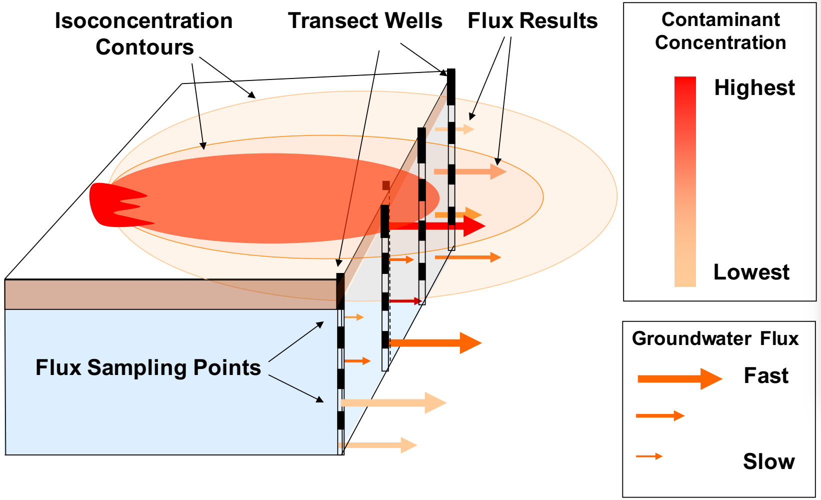
# Update Hydrogeology

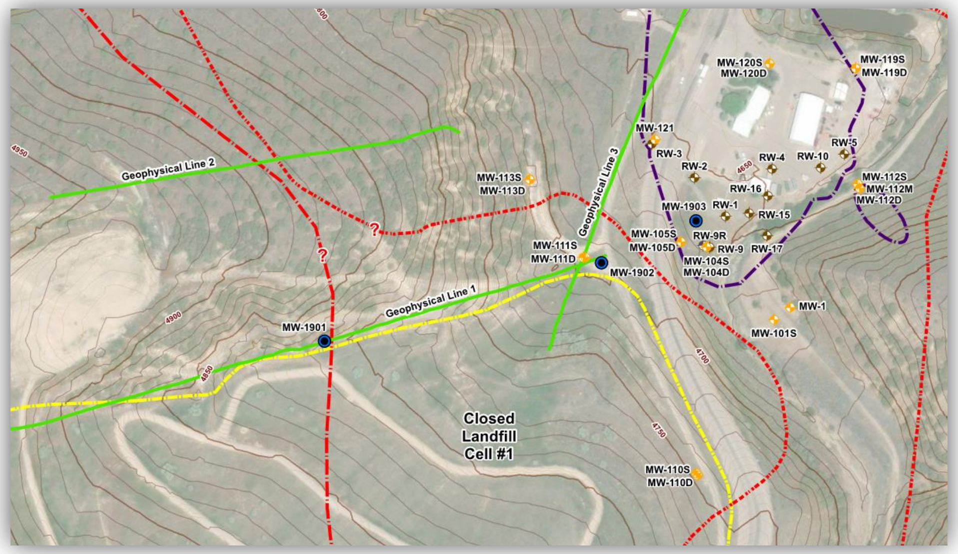


# Mass Discharge Strategy

- Following borehole and aquifer test evaluations select a transect of wells to represent each of the primary stratigraphic units (alluvium and fractured Starlight)
- Transect Evaluation



# Site Characterization

- Develop updated CSM, including more complete bedrock characterization for 3D and numerical modeling updates
- Phase 1 evaluation will be used to determine if additional data are needed - potential for a Phase 2 in 2020
- Make recommendations for optimizing and/or replacing existing groundwater treatment system

# Questions?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