Electrical Resistance Heating and Bioremediation

Compatibility, Effectiveness, and Post-Heating Bio-Polishing

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CASCADE DRILLING | TECHNICAL SERVICES

TERRATHERM a Cascade Company

microbialinsights

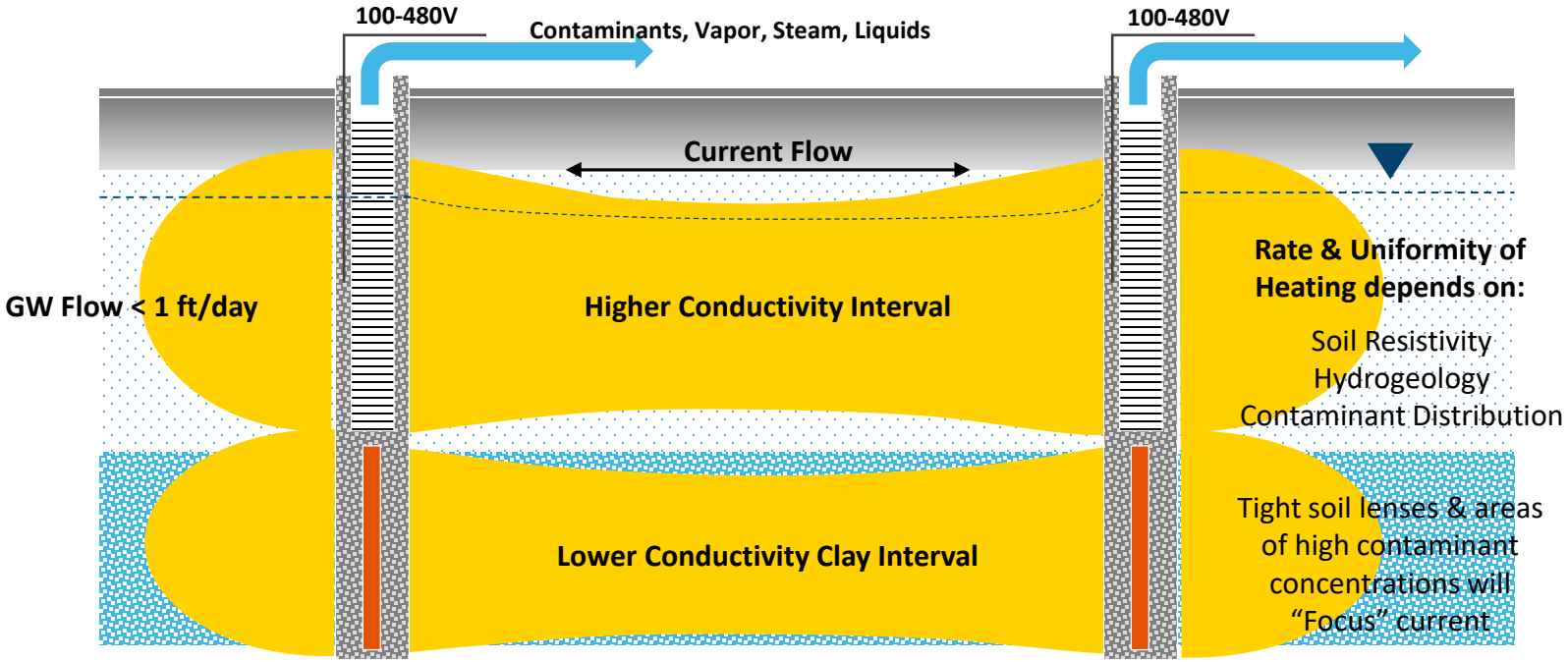
Heating Technologies

Thermal Conduction Heating (TCH)
Electrically powered thermal conduction heating
20 - 400 °C

Steam Enhanced Extraction
Steam injected through screen wells
100 °C

Electrical Resistance Heating (ERH)
Passes current between electrodes in the subsurface
Electrical resistance of soil generates heat
20 - 100 °C

Electrical Resistance Heating (ERH)



Advantages of Thermal Technologies

Reduce source mass & overall lifetime project cost

- Multiple removal mechanisms work in concert:
- Direct volatilization, steam stripping, enhanced evaporation
- Dissolution rates increase
- Desorption rates increase
- Abiotic degradation rates increase
- Biotic degradation rates increase (moderate heating)

Combining with Bioremediation

Bio-Polishing

- Residual energy from completed ISTR system
- Enhanced degradation

Low Temp Heat Enhanced Bioremediation

- ISTR system with operational temps of 30 to 35°C
- Maximize degradation rates
- Increase free product extraction (if present)

Source – ISTR Downgradient – Heat Enhanced Bioremediation

- ISTR system with operational temps of 100°C
- Downgradient moderate heating (recirculation system)
- Enhance degradation rates

Background

Dry cleaning facility operating for 67 years

Contaminants

- Tetrachloroethene (PCE)
- Some daughter products
- Stoddard solvent
- HMW hydrocarbons (DRO, ORO)

No discernable groundwater flow direction

Ongoing SVE system (modified for ERH operations)

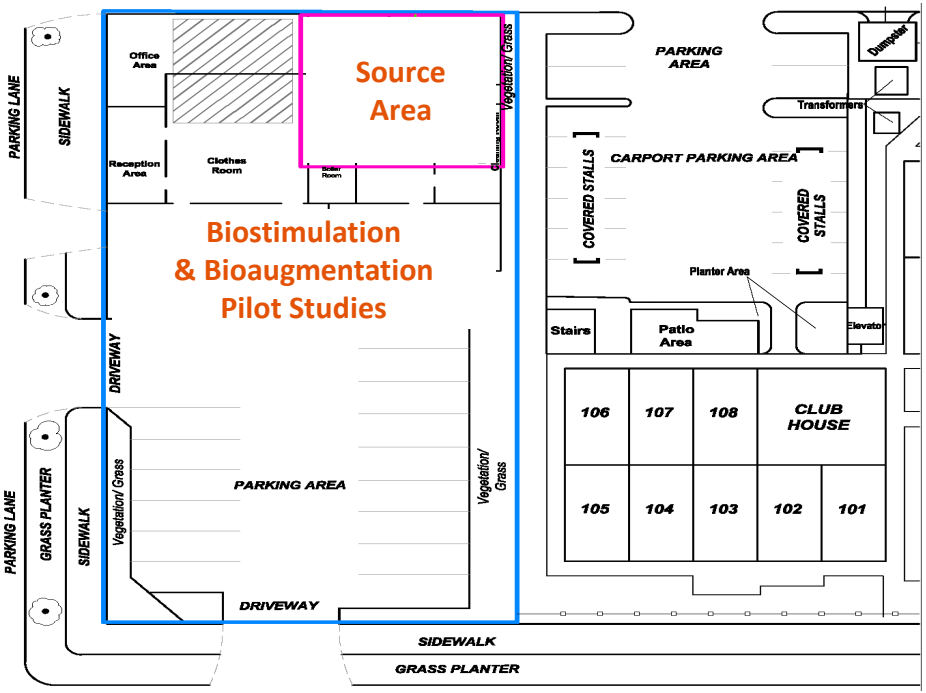
Site Layout

Source Area

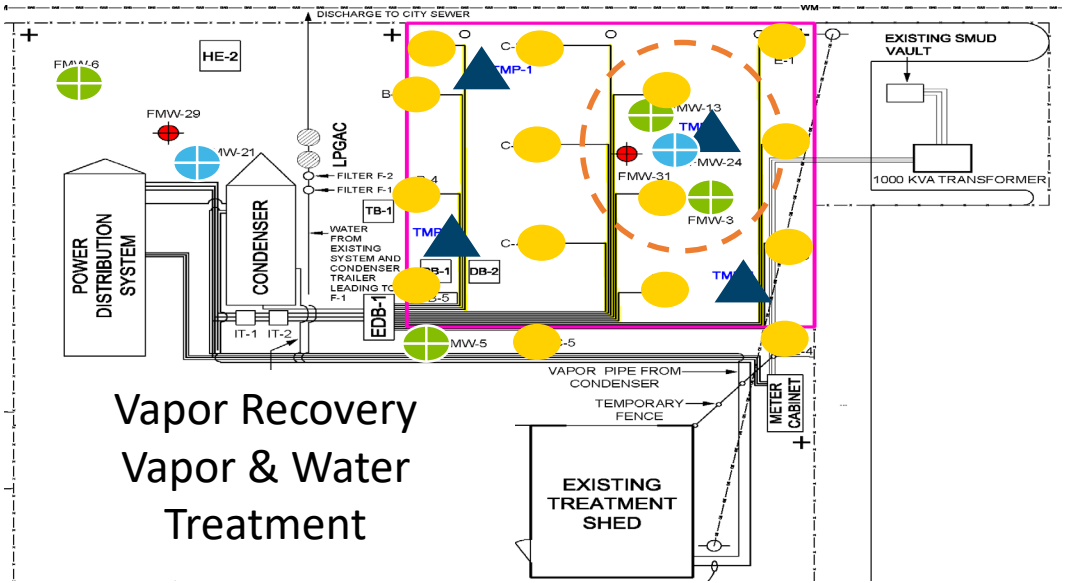
USTs
Dry Cleaning Rooms
ERH Treatment System

Plume

Biostimulation/
Bioaugmentation
Pilot studies

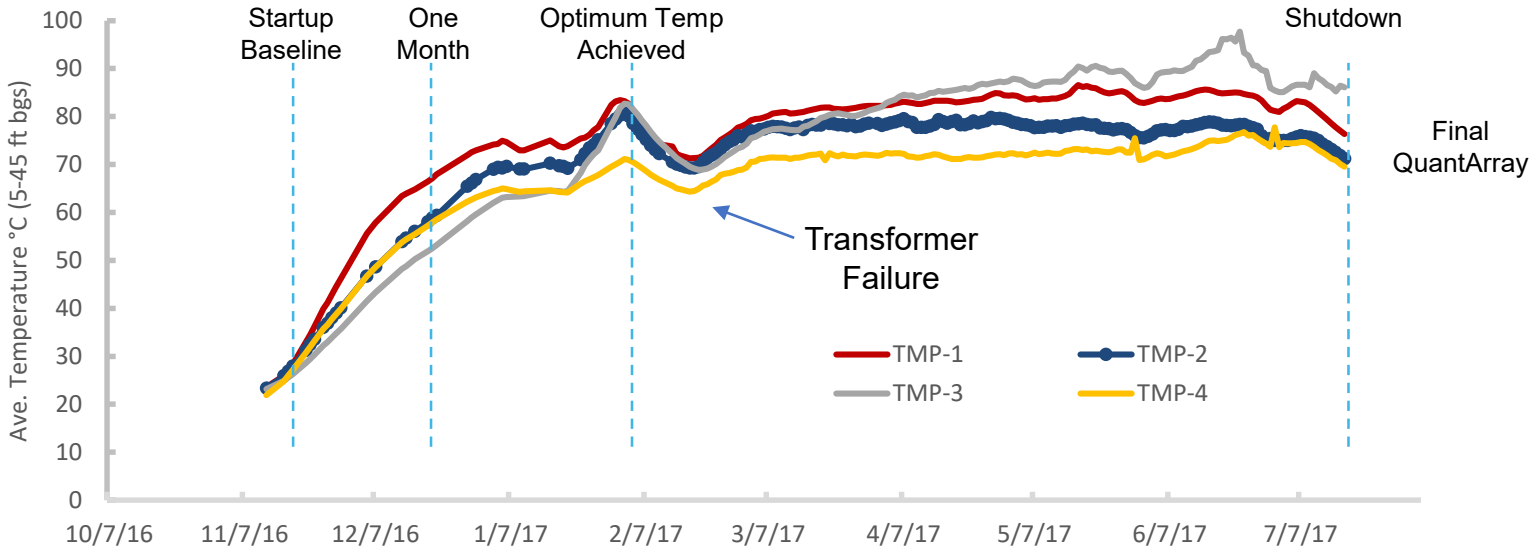


Source Area ERH System



- Total of 15 combined electrode/vapor recovery wells
- Shallow monitoring wells (FMW-3)
- Intermediate monitoring wells (FMW-24)
- Temperature probes (TMP-2)

ERH Operation



ERH Performance - Soil

Contaminant	Highest Pre-ERH Concentration (mg/kg)	Highest Post-ERH Concentration (mg/kg)	Average Post-ERH Concentration (mg/kg)	Percent Reduction (%)
PCE	26	0.054	0.0052	**>99.9%**
TCE	11	0.002	0.0003	**>99.9%**
Stoddard Solvent	3100	2600	246	**~ 93%**

ERH Performance - Groundwater

Contaminant	Highest Pre-ERH Concentration (µg/L)	Highest Post-ERH Concentration (µg/L)	Average Post-ERH Concentration (µg/L)	Percent Reduction (%)
PCE	6,600	98	51.3	**>99%**
TCE	5,900	7.5	4.6	**>99%**
cDCE	28,000	ND	ND	**~ 100%**
Vinyl chloride	4.1	ND	ND	**~ 100%**

ERH Conclusions

Highly effective contaminant mass removal

- Greater than 99% decrease in soil CVOCs
- 99% decrease in groundwater CVOCs
- Approximately 93% decrease in soil SS concentration

Temperatures achieved

- 80°C reached at 75% of treatment volume
- 90°C reached at 58% of treatment volume

Heterogeneity of subsurface soils impacted heating

Goals - Microbiology

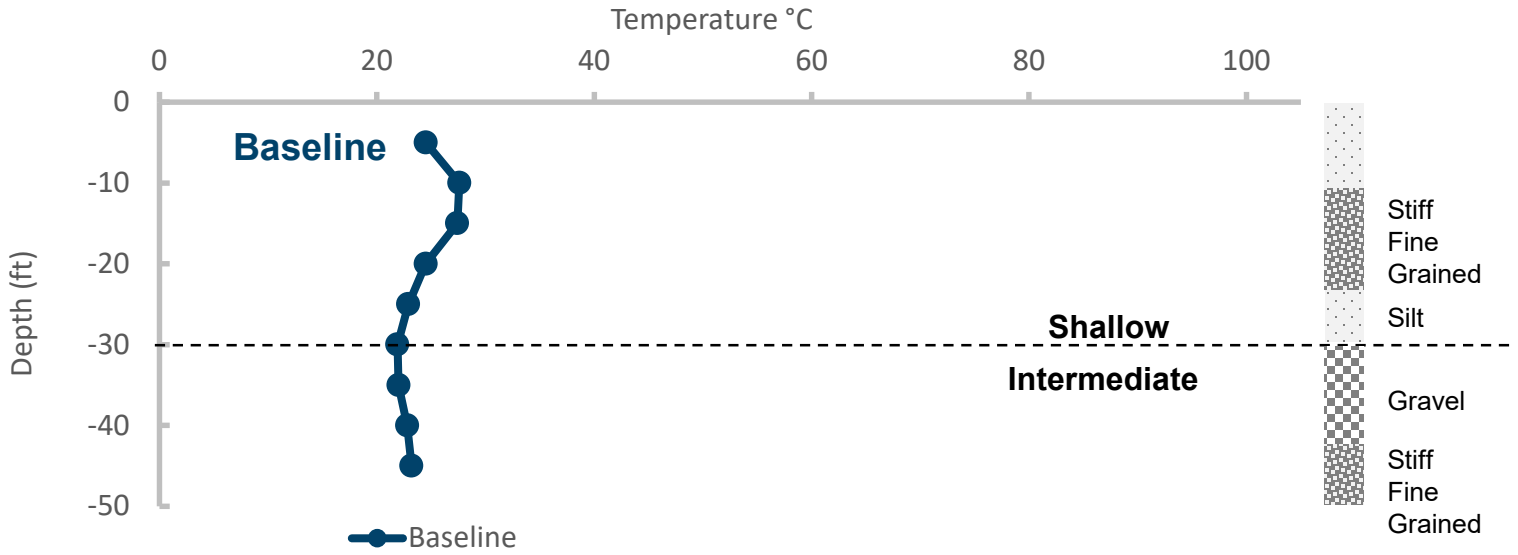
Evaluate potential for

- Post-ERH bioremediation in source zone
- Enhanced biodegradation in downgradient areas

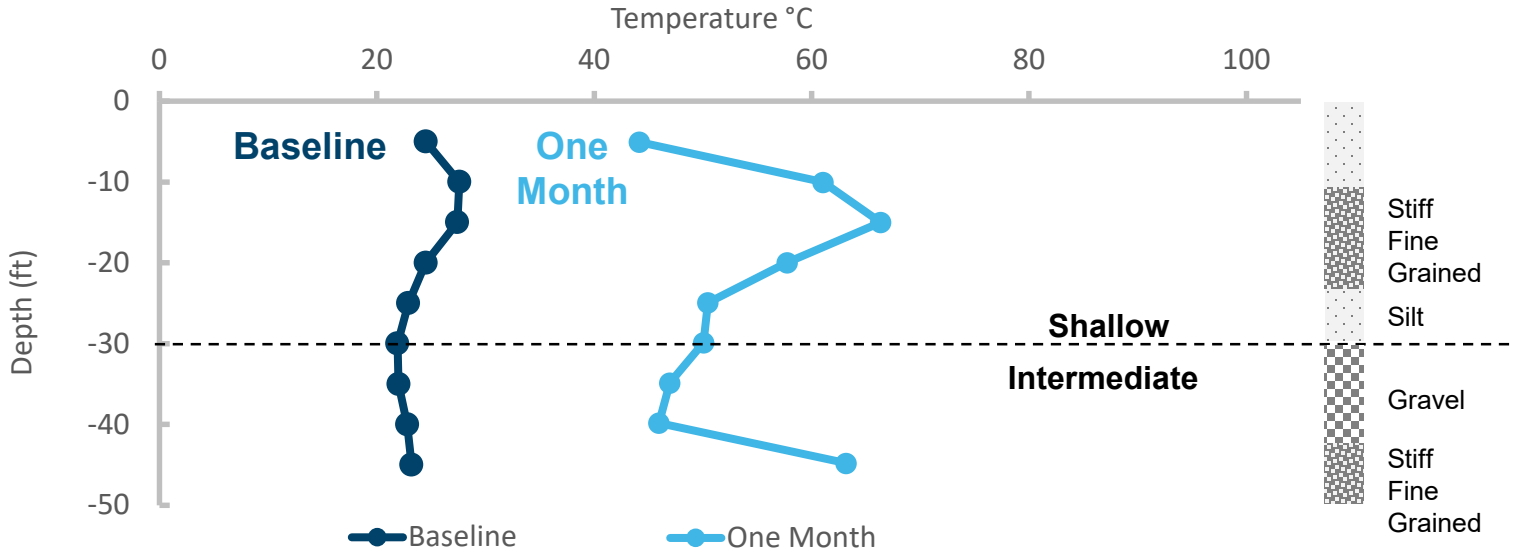
QuantArray analysis of groundwater samples

- Baseline
- One month after startup
- One month after ERH shutdown
- One year after ERH shutdown

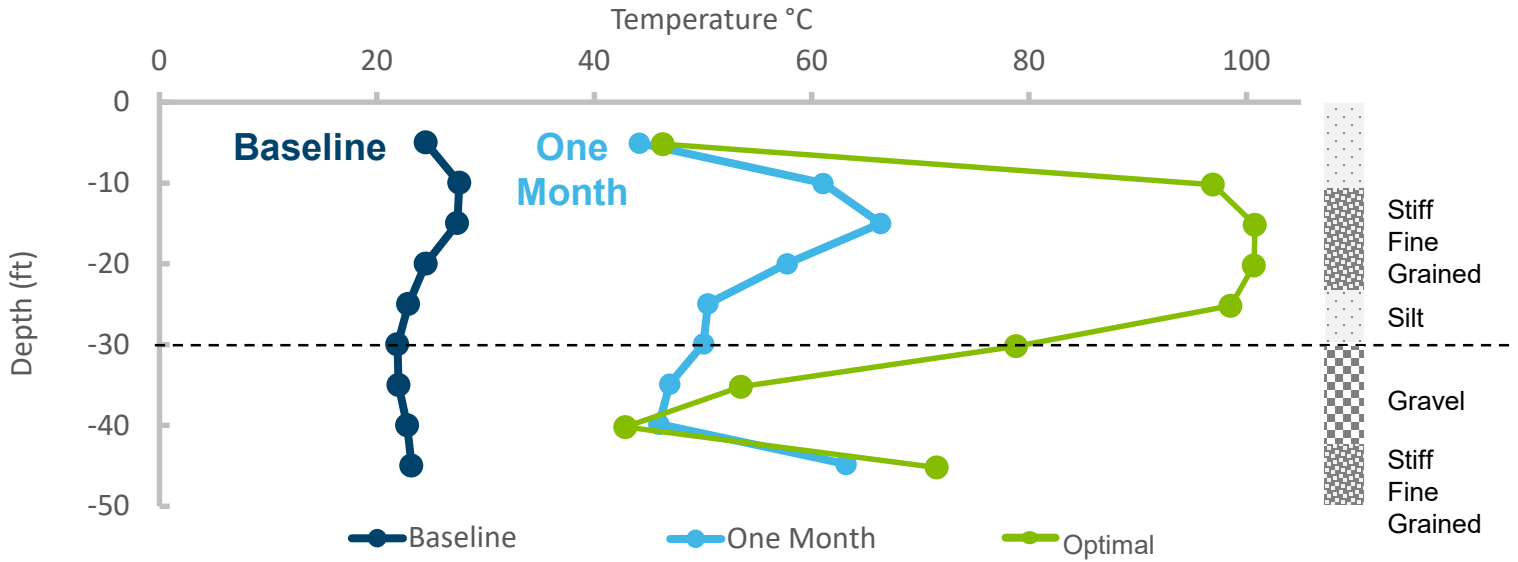
Temperature with Depth (Baseline)



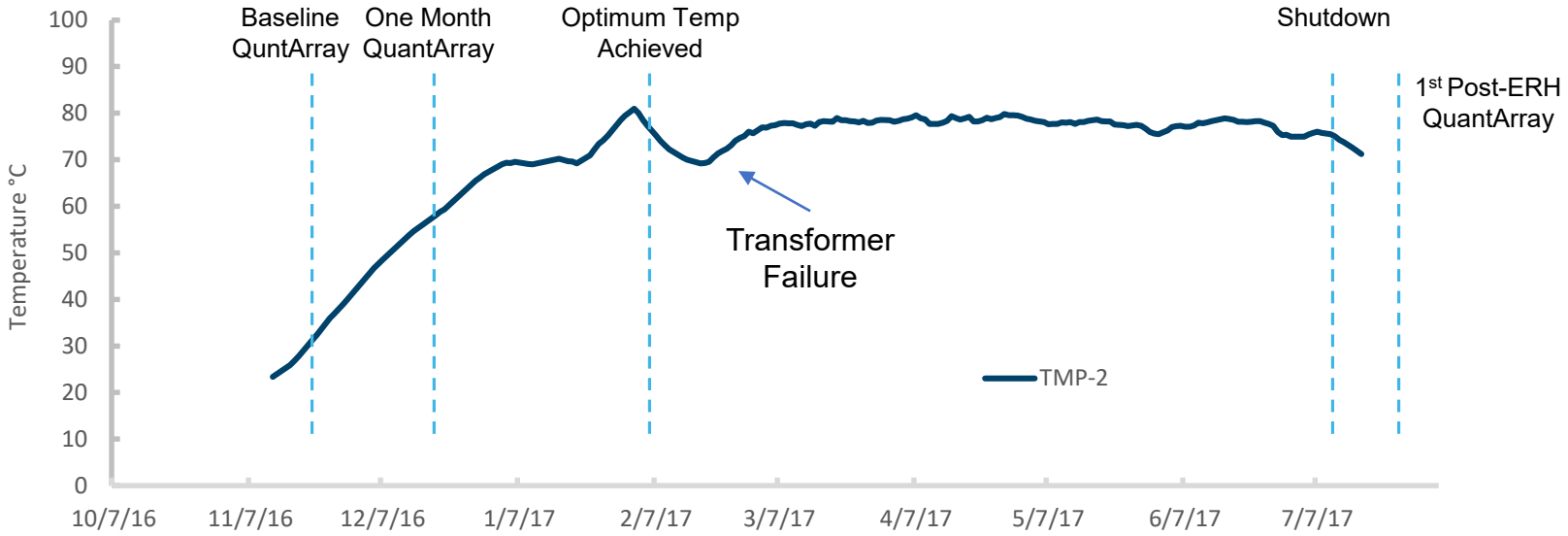
Temperature with Depth (One Month)



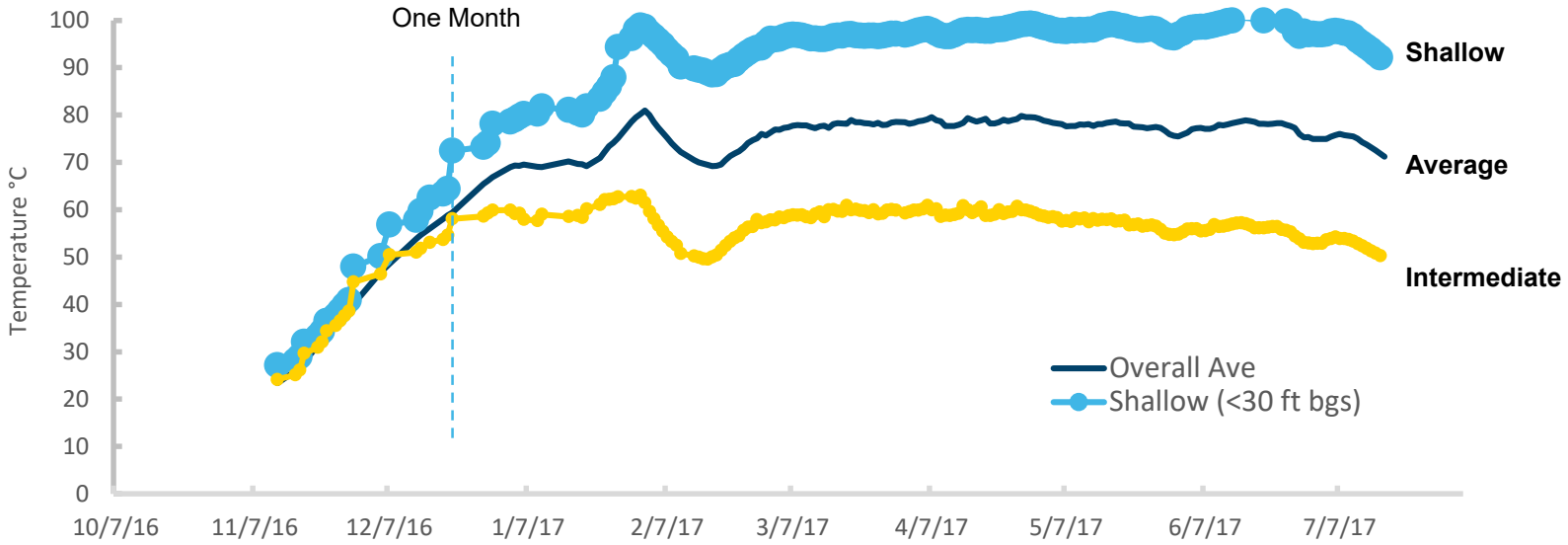
Temperature with Depth (Optimal)



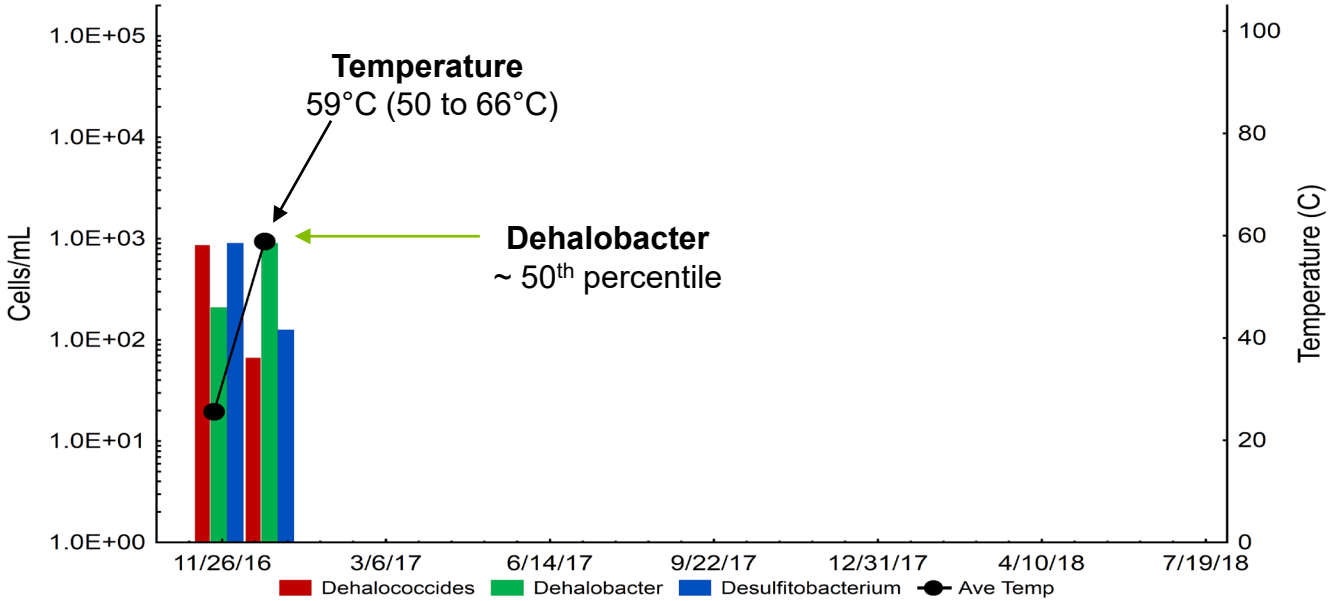
Temperature over Time



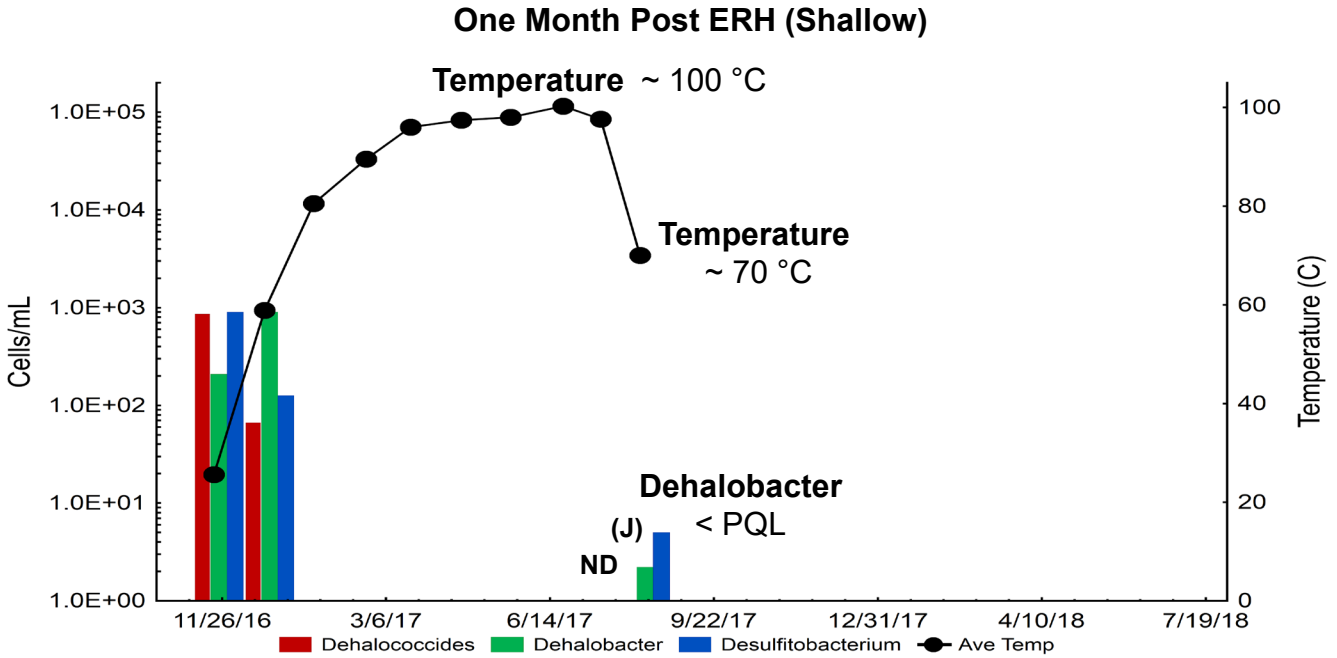
Temperature over Time



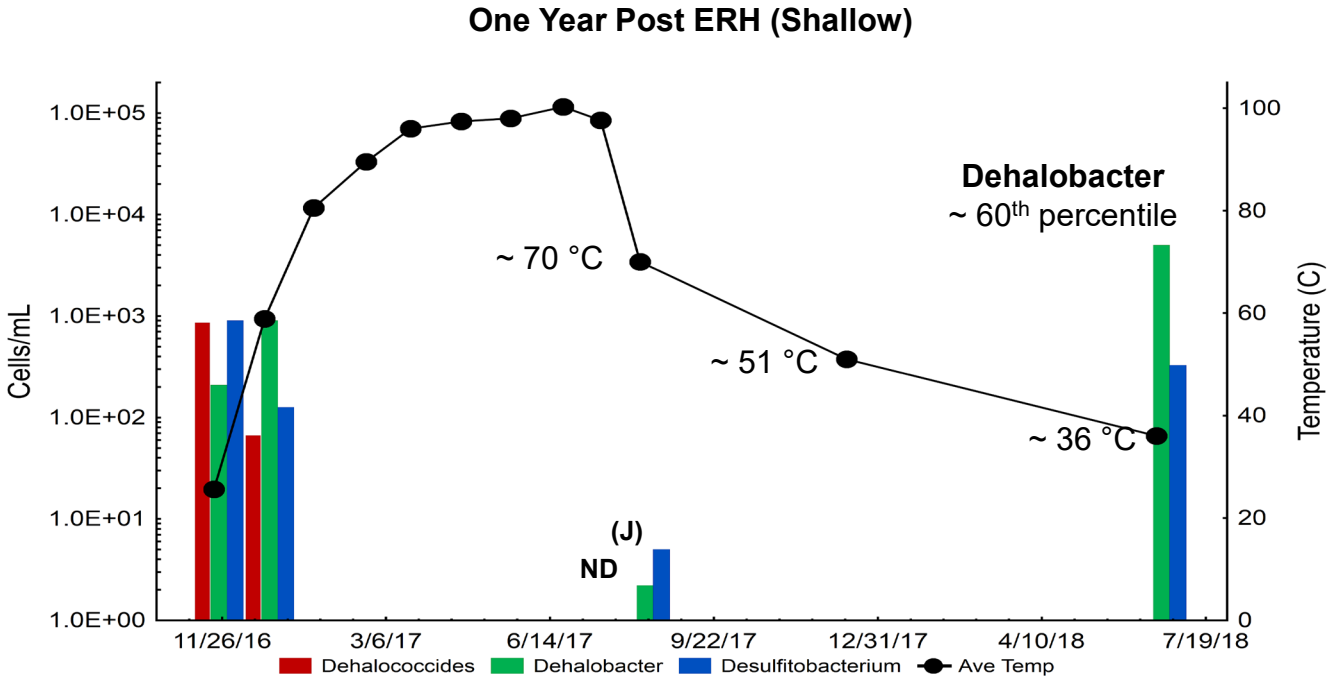
Baseline vs One Month (Shallow)



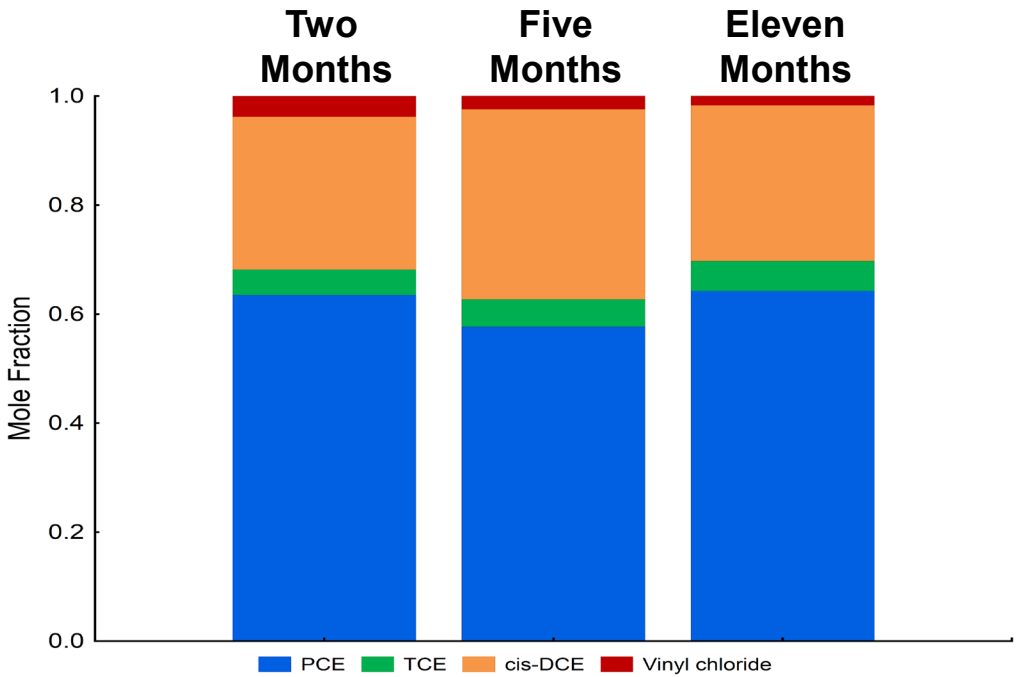
Shutdown


One Month Post ERH (Shallow)
Temperature ~ 100 °C
Temperature
~ 70 °C
Dehalobacter
< PQL
(J)
ND
Cells/mL
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
Temperature (C)
100
80
60
40
20
0
11/26/16
3/6/17
6/14/17
9/22/17
12/31/17
4/10/18
7/19/18
Dehalococcides
Dehalobacter
Desulfitobacterium
Ave Temp

Shutdown

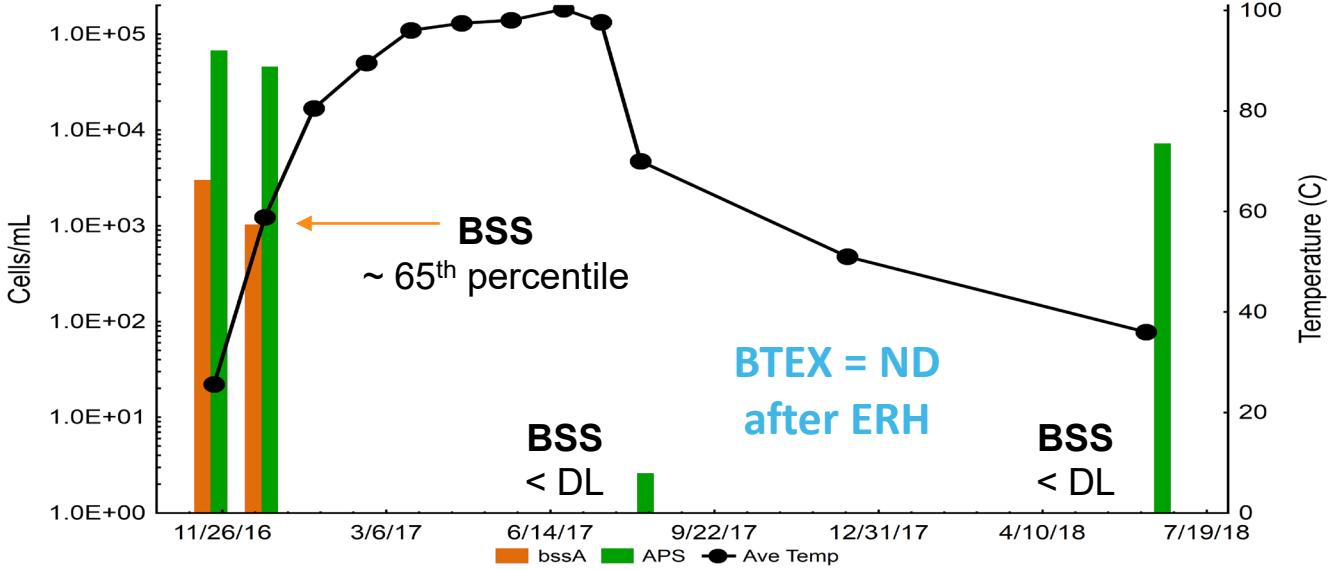

One Year Post ERH (Shallow)
Cells/mL
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
Temperature (C)
100
80
60
40
20
0
11/26/16
3/6/17
6/14/17
9/22/17
12/31/17
4/10/18
7/19/18
Dehalobacter
~ 60th percentile
~ 70 °C
~ 51 °C
~ 36 °C
(J)
ND
Dehalococcides
Dehalobacter
Desulfitobacterium
Ave Temp

Post ERH Reductive Dechlorination

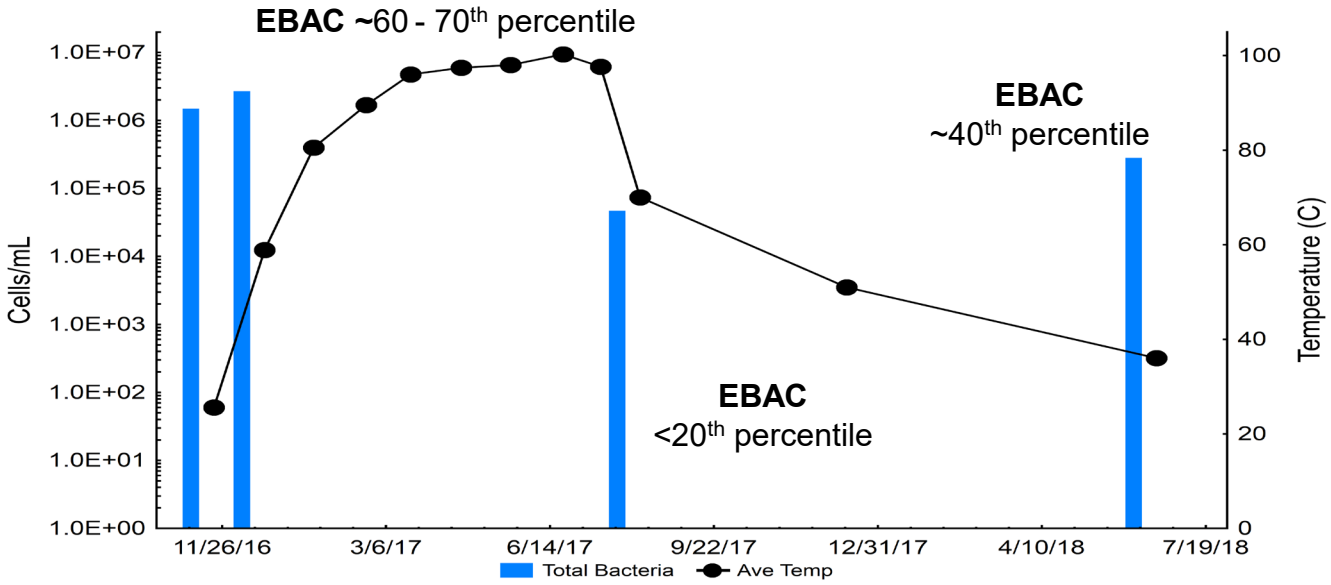


Evident by next sampling event?

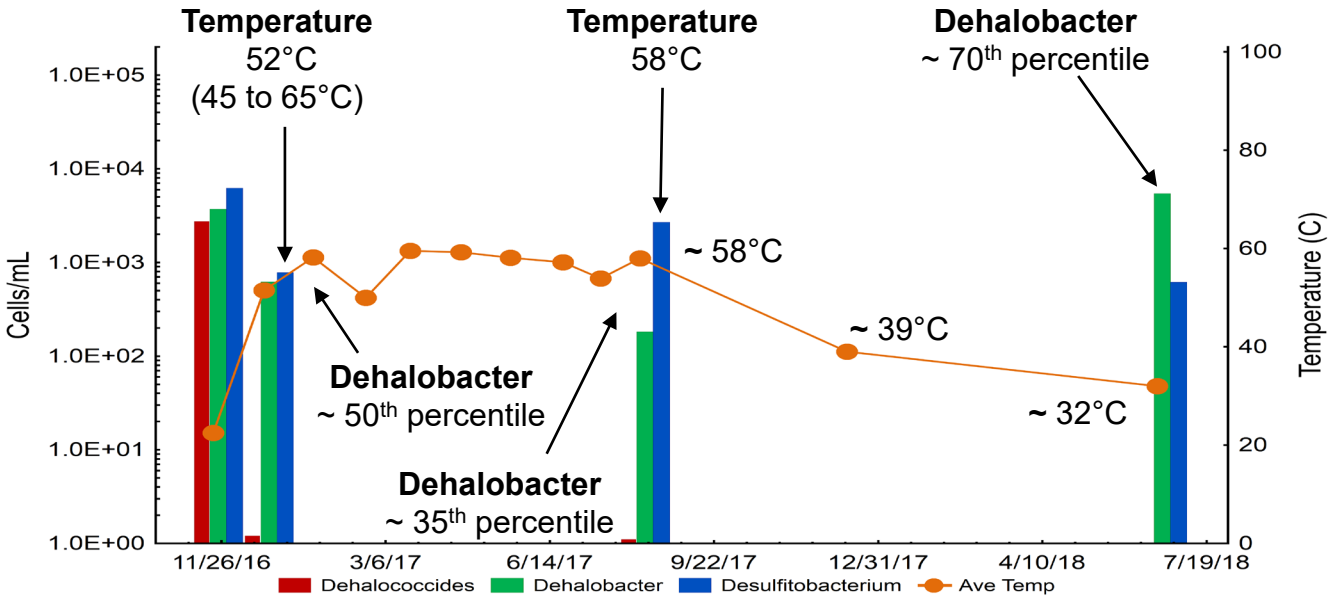
Post ERH (Shallow)



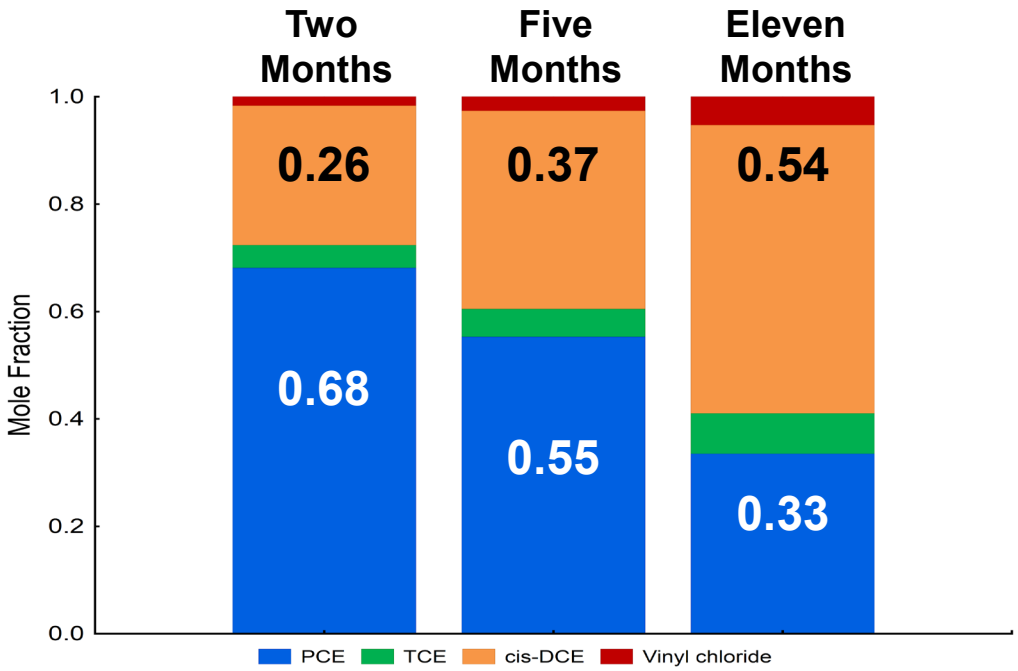
Post ERH (Shallow)



Intermediate



Post ERH Reductive Dechlorination



Reductive dechlorination of PCE to cis-DCE

Microbiology Conclusions

ERH was operated for mass removal & destruction (~ 100°C)

No additional electron donor in ERH (source) area

However, halorespiring bacteria survived at 40 - 50°C

Survival in lower temperature zones after 8 months of ERH

Rebound in Dehalobacter populations after cooling

Indicate the Potential for

Post-ERH Bio-Polishing or Biostimulation

Enhanced biodegradation downgradient during ERH

Low Temperature ERH with concurrent biodegradation

More Comprehensive Sampling Plans are Needed

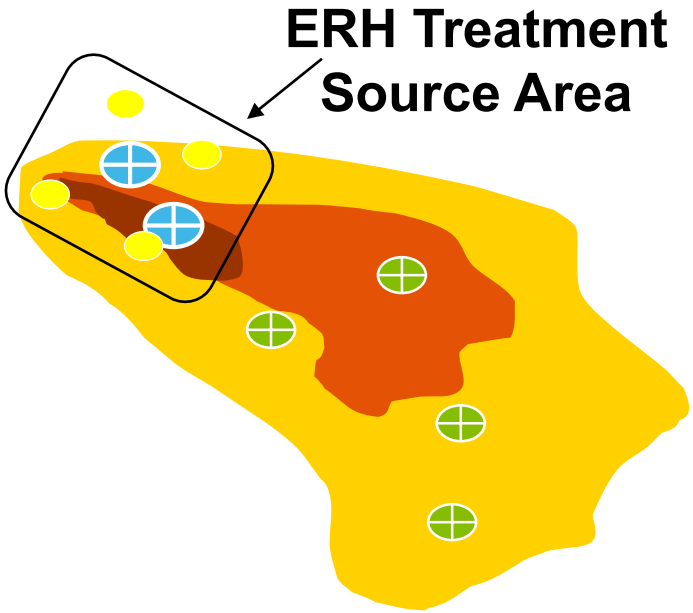
Recommendations

Conventional ERH (100°C)

- Source wells after ERH treatment
- Assess Bio-Polishing
- Downgradient wells throughout treatment
- “Halo Effect” of heat enhanced biodegradation

Low Temperature ERH (30-35°C)

- ERH treatment zone wells throughout treatment
- Downgradient wells throughout treatment



Full chemical, geochemical and microbial analyses

Questions?

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