Successful DNAPL Remediation Using Radio Frequency Heating and Return to Thermal Equilibrium

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Environmental Resources Management

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ERM

Summary of Topics

- Radio frequency (RF) heating concepts
- Applications/implementation
- Case study – bedrock remediation

About ERM

ERM:

- Is leading global provider of environmental, health and safety, risk, and social consulting services.

- Delivers innovative solutions for business and government clients, helping them understand and manage their impacts on the world around them.

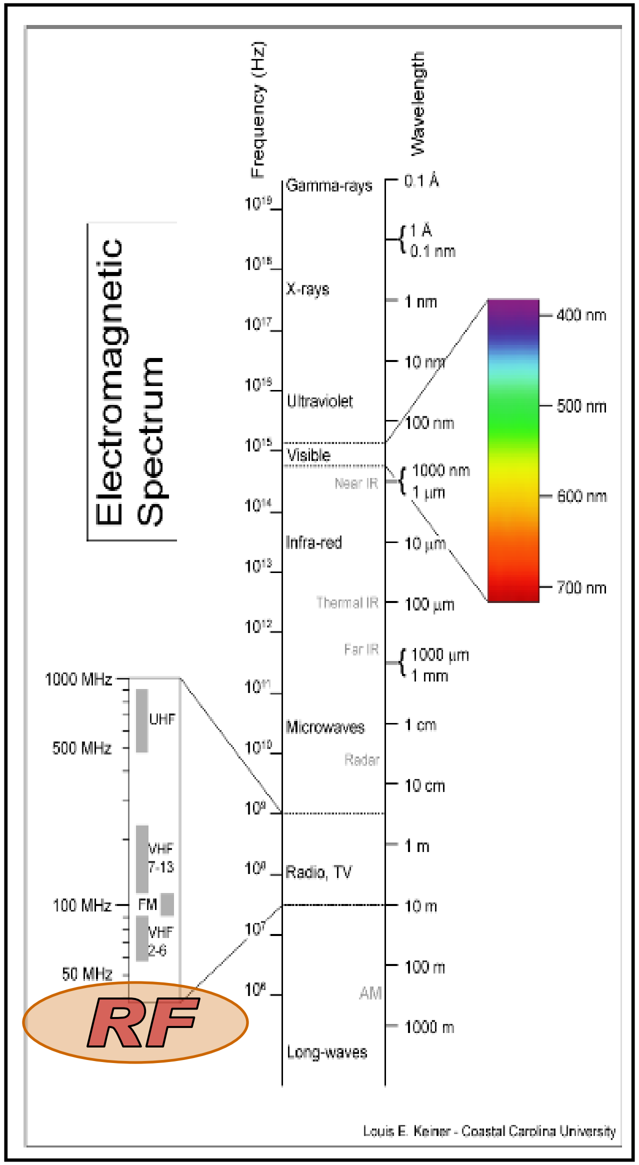
- Has 137 offices in 39 countries and employs approximately 3,300 staff.

About JR Technologies

- JR Technologies, LLC is a leading research and development company in applying patented radio frequency (RF) engineering and high voltage engineering techniques and apparatus in environmental remediation, enhanced oil/gas production and medical hyperthermia treatment.

RF Heating - Concepts

- Is electromagnetic radiation directed toward a non-conducting material (e.g., bedrock).
- 27-megahertz (MHz), 4-channel, 20-kilowatt (kW) system.
- Is absorbed by target conductive materials to produce heat.
- Is analogous to a microwave - generation of heat on a molecular level.



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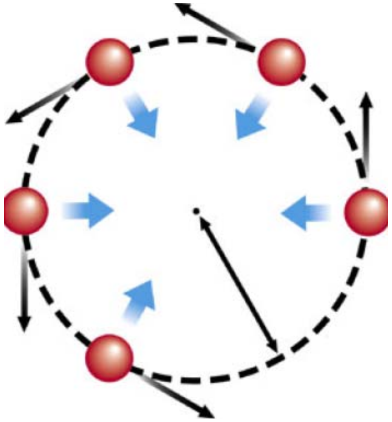
RF Heating - Concepts



- Propagates further into the subsurface, with greater absorption of energy.
- Delivers a focused, directional subsurface heating pattern.
- Requires installation of fewer heating wells, with the wells located father apart than with other thermal technologies.

RF Heating - Concepts

- Delivers safe, dependable operation inside buildings or at remote locations.
- Is particularly advantageous in very low-permeability unconsolidated and consolidated aquifers.
- Does not necessarily require as detailed an understanding of hydrogeologic conditions as other remedial technologies.

System Description

- 4 antennae per RF generator/trailer
- Each RF antenna is typically 15 feet long and 5 inches in diameter (other designs available)
- Antenna are water tight

Thermal Remediation Approaches

Degrade

- 40-60°C
- TCA
- SVE may not be needed

Volatilize

- Up to 100°C
- BTEX, PCE
- SVE likely needed

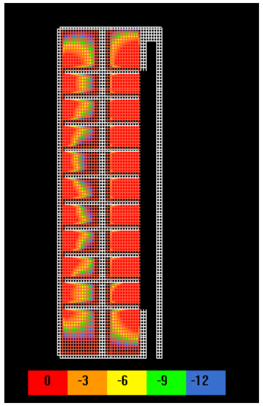
Change viscosity

- 40-100°C
- Coal tar, oil, LNAPL
- Need capture/treatment system

Stabilize/Destruct

- 100-400°C
- SVOCs
- PCBs

RF Implementation



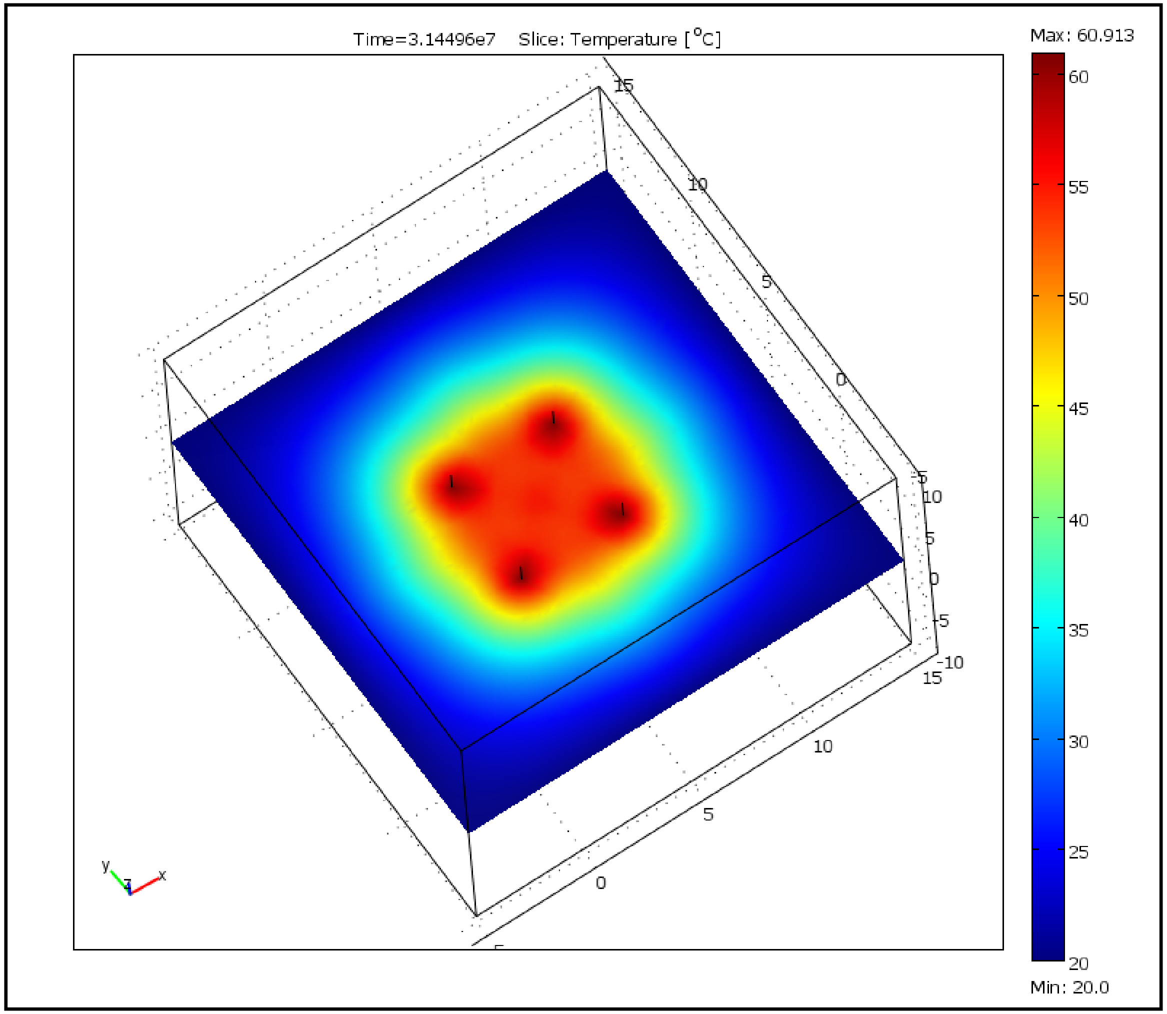
- Computer modeling
- Bench-scale
    - Determine rates of heating, target temperature
    - Often necessary for field design
- Pilot-scale
    - Can be first step if bench-scale not needed
- Full-scale

Computer Modeling

- Uniform heating, avoidance of hot spots

- Factors influencing heat pattern include antenna length and position, target temperature

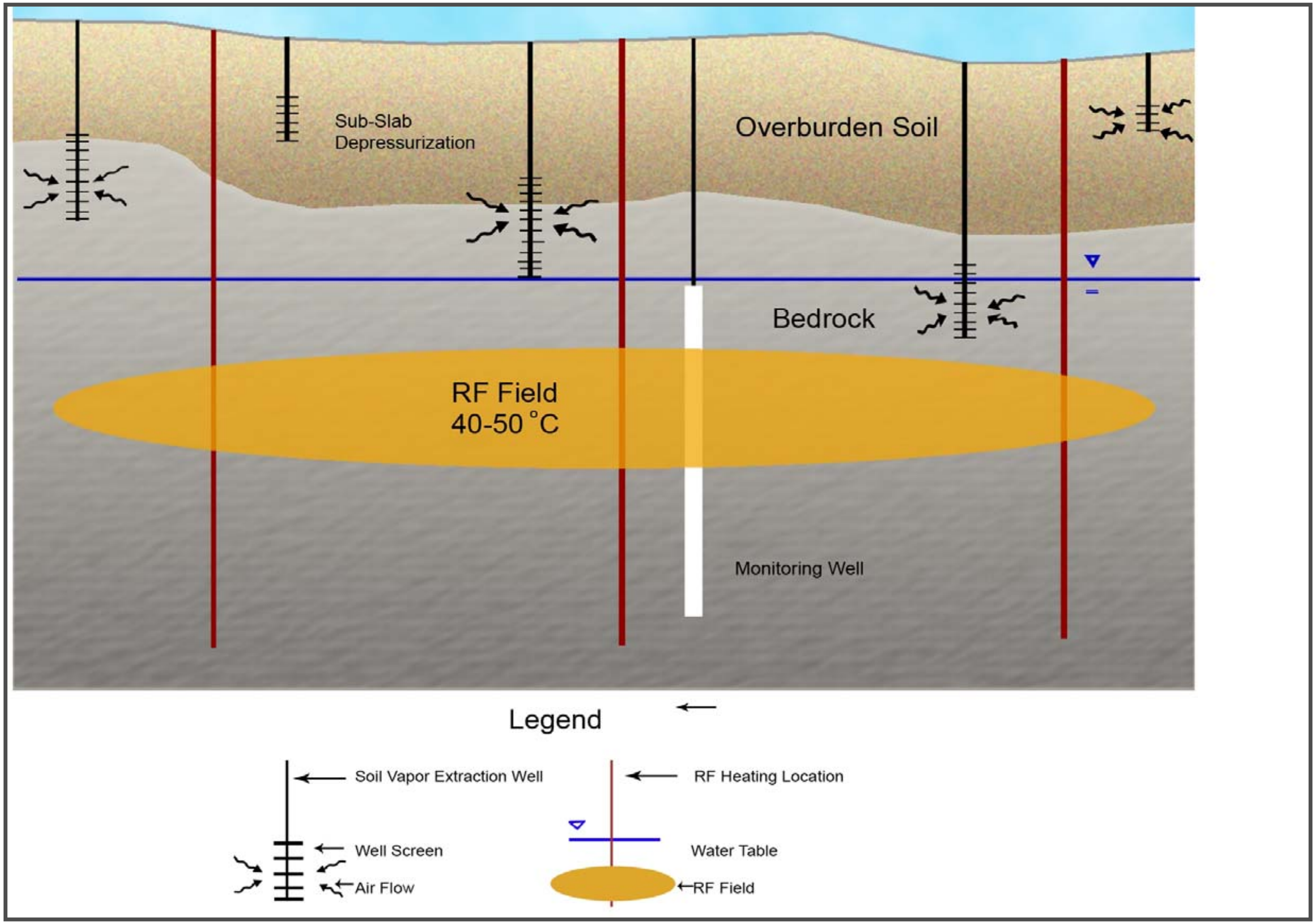
Temperature Profile



Case Study - Implementation

DNAPL (TCA) Remediation Using Radio Frequency Heating

Bedrock Remediation – Cross-Section



Site Information

- **Target Treatment Area (Residual DNAPL Zone)**
  - Area: 750 sq ft
  - Vertical treatment interval: 30 - 80 ft
  - Beneath occupied building
- **TCA Concentrations**
  - 410 to 640 mg/l in wells containing residual DNAPL
  - 31 to 140 mg/l in other source area wells
- **Bedrock Hydrogeology**
  - Fractured crystalline bedrock of very low yield (<<1 gpm), poor interconnection of fractures/joints
  - Treatment area capped by building, located at drainage basin divide minimized infiltration/flushing

TCA Half-Life

Temperature (°C)	TCA Half-life
10	12 yrs (1)
15	4.9 yrs (1)
20	1.7(2) / 3.2-3.8(3) / 0.95(1) yrs
25	0.5(5) / 1(2) / 0.8-1.3(4) yrs
40	35(4) / 22-27(2) d
55	3.6(2) / 4.6(4) d
60	1.2-3.8(2) / 22(4) d
80	5.5(4) / 2.7-4.0(2) h

References:

[1] McCarty (1994)

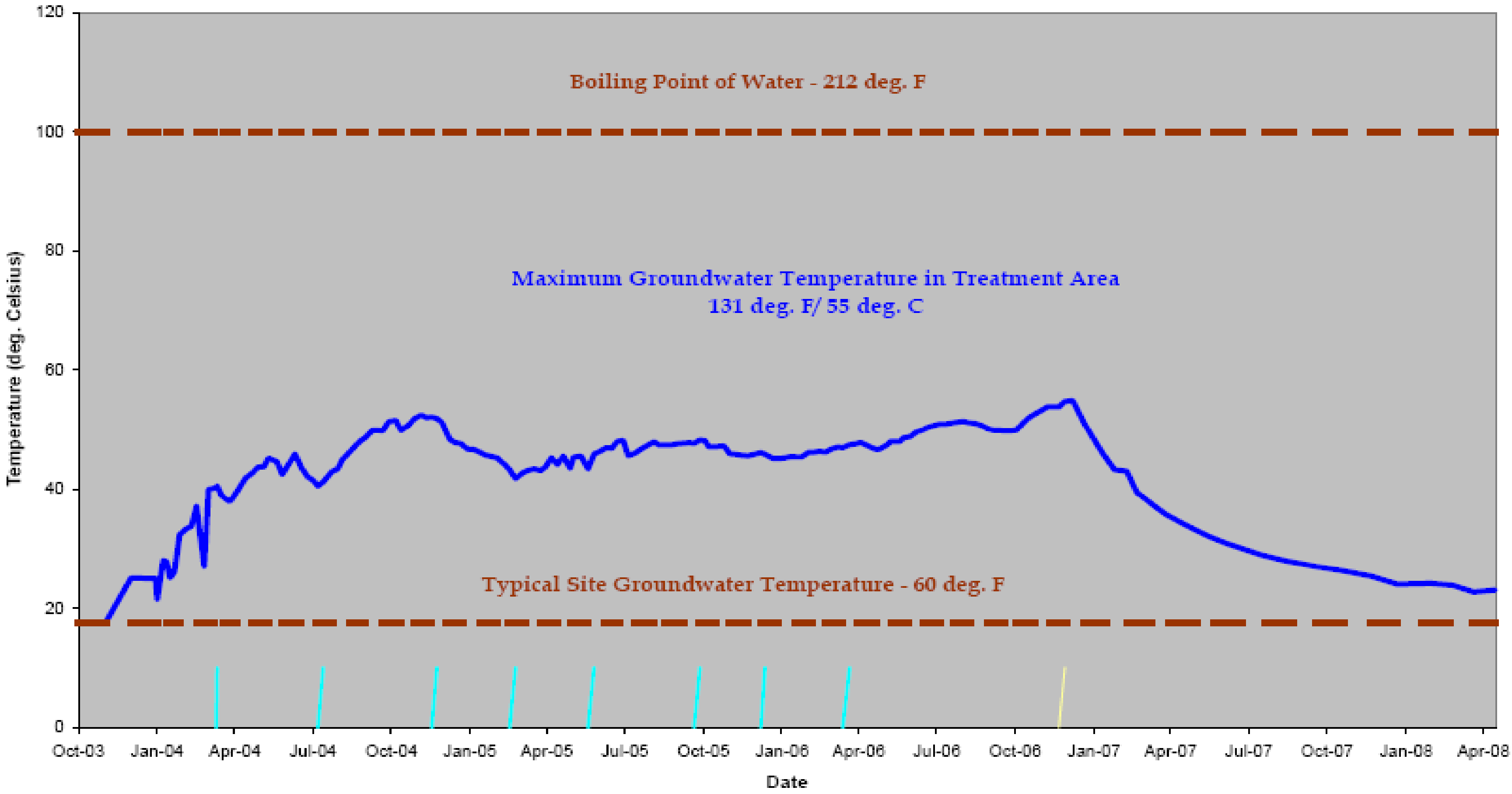
[2] Gerkens & Franklin (1989)

[3] Klecka et al. (1990)

[4] Haag & Mill (1988)

[5] Dilling et al. (1975)

Groundwater Temperatures



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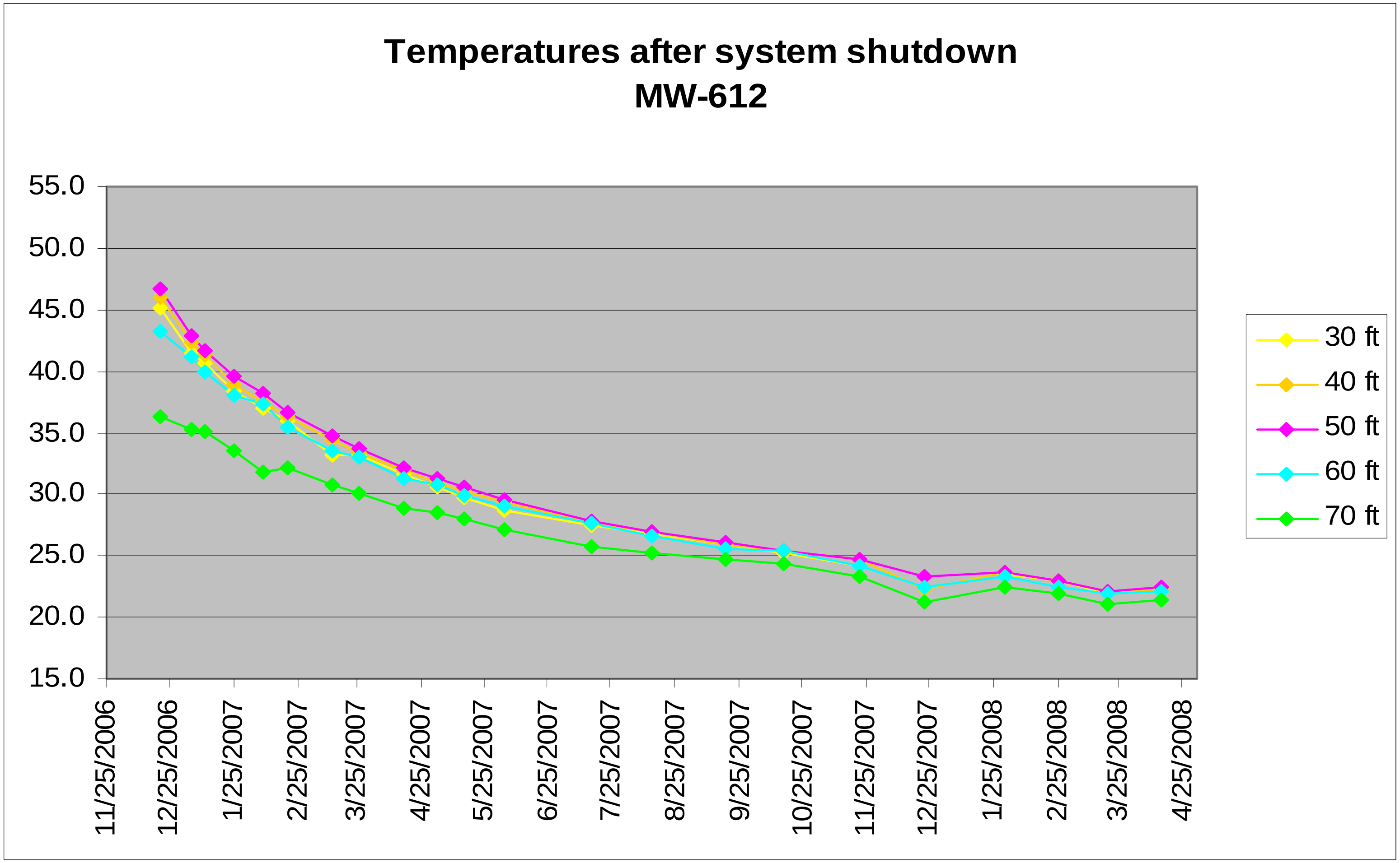
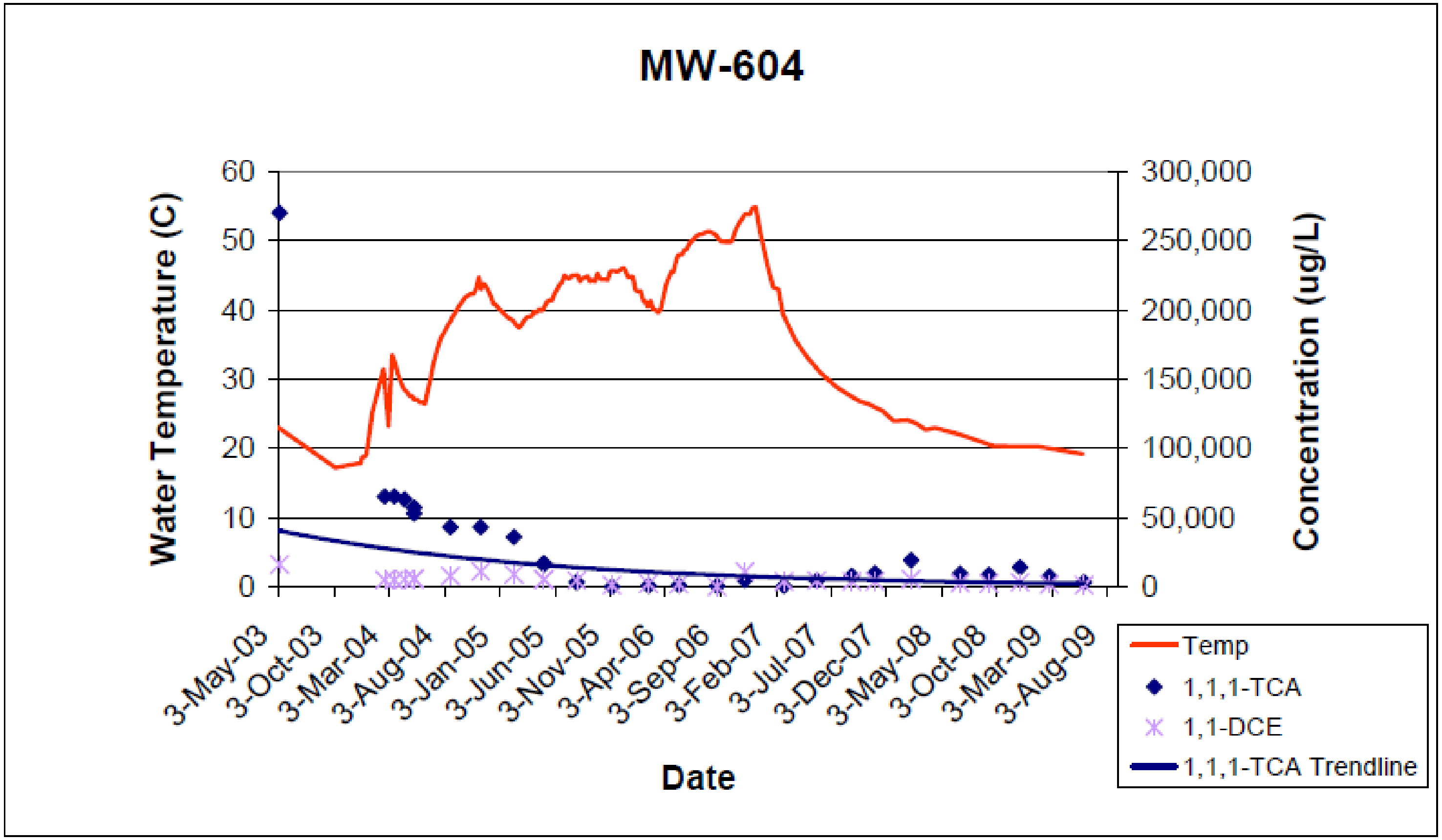
Groundwater Temperatures

(RF Operation Suspended November 2006)



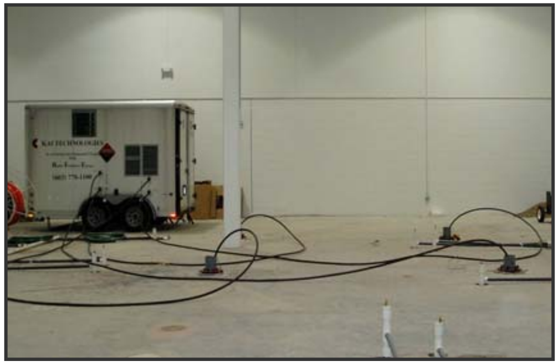
Temperature and Concentration

(RF Operation Suspended November 2006)



Average Source Area TCA Concentrations in Groundwater

May-03	146,800	µg/L
May-04	35,600	µg/L
May-05	14,300	µg/L
May-06	1,000	µg/L
May-07	3,000	µg/L
June-08	5,000	µg/L
May-09	8,300	µg/L
May-10	3,800	µg/L



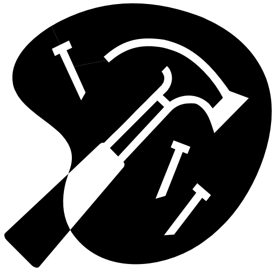
RF Heating Success Factors to Application

- **Targeted TCA** - amenable to hydrolysis and abiotic elimination at low temperature (60°C).

- **Cleanup goal** - reduction in mass/dissolved phase in source area to risk based concentrations, not MCLs.

- **RF Advantages**:
  - Preferentially heated target (TCA/water in fractures) versus mass of bedrock (thermally cost prohibitive).
  - RF field propagated over a volume, overcoming limitations of low yield, poorly interconnected bedrock.

RF Heating Enhancements

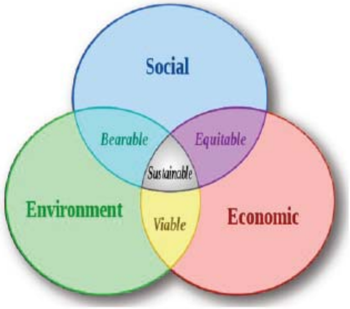


- Application of catalysts – to enhance abiotic elimination or biodegradation at fringes to further reduce mass of daughter products.

- Increase power – higher power levels possible in unoccupied or access-restricted locations.

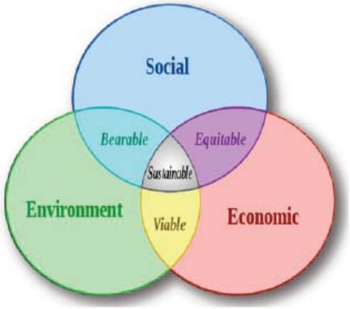
- Use of multiple RF generators and heating arrays – shortens remediation duration.

Sustainable Aspects of RF Heating = Net Benefits to Triple Bottom Line



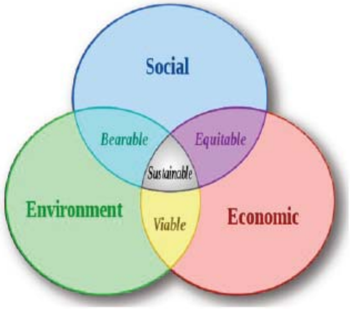
- **Social benefits**
  - Feasible DNAPL abatement versus "technical infeasibility" based closure = positive public and regulatory stakeholder support
  - Accelerated restoration of down-gradient potable aquifer as future drinking water resource (current use suspended)
  - Source and down-gradient plume reductions = reduce "stigma" of long-term impact to property values

Sustainable Aspects of RF Heating = Net Benefits to Triple Bottom Line



- **Economic**
  - Fewer heating locations (boreholes, waste, materials) than other thermal methods
  - Lower energy requirements/cost than other thermal methods that heat host and target
  - Less monitoring than other in situ treatment technologies (ISCO, ISCR, M&A) – fewer site visits, reduced labor, consumables

Sustainable Aspects of RF Heating = Net Benefits to Triple Bottom Line



- **Environmental benefits**
  - Lower carbon requirements (less energy, materials, fewer site visits, augmentation via renewable sources)
  - Reduced vapor emissions (lower temperature means less vapor control)
  - Reduced water use and transportation (i.e., over ISCO requiring transport and mixing of injection media)
  - Lower potential for DNAPL displacement than with in situ injection