



McMillan-McGee Corp.  
[www.mcmillan-mcgee.com](http://www.mcmillan-mcgee.com)  
Mc<sup>2</sup>

# **An Experimental Investigation of Thermal Methods for In-situ Remediation of MTBE- Impacted Groundwater**

**Bruce C. W. McGee, McMillan-McGee Corp.**

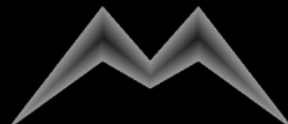
**Barry Nevokshonoff, Sequoia Environmental.**

**James A. M. Thomson, Applied Hydrology Associates, Inc.**

**Michael J. Day, Applied Hydrology Associates, Inc.**

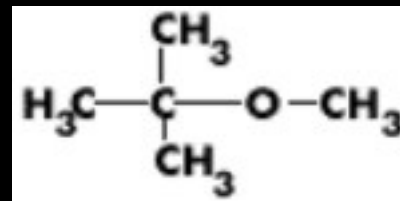
# *Presentation Outline*

- Review of MTBE
- Experiment Objectives
- Experimental Procedure
- Experimental Results
- Implementation of Soil Heating in the Field
- Conclusions.





# Properties of MTBE



- MTBE has a high solubility in water. It is ~ 24 times more soluble in water than Benzene (43,000 to 50,000 mg/L).
- MTBE has a high vapor pressure, more than 2½ times greater than the vapor pressure of Benzene at 25 °C. The vapor pressure of MTBE (and BTEX) increases exponentially with temperature.
- MTBE has a low Henry's Law Constant (air-water partitioning coefficient) in comparison to the BTEX components that increases with temperature (more than doubles from 20 to 40 C).
- The biodegradation rate of MTBE is an order of magnitude lower than that of the BTEX fuel components.
- MTBE has a low organic partition coefficient in comparison to BTEX components, reflecting its lesser affinity for soil adsorption.
- MTBE is lower specific gravity than water and a higher vapor density than air
- MTBE has a low taste and odor threshold.

## Development of an in-situ remediation strategy for MTBE?



# Properties of MTBE & BTEX

Property	MTBE	Benzene	Toluene	Ethylbenzene	Xylene
% Volume in Fuel	15	1	5	<1	8
Water Solubility, [mg/L]	43,000	1,780	535	161	146
Vapor Pressure, [mmHg]	251	95	28	9	8
Henry's Constant	0.020	0.22	0.24	0.35	0.00024
Biodegradation Rate, [%/D]	0.01	0.1-1.0	0.1-1.0	0.1-1.0	0.1-1.0
Adsorption, $\log(K_{oc})$	1.05	1.90	2.0	2.50	2.6
Molecular Weight, [g/mol]	88	76	92	106	106
Specific Gravity	0.74	0.88	0.87	0.87	0.87
Specific Vapor Density	3.80	3.36	3.97	4.57	4.57
Odor Threshold, [ppbv]	95	3,000	160	6,000	20,000
Taste Threshold, [ $\mu\text{g/L}$ ]	10-130	2,500	na	na	na



## *Properties of MTBE suggest:*

- Might be difficult to remove from the soils using vapor extraction or multi-phase extraction.
- Bio-remediation may not be as effective for remediation of MTBE as for other fuel components.
- Plumes might be relatively larger in extent and remediation may require the pump and treat of huge volumes of groundwater and significant ex-situ treatment.
- Begs the question . . . . .

**Will Heat Help?**

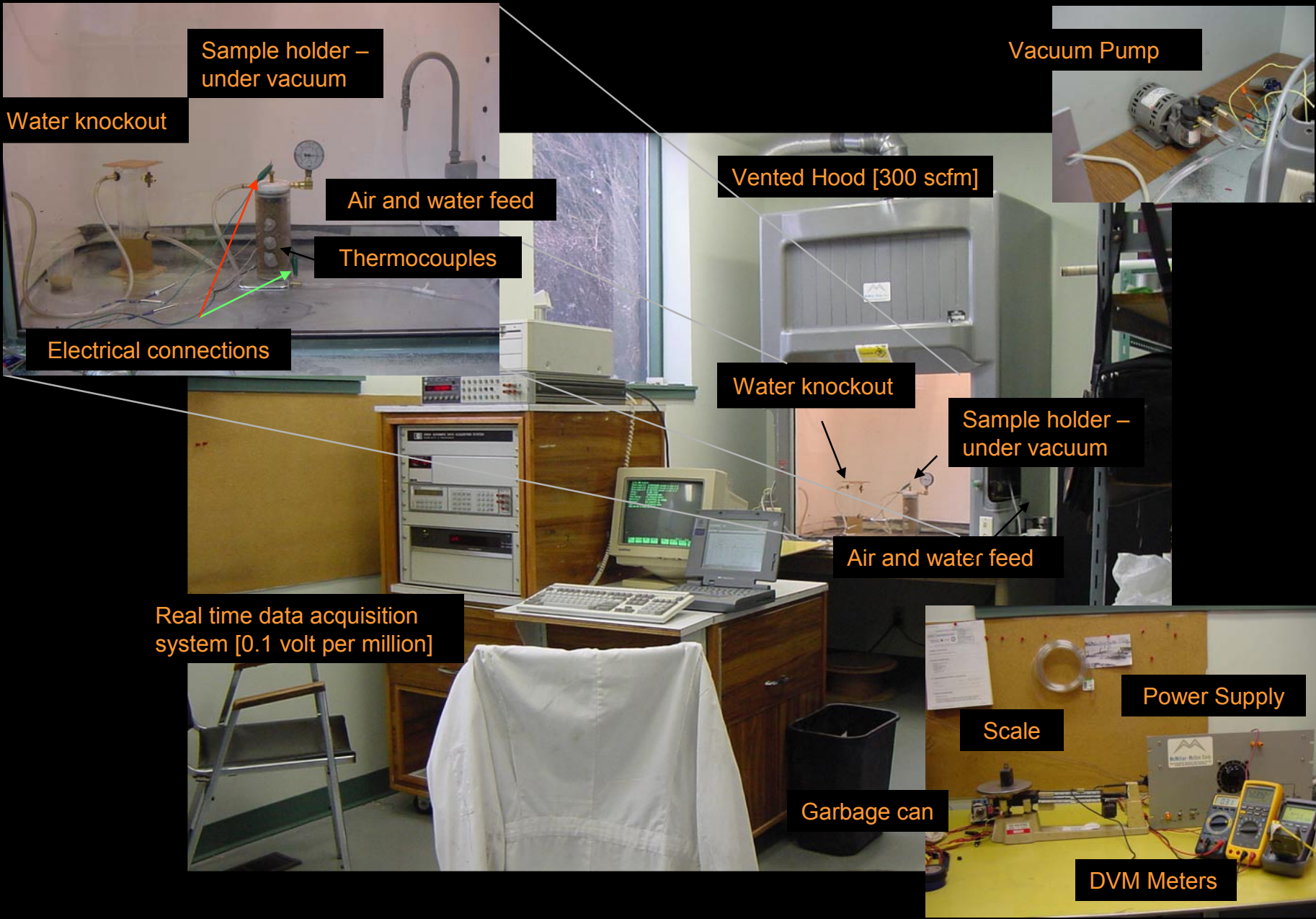


## *Objective of Experimental Investigation*

- Determine whether the addition of heat by the conversion of electrical energy in the porous media enhances the in-situ remediation of MTBE from the water saturated sand, in this case in combination with air sparging and soil vapor extraction.

***Test the Hypothesis***  
**Heat helps in the remediation  
of MTBE impacted soils.**





Sample holder –  
under vacuum

Vacuum Pump

Water knockout

Vented Hood [300 scfm]

Air and water feed

Thermocouples

Electrical connections

Water knockout

Sample holder –  
under vacuum

Real time data acquisition  
system [0.1 volt per million]

Air and water feed

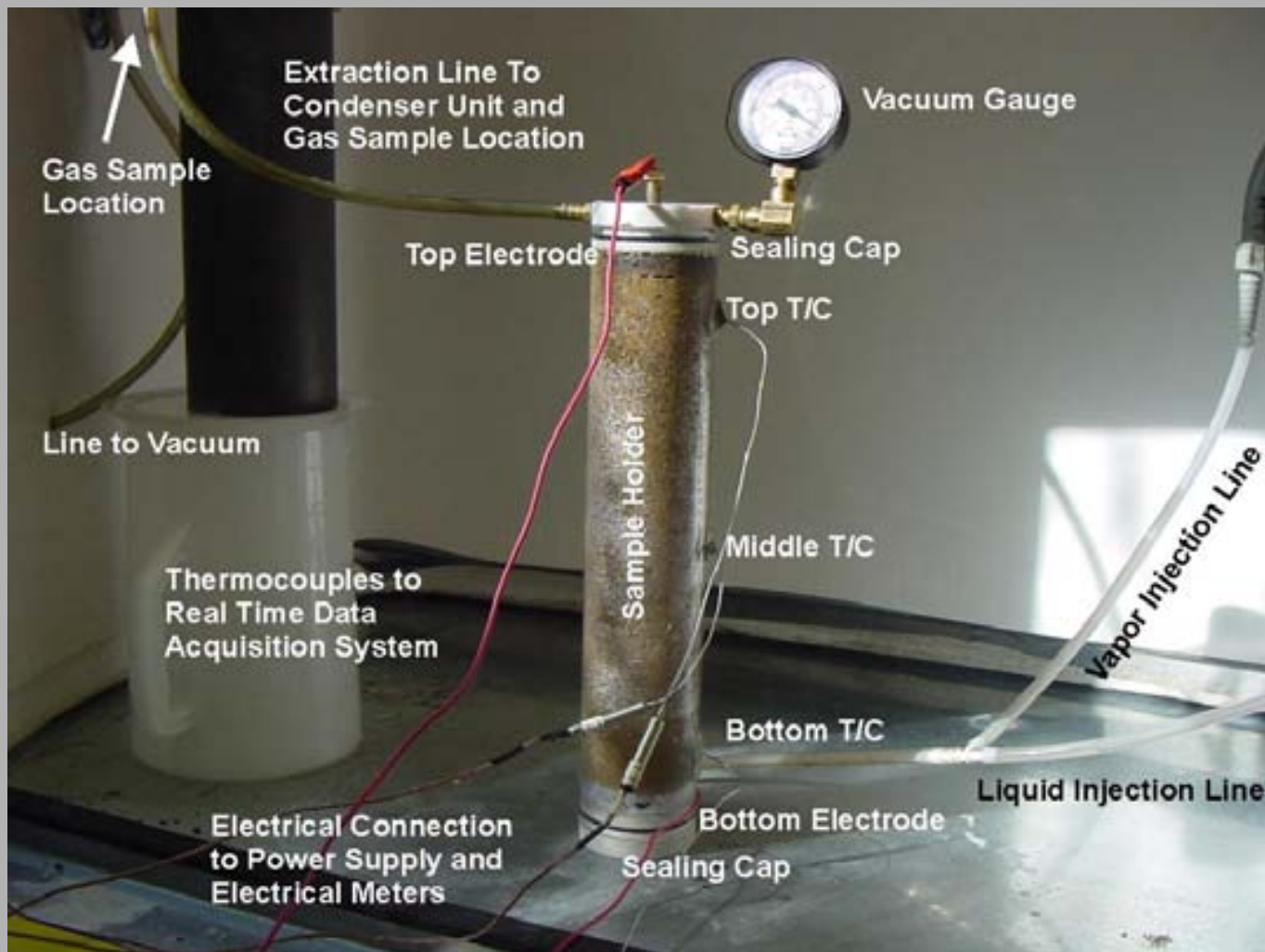
Power Supply

Scale

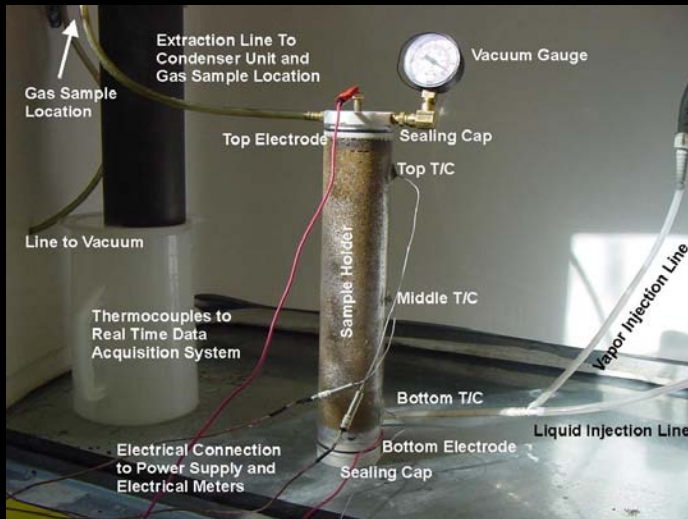
Garbage can

DVM Meters





# Animation of the Bench Scale Investigation



Condenser Unit



Air Sparging



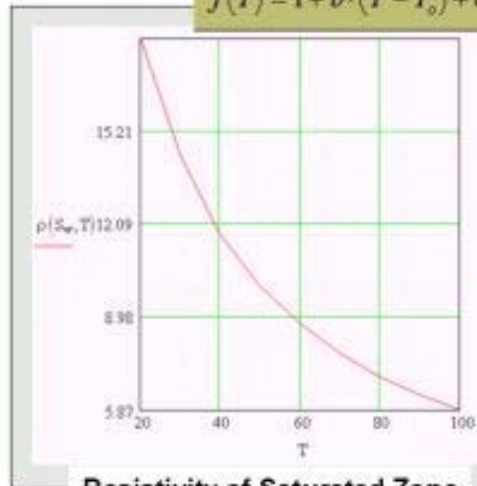
Electrical Heating and Air Sparging



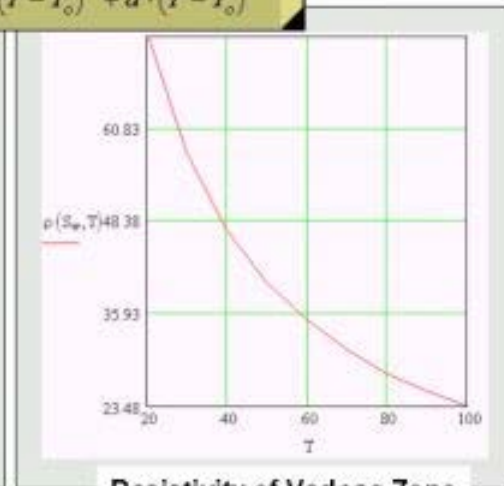
Electrical Heating in the Vadose zone and below the water table since ....

$$\sigma_s(S_w, T) = \left[ \sigma_w \frac{\phi^{37}}{P_f} \cdot S_w^2 + (1 - \phi) \cdot \sigma_r \right] \cdot f(T)$$

$$f(T) = 1 + b \cdot (T - T_o) + c \cdot (T - T_o)^2 + d \cdot (T - T_o)^3$$



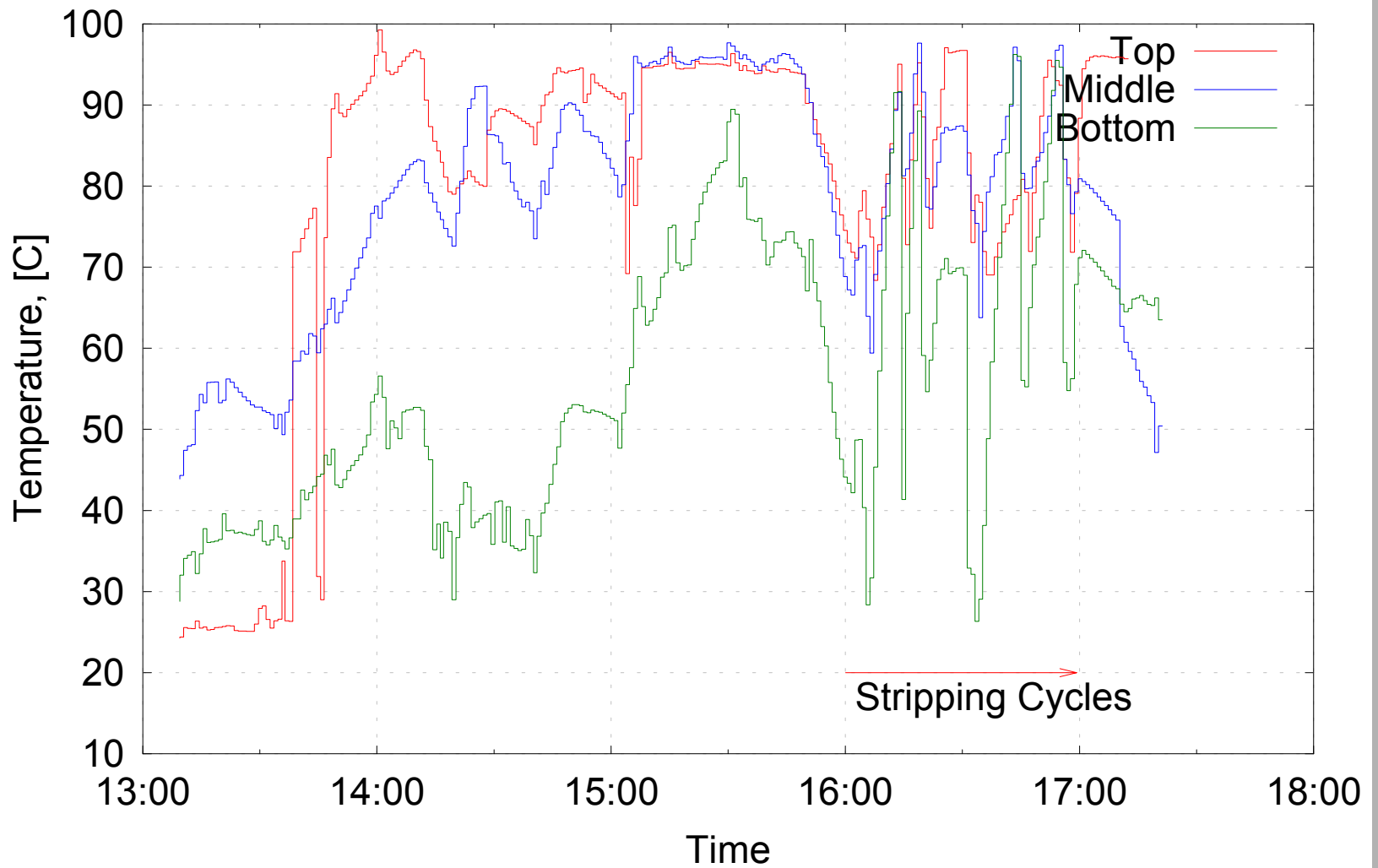
**Resistivity of Saturated Zone**  
Water Saturation is ~100%



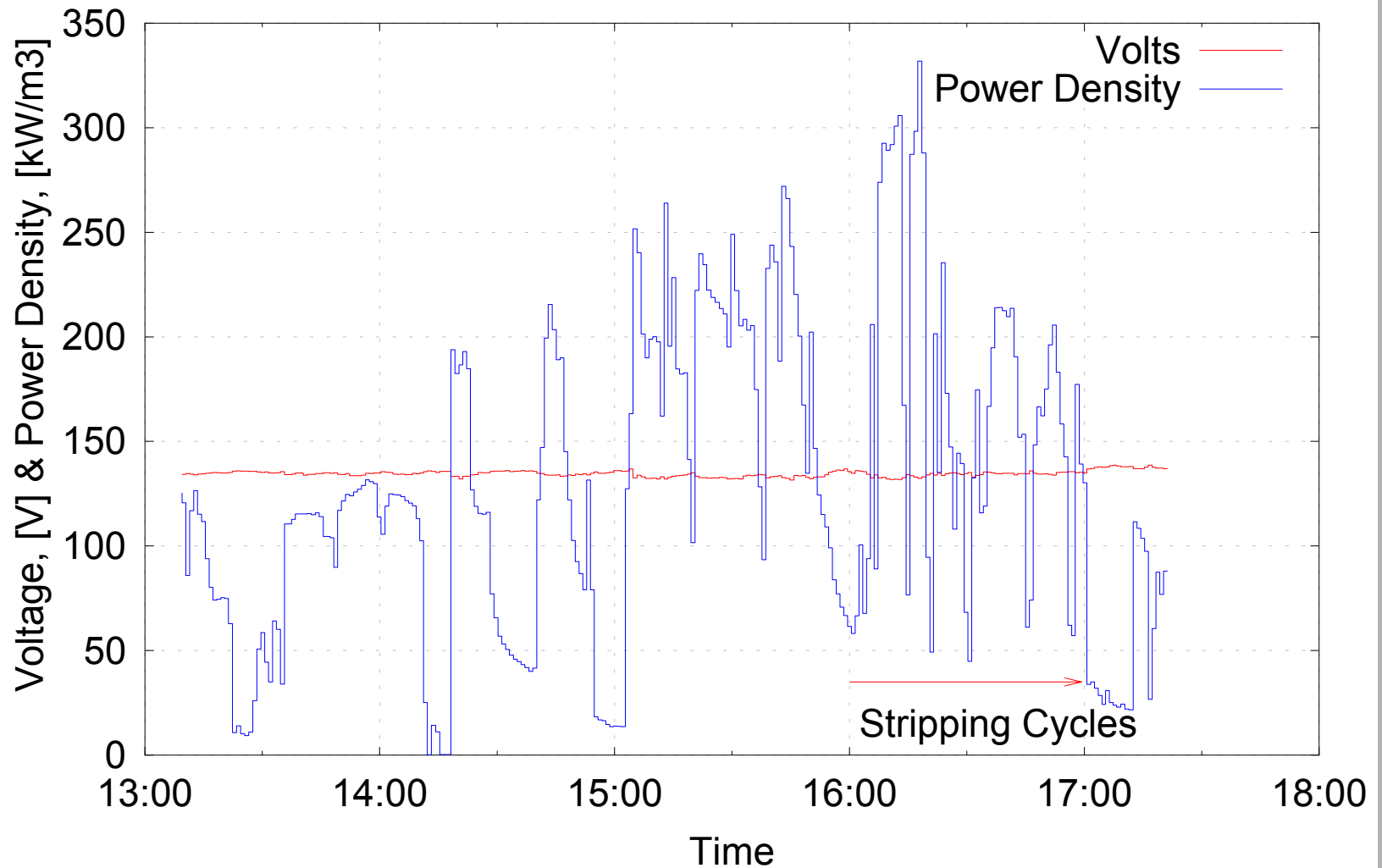
**Resistivity of Vadose Zone**  
Water Saturation is ~ 50%



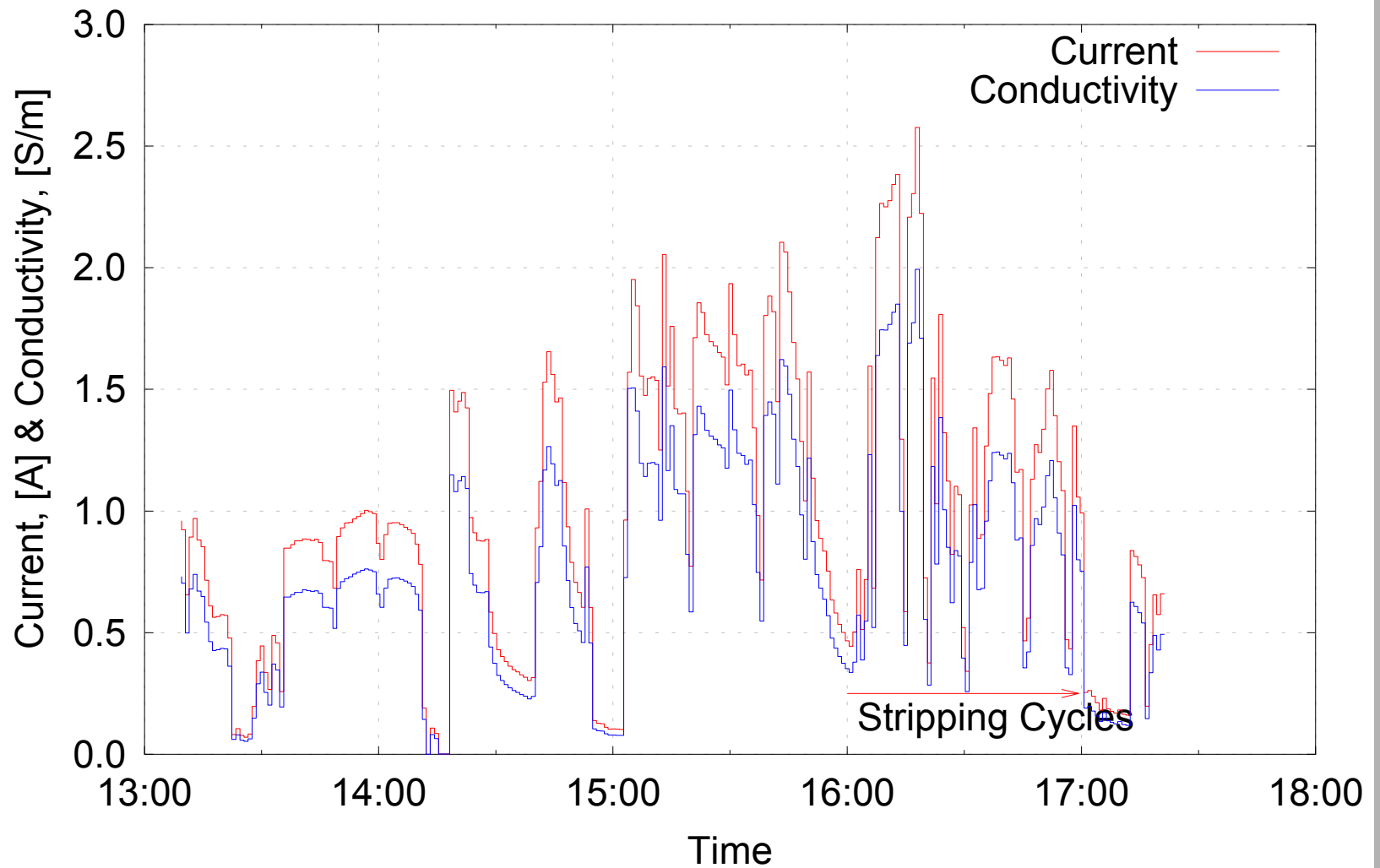
# Temperature Data



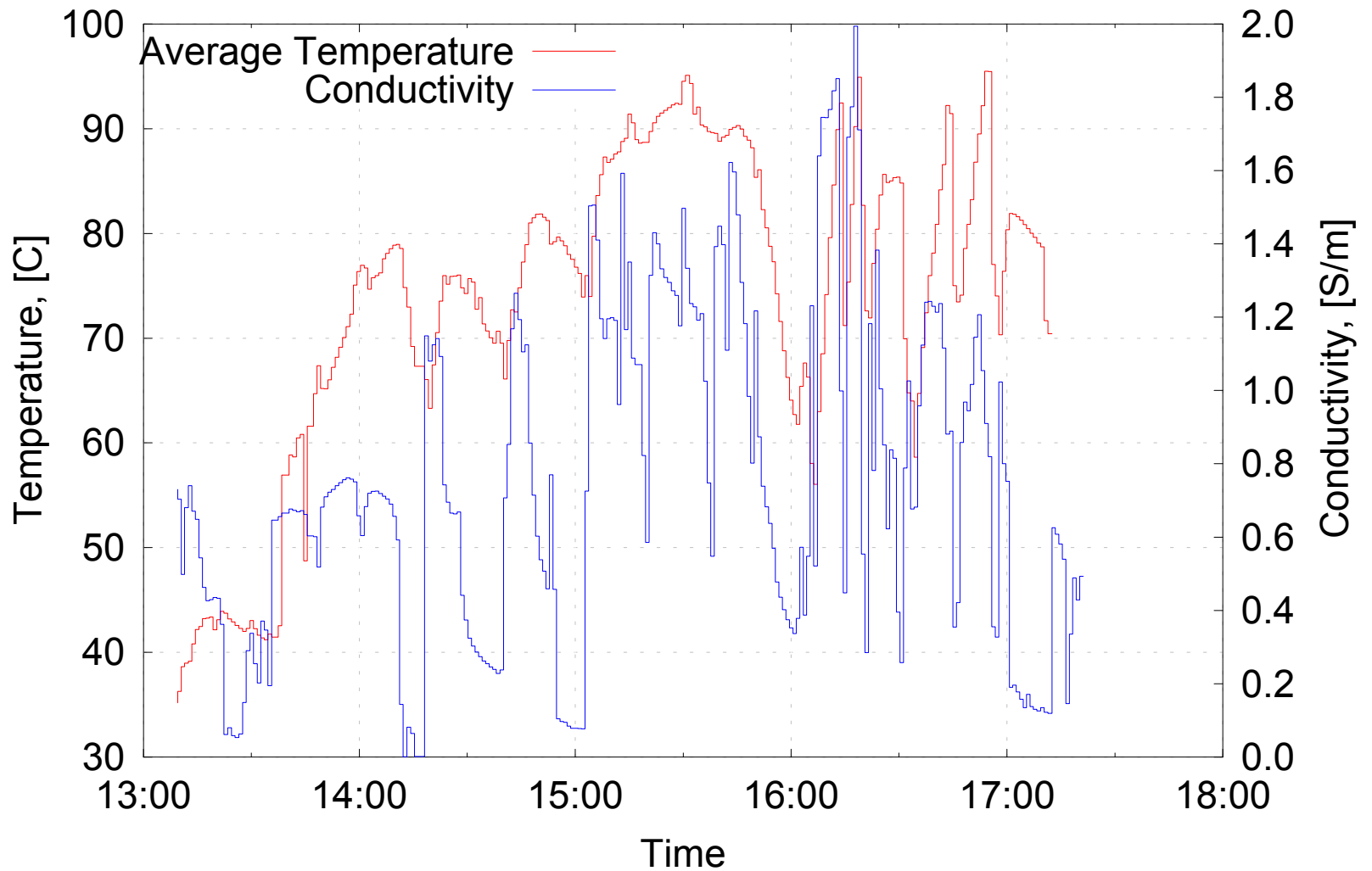
# Electrical Data



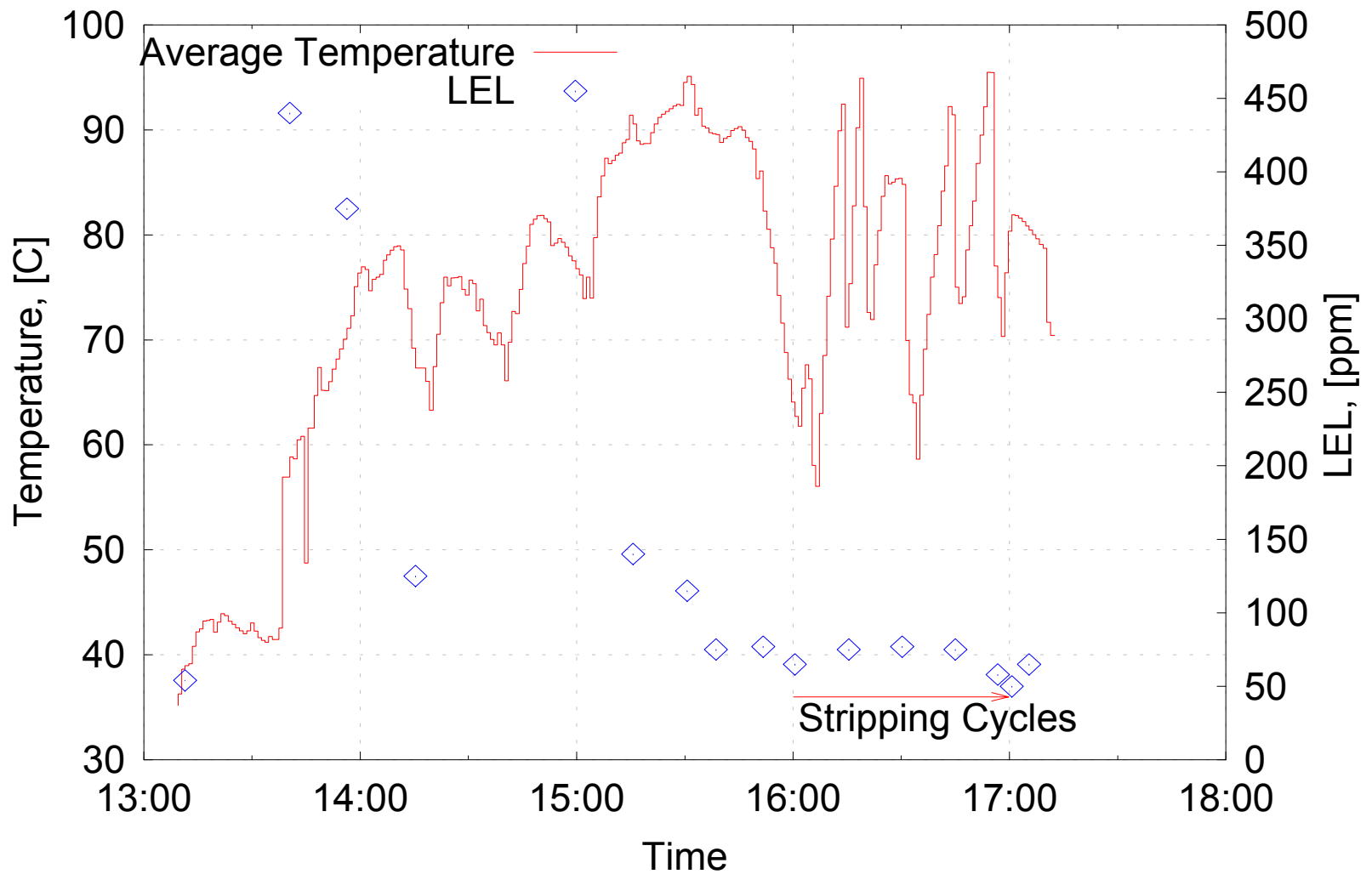
# Current and Conductivity Data



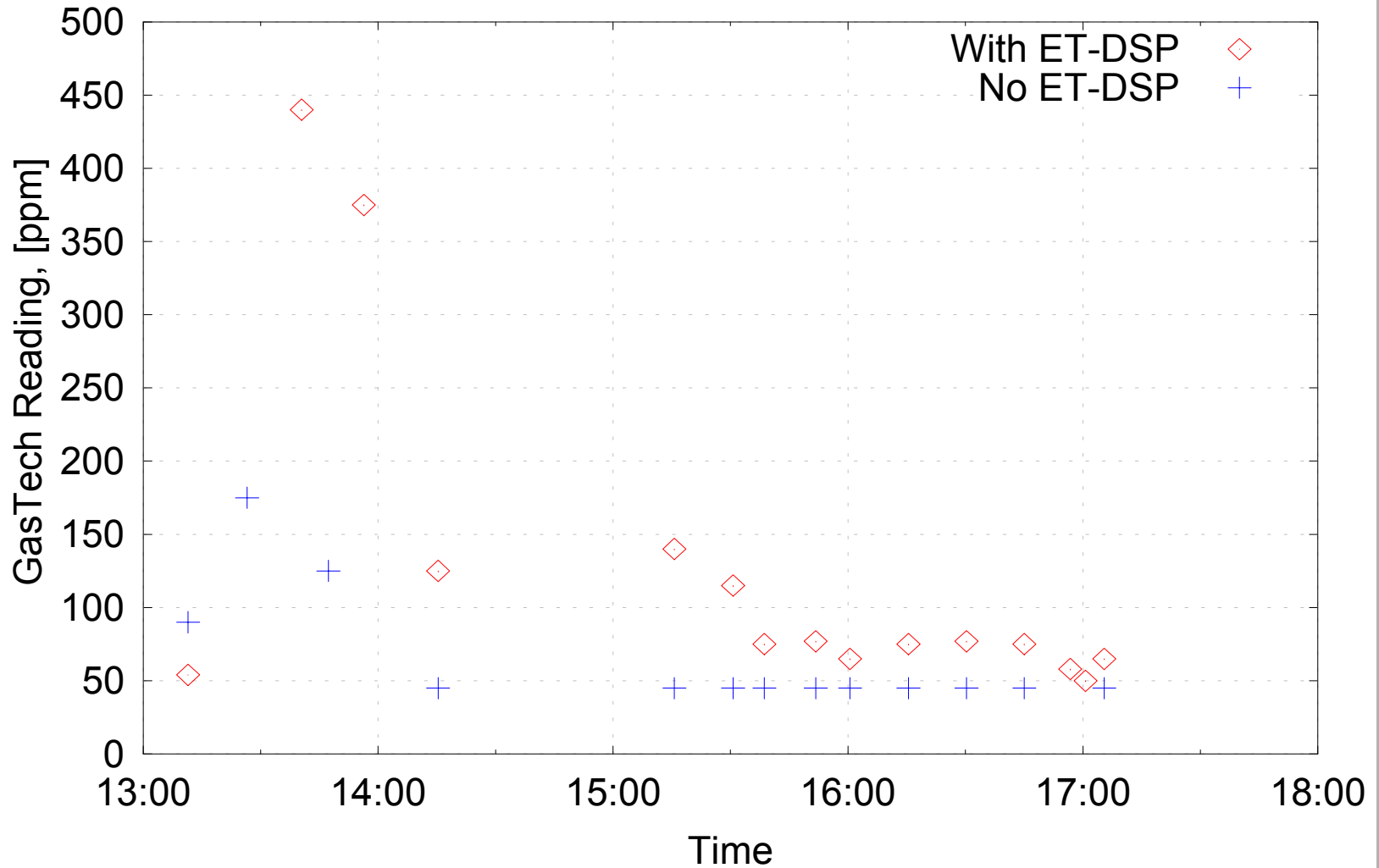
# Average Temperature and Electrical Conductivity



# Average Temperature and GasTech Response



# GasTech Readings With and Without Heat



# Summary of Air Sparging – No Electrical Heating Experiment

Air Sparging - No Heating Data		
Item	Data	Units
Inside Diameter	6.33	cm
Outside Diameter	7.65	cm
Length	19.00	cm
Volume	274.46	cm <sup>3</sup>
Total Sand	1,154.00	grams
Total Water	253.80	grams
Porosity	0.34	fraction
Pore Volume	93.32	cm <sup>3</sup>
Air Injection Rate	31.94	cm <sup>3</sup> /s
Air Injection Rate	0.34	PV/s
Duration of Experiment	81,216	seconds
Total PV of Air Injected	27,798	PV



# Summary of Air Sparging – With Electrical Heating Experiment

Air Sparging - With Heating Data		
Item	Data	Units
Inside Diameter	6.33	cm
Outside Diameter	7.65	cm
Length	32.20	cm
Volume	465.14	cm <sup>3</sup>
Total Sand	1,952.50	grams
Initial Water	423.80	grams
Porosity	0.35	fraction
Pore Volume	162.80	cm <sup>3</sup>
Air Injection Rate	30.48	cm <sup>3</sup> /s
Air Injection Rate	0.19	PV/s
Duration of Experiment	16,560	seconds
MTBE Water Added	317.85	grams
Electrolyte Added	84.65	grams
Total PV of Air Injected	3,101	PV
Total Electrical Energy Injected	384.01	kWhr/m <sup>3</sup>



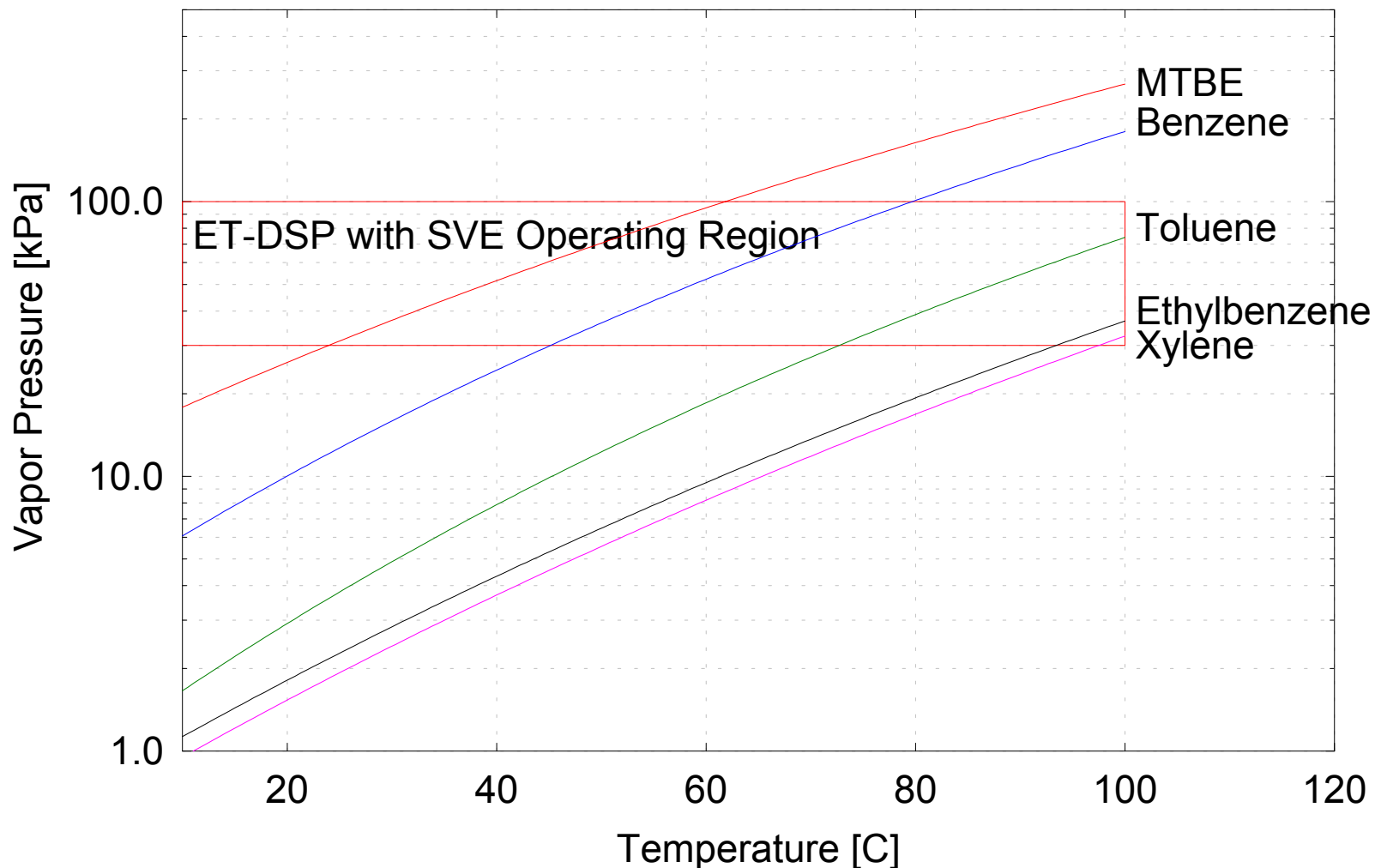
# Summary of Experimental Results (cont.)

Summary of Laboratory Results	
Results	Conc. [ppm]
Initial Concentration of MTBE by Volume	311
Initial Measured Concentration of MTBE	43.4
Concentration of MTBE after Air Sparging-No Heating	1.40
Concentration of MTBE after Air Sparging- With Heating	0.005
Adjusted for injected electrolyte	0.006

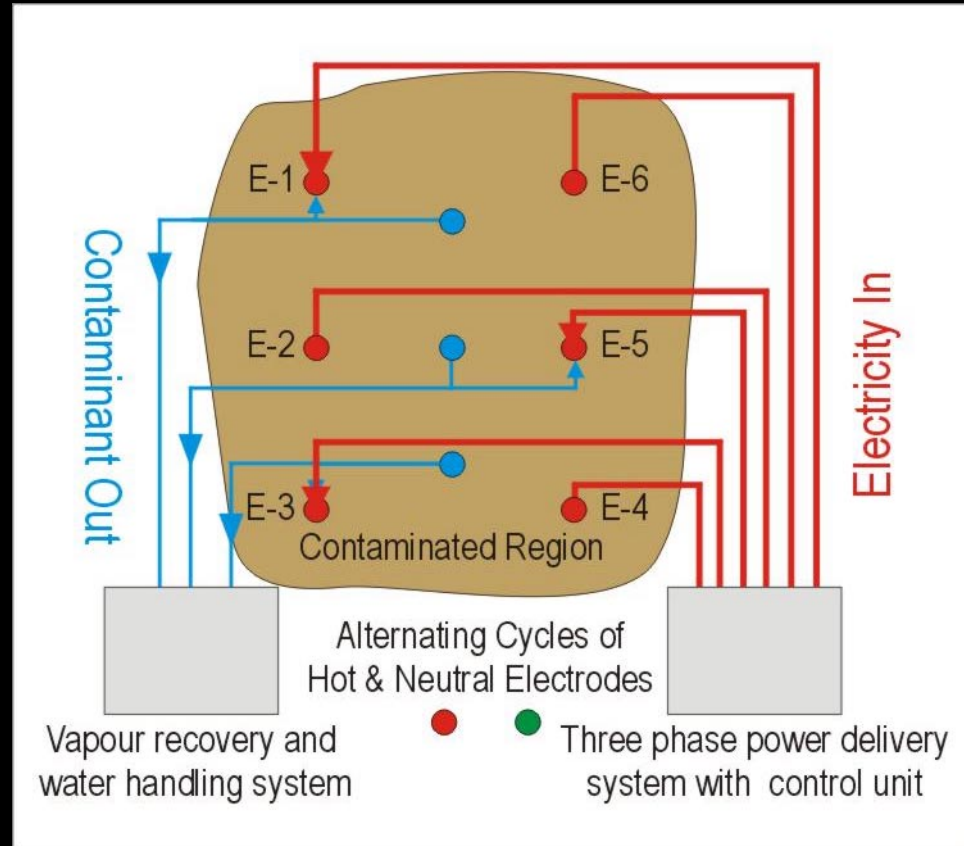
Note that laboratory ND level is 5 ppb



# Vapor-Pressure of MTBE and BTEX Components



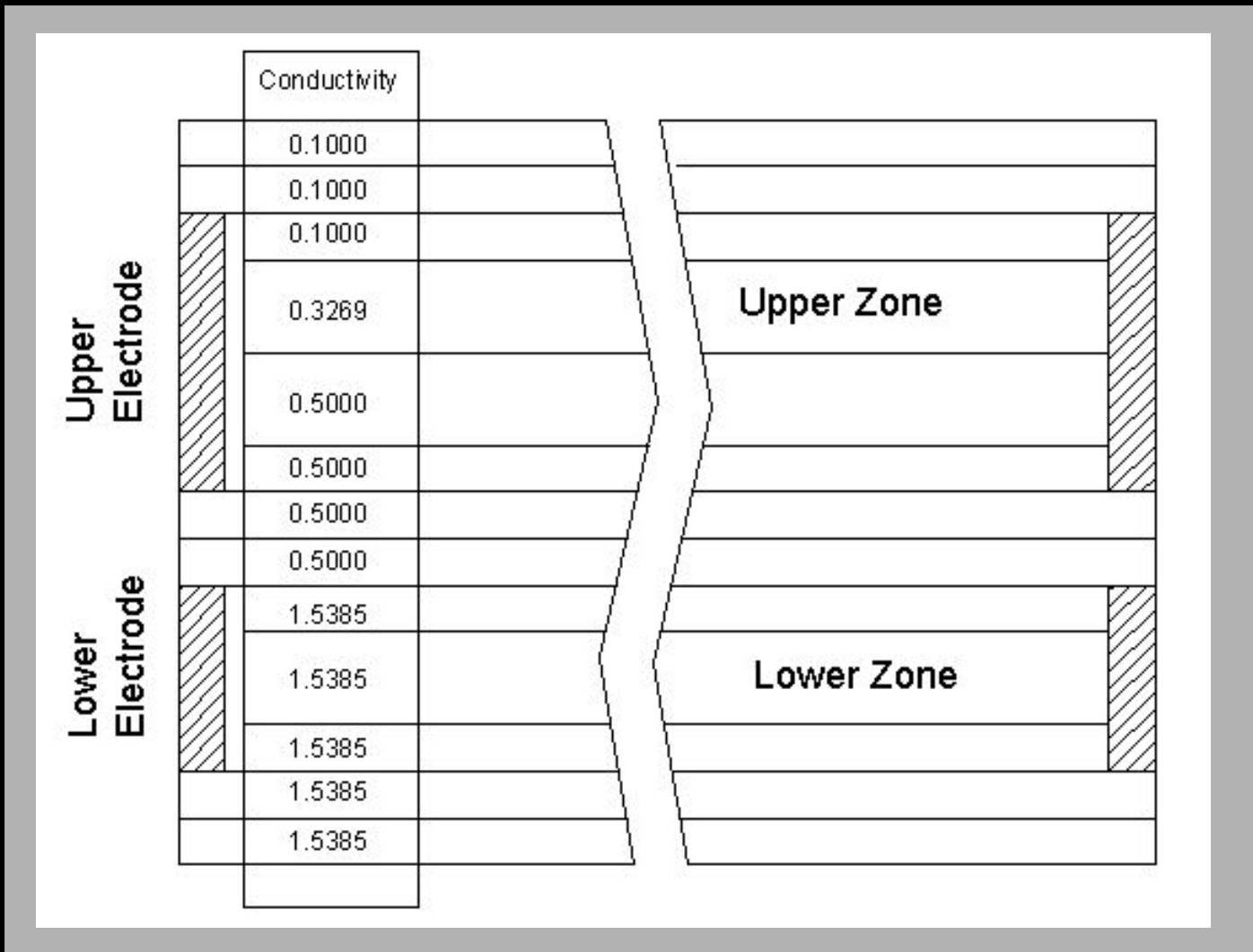
# Electro-Thermal Dynamic Stripping Process An Electrical Soil Heating Technology

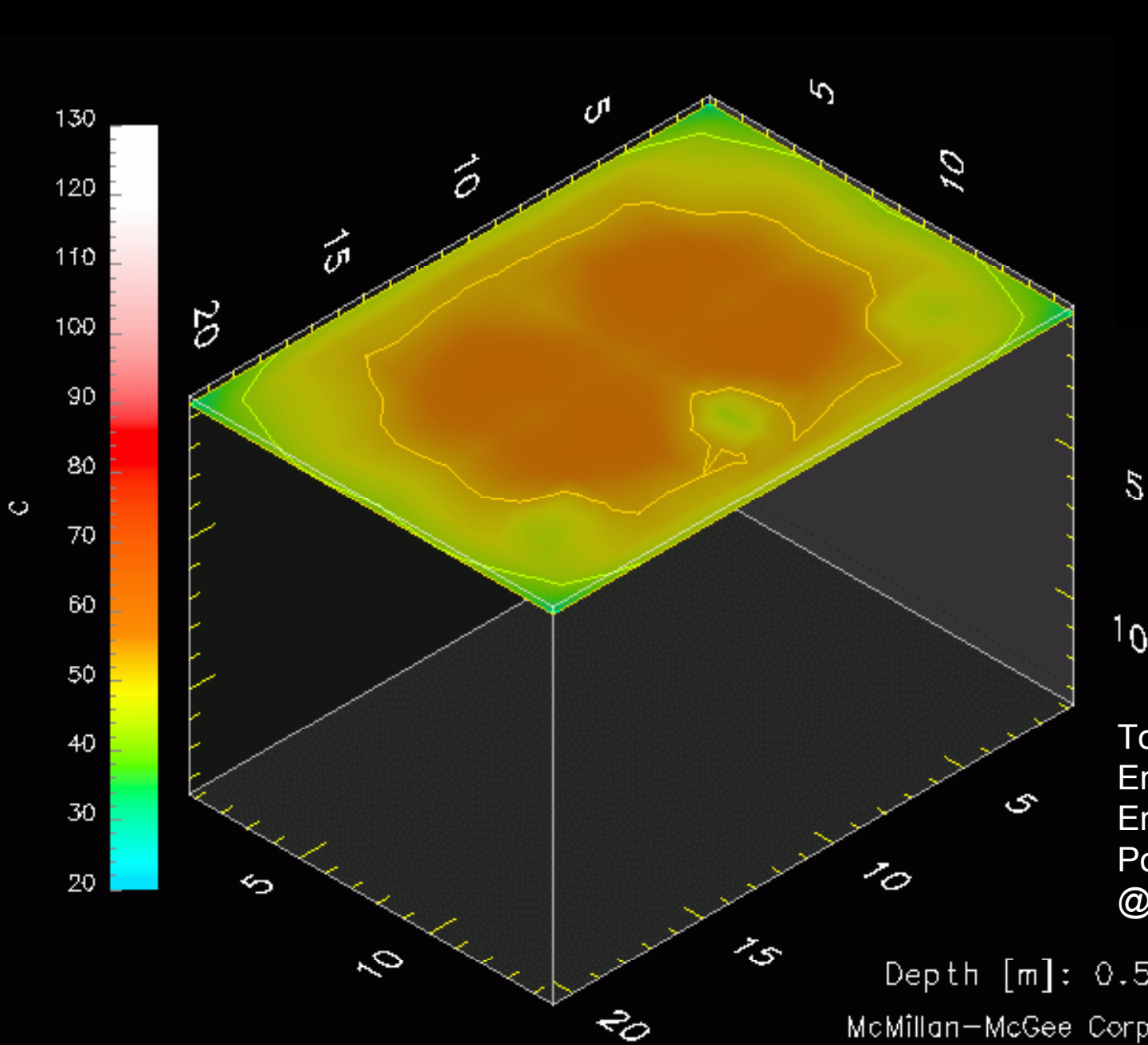




March 22, 2001

AEHS –NAVFAC 11<sup>th</sup> An





Total Volume: 4,150 m<sup>3</sup>  
 Energy: 547,000 kWhr  
 Energy: 132 kWhr/m<sup>3</sup>  
 Power Cost: \$7.91/m<sup>3</sup>  
 @ \$US0.06 per kWhr

Depth [m]: 0.5

McMillan-McGee Corp.



# *Conclusions*

## **Heat Helps in the Remediation of MTBE**

