IN-SITU THERMAL TREATMENT

Presentation Objectives

- – Describe various in-situ thermal treatment technologies and applicability
- – Identify data needs for technology screening, design
- – Recommend pilot testing approach
- – Provide overview of design considerations
- – Discuss operational strategies
- – Identify patent issues

In-situ Thermal Remediation

- Technologies
  - Electrical resistivity heating
  - Conduction heating
  - Steam injection
- Resources
  - Final Draft EM on In-Situ Thermal Remediation in Press
    - http://www.environmental.usace.army.mil/sve.htm
  - EPA/540/S-97/502 How Heat Can Enhance In-situ Soil and Aquifer Remediation, Apr 97:
    - http://www.epa.gov/tio/tsp/download/heatenh.pdf
  - EPA/542/R-97/007 Analysis of Selected Enhancements for SVE, Sep 97 see: http://www.environmental.usace.army.mil/sve.htm
  - SITE Reports: RF Heating (EPA/540/R-94/527):
    - http://www.epa.gov/ORD/SITE/reports/540r94527/540r94527.htm
  - EPA/540/S-97/505 Steam Injection for Soil and Aquifer Remediation, Jan 98: http://www.epa.gov/tio/tsp/download/steaminj.pdf

Benefits Of In-situ Thermal Treatment

- Less dependent on permeability distribution
- Increased volatilization (vapor pressure)
- Remove moisture (improve air flow)
- Increased contaminant solubility
- Lower viscosity of NAPL (more mobile)
- Decrease density
- Increase permeability to NAPL
- Other benefits of specific technologies

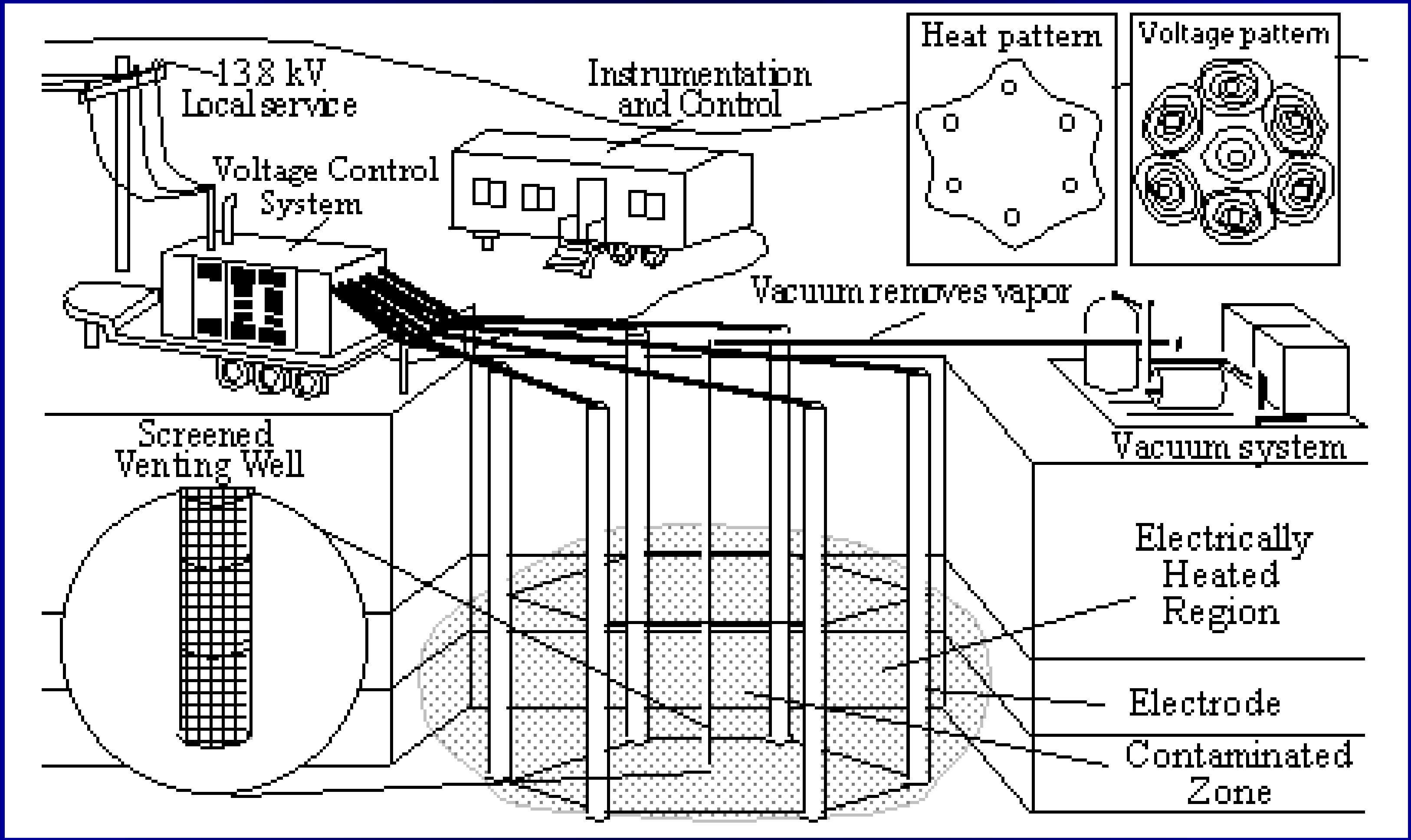
Application Of In-situ Thermal Remediation

- Source removal/reduction
  - Controversy over benefit of aggressive source treatment, especially for DNAPL
  - Remove mass to allow other technologies or processes to polish
- Dissolved plume remediation
  - Expensive to apply to low concentrations
- Ground water control may be necessary
  - Hydraulic control
  - Barriers
- Energy use/carbon emissions

Electrical Resistivity Heating (ERH)

- Concept:
  - Pass electric current through soil
  - Soil acts as a resistor and warms
  - Limit to approximately 100 deg C
- Components
  - Electrical supply (6-phase, 3-phase)
  - Electrodes
  - SVE wells or other collection means
  - Cover (optional)
  - Monitoring system

Electrical Resistivity Heating



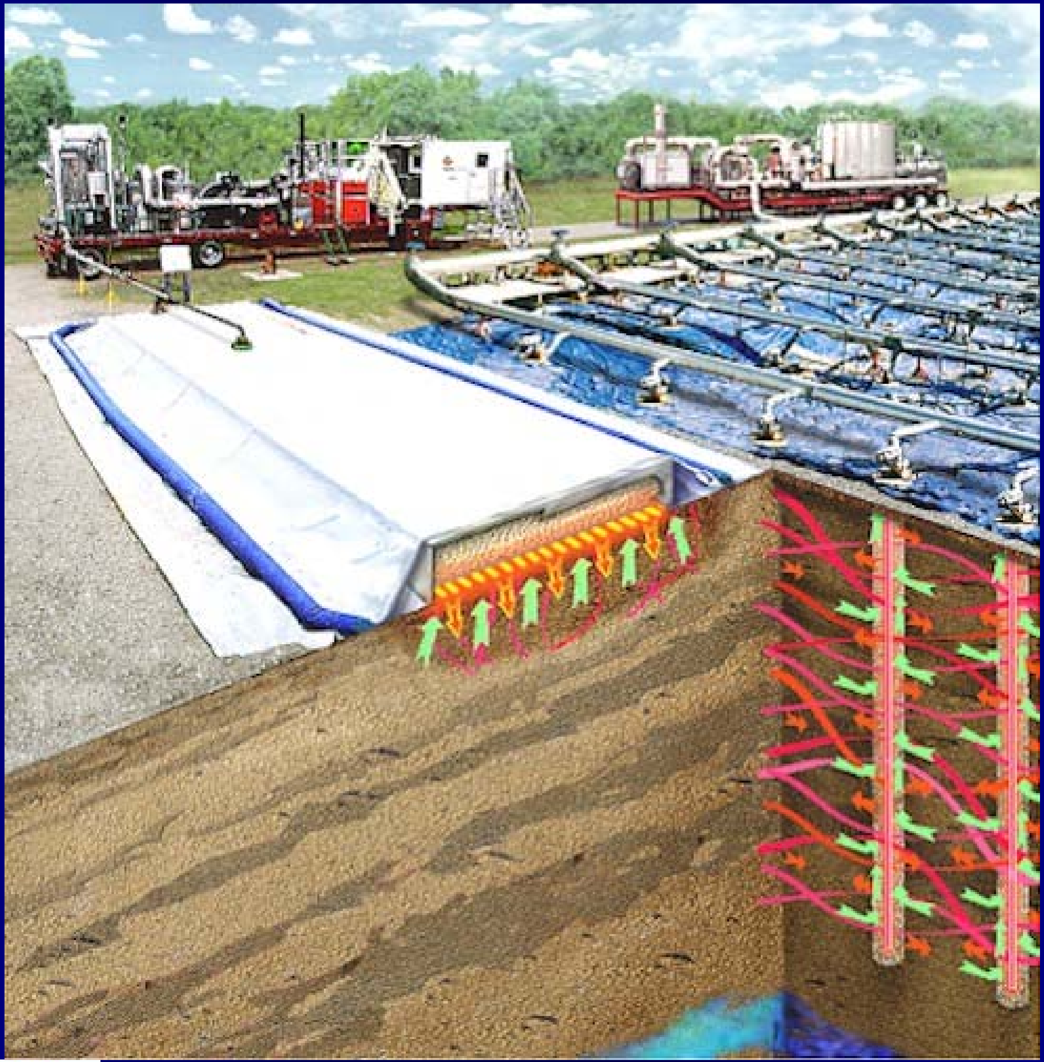
Electrical Resistivity Heating

- Applicability
  - Volatile organics
  - Light semivolatile organics
  - Preferentially heats clays
  - Vadose zone, saturated zone
  - Can be used with other thermal techniques
- Limitations
  - Limits on temperatures, boiling points
  - Ground water flow can be limiting
  - Soil electrical properties
  - Subsurface features (utilities, buried debris, drums)

Thermal Conduction Heating (TCH)

- Concept
  - Use high temperature heaters to heat soil by thermal conduction
  - Thermal effects propagate as allowed by thermal properties of soil
  - Draw vacuum on heater wells/trenches to collect created vapors. Heaters destroy many vaporized contaminants
- Components
  - Electric heaters on surface (trenches) or in steel wells
  - Vapor extraction system
  - Surface cover/insulation
  - Supplemental treatment
  - Monitoring system

Thermal Conduction Heating



Air-Based Remediation Technologies

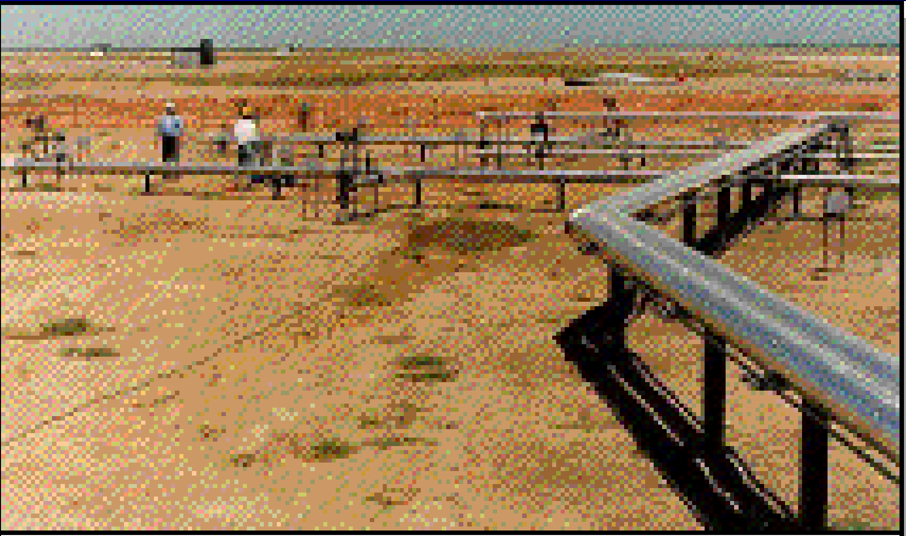
Thermal Conduction Heating

- Applicability
  - Volatiles & most semivolatile organics
  - High temperatures >400 deg C (lower temperatures adequate for VOC removal)
  - NAPL, PCBs, mercury
  - Vadose zone or saturated zone
  - Minor impact of soil type
  - High likelihood of success, high removal efficiency
- Limitations
  - Soil poor conductor of heat
  - Strongly limited by water flow
  - Subsurface features (e.g., utilities)

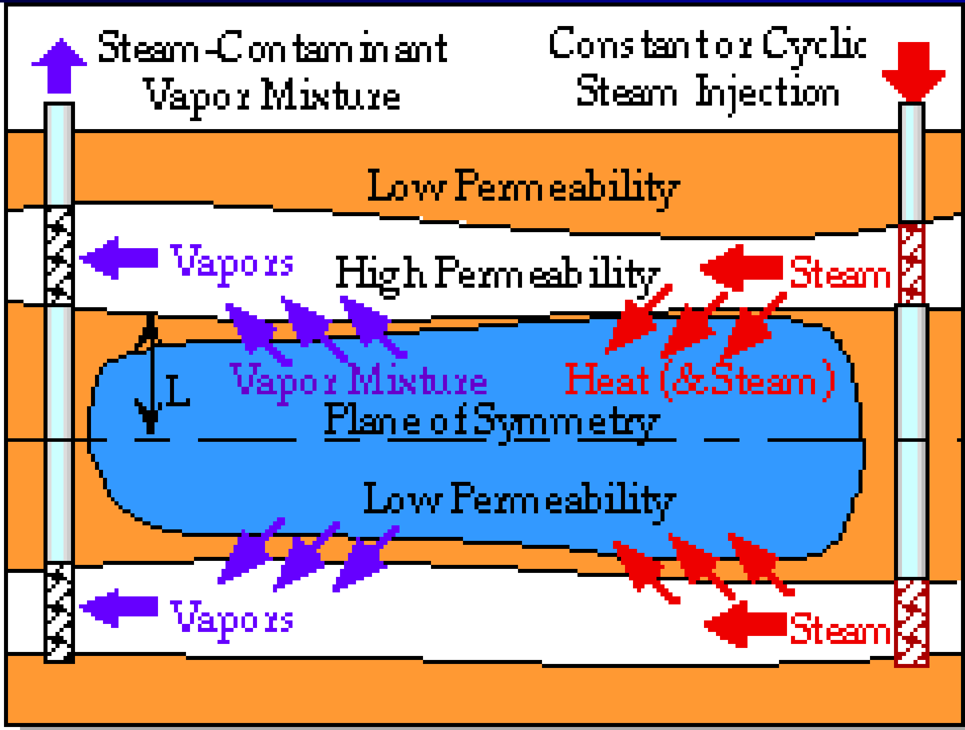
Steam Injection

- Concept
  - Injection of steam heats soil, volatilizes contaminants, steam strips contaminants, increases solubility, mobilizes NAPL
  - Hydrolysis, pyrolysis, oxidation processes (?)
  - Total fluids recovered from other wells
  - Vapor extraction of steam, vapors
- Components
  - Steam boiler of adequate capacity, piping
  - Steam injection wells
  - Recovery wells
  - Separation/treatment plant
  - Monitoring system

STEAM INJECTION



SEE demonstration at NAS Lemoore, 1994.
More than 70,000 gallons of JP5 were recovered.



Air-Based Remediation Technologies

STEAM INJECTION

- Applicability
  - Many organics
  - Creosote, PCP
  - Immiscible product
  - Stratified soils
- Limitations
  - Shallow contaminants
  - Ground water flow
  - Flow limitations
  - “override”
  - DNAPL access, density effects
  - Fuel availability

ISTR Data Needs

- ISTR general data needs
  - Stratigraphy
  - NAPL, contaminant location
  - Subsurface features
  - Moisture content/ground water flow conditions
- ERH data needs
  - Soil resistivity
  - Power source

ISTR Data Needs, Continued

- TCH data needs
  - Soil thermal conductivity (can be estimated)
  - Power source
- Steam injection data needs
  - Density and viscosity vs. Temperature
  - Soil thermal conductivity estimates
  - Permeability (water, vapor), ground water flow rates
  - Contaminant removal vs. pore-volume flush

ISTR Pilot Testing

- Bench testing
  - Contaminant removal at different heating times, pore-volume flushes of steam
- Pilot testing
  - Localized area with high concentrations of contaminants
  - Possible expansion to adjacent areas if promising
  - Ground water control may be needed
  - Vapor barrier at surface
  - Monitor
    - Vapor, liquid recovery and concentrations
    - Subsurface temperatures - thermocouples
  - Need equipment capable of treating high concentrations
  - Verification of treatment effectiveness – groundwater, soil

Design Considerations

- Technologies usually contracted with vendors who design, construct, operate
- Important considerations
  - Ground water control
  - Vapor control
  - Prevention of vertical and lateral migration of immiscible product
    - Heat below the target zone first
  - Adequate treatment system
  - Options for longer treatment time
  - Impacts on utilities, soils

Design Considerations, Continued

- Wells
  - Steel used for casing and screen
  - ERH – casing is electrode, steel beads in filter pack
- Equipment
  - Heat exchangers to condense steam, other liquids
  - Air-liquid separator, non-condensible gases to treatment
  - Product/water separators, air flotation
  - Product recovery, water treatment
- Monitoring and control
  - Temperature, pressures/vacuums, concentrations, flow control
  - Vertical strings of thermocouples to monitor temperatures

Off-site and Safety Considerations

- General – vapor migration
- General - air emission control
- Hot materials and piping
- Contaminant migration (controlled by careful engineering)
- ERH – stray voltage (controlled by careful engineering)
- TCH – change in soil structure due to desiccation
- Steam injection – fuel demand, steam breakthrough

Implementation

- Typically Vendor Design/Build
- Performance Contract
  – Minimum Temperature in Target Area
  – Heating Time
  – Treatment Goals

ISTR System O&M Monitoring

- Subsurface monitoring
  - Flow, concentrations, temperature, pressure/vacuum at each extraction well
    - Flow, pressure, temperature, steam injection rate at steam injection wells
  - Subsurface temperatures (thermocouples typically used)
  - Hydraulic head (for ground water flux computation)
  - Contaminant concentrations in vapor and ground water
- Treatment system
  - Condensate production rates, concentrations, temperatures
  - Vapor concentrations, flow rates, temperatures
  - Pressures/vacuums in system

Electrical Resistivity Heating

- Implementation
  - Triangular pattern - scale 10's of feet
  - Treat soils in increments
- Technology performance
  - Several full-scale commercial applications
  - May be under $130/cu m
  - Observed bioremediation by thermophilic bacteria

Conduction Heating

- Implementation
  - Tight spacing of heater wells/trenches
  - Treat site incrementally
  - Time / cost depends on temperature needed
- Technology performance
  - Generally very effective
  - Costs <$130/cu m to > $200/cu m, depends on temp

Steam Injection

- Implementation
  - Pattern of wells, use as injectors/extractors
  - Pulse steam injection, air injection (“huff and puff”)
  - Typically few pore volumes
  - Heat aquitards from below
  - Long cool-down period, bioremediation activity

Steam Injection

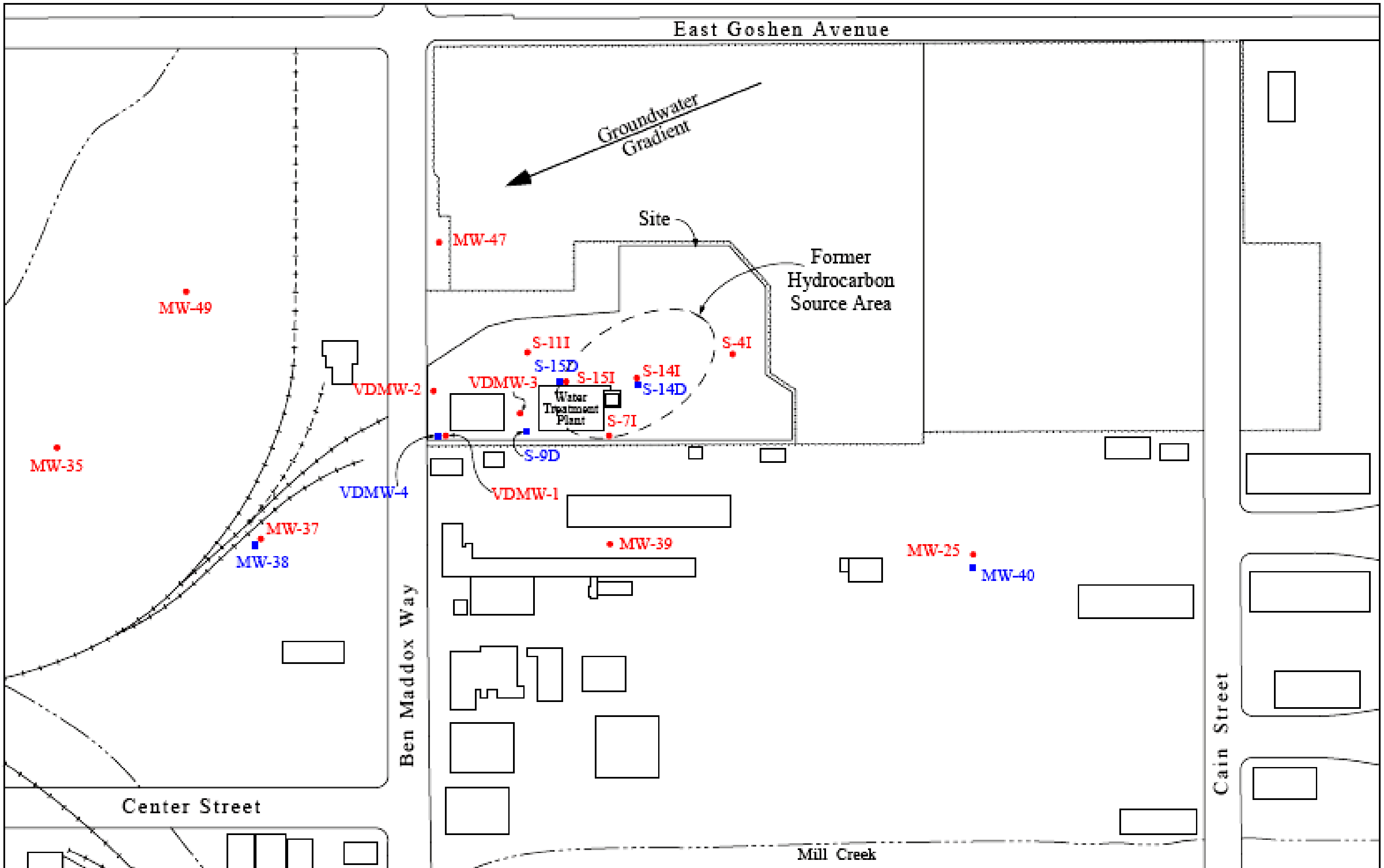
- Technology performance
  - Visalia (Southern California Edison)
  - US Navy projects
  - US EPA region 10 project

ISTR Case Study
Visalia, California USA

- Utility Pole Treatment Facility 1925-1980
- Contaminants
  - Creosote, diesel
  - Pentachlorophenol
  - Dioxins, furans
- Soil and groundwater affected
  - 270,000 cu meters
  - Depth: 45 m
- Hydrogeology
  - Sand/gravel aquifers and fine sand/silt aquitards
  - Water table depth: 20-25 m

ISTR Case Study
Visalia, California USA, Continued

- Applied Technology
  - Steam injection for 36 months
  - 11 injection wells, 7 extraction wells
  - 54,000 kg/hr steam injection rate
  - Total 300,000,000 kg steam total
  - 1500 L/min liquid treatment by separation and flotation, filtration, carbon adsorption
  - Recovered vapors used in boilers
- Heated aquitards from below
- Extracted groundwater for several years following steam injection



LEGEND

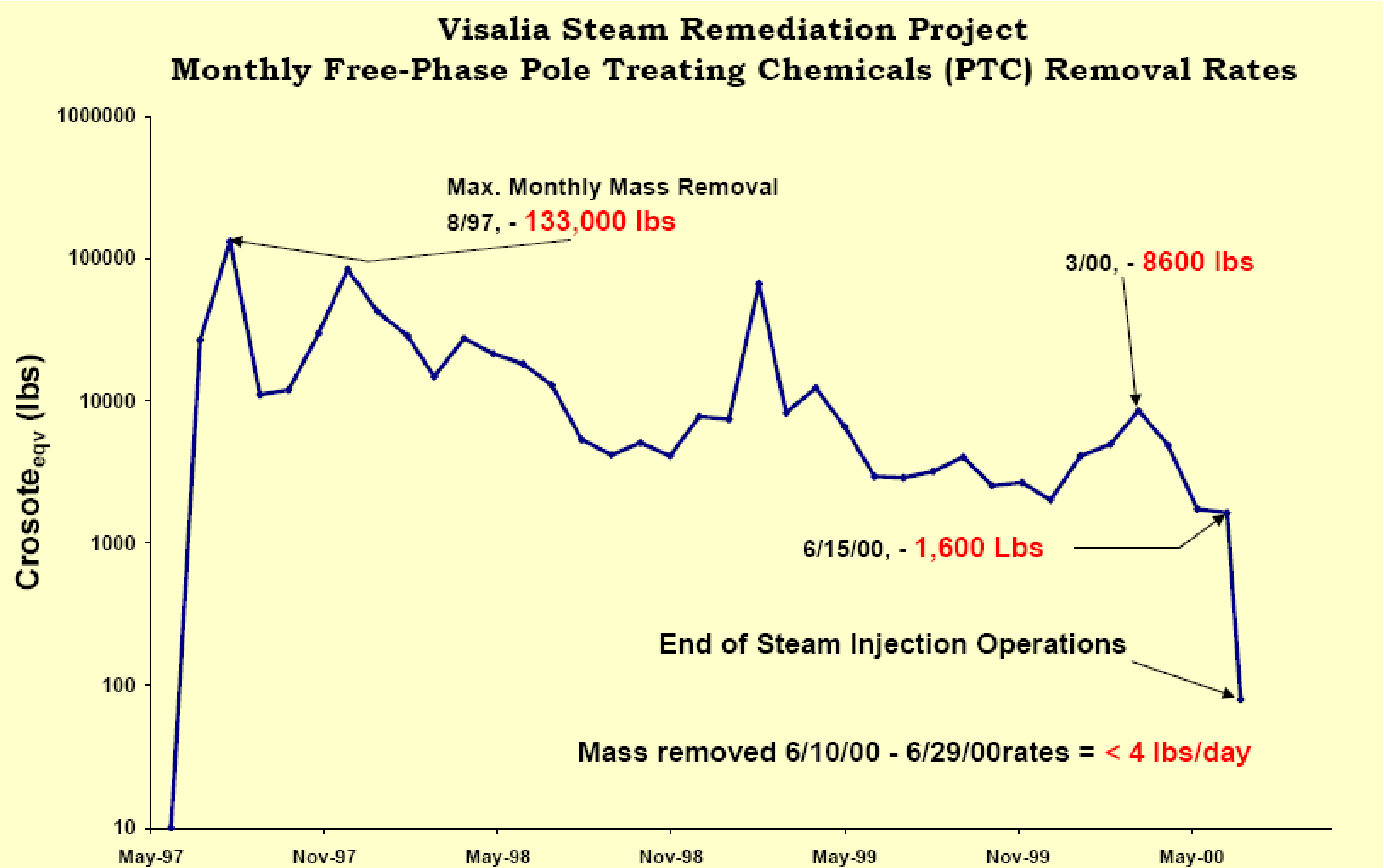
- Intermediate Aquifer Monitoring Well
- Deep Aquifer Monitoring Well

DEMONSTRATION OF REMEDIAL ACTION MONITORING WELL LOCATION

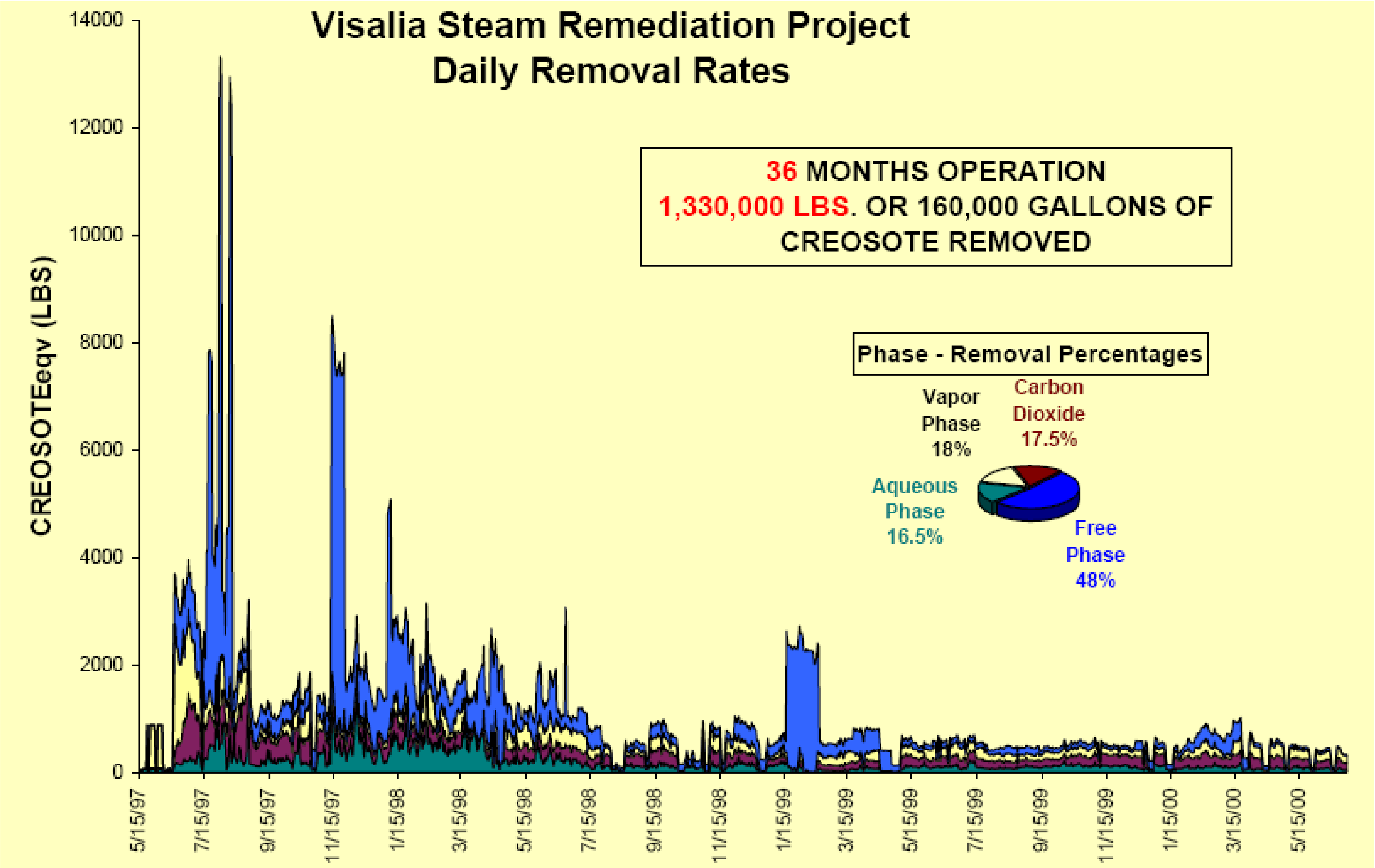
SOUTHERN CALIFORNIA EDISON

An EDISON INTERNATIONAL Company

FIGURE 1



Visalia Steam Remediation Project
Monthly Free-Phase Pole Treating Chemicals (PTC) Removal Rates
Max. Monthly Mass Removal
8/97, - 133,000 lbs
3/00, - 8600 lbs
6/15/00, - 1,600 Lbs
End of Steam Injection Operations
Mass removed 6/10/00 - 6/29/00rates = < 4 lbs/day
Crosote$_{eqv}$ (lbs)
1000000
100000
10000
1000
100
10
May-97
Nov-97
May-98
Nov-98
May-99
Nov-99
May-00



Visalia Steam Remediation Project
Daily Removal Rates
36 MONTHS OPERATION
1,330,000 LBS. OR 160,000 GALLONS OF CREOSOTE REMOVED
Phase - Removal Percentages
Vapor Phase 18%
Carbon Dioxide 17.5%
Aqueous Phase 16.5%
Free Phase 48%
CREOSOTEeqv (LBS)
14000
12000
10000
8000
6000
4000
2000
0
5/15/97
7/15/97
9/15/97
11/15/97
1/15/98
3/15/98
5/15/98
7/15/98
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3/15/99
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5/15/00

Figure 1

ISTR Case Study
Visalia, California USA, Continued

- Results
  - Achieved goals for soil, groundwater
    - Benzo-a-pyrene: 0.2 ug/L
    - Pentachlorophenol: 1 ug/L
    - Tetrachlorodibenzo-p-dioxin: 30 ug/L
  - Site closed 2008
- Estimated cost: <\$60/cu m

Presentation Summary

In-Situ Remediation Technologies

- For in-situ thermal treatment technologies
  - Described technology and applicability
  - Identified data needs
  - Discussed implementation and performance
- Major points
  - Heat improves recovery of vocs, some svocs
  - In many cases, high level of removal
  - Costs modest to high, though time frames short
  - Moisture content, water flow important
  - Need access to power or fuel

GROUNDWATER CIRCULATION WELLS

Presentation Objectives

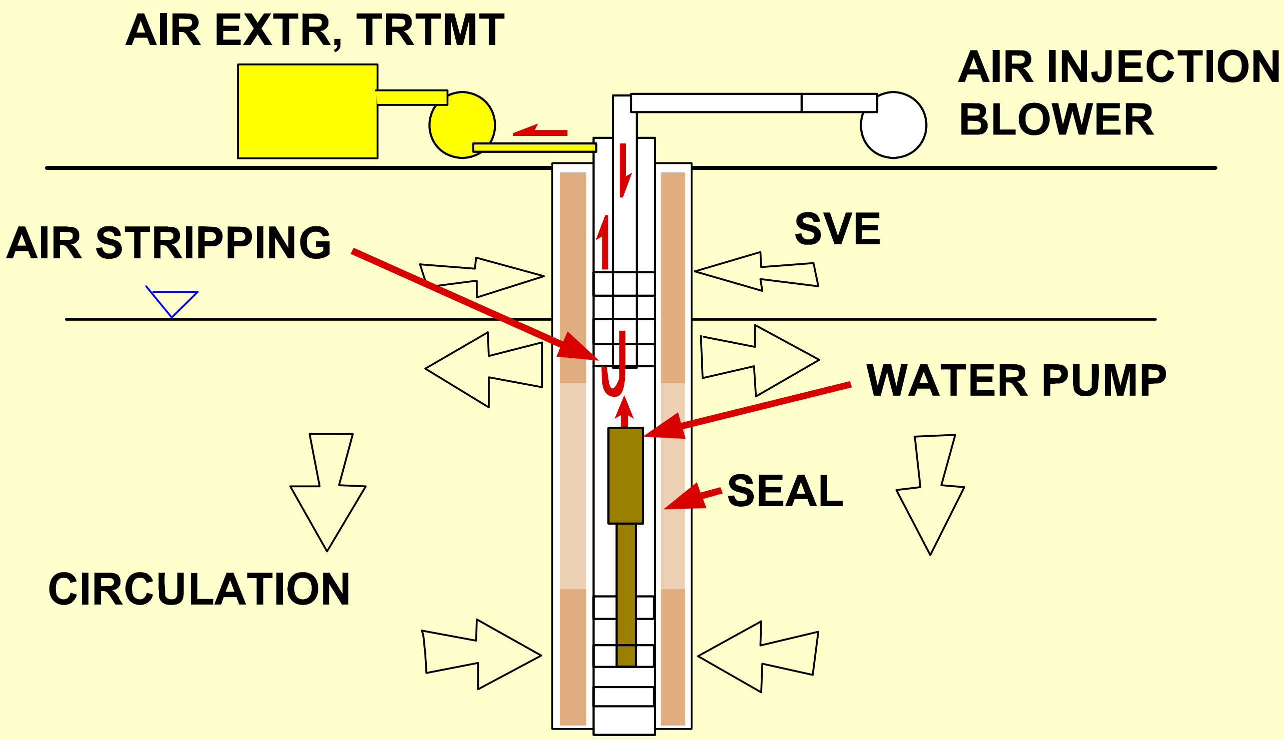
Groundwater Circulation Wells (GCWs)

- Discuss important processes affecting success
- Describe GCW principles, applicability
- Identify data needs for technology selection/design
- Recommend pilot testing approaches
- Provide design considerations
- Discuss operational issues and data collection
- Identify closure strategies
- Identify GCW frontiers

GCW Technology Description

- Concept description
  - Treat water in wellbore, volatilize contaminants into air
  - Aerate water - promote bioremediation
  - Dual well screens set up circulation cell
- Basic components
  - Artificial lift system, pumping or air lift
  - Dual well screens
- Other components
  - Treatment system (vapor and liquid)
  - Monitoring
  - Reach typically measured in 10s of meters

Schematic of GCW



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GCW References

- General USEPA CLU-in Website
  http://www.cluin.org/techfocus/default.focus/sec/Ground-Water_Circulating_Wells/cat/Overview/
- USEPA Site Reports:
  - UVB http://www.epa.gov/ORD/SITE/reports/540r99503/540r99001.pdf
  - DDC http://www.epa.gov/ORD/SITE/reports/540r02500/540R02500.pdf
  - NoVOCS http://www.epa.gov/ORD/SITE/reports/540r00502/540r00502.pdf

GCW Applicability

- Contaminants
  - Chlorinated volatiles, volatile hydrocarbons
  - Low solubility/high vapor pressure compounds
  - Biodegradable contaminants
- Better in high permeability but suitable for layered varied conductivity formations
- Limitations
  - Preferred pathways
  - Mixing of plume

GCW Data Needs

- Geologic strata
- Water table fluctuations
- Hydraulic conductivities (estimated) of various saturated layers
- Air permeability of unsaturated soil
- Contaminant concentrations (defined horizontally and vertically)
- Ground Water geochemistry (cations and anions, alkalinity, hardness)
- Biodegradation potential

Surface Equipment

- Piping:
  - Can use flexible tubing
  - Air under pressure - materials need to handle pressures
  - Calculate balanced flow for individual piping legs
  - Spreadsheets useful to design
- Blowers/compressors
  - Type: typically rotary vane or air compressor,
  - Identify necessary pressure to inject air, predict flow
  - Match blower performance curve to system conditions, including the losses in piping

Monitoring Equipment

- Monitoring systems
  - Parameters: pressure/air flow, ground water and soil gas concentrations
  - Permanent probes, small diameter
    - Multiple depths - use to confirm design
    - Choose representative locations based on geology, contaminants
  - Flow control valves, pressure gauge at each well
  - Flow measurement device for each wellhead
    - Pitot tubes, orifice plate, rotometers, anemometer
  - Temperature, vacuum/pressure measurement before/after blower

Other Components, Continued

- Control system
  - Typically unattended operation
  - Typically modest level of automation
  - Automatic pulsing
  - Auto-dial for shut-down condition
  - Thermal cut-off on blower motor, high pressure
  - Pressure relief valves

Start-up Of GCW Systems

- Verify flow distribution
- Monitor water table rise
- Monitor contaminant and DO concentrations in subsurface
- Monitor equipment performance (current draw, temperature)
- Operate equipment

GCW Operations And Maintenance

- Periodic system checks and routine maintenance
  - Check, lubricate blower
  - Check/clean particulate filter
  - Verify flow rates (total, individual wells)
  - Balance multi-well system
  - If simple offgas treatment O&M not costly

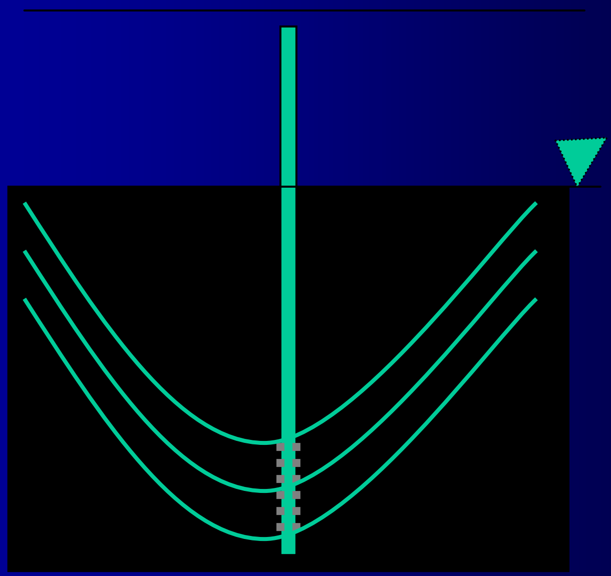
GCW System Optimization

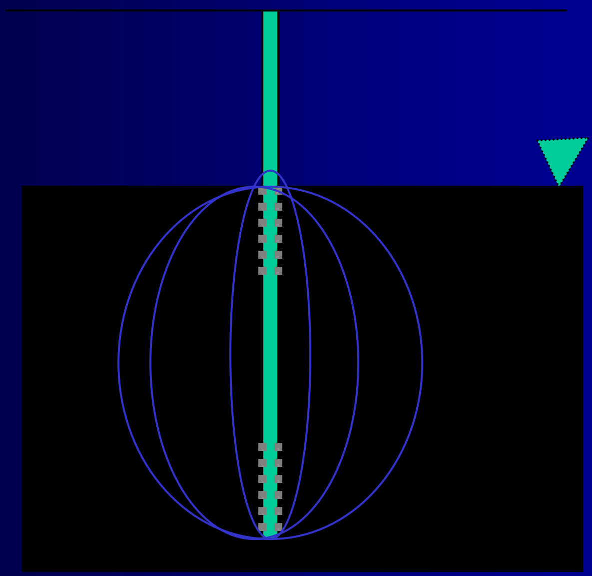
- Periodic analysis of monitoring data critical
  - Verify adequacy of air flow, distribution
  - Evaluate ground water concentrations
  - Recommend changes in operation
- Tracer testing
- System rebound - analysis of data clarifies progress toward cleanup
- Rebound is very common at sites with poor monitoring system design
- Subsurface performance evaluation checklist

GCW Site Shutdown & Closure

- Closure goals
  - Meet absolute concentration in ground water
  - Minimum rebound

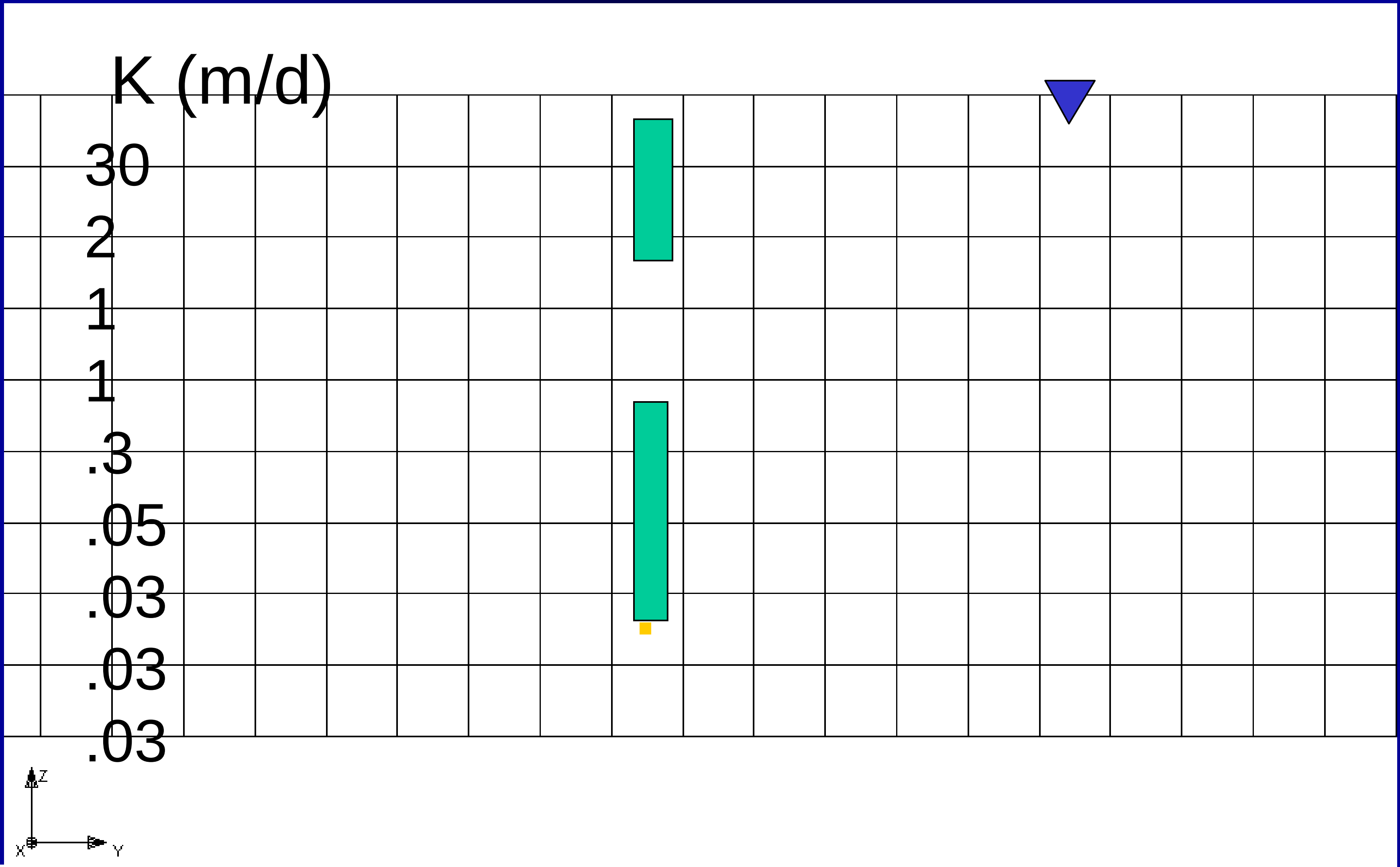
Extraction Well vs. GCW Well



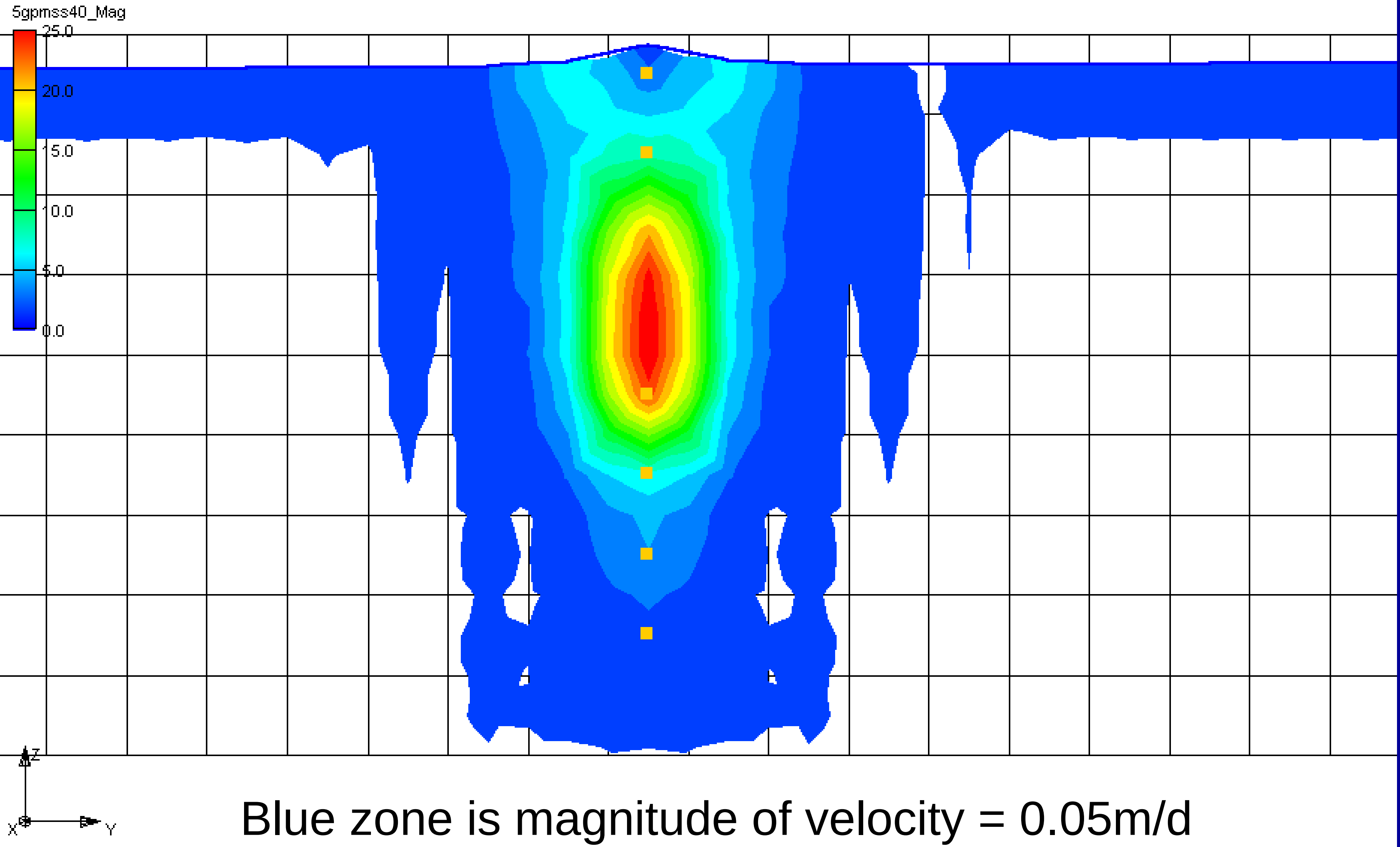


GCW Case Study - Project Location

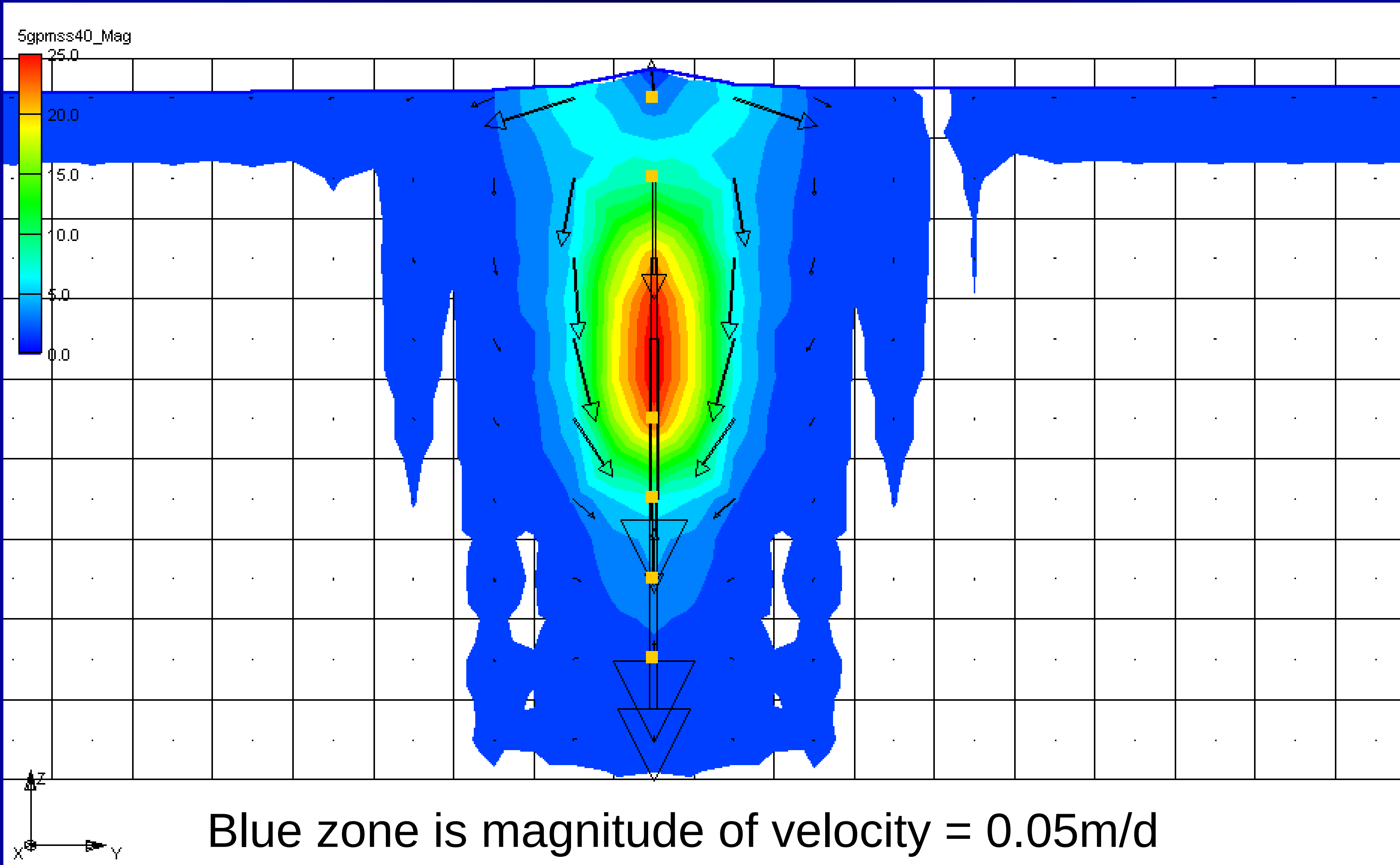
MODFLOW Cross Section



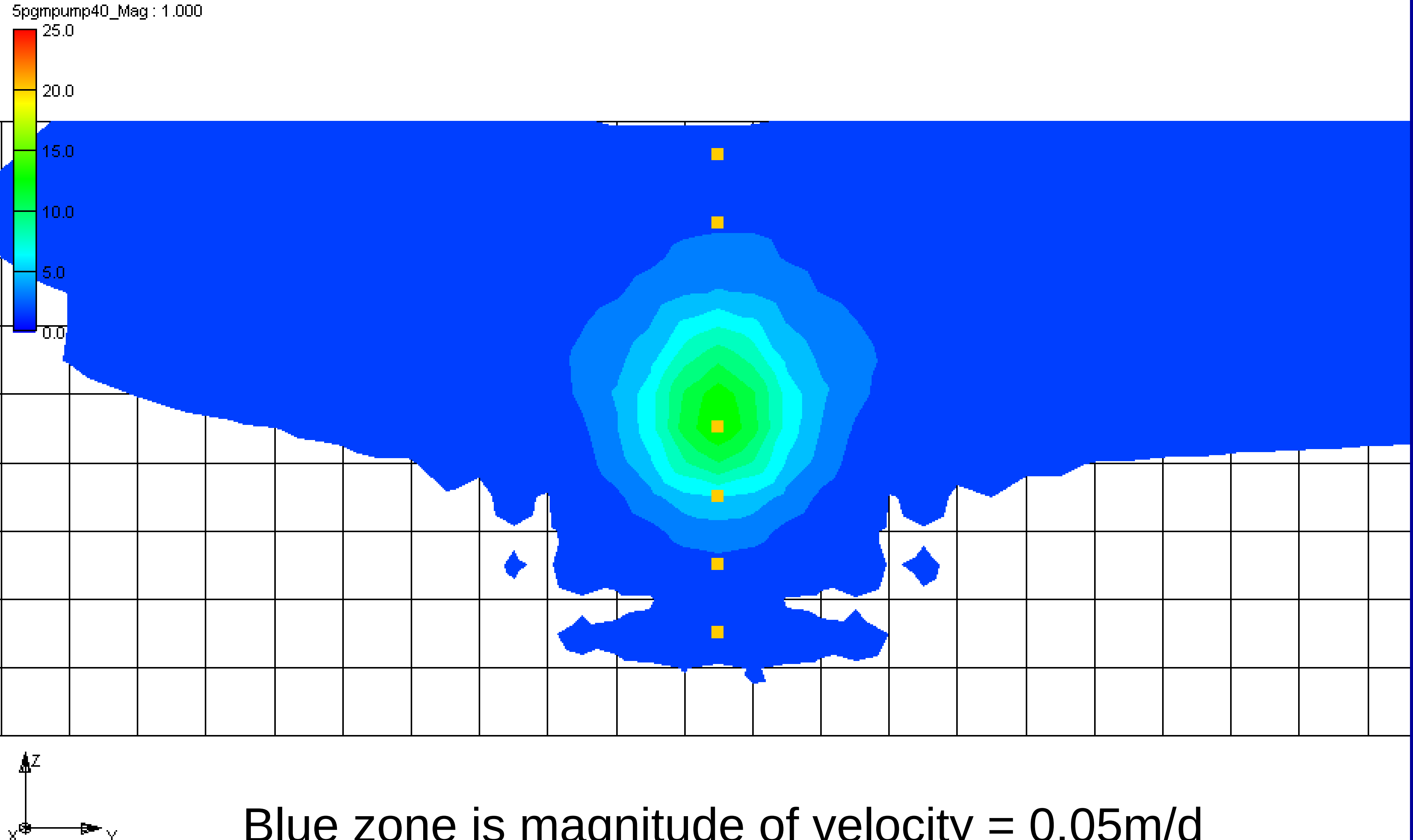
Air-Based Remediation Technologies



Blue zone is magnitude of velocity = 0.05m/d



Blue zone is magnitude of velocity = 0.05m/d



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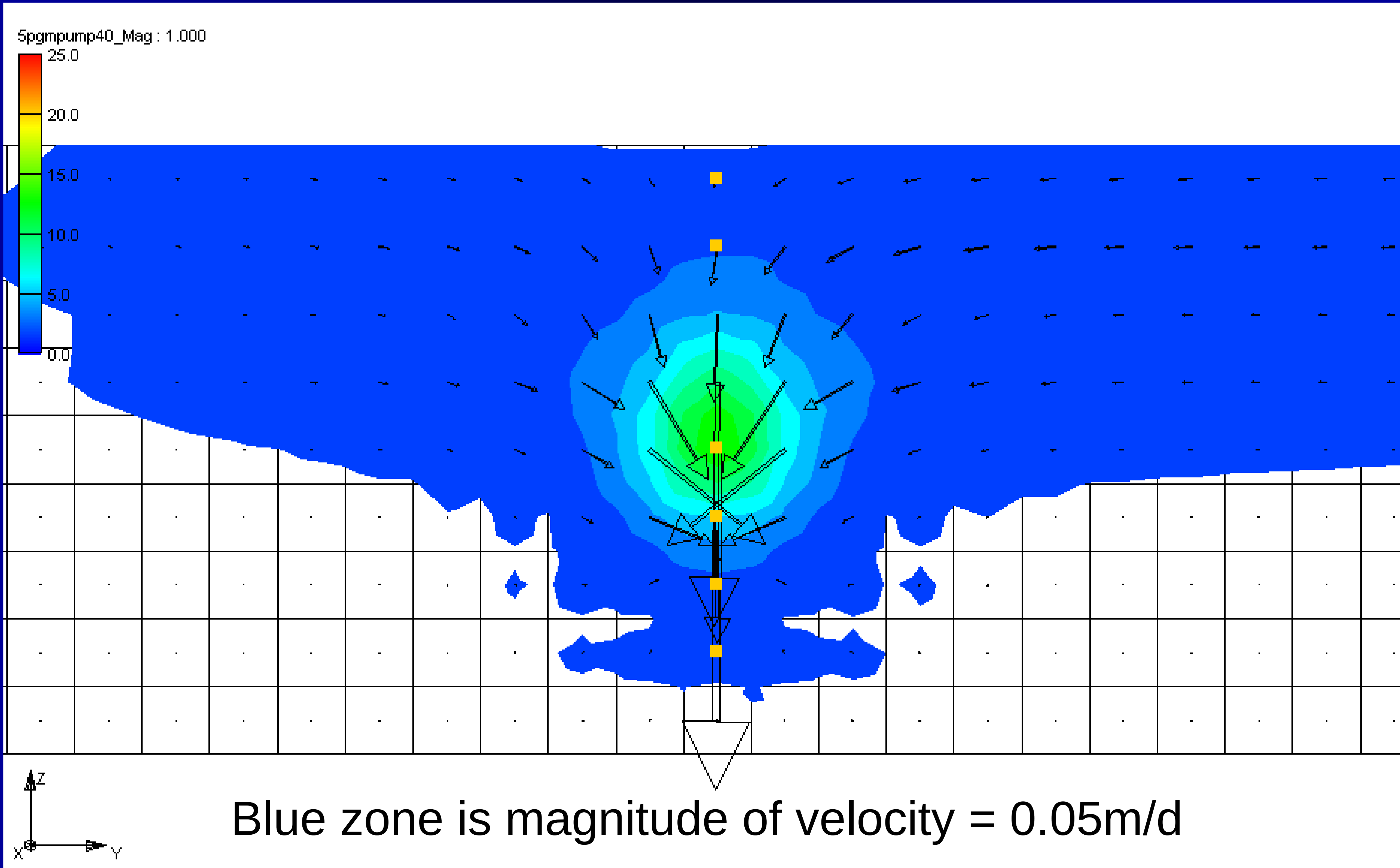


Blue zone is magnitude of velocity = 0.05m/d

Project Goals

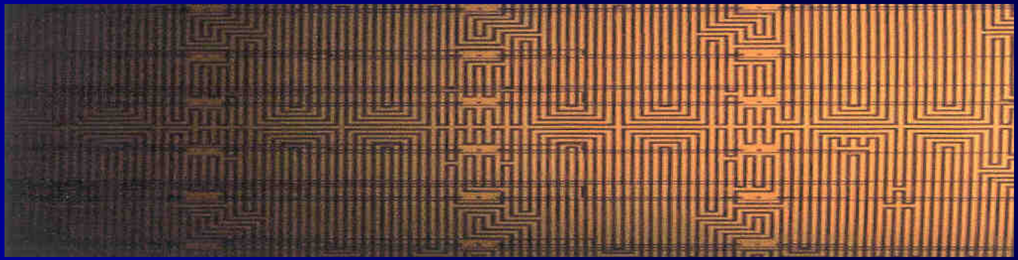
- Assess the hydraulics of the circulation cell around a GCW
  - Strength of Circulation Cell Flow
  - Transience of Circulation Cell Formation
- Evaluate the performance of the in situ groundwater flow sensors

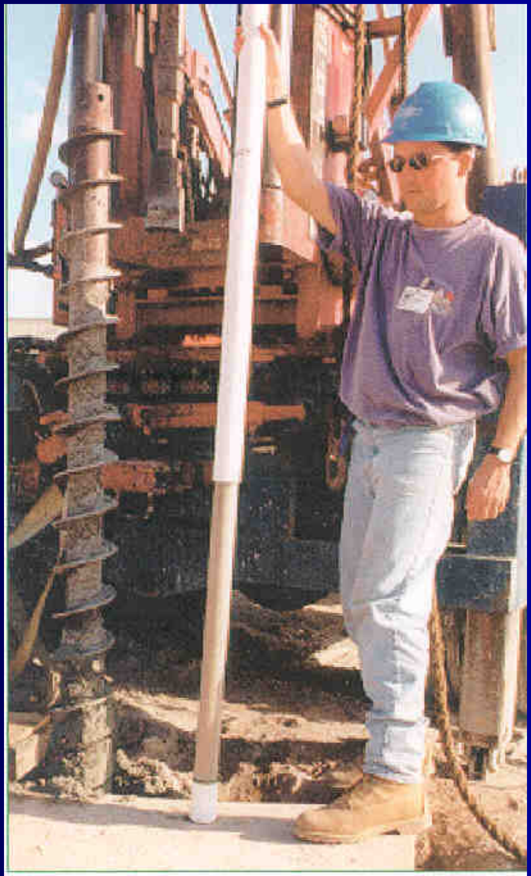
DOWNHOLE PRESURE TRANSDUCERS

Air-Based Remediation Technologies

In Situ Flow Sensor Description

- Sensor
- Calibration of Heat



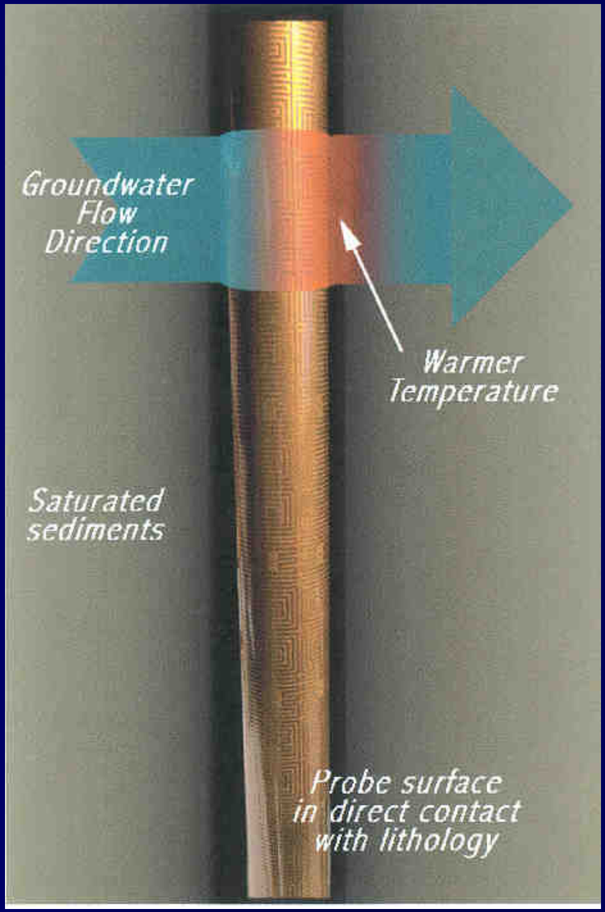


FOR MORE INFO...

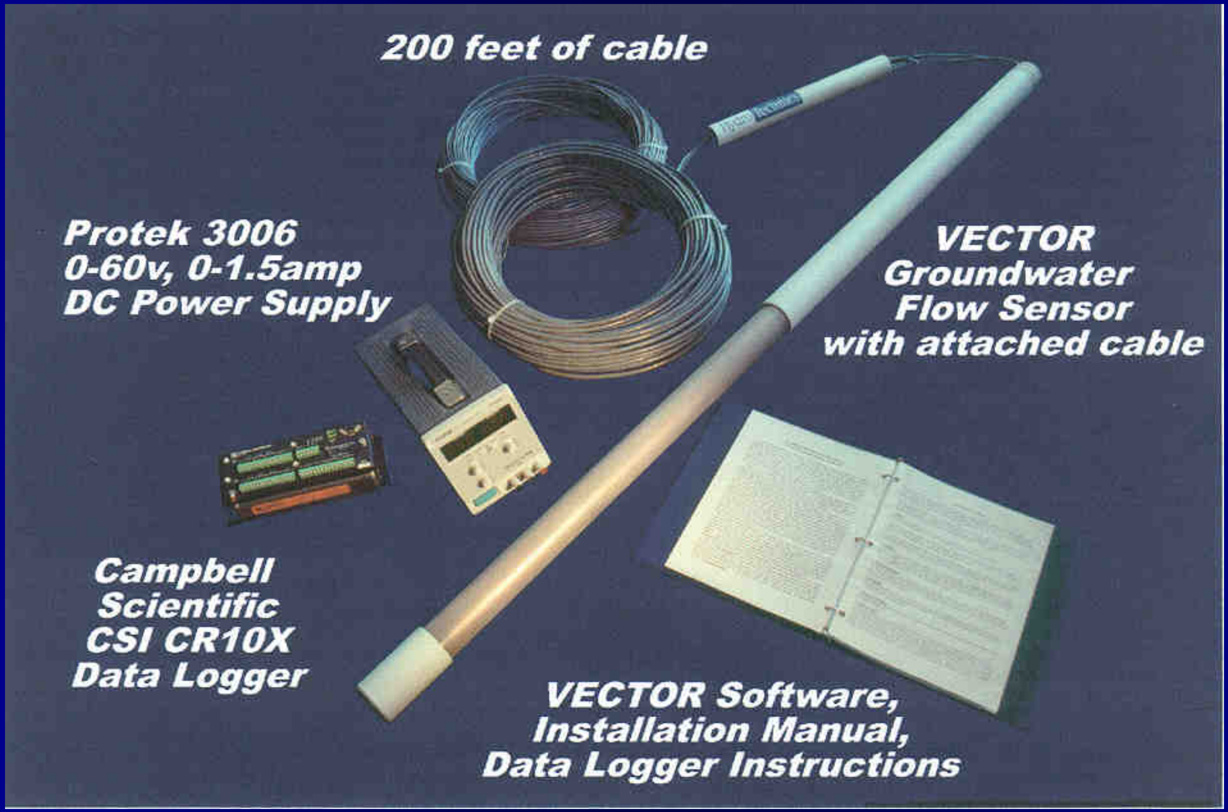
HydroTechnics - (505) 797-2421
info@hydrotechnics.com

Air-Based Remediation Technologies

Principle of In Situ Flow Sensor Operation

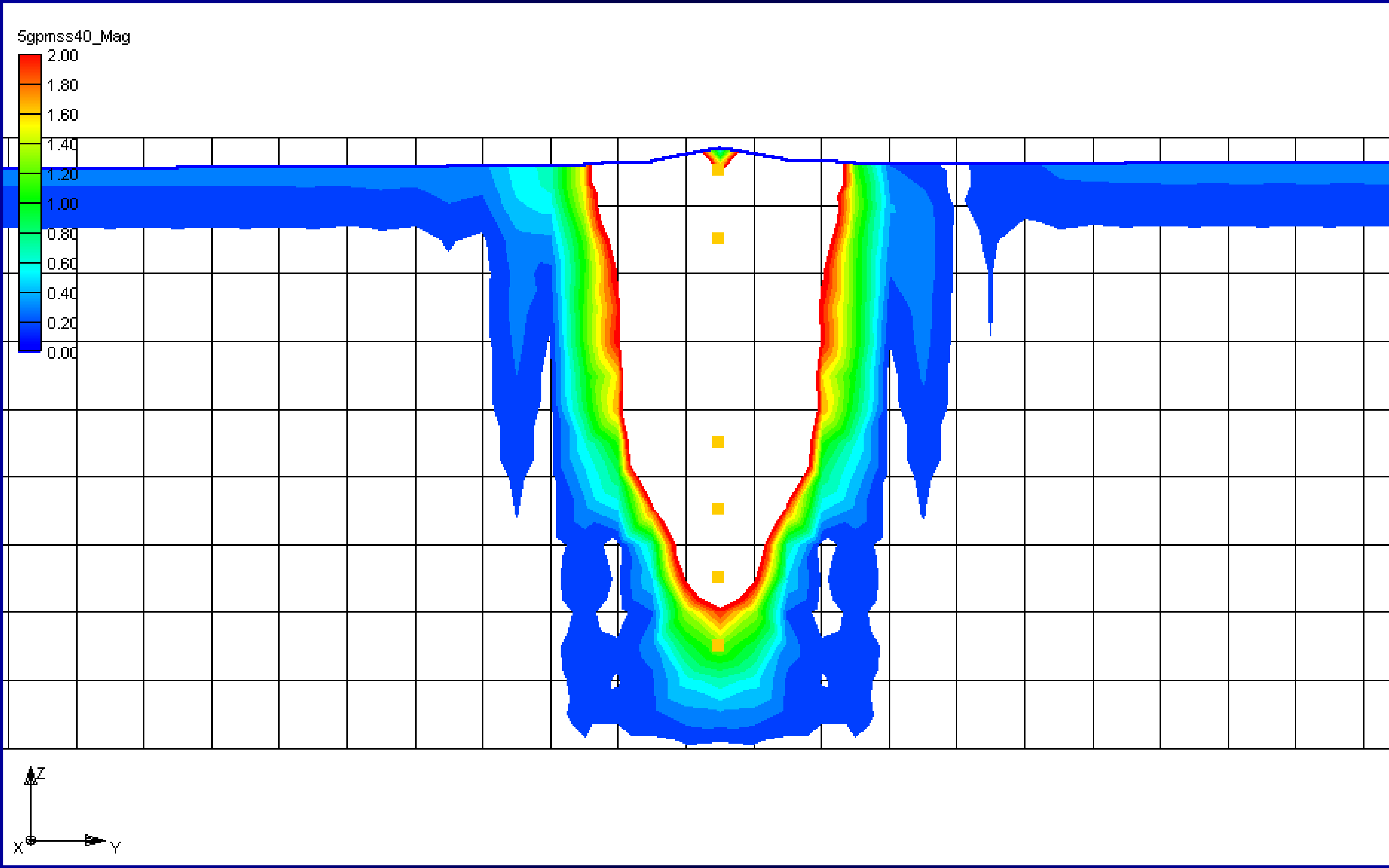


Schematic of In Situ Flow Sensor

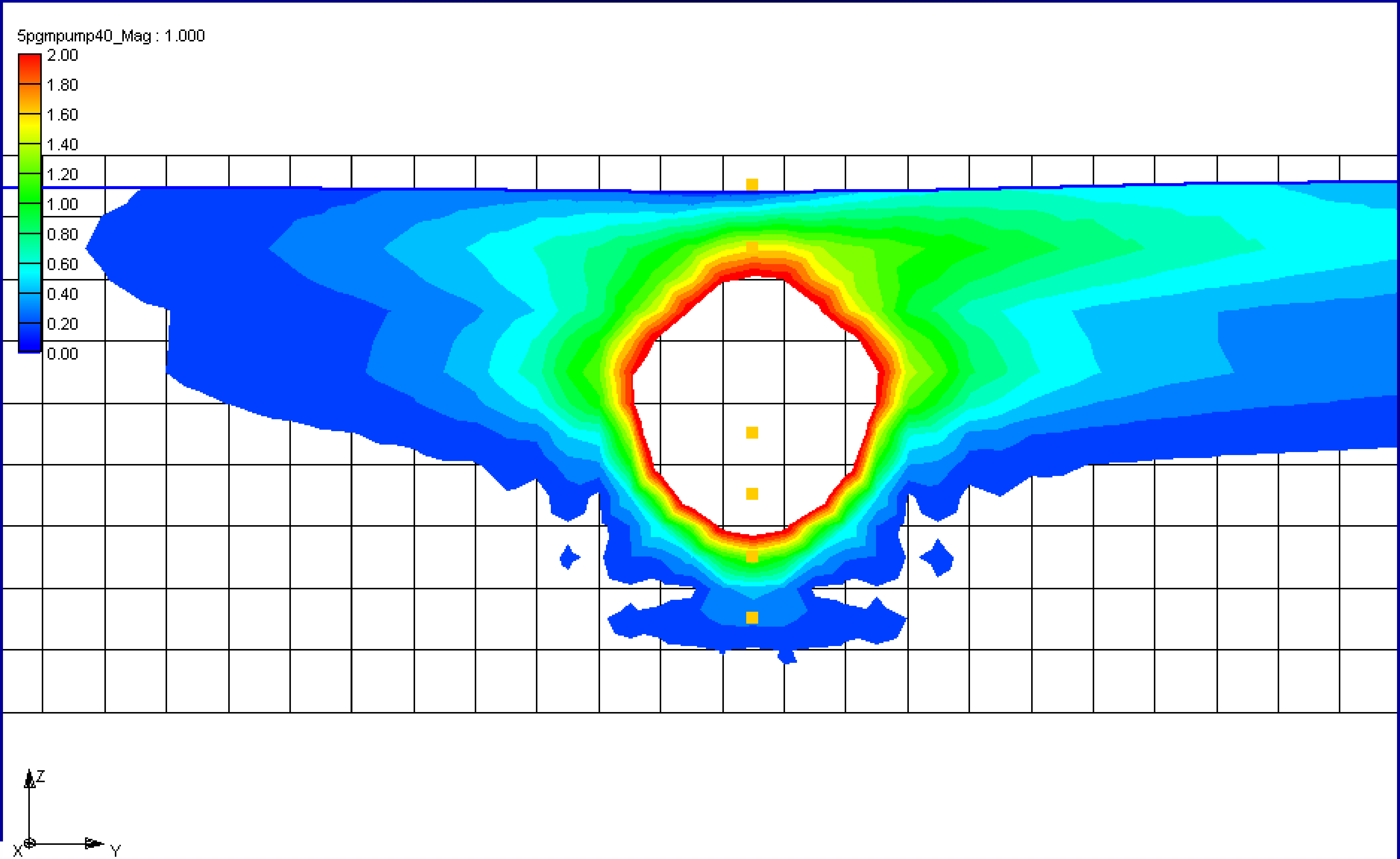


In Situ Flow Sensors

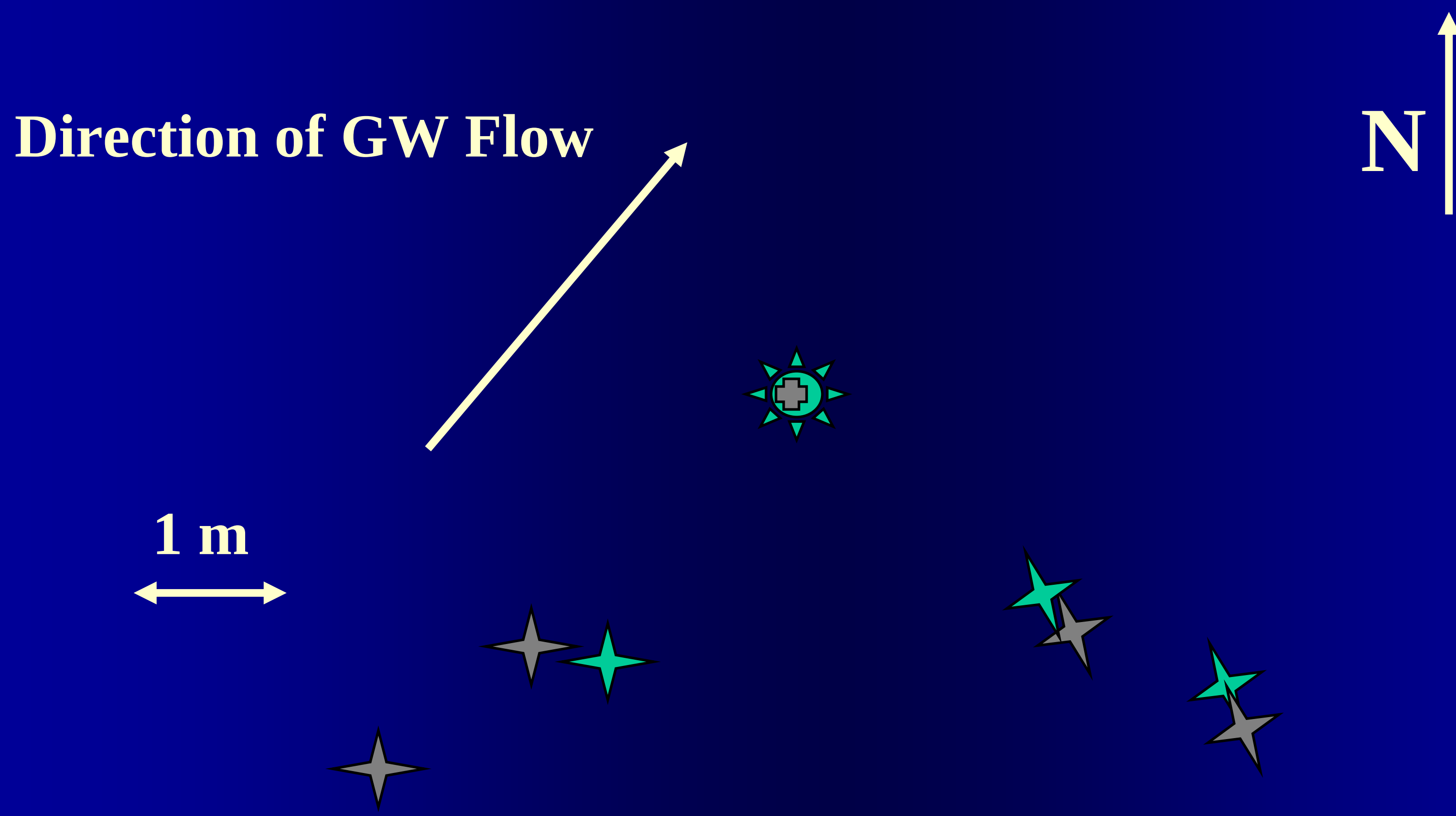
- Part of collapsed formation
- Measures true groundwater flow velocity as opposed to flow in wellbore
- Caveats
  - **Submergence - 1.5 m**
  - **Thermal Equilibrium - one week**
  - **Range 0.01 - 2.0 ft/day (0.003- 0.6 m/day)**
  - **Accuracy 0.1 % FS**



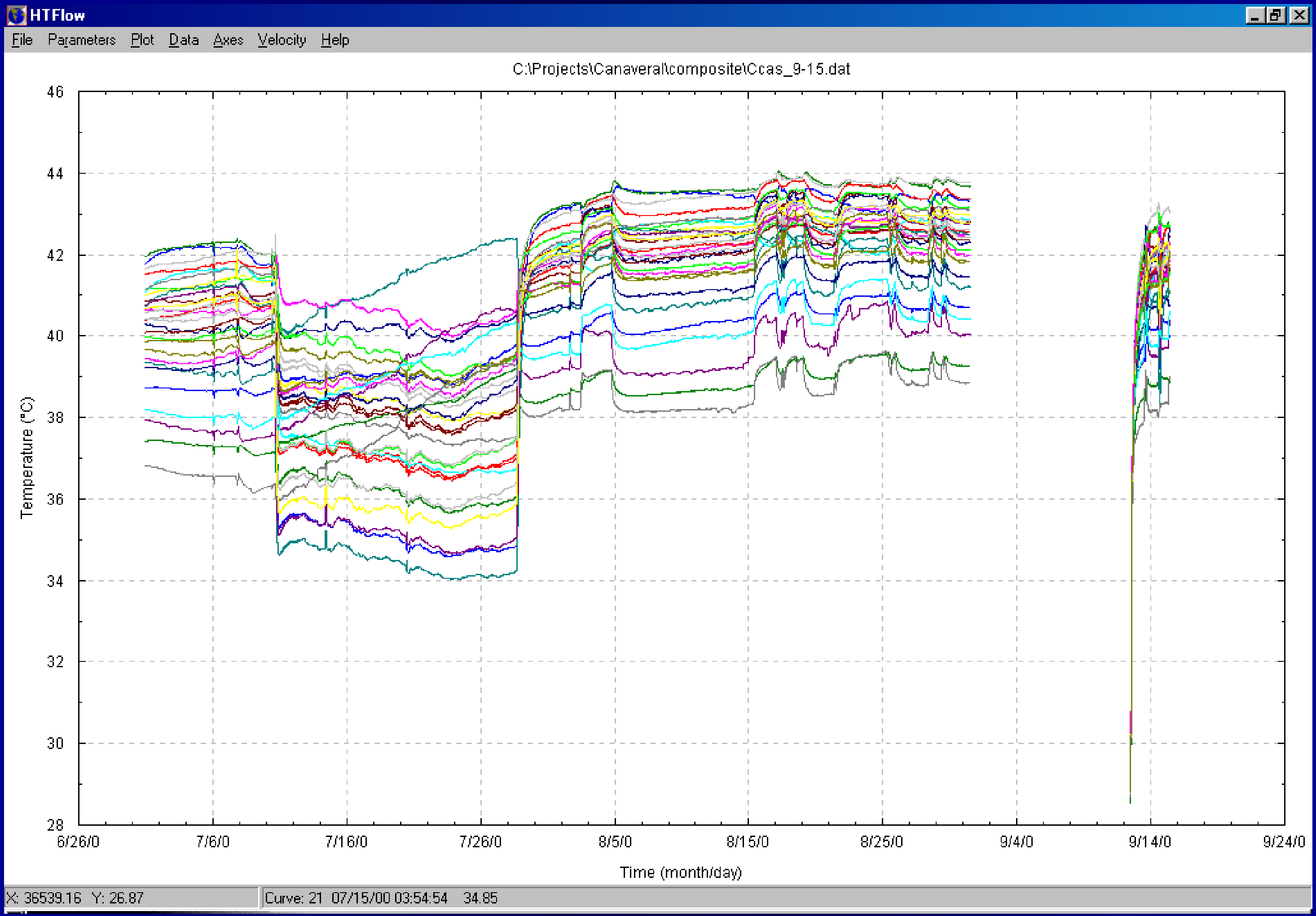
Air-Based Remediation Technologies


5pgmpump40_Mag : 1.000
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Z
X
Y

Location of Probes

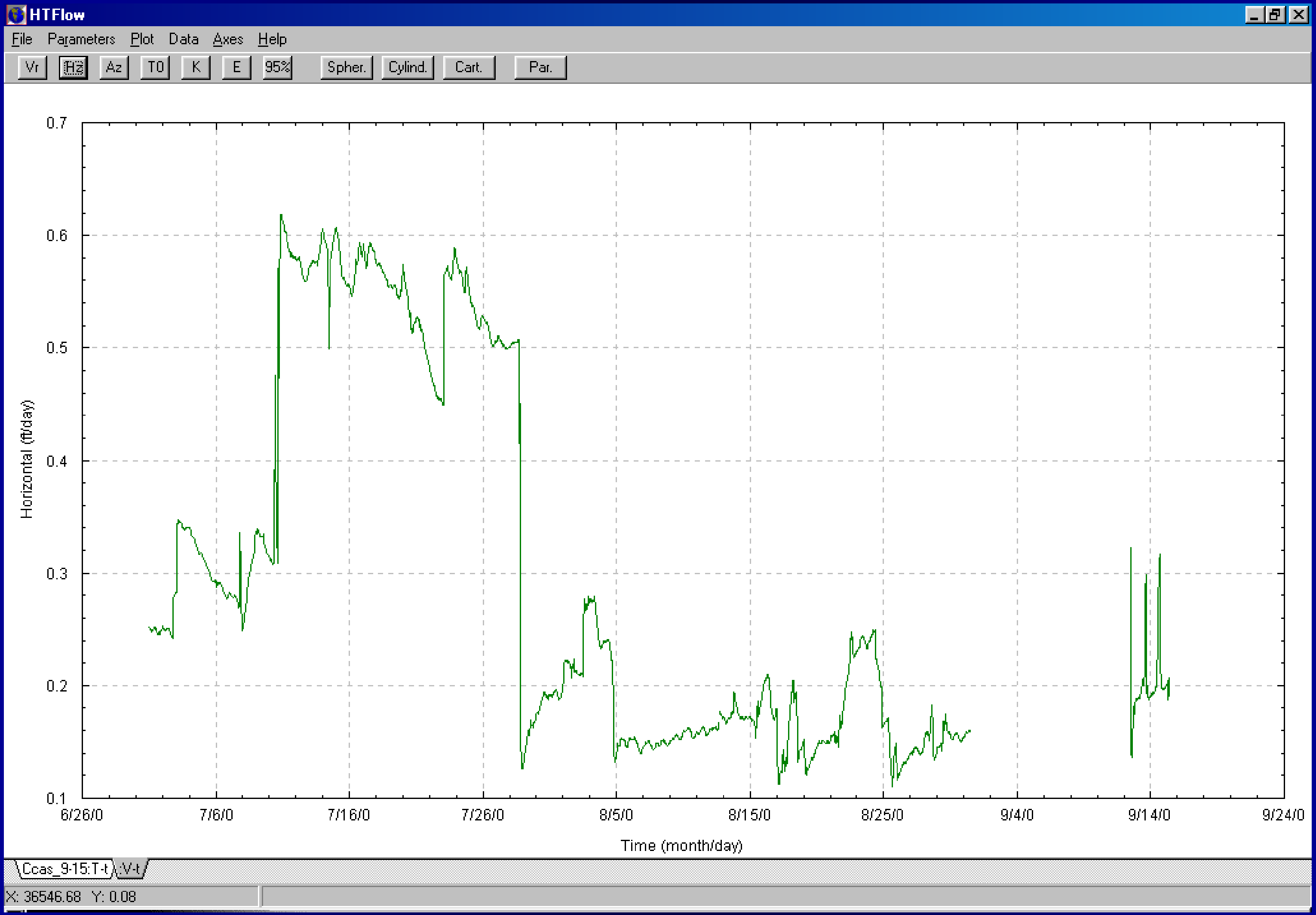


Transient Temperature Effects for Sensor C-01



Air-Based Remediation Technologies

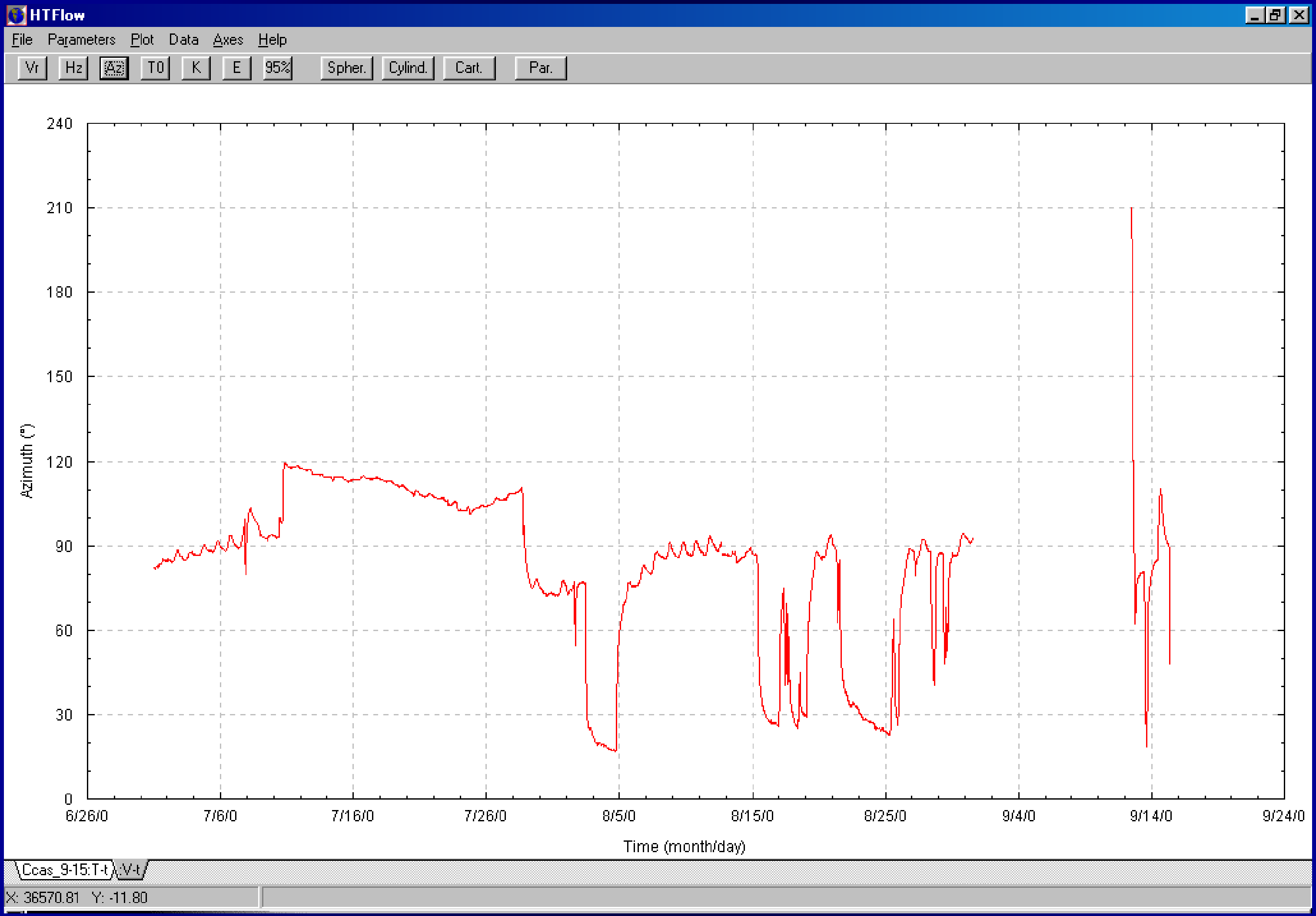
Long-Term Horizontal Flow Velocity for Sensor C-01



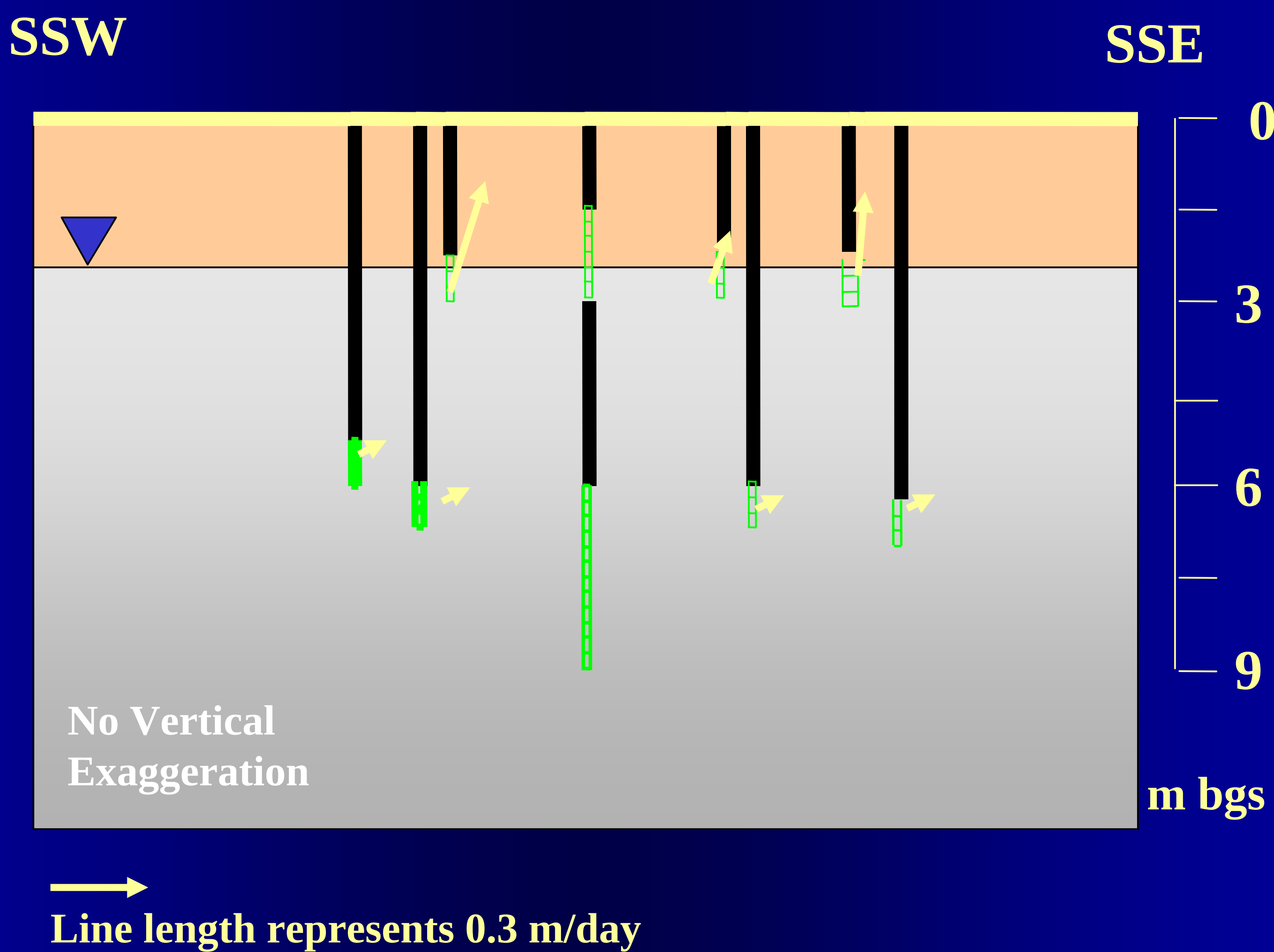
Long-Term Vertical Flow Velocity for Sensor C-01

Air-Based Remediation Technologies

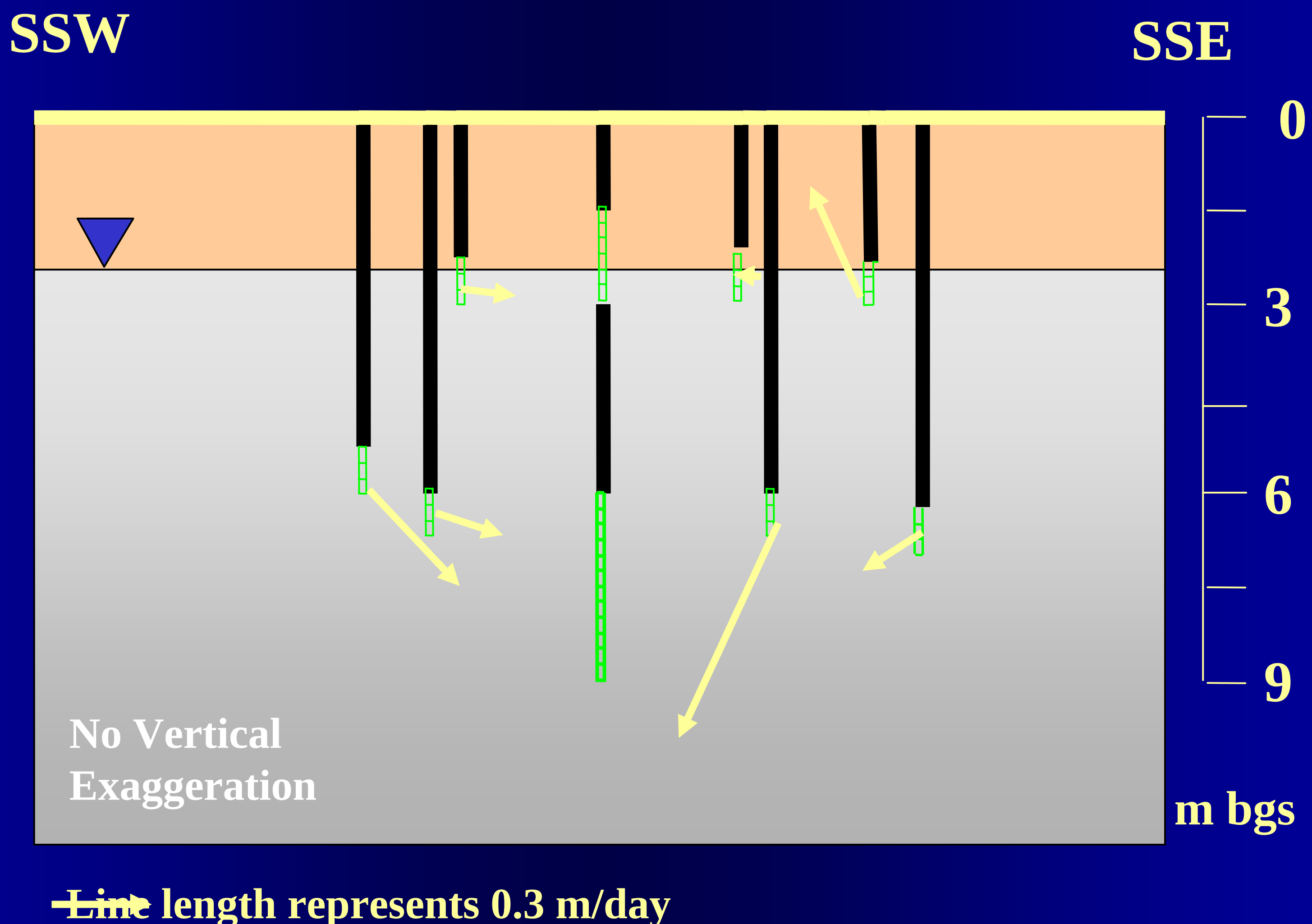
Long-Term Direction of Horizontal Flow for Sensor C-01



Air-Based Remediation Technologies

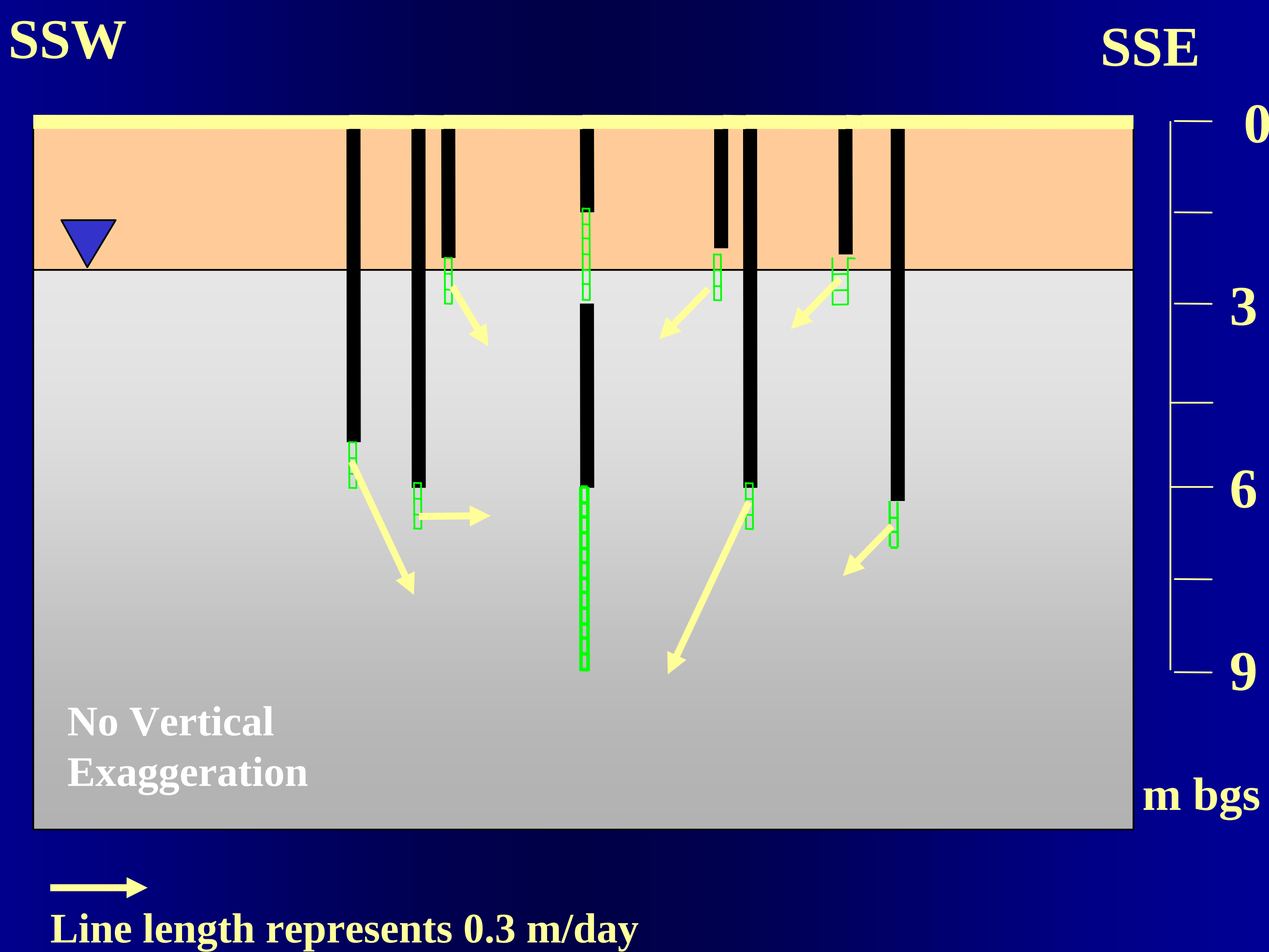


Flow under Natural Conditions

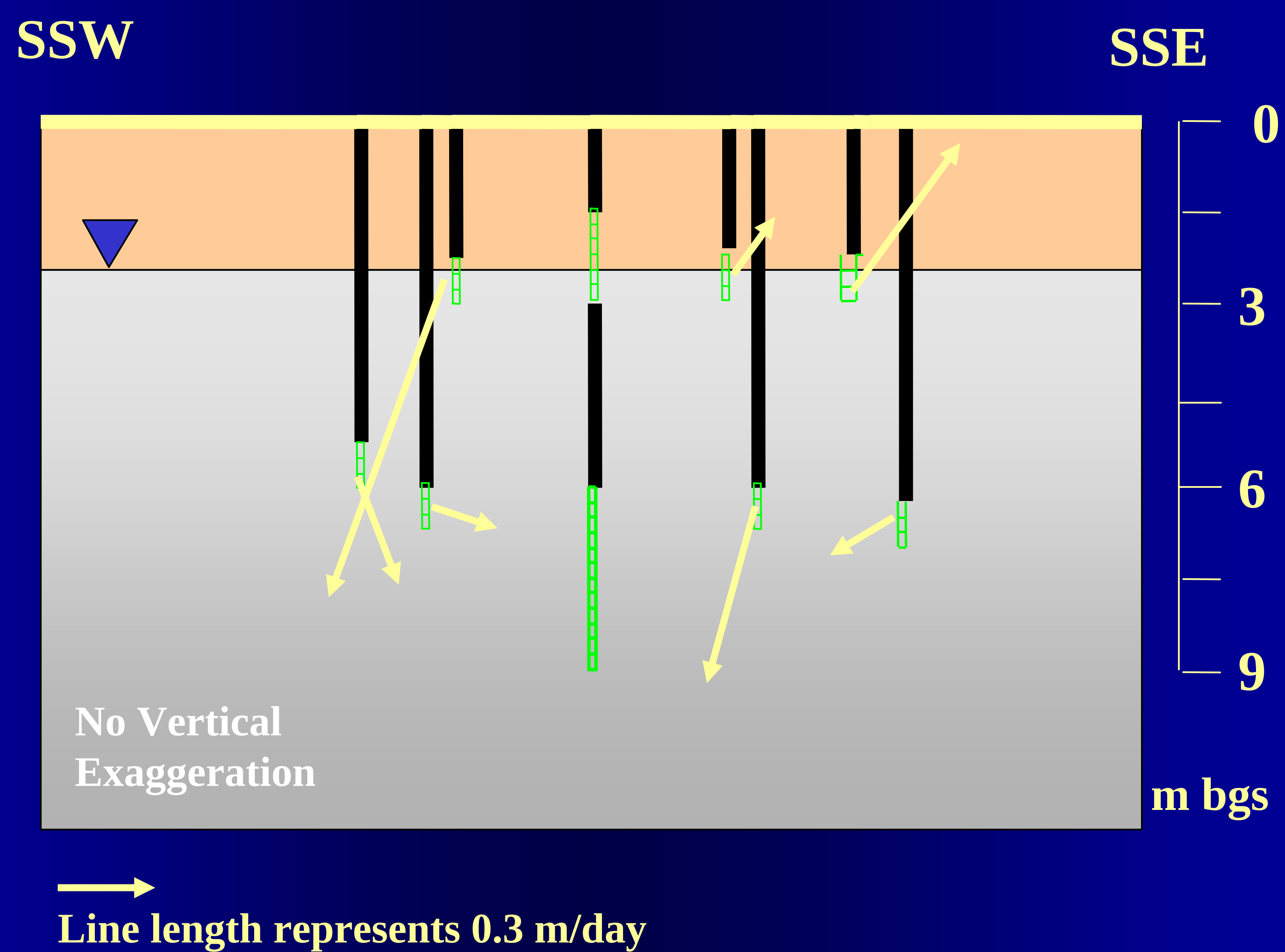


Flow under Pumping Conditions - Actual Data

Air-Based Remediation Technologies

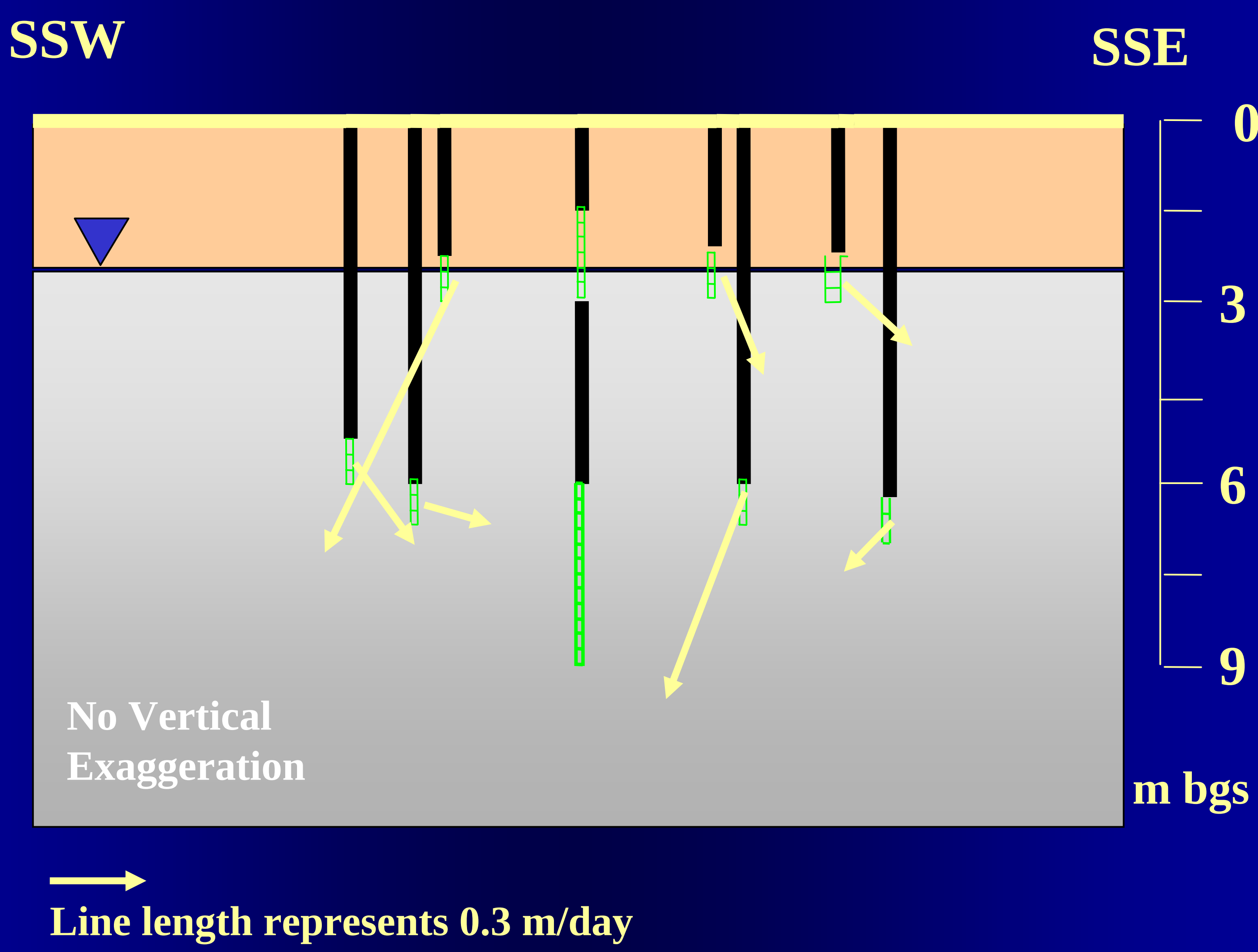


Flow under Pumping Conditions - Background Removed



Flow under Recirculating Conditions - Actual Data

Air-Based Remediation Technologies



Flow under Recirculating Conditions - Background Removed

Conclusions

- Not much difference in the vertical flow pattern between GCW and pumping for this formation
- Strength of the circulation cell was greater than initially anticipated
- Subtle transience of circulation cell in 20 day time frame

Presentation Summary

- Applicability: VOCs, aerobically degradable organics
- Pilot tests: determine groundwater flow rates and VOC concentration response
  - Collect subsurface, above-ground equipment data
  - Check/maintain equipment
- Closure
  - Evaluate concentrations remaining
  - Rebound tests