

IN-SITU THERMAL TREATMENT



Air-Based Remediation Technologies

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



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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>



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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



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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



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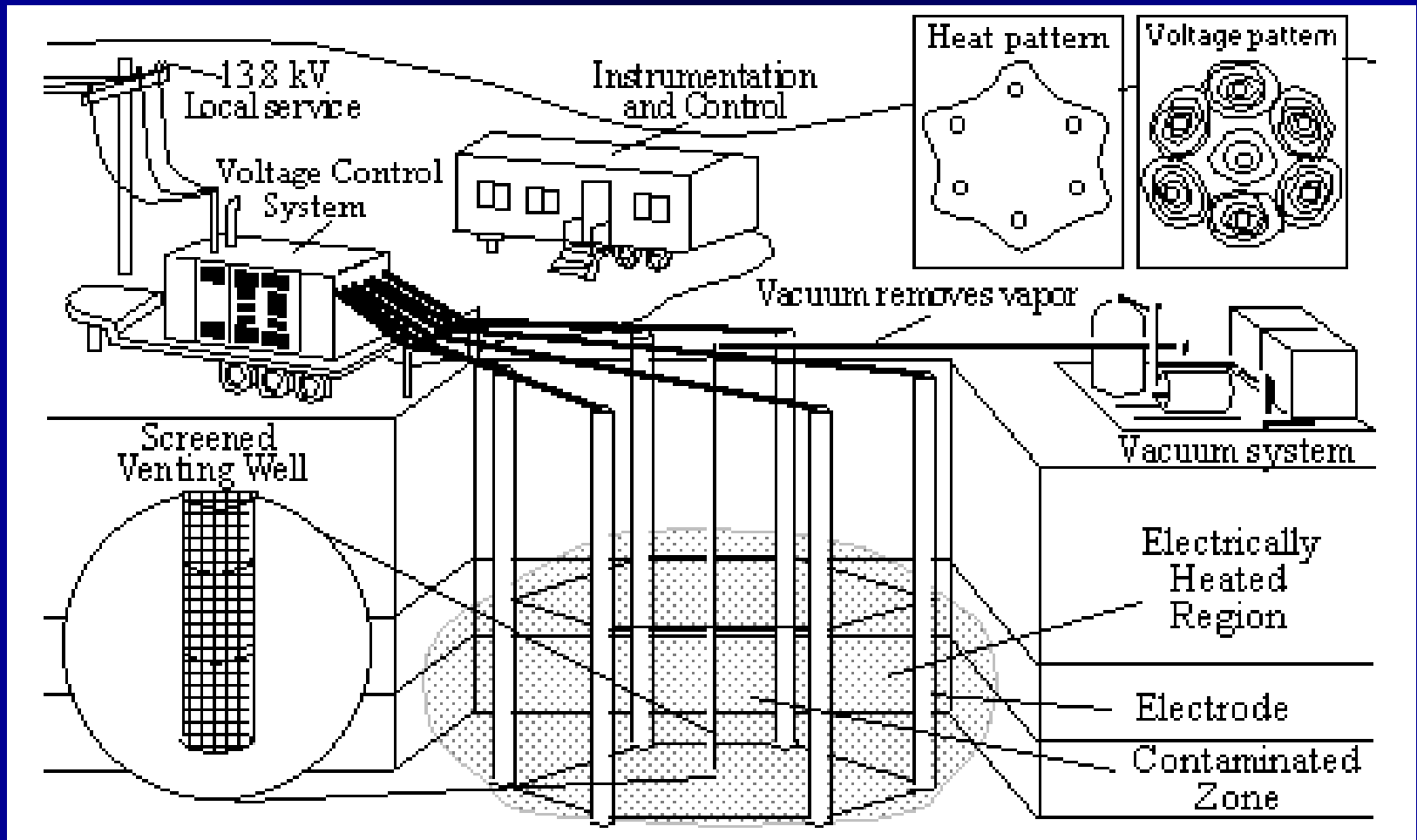
Electrical Resistivity Heating (ERH)

- 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



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Electrical Resistivity Heating



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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)



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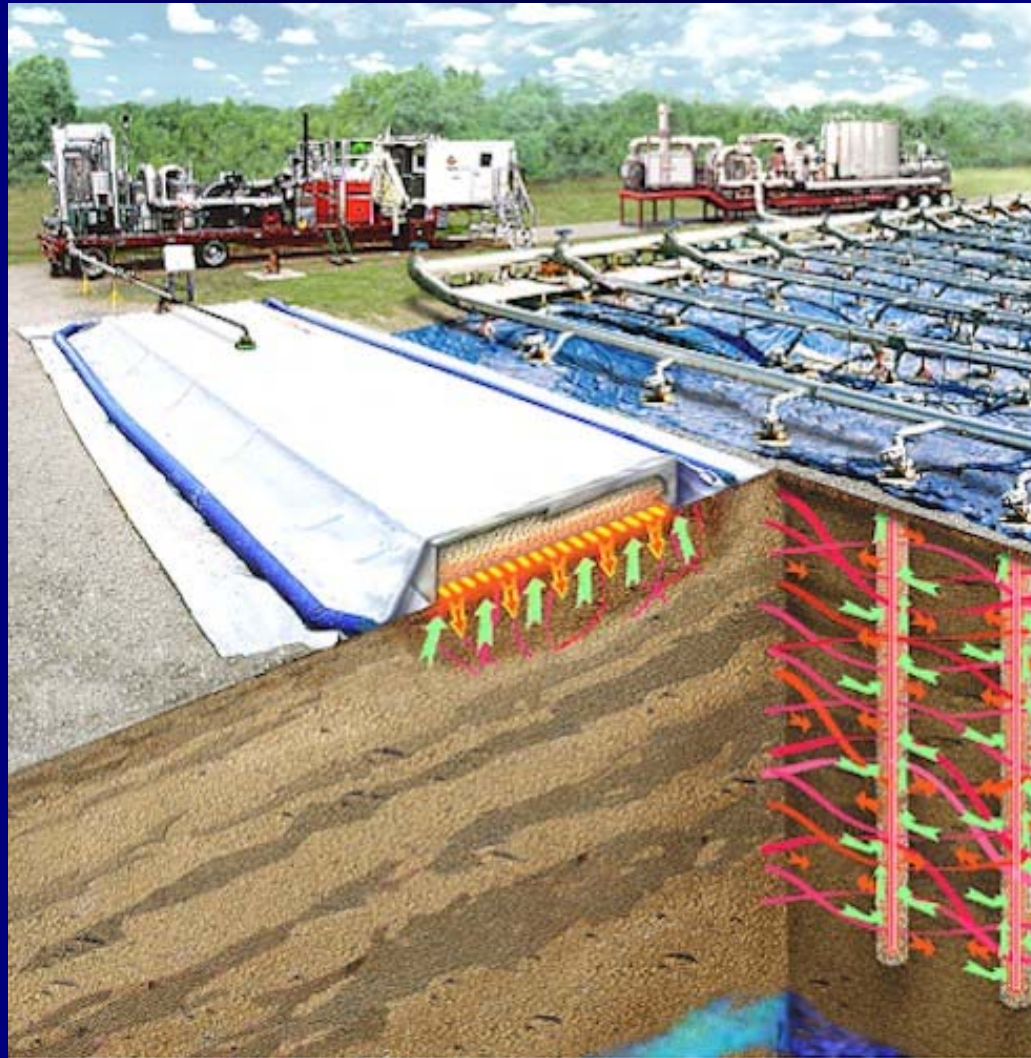
Thermal Conduction Heating (TCH)

- 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



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Thermal Conduction Heating



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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)



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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

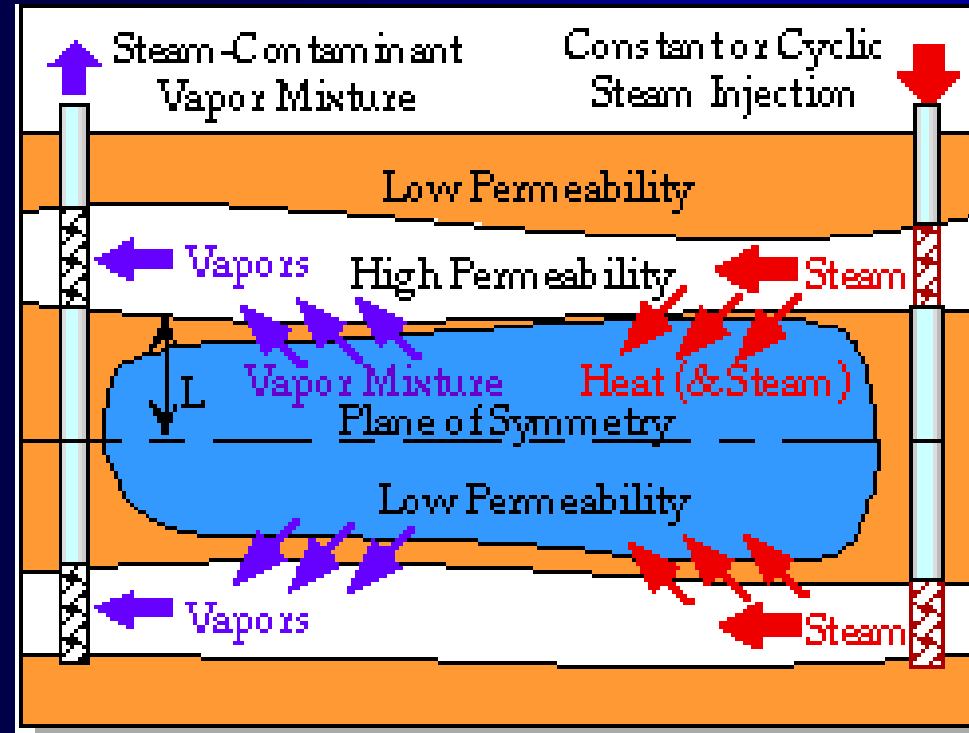


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STEAM INJECTION



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



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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



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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



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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



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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



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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



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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-condensable 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



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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



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Implementation

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



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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



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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



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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



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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



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Steam Injection

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



Air-Based Remediation Technologies

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



Air-Based Remediation Technologies

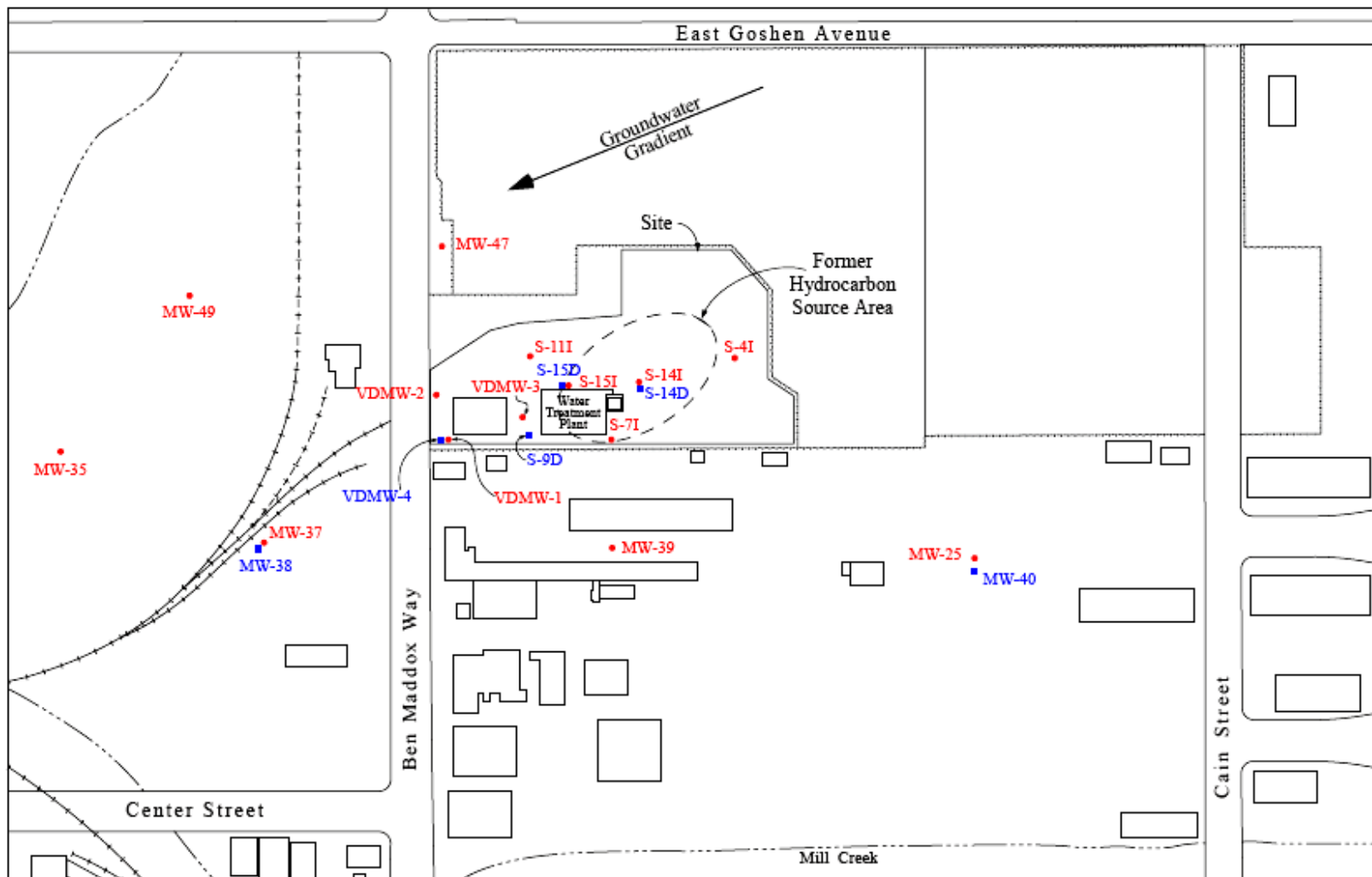
ISTR Case Study

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



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LEGEND

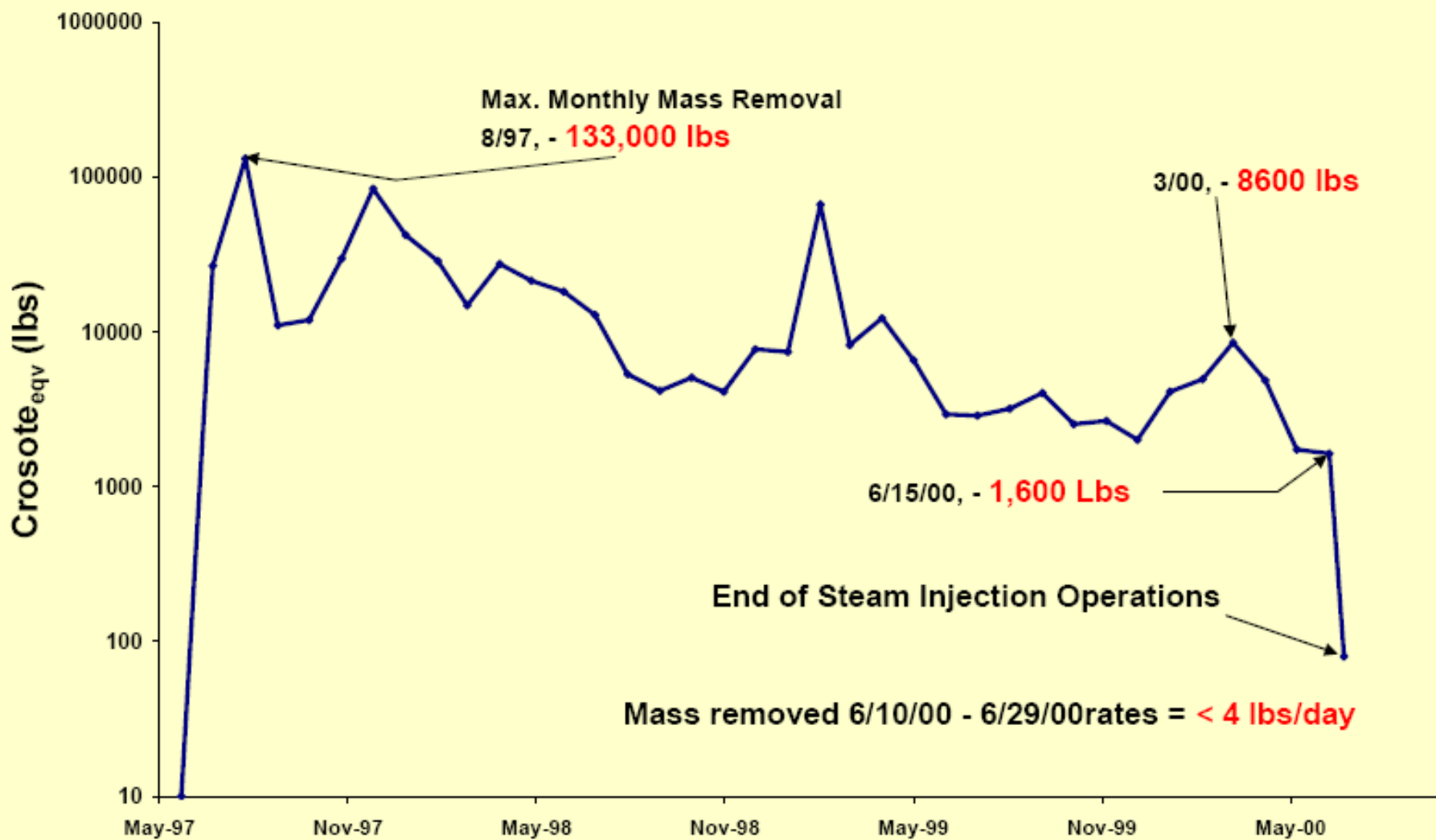
- Intermediate Aquifer Monitoring Well
- Deep Aquifer Monitoring Well

**DEMONSTRATION OF REMEDIAL ACTION
MONITORING WELL LOCATION**



FIGURE 1

Visalia Steam Remediation Project Monthly Free-Phase Pole Treating Chemicals (PTC) Removal Rates



Visalia Steam Remediation Project Daily Removal Rates

36 MONTHS OPERATION
1,330,000 LBS. OR 160,000 GALLONS OF
CREOSOTE REMOVED

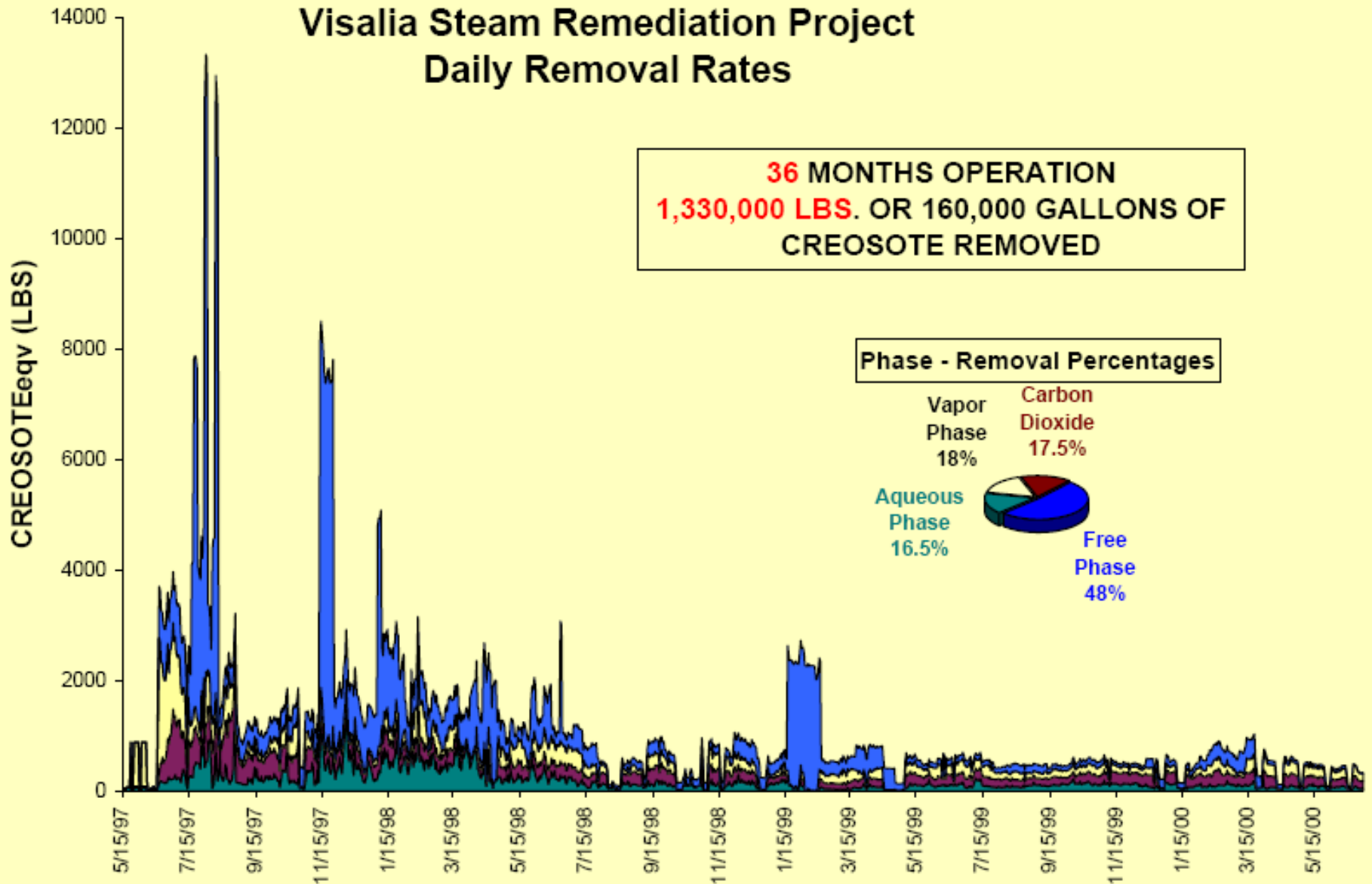


Figure 1

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



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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



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GROUNDWATER CIRCULATION WELLS



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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



Air-Based Remediation Technologies

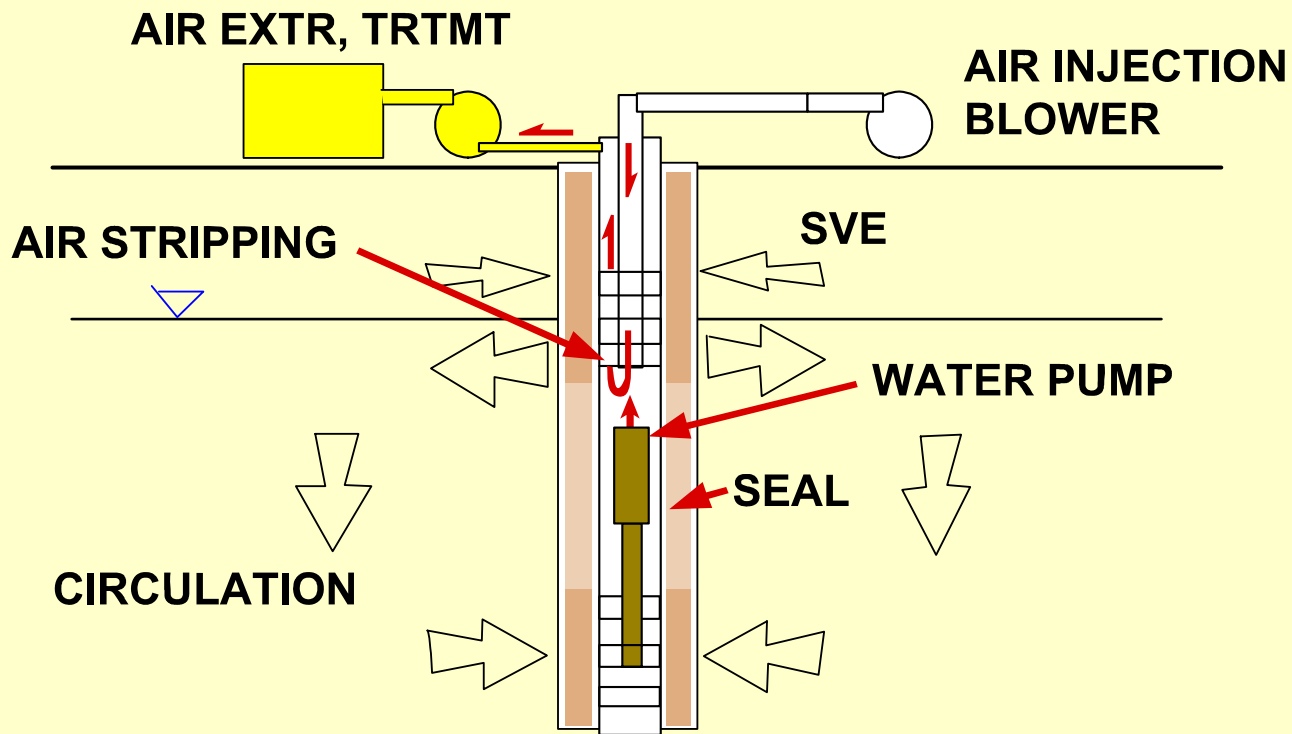
GCW Technology Description

- 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



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Schematic of GCW



39522-09



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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>



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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



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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



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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



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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



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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



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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



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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



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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



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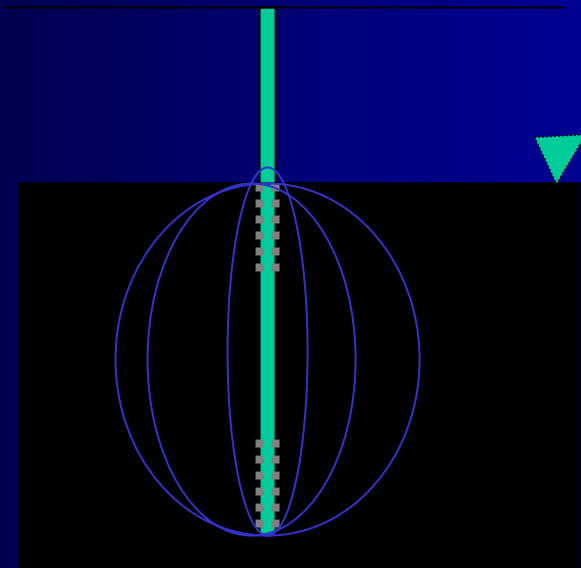
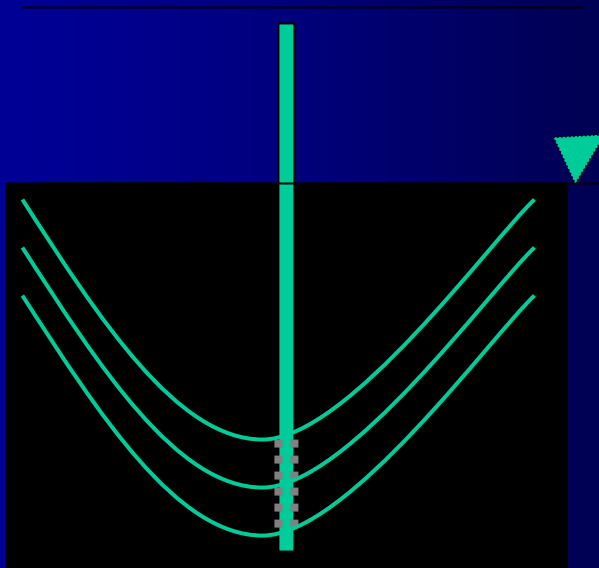
GCW Site Shutdown & Closure

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



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Extraction Well vs. GCW Well



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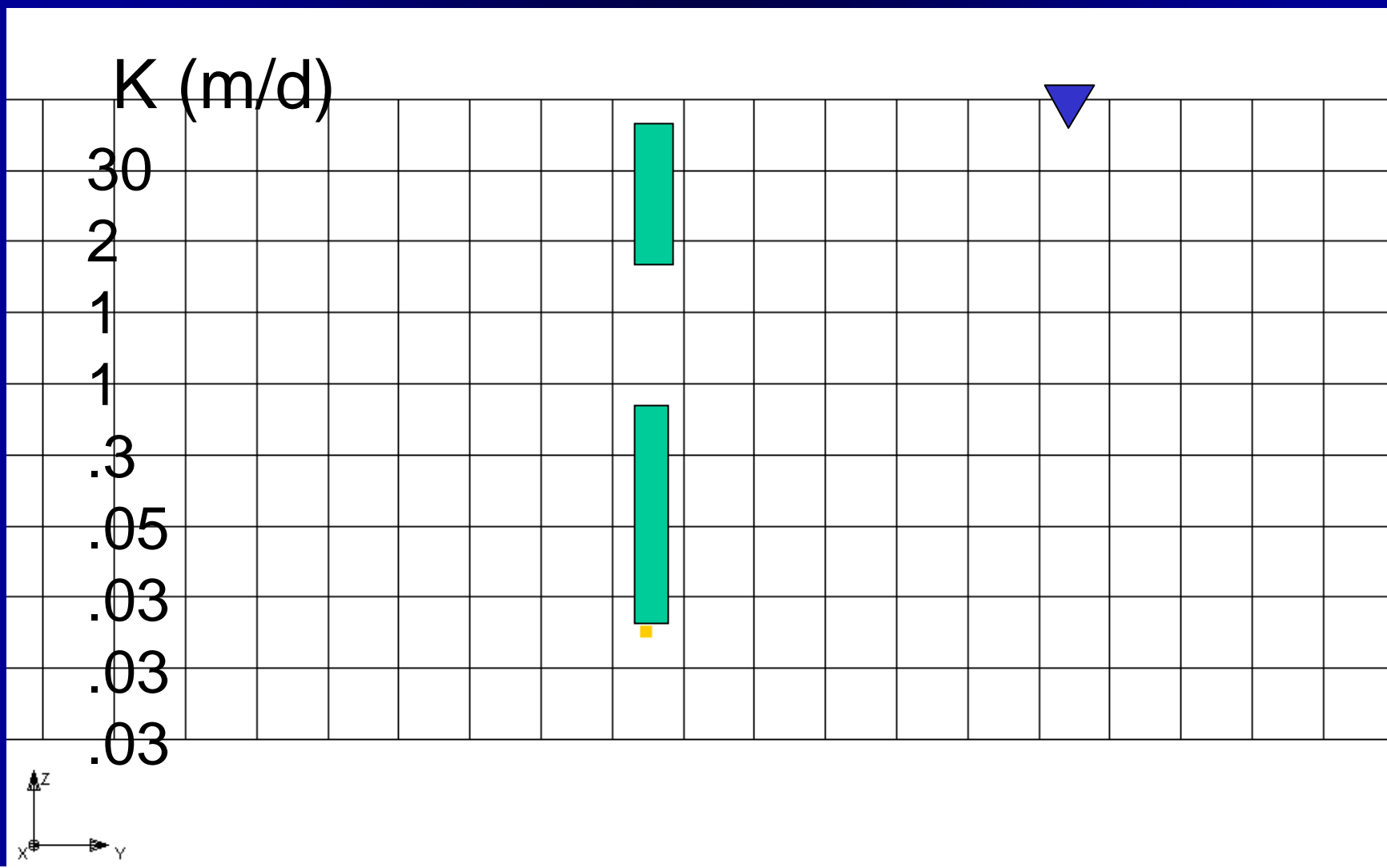
GCW Case Study - Project Location



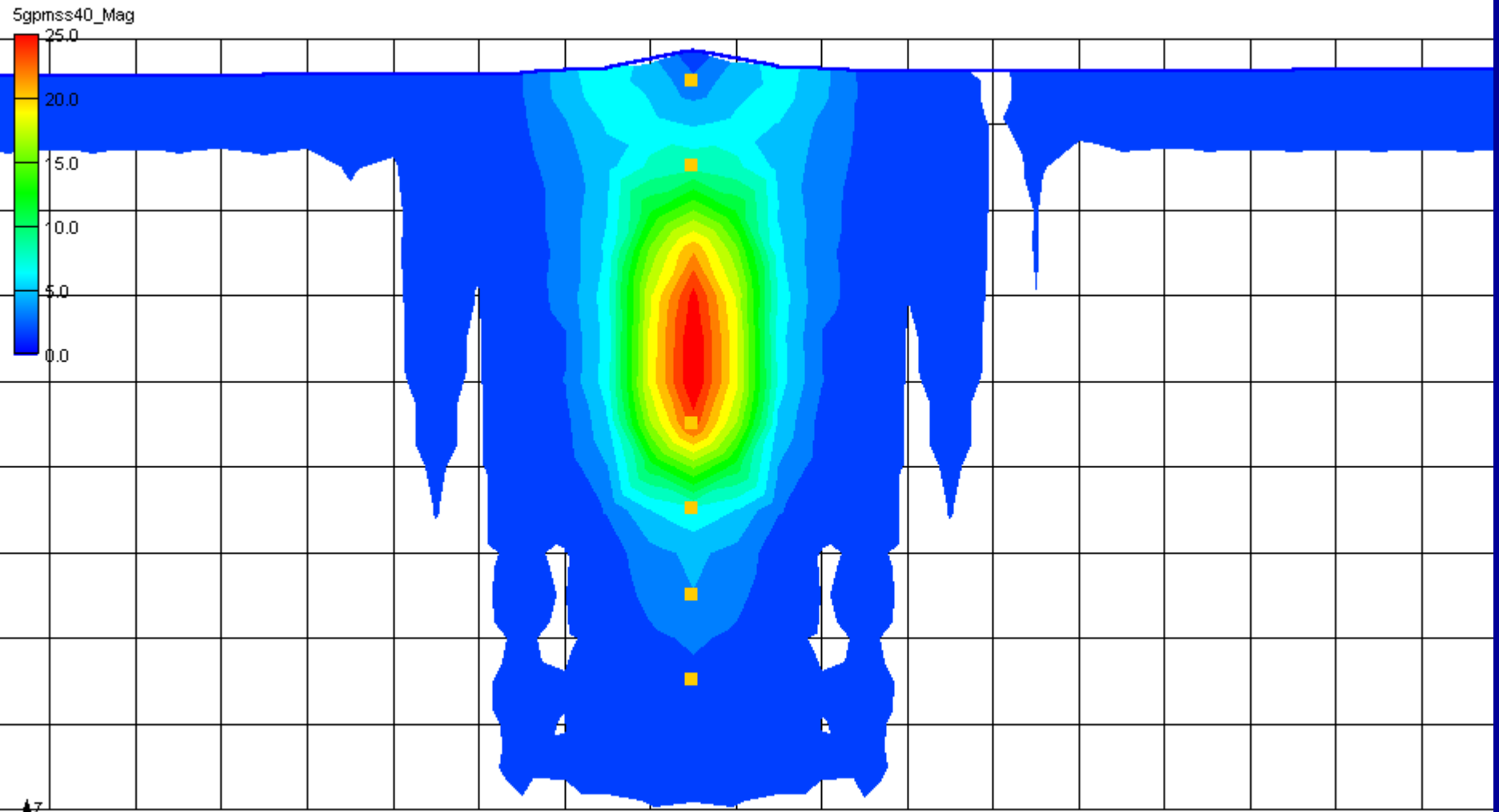
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MODFLOW Cross Section



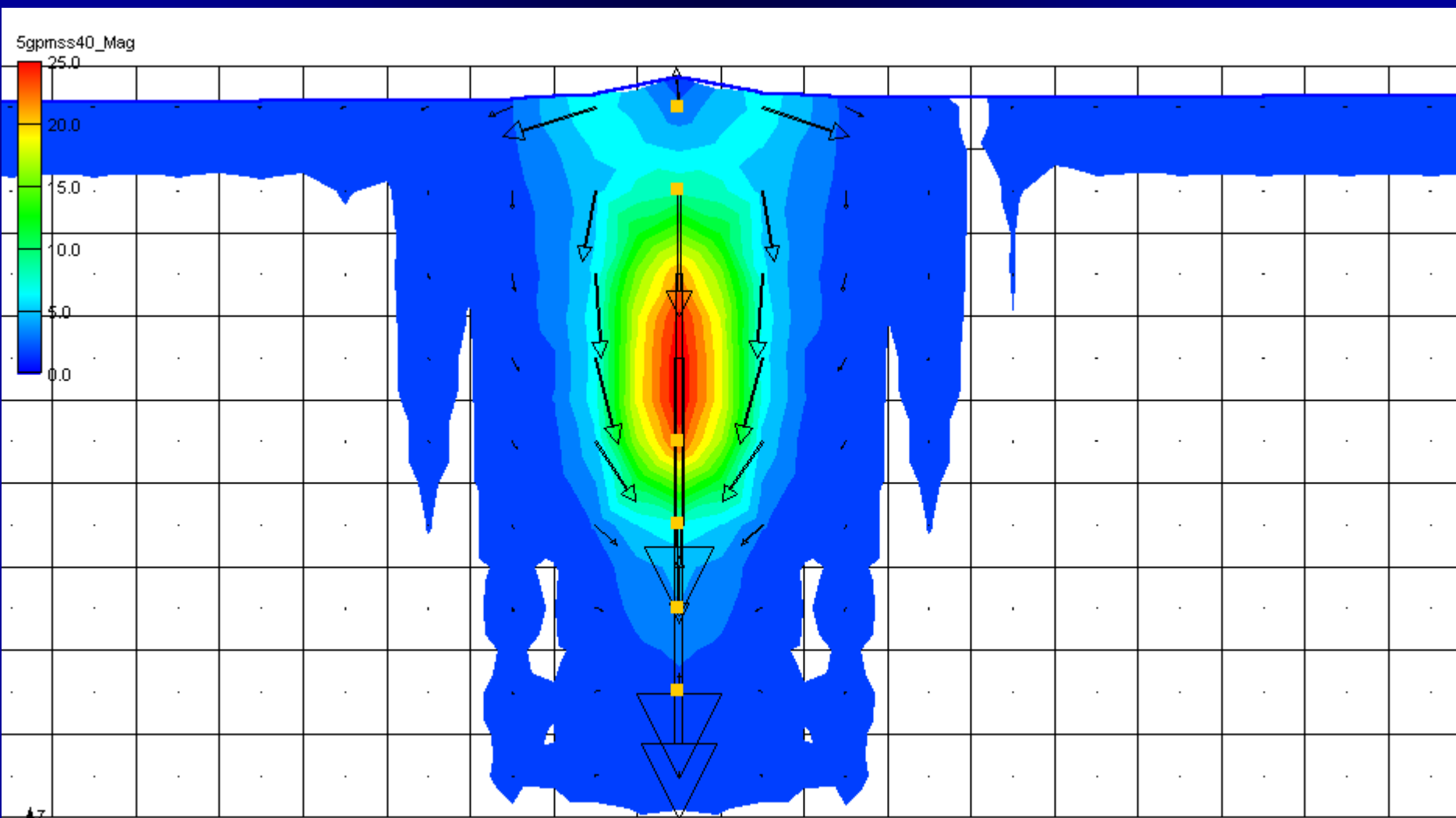
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Blue zone is magnitude of velocity = 0.05m/d



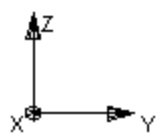
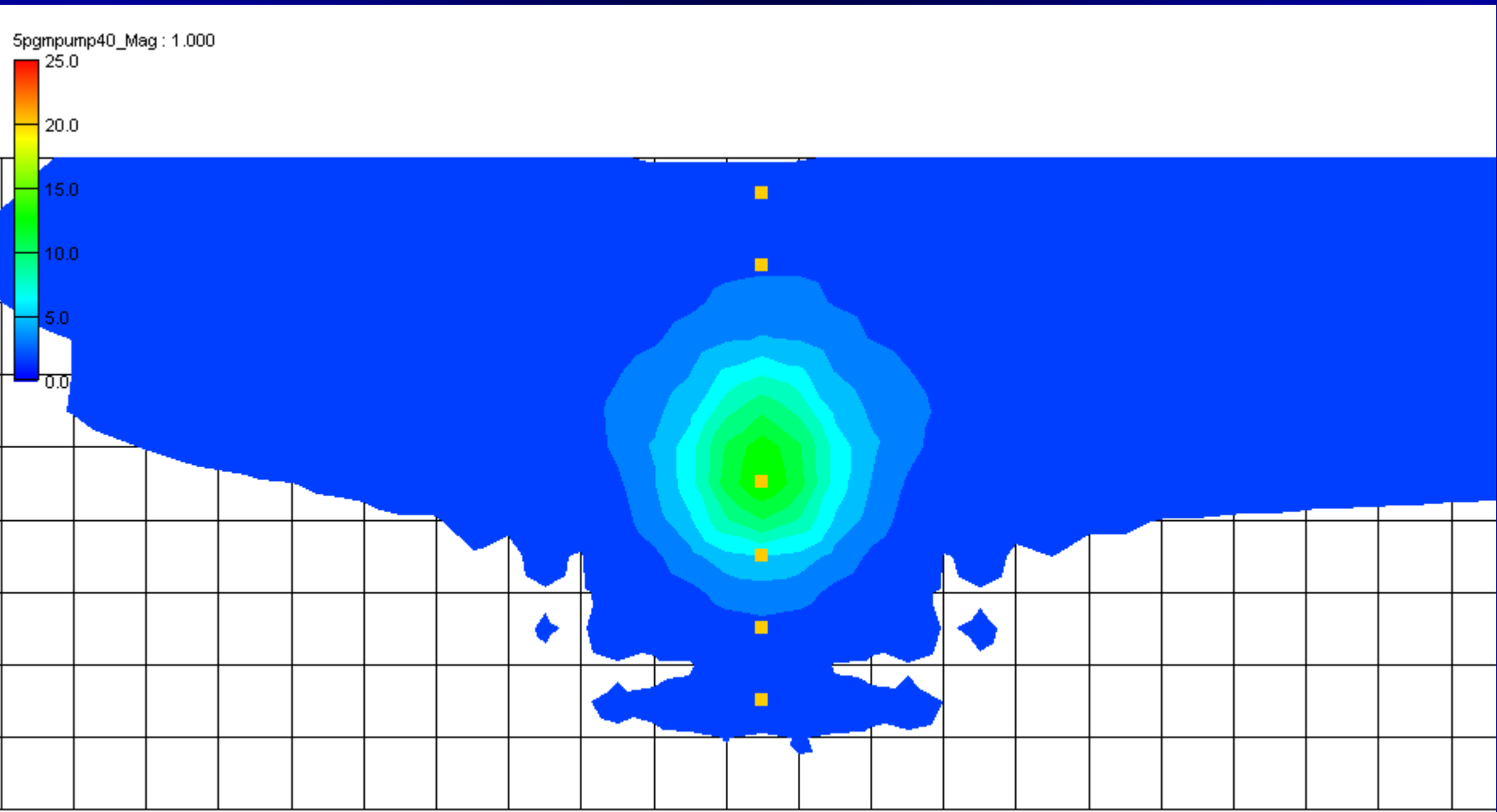
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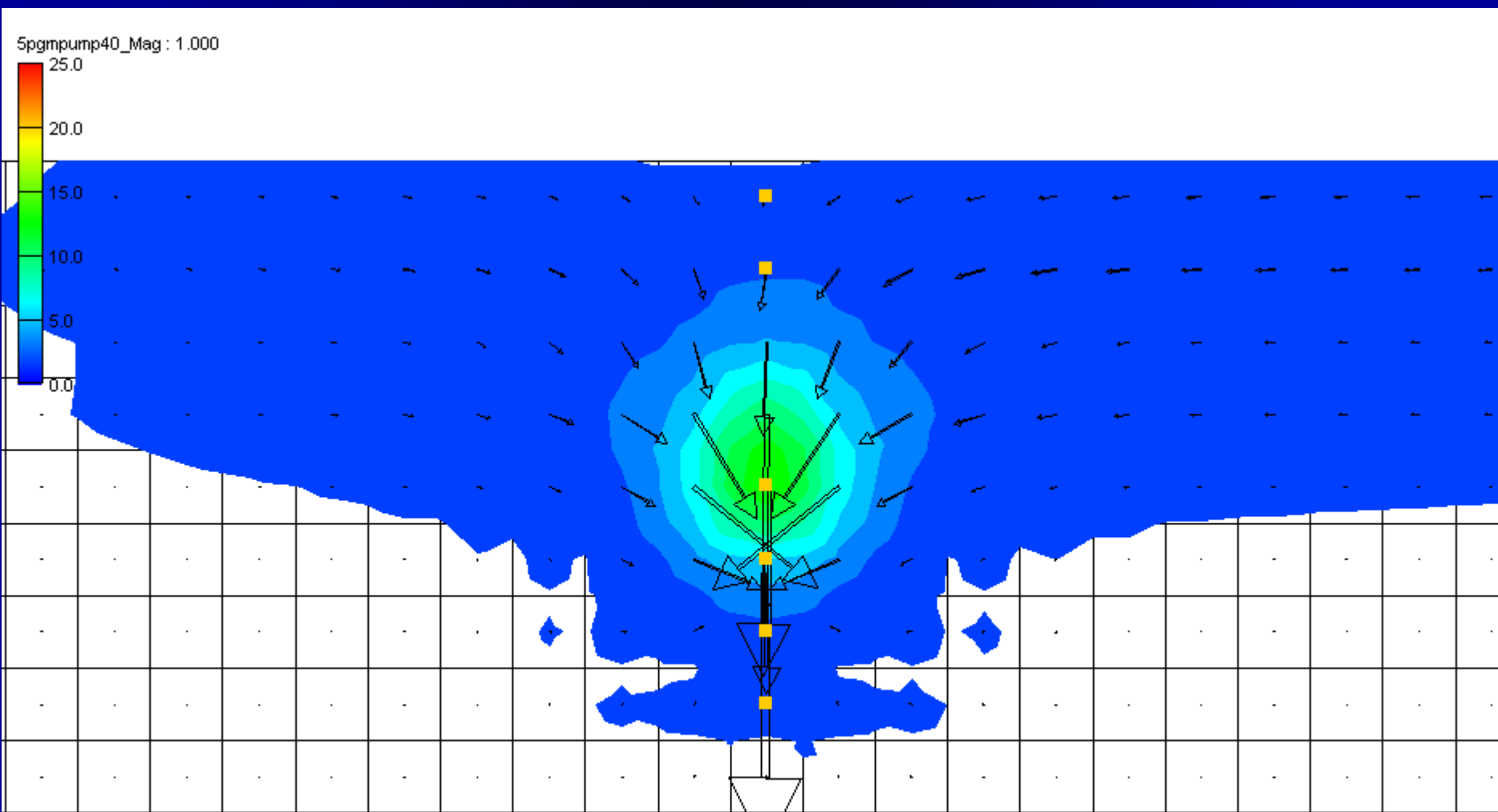
Air-Based Remediation Technologies



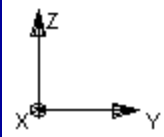
Blue zone is magnitude of velocity = 0.05m/d



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Blue zone is magnitude of velocity = 0.05m/d



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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



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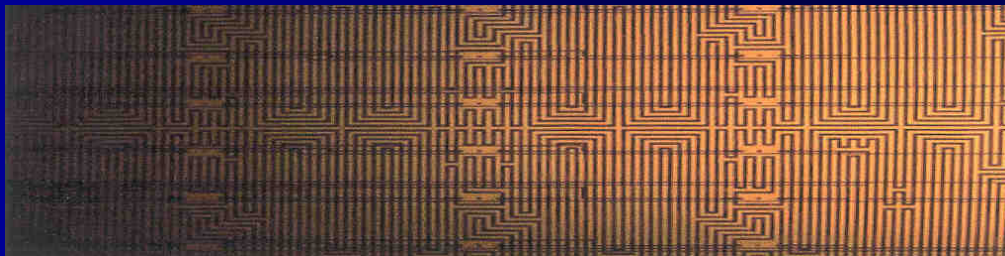
DOWNHOLE PRESURE TRANSDUCERS



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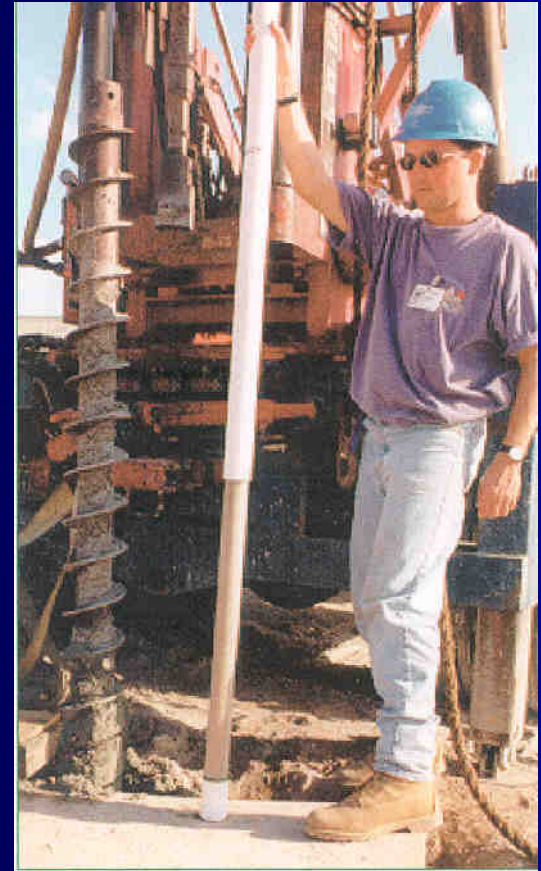
In Situ Flow Sensor Description

- Sensor
- Calibration of Heat



FOR MORE INFO...

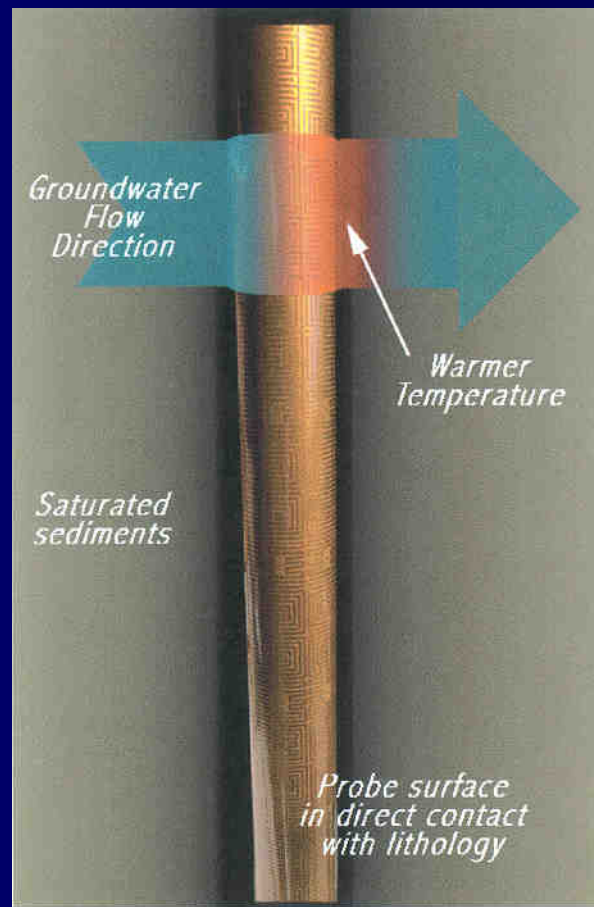
HydroTechnics - (505) 797-2421
info@hydrotechnics.com



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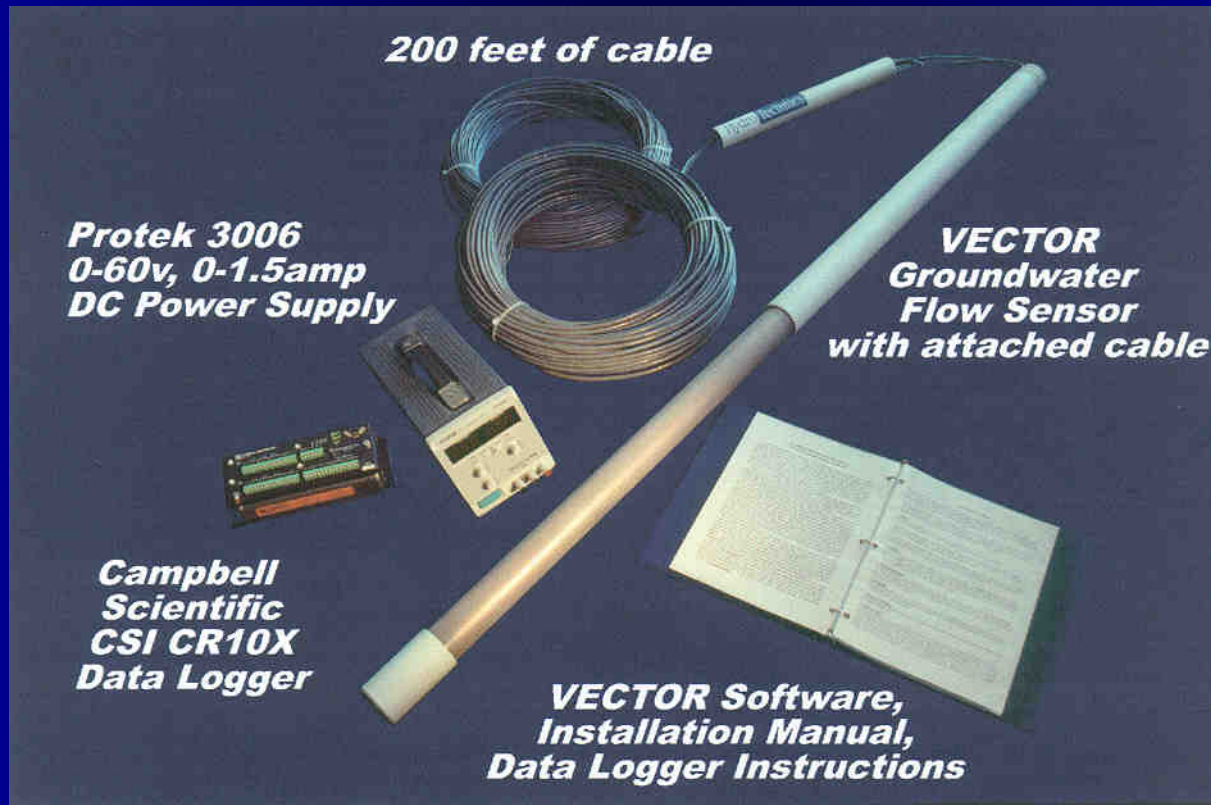
Principle of In Situ Flow Sensor Operation



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Schematic of In Situ Flow Sensor



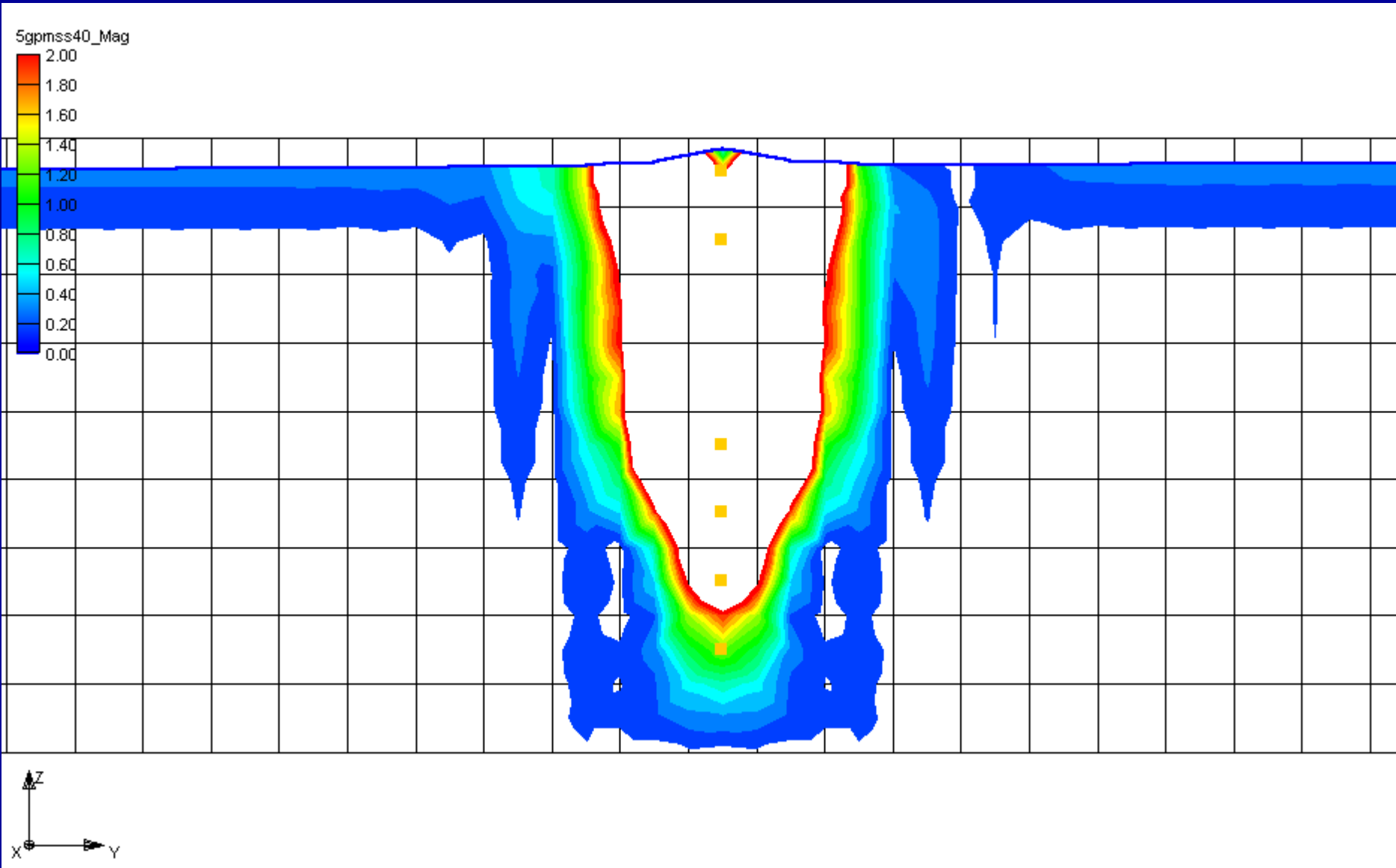
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In Situ Flow Sensors

- 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

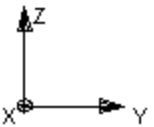
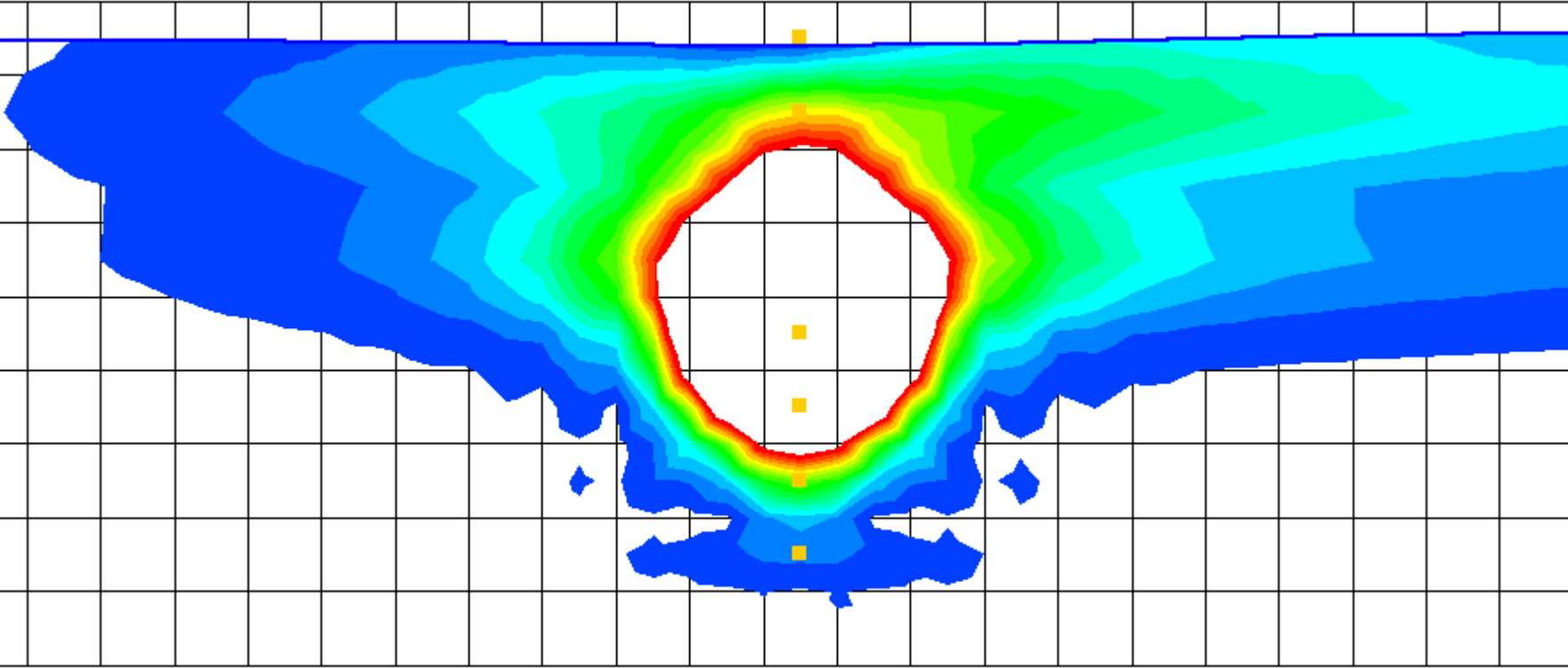
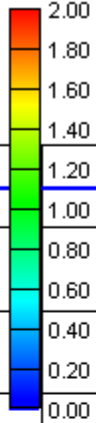


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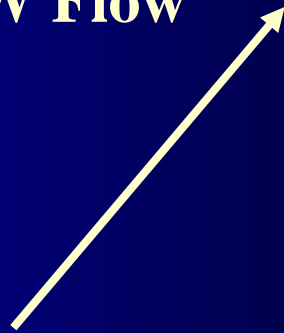
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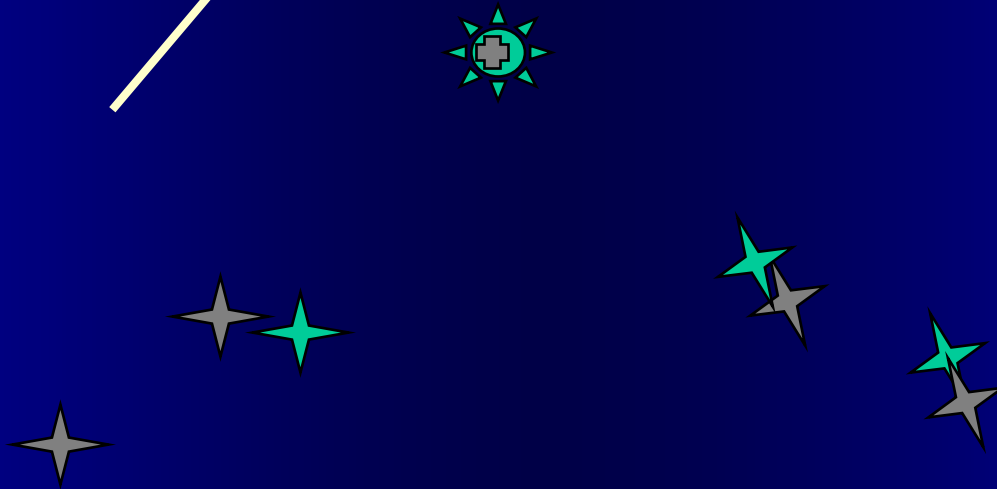
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Location of Probes

Direction of GW Flow

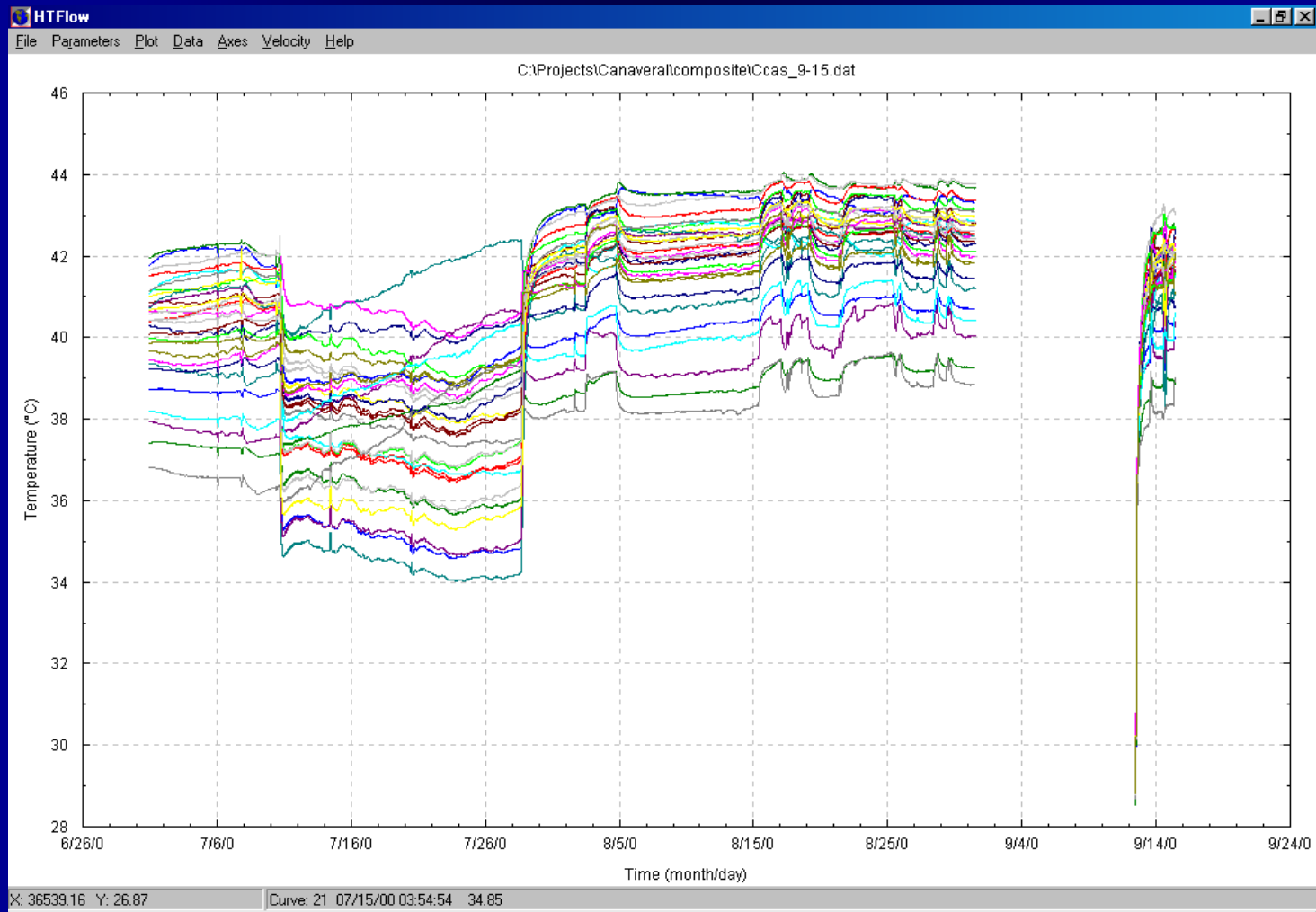


1 m



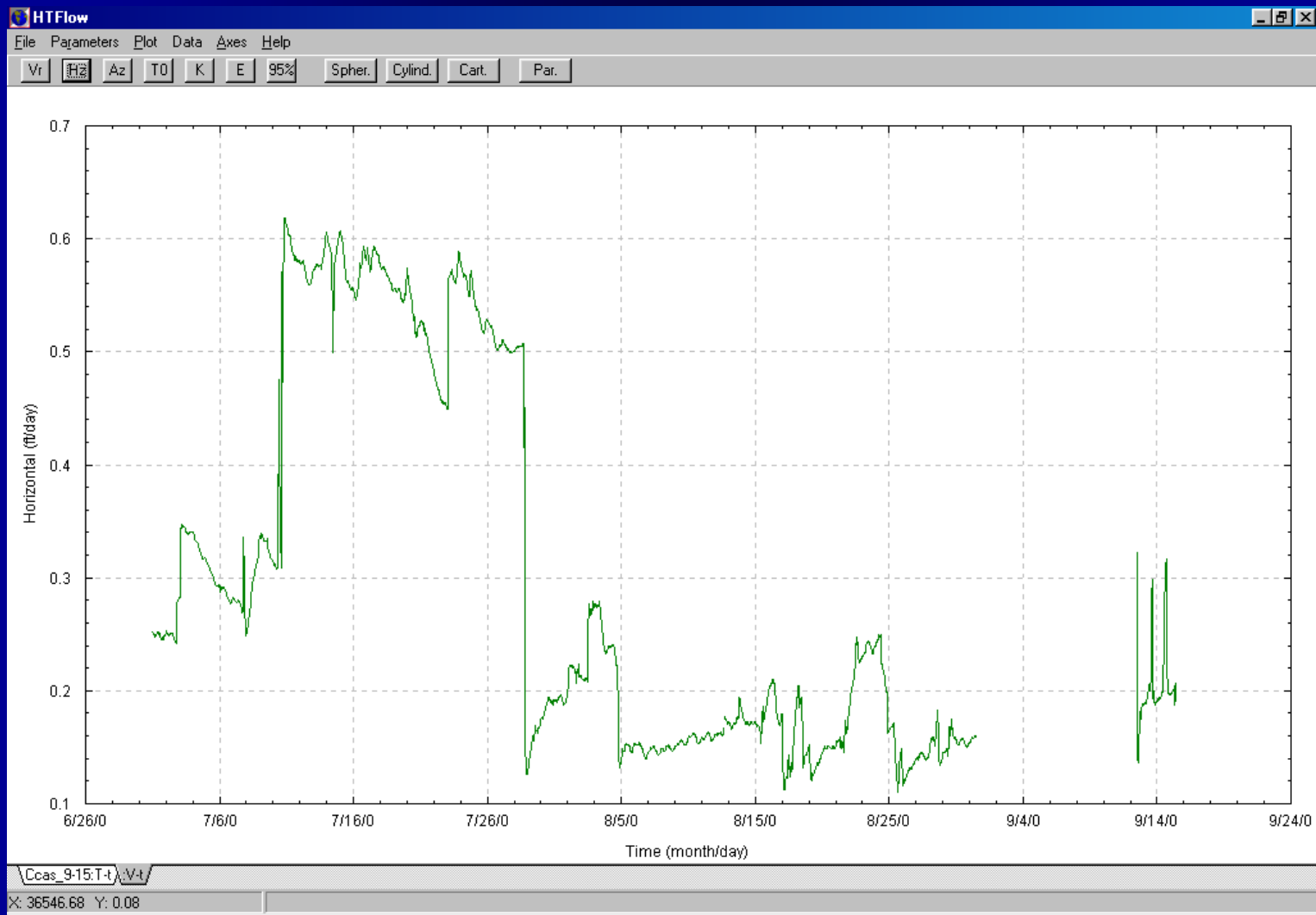
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Transient Temperature Effects for Sensor C-01



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Long-Term Horizontal Flow Velocity for Sensor C-01



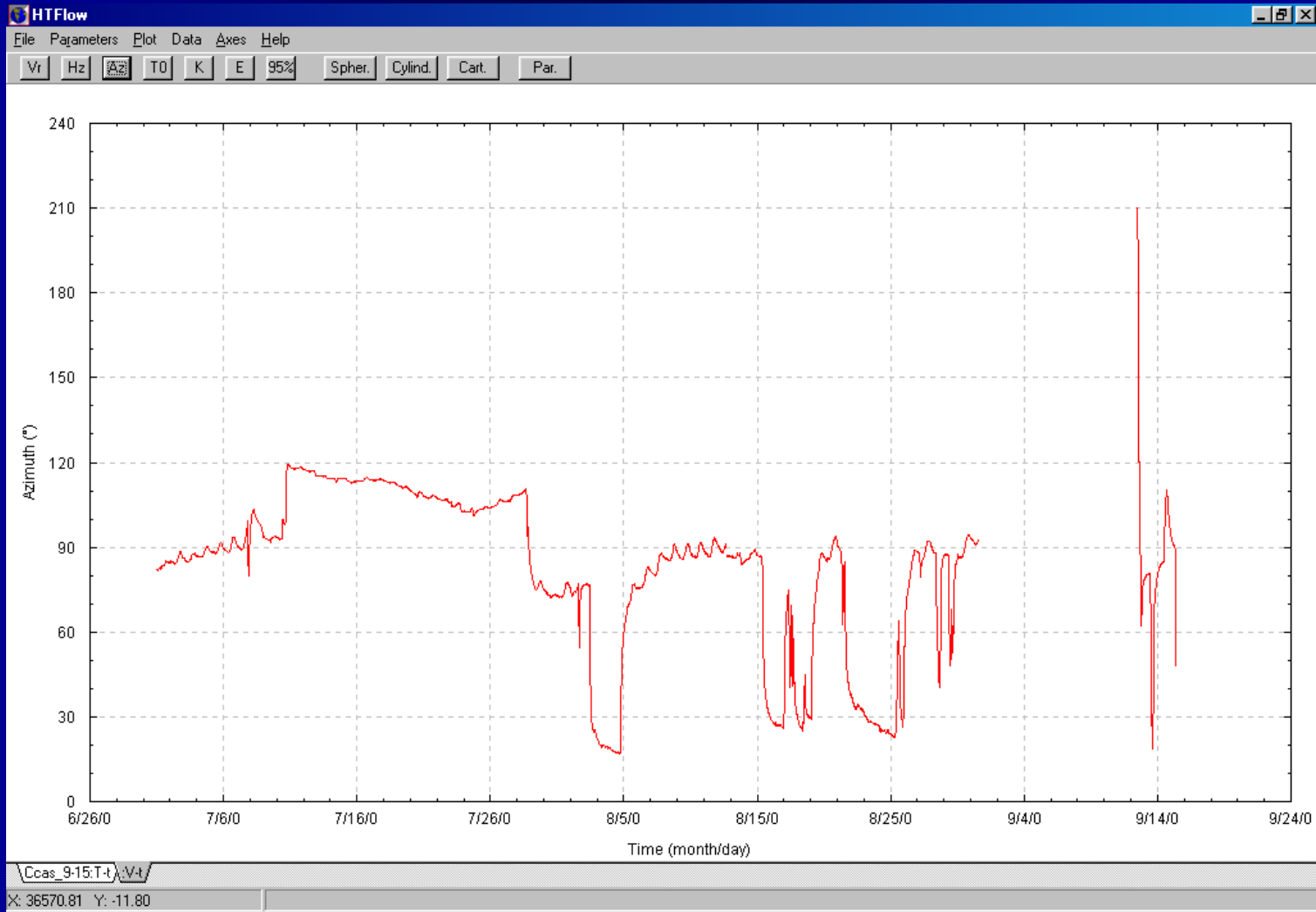
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Long-Term Vertical Flow Velocity for Sensor C-01



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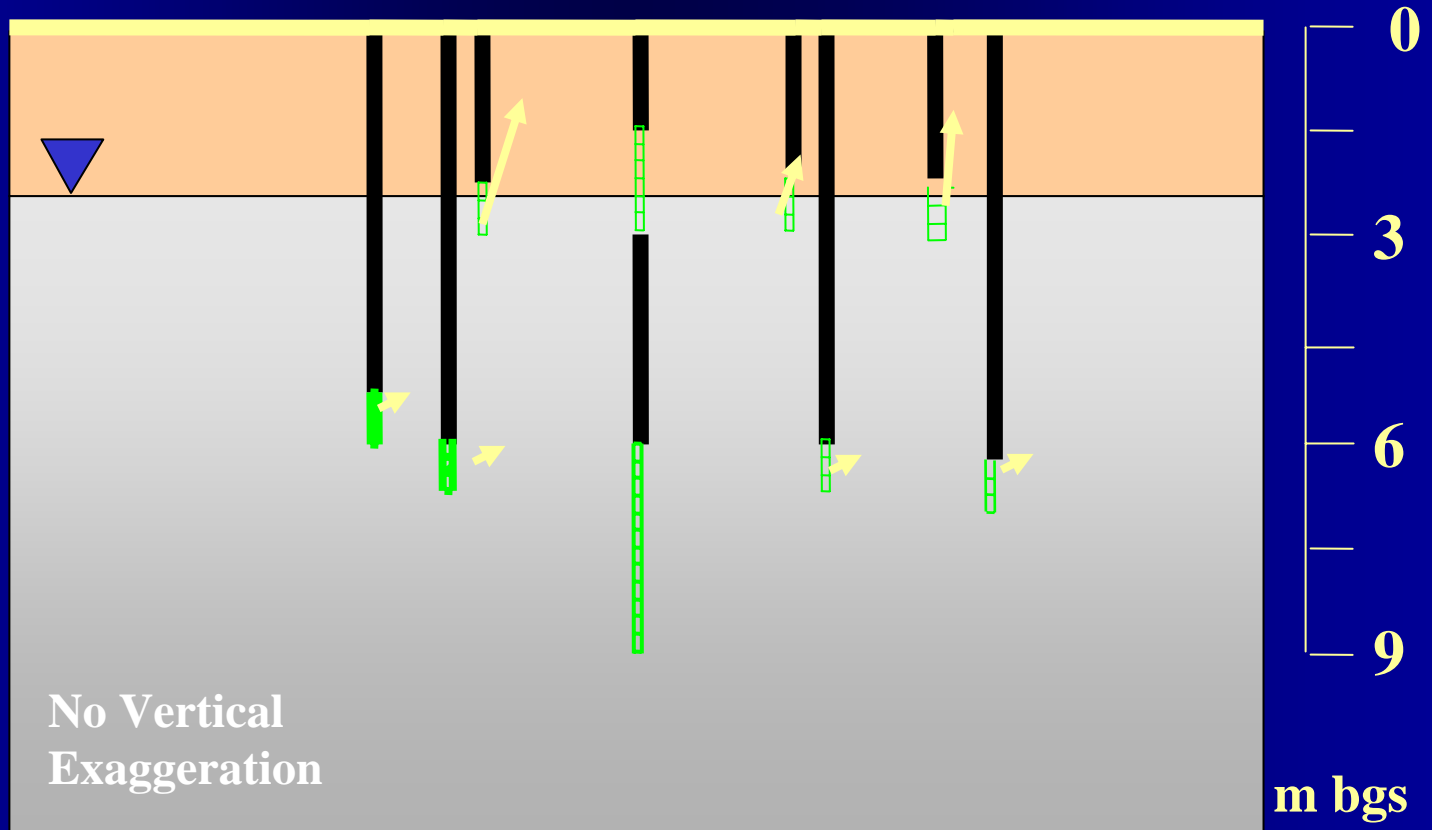
Long-Term Direction of Horizontal Flow for Sensor C-01



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SSW

SSE



Line length represents 0.3 m/day

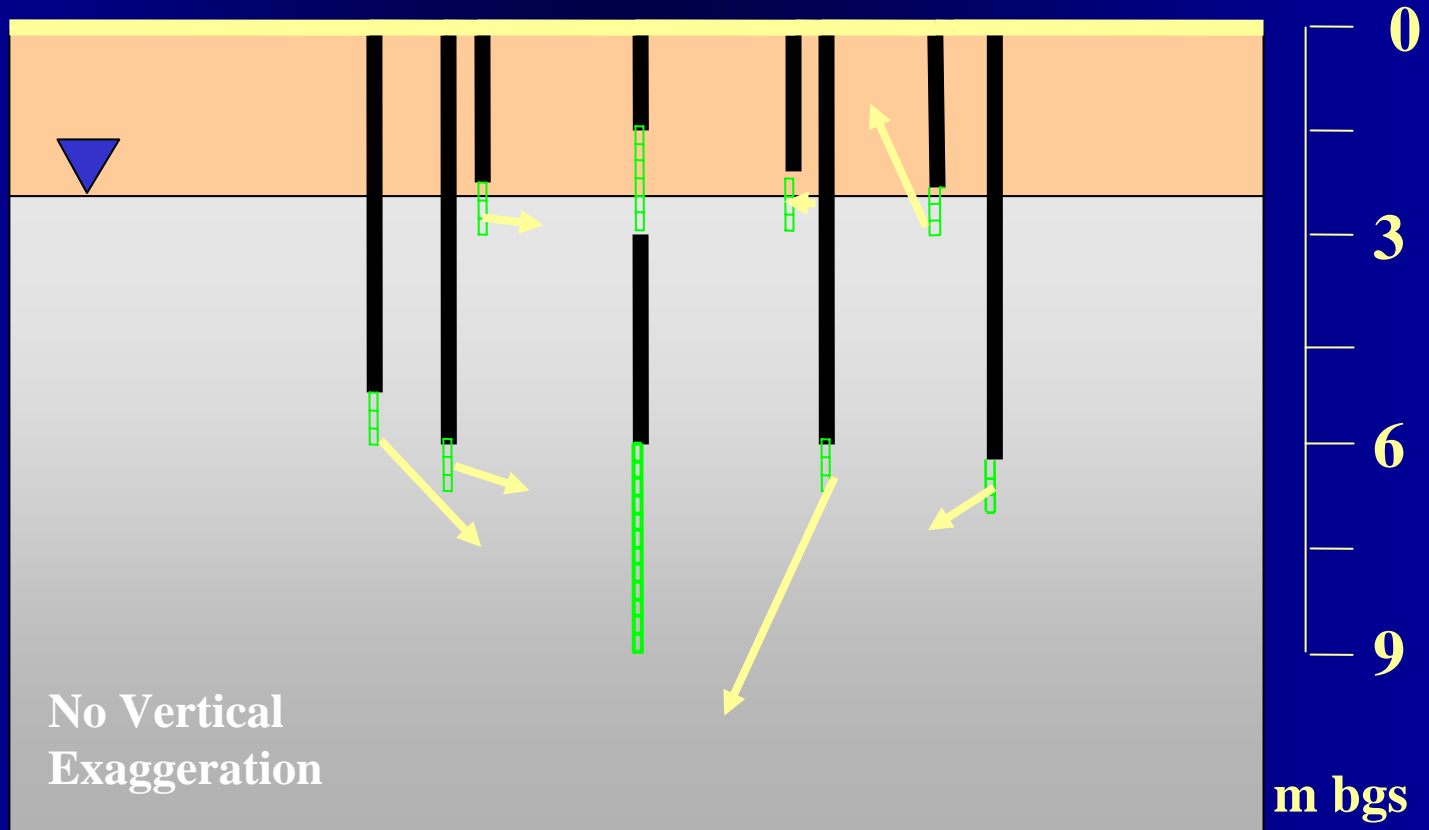
Flow under Natural Conditions

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SSW

SSE



→ length represents 0.3 m/day

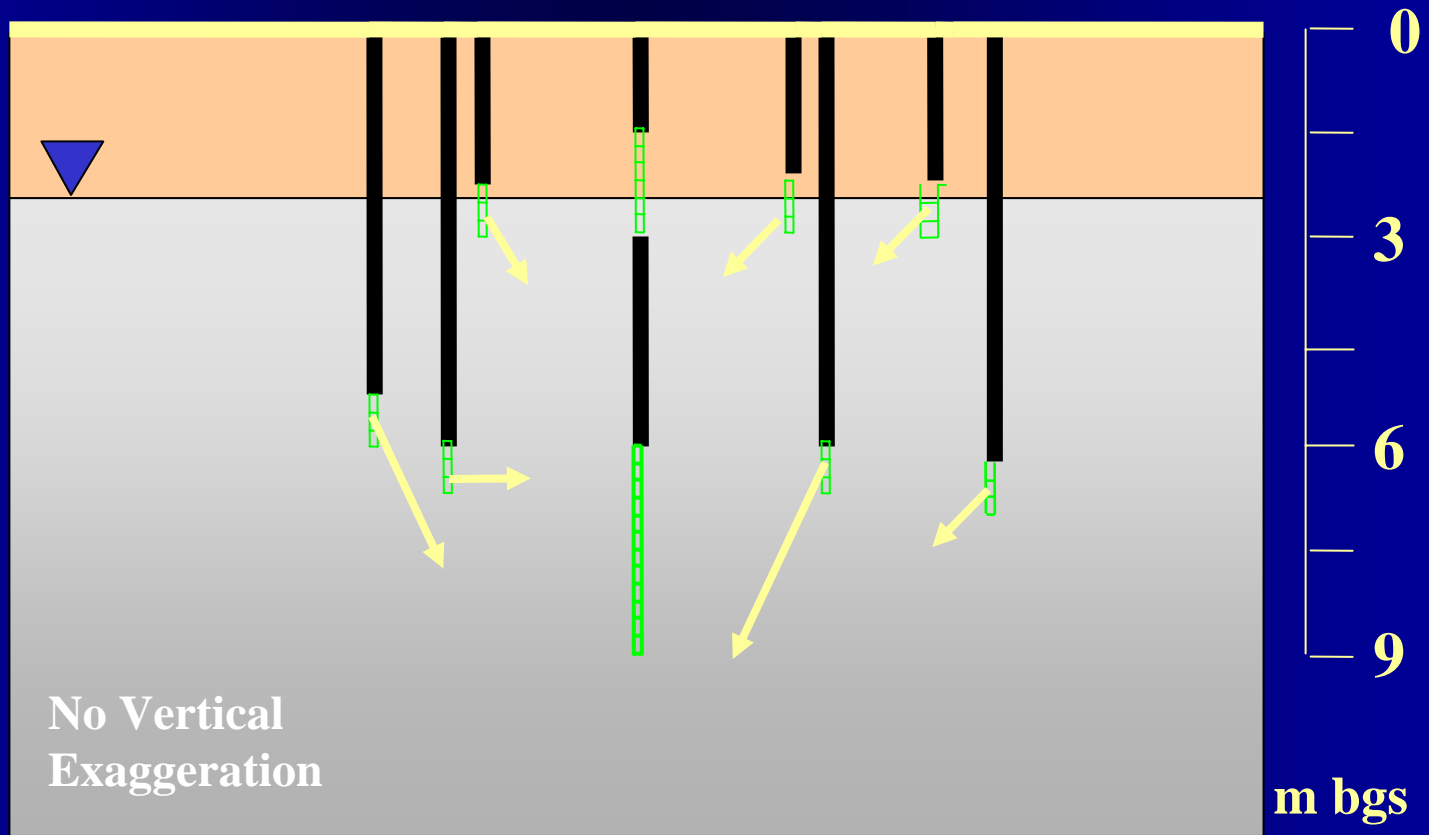
Flow under Pumping Conditions - Actual Data



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SSW

SSE



Line length represents 0.3 m/day

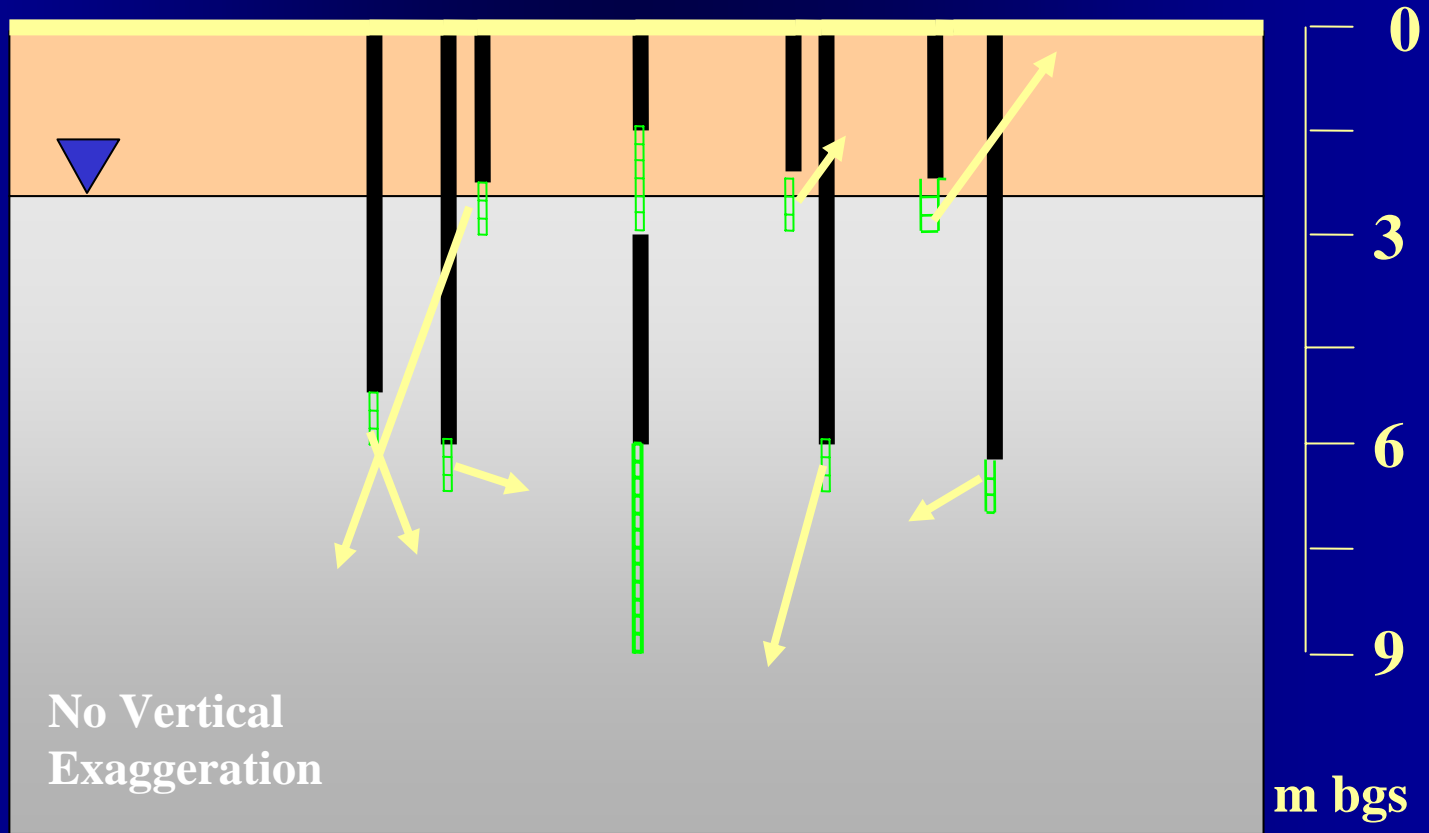
Flow under Pumping Conditions - Background Removed

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SSW

SSE



Line length represents 0.3 m/day

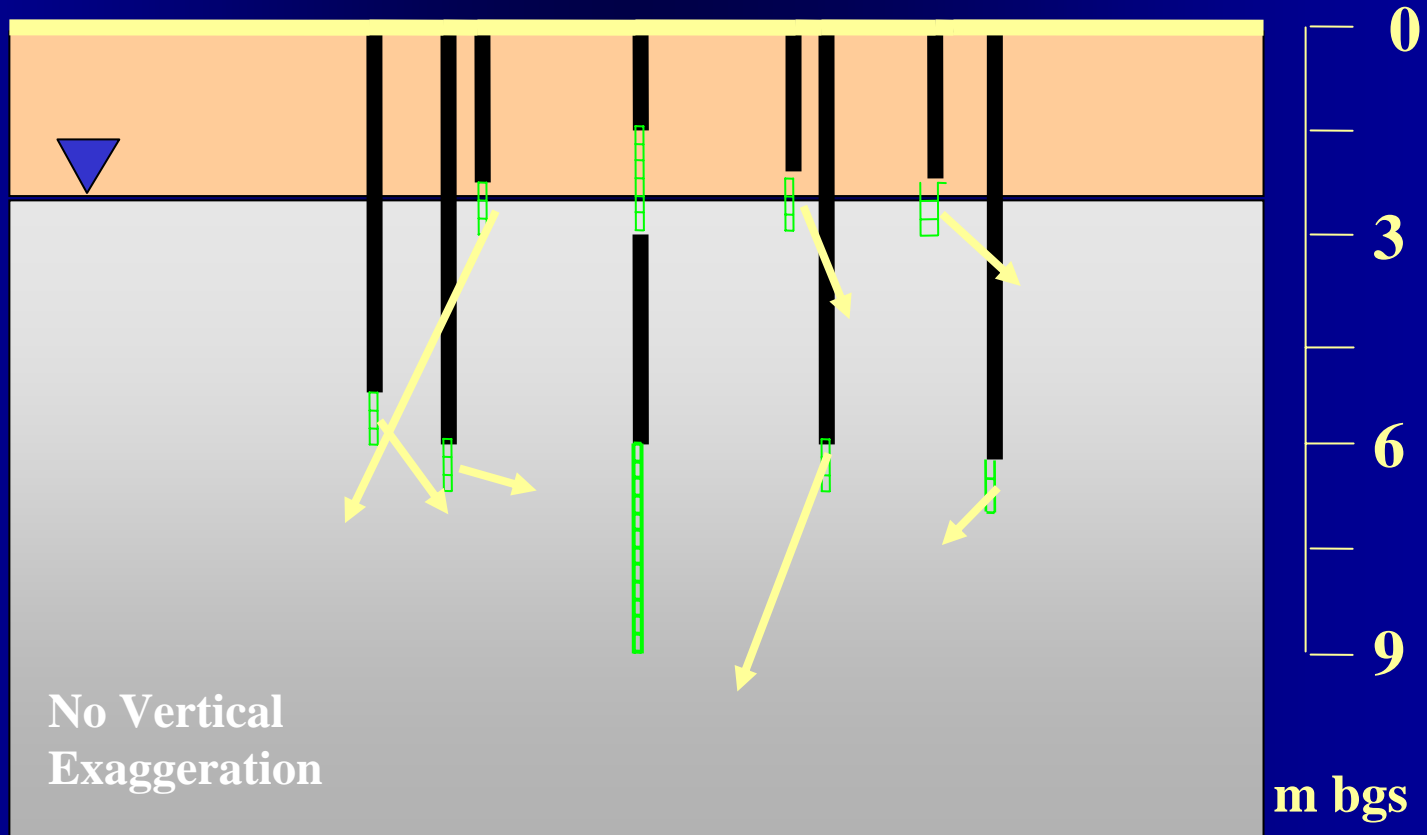
Flow under Recirculating Conditions - Actual Data

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SSW

SSE



Line length represents 0.3 m/day

Flow under Recirculating Conditions - Background Removed

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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



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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



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