A Review of Emerging Sensor Technologies for Facilitating Long-Term Ground Water Monitoring of Volatile Organic Compounds

Doug Sutton, Ph.D., GeoTrans, Inc.
Kathy Yager, EPA-OSRTI

Accelerating Site Closeout, Improving Performance, and Reducing Costs through Optimization
Dallas, TX – June 15-17, 2004

EPA

Background

- This presentation is based on the following EPA report

A Review of Emerging Sensor Technologies for Facilitating Long-Term Ground Water Monitoring of Volatile Organic Compounds (August 2003)
EPA 542-R-03-007

- Prepared by GeoTrans for EPA OSRTI

- Information gathered by
  - Interviewing environmental consultants
  - Reviewing publicly available literature
  - Interviewing research and/or commercial teams of each technology

Downloaded the report from www.cluin.org

Presentation Topics

- Current long-term ground water monitoring practices
- Requirements for an effective sensor-based instrument for long-term monitoring of ground water quality
- Emerging sensor-based technologies
  - In-situ sampling and analysis
  - Commercialized technologies for automated sampling with above-ground analysis
  - Hand-held or otherwise portable analytical units
- Considerations for implementing these technologies
- Conclusions

Current Practices

- Field work
  - Measure water elevation in the well
  - Sample
    - Three-well purge
    - Low-flow sampling
    - Passive diffusion bags
  - Prepare and ship samples (including QA samples)
  - Decontaminate equipment

- Analytical work
  - Independent laboratory
  - Standard methods (e.g., 8260b, 8021b, etc.) with backup
  - Standard turnaround times ranging from 2-3 weeks
  - Provide data in electronic format

Current Practices

- Approximate sampling cost (assume 20 monitoring wells)
  - Three-well purge or low-flow sampling
    - $3,000 to $8,000 per event
  - Passive diffusion bags
    - $2,000 to $3,000 per event

- Approximate analytical cost (assume 20 monitoring wells)
  - $2,500 per event (including analysis of QA samples)

- Sensor technologies would attempt to
  - Reduce labor and costs
  - Provide real-time data
  - Reduce errors associated with collecting and transporting samples

Requirements for an Effective Sensor-Based Instrument

- An effective sensor-based instrument would…
  - Have the necessary detection limit
  - Be accurate and precise
  - Revert to a common baseline for each sample)
  - Provide results in a reasonable time frame
  - Withstand field conditions
  - Require little maintenance
  - Be easy to use and calibrate
  - Distinguish one VOC from another
  - Be cost-effective
  - Be acceptable to regulators and other stakeholders

Emerging Technologies

- In-situ sampling and analysis
  - Most sensors in this category are in the research and development phase with operational and testable prototypes
  - Most are designed to analyze for one constituent or one family of constituents
  - Some sensors conduct analysis in the vapor phase, rely on VOCs to partitioning according to Henry's Law
    - Chemiresistors
    - Quartz crystal microbalance
    - High resolution ion mobility spectrometry (IMS)
  - Other sensors make the measurement directly in the aqueous phase
    - Resonance Enhanced Multiphoton Ionization (REMPI)
    - Wave-guides
    - Mid-infrared fiberoptic sensors

Emerging Technologies

- Commercialized automated sampling with above-ground analysis
  - VOC Monitor (Waste Technologies of Australia)
    - Measures total VOCs
    - Detection range of 100 ug/L to 20,000 ug/L
    - Approximately $4,000 per well (assumes one system for 4 wells)
    - Improvements in detection range, selectivity, and cost reduction underway
    - www.wastetechnologies.com

  - Burge Environmental Sampling System and TCE Optrode
    - Measures TCE or chloroform (other constituents under development)
    - Detection range (1 ug/L for TCE)
    - Calibration, QA sampling, etc. is automated
    - Approximately $5,000 per well (assumes one system for 6 wells)
    - www.burgenv.com

Emerging Technologies

- Hand-held analytical technologies
  - µChemlab™ –miniaturized GC and surface acoustic wave (SAW) sensor
    - Similar in size to a personal digital assistant (PDA)
    - Separate unit required for analyzing aqueous samples
    - Sample time is approximately 2 minutes
    - Detects multiple constituents in a single sample (DL is < 5 ug/L for TCE)
    - In prototype stage, has commercialization partner
    - Cost might be under $5,000
    - www.sandia.gov/microchemlab

  - Hand-held GC – miniaturized GC and a glow-discharge detector (GDD)
    - Similar in size to a brick
    - Accepts gas and liquid samples
    - Detects multiple constituents in a single sample (DL is < 5 ug/L for TCE)
    - Commercialized
    - Cost might be under $30,000
    - www.handheldgc.com

Emerging Technologies

- Field portable analytical equipment
  - Five technologies evaluated by the EPA ETV Program in 1997 for ability to detected chlorinated VOCs in ground water
    - Electronic Sensor Technology (ESTCAL) – EPA 600-R-98-141
    - Inficon, Inc. HAPSITE – EPA 600-R-98-142
    - Innova Air Tech Multi-Gas Monitor – EPA 600-R-98-143
    - Perkin-Elmer Voyager Photovac Monitoring Instrument – EPA 600-R-98-144
    - Sentex Systems Scentograph Plus II – EPA 600-R-98-145

  - Two instruments provided comparable results to an off-site laboratory. Instruments could be used for investigations and routine monitoring.
    - HAPSITE – cost of $76,000, requires a chemist with experience and 3 days of training
    - Scentograph Plus II – cost of $28,000, requires a technician with 1 day of training

Considerations

- Demonstrating reliability
  - Sensor reliability
  - Instrument reliability

- Site-specific conditions
  - Sensitivity
  - Addressing multiple contaminants
  - Other constituents of ground water (bacteria, turbidity, metals, pH, etc.)
  - Well construction and yield

- Regulatory approval
  - Sampling well water vs. sampling aquifer water
  - Precision and accuracy
  - QA/QC measures (calibration, blanks, etc.)

Considerations

- Cost-effectiveness
  - Consider the following scenario
    - Site with 20 monitoring wells with quarterly sampling
    - One type of sensor could replace traditional sampling
    - Sensor lasts for 5 years before needing replacement
    - Significant travel is not required
  - Consider the following sensor options
    - Option 1 – one sensor for each well
    - Option 2 – two technicians, each with a probe, sample wells at a rate of one well per hour
    - Option 3 – Automated sampling with above-ground analysis
    - Option 4 – Traditional sampling, but using hand-held or field portable instruments for analysis

Considerations

Summary of Cost-Effectiveness

Year	Traditional Low-end	Traditional Upper-end	Option 1	Option 2	Option 3	Option 4
1	$22,000	$42,000	$105,000	$23,000	$78,000	$31,000
2	$22,000	$42,000	$5,000	$13,000	$3,000	$16,000
3 4 5	… … …	… … …	… … …	… … …	… … …	… … …
Total	$110,000	$210,000	$125,000	$75,000	$90,000	$95,000

Sensor costs also include estimated cost for basic maintenance.

Conclusions

- Permanently installing a sensor-based instrument in each well
  - Might not be cost-effective
  - Would make calibration and maintenance difficult
- Other presented options
  - Might be cost-effective
  - Would make calibration and maintenance easier
- Cost-effectiveness increases with required sampling frequency.
- There are potential linkages between some of the automated sampling technologies and some of the hand-held analytical technologies.

Question and Answer Session

EPA

Emerging Technologies

- Chemiresistors
    - Clifford Ho (www.sandia.gov/sensor)
- Quartz crystal microbalance
    - Joel Roark (www.nomadics.com), Joseph Salvo (www.crd.ge.com)
- High resolution ion mobility spectrometry (IMS)
    - Joe Hartman (http://coen.boisestate.edu/sensor/sensorweb.html)
- Resonance Enhanced Multiphoton Ionization (REMPI)
    - University of South Carolina
- Wave-guides
    - Georgia Institute of Technology
    - New Jersey Institute of Technology
- Mid-infrared fiberoptic sensors
    - Boris Mizaikoff (http://asl.chemistry.gatech.edu)