USGS Research on Monitoring the Fate of Contaminants in the Unsaturated Zone

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Long-Term Performance Monitoring of Metals and Radionuclides in the Subsurface: Strategies, Tools, and Case Studies
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Outline

- USGS research programs
- Unsaturated-zone field sites
- Unsaturated-zone research studies
- USGS unsaturated-zone simulation models
- Metals transport and fate studies
USGS Research Programs

• Toxic Substances Hydrology Program
• National Research Program
• National Water-Quality Assessment Program
• Cooperative Water Program
• USGS Department of Defense Environmental Conservation (DODEC) Hydrology Program
Toxic Substances Hydrology Program

• Program Goal
  – Provide scientific information, methods, and tools on toxic substances in the Nation’s hydrologic environments, to:
    • Improve characterization and management of contaminated sites,
    • Protect environmental and human health, and
    • Reduce potential future contamination problems.

http://toxics.usgs.gov/
Toxic Substances Hydrology Program

• Major program goals/investigation types
  – Point-source subsurface contamination
  – Regional- and watershed-scale contamination
Toxic Substances Hydrology Program

• Research approach
  – Establish long-term, representative field research sites/study areas (field labs)
  – Develop interdisciplinary research teams
  – Holistic (system-concept) approach
  – Natural response to contamination
  – Generalize results to other similar sites
  – Develop and transfer methods/models
Toxics Program
Research Sites

- Peanut Agriculture (pesticides)
- Point-source Subsurface Investigations
- Regional- and Watershed-Scale Investigations
- National Investigations:
  - Mercury in Aquatic Ecosystems
  - Emerging Contaminants
National Research Program

• Mission
  – Develop new information, theories, and techniques to understand, anticipate, and solve water-resource and water-quality problems facing the United States and other nations

http://water.usgs.gov/nrp/
National Research Program

• The NRP generates and disseminates knowledge
  – By conducting fundamental and applied research on complex hydrologic biochemical and geochemical problems
  – By developing techniques and methodologies
  – By providing scientific leadership in hydrology to the USGS, academia, and other government agencies
  – By focusing generally on long-term investigations integrating hydrological, geological, climatological and biological information
Example NRP Research Topics

- Unsaturated-zone hydrology and geochemistry
- Unsaturated-zone simulation modeling
- Flow of immiscible contaminants
- Fractured rock hydrology
- Hydrology of low-permeability systems
- Borehole and surface geophysics
Unsaturated-Zone Field Sites

Amargosa Desert Research Site (ADRS), Beatty, NV

Bemidji Crude Oil Spill Site, Bemidji, MN

Yucca Mountain Project, Yucca Mt., NV
Amargosa Desert Research Site (ADRS)

Adjacent to the Beatty low-level waste-disposal facility
Amargosa Desert Research Site (ADRS)

- Investigating the movement of radioactive and mixed organic contaminants in a thick arid unsaturated zone.
- A 65-foot casson instrumented to observe gas and water movement in 300-ft unsaturated zone.

http://toxics.usgs.gov/sites/adrs_page.html
Tritium in Water Vapor – UZB-2

Graph showing tritium concentrations in water vapor over time, with markers for Core, Core Vapor, Apr 1994, May 1997, May 1999, and Apr 2000. The depth in meters is on the y-axis, and tritium concentrations in tritium units are on the x-axis.
Simplified Method for Detecting Tritium Contamination in Plants and Soil

- Uses plants as “tritium detectors”
- Solar distillation of plant foliage in plastic bags
- Cost-effective, saves time
- Plume mapping

http://toxics.usgs.gov/highlights/tritium.html
Map of Tritium in Plant Water
Plants Control Moisture Movement in Arid Areas

- Southwestern deserts have been drying out for 16,000 years
- Moisture is moving upward rather than downward
- Effect extends hundreds of feet down into the subsurface

http://toxics.usgs.gov/highlights/drying_deserts.html
Alternative Landfill Cover Assessment

- Fort Carson, CO
- Soil-water measurement technology developed for dry-soil investigations
- Evapotranspiration landfill cover

- Plants limit the amount of water that percolates beneath the root zone

http://toxics.usgs.gov/topics/rem_act/alternative_landfill.html
Bemidji Crude Oil Spill Research Site

- Fate of crude oil in unsaturated zone and saturated zone
- Distribution of oil in subsurface
- Geochemical evolution of contaminant plume
- Limitations of natural attenuation
- Unsaturated-zone fate and transport

http://toxics.usgs.gov/sites/bemidji_page.html
Distribution of Oil, Bemidji, MN

The diagram illustrates the distribution of oil in Bemidji, MN, with various layers and percentages indicated. The altitude above sea level is measured in meters, and the distance from the approximate center of the oil body is also measured in meters. The diagram includes labels for observation wells, sampled intervals, land surface, and the water table.
Geochemical Zones
Unsaturated-Zone Tracer Test

- Hypothesis - Tracer movement will be attenuated as tracers pass through crude-oil contaminated sand and crude oil floating on the water table, compared to movement in an adjacent clean area.
Unsaturated-Zone Instrumentation

- Soil-moisture sensors
- Tensiometers

Black oil-contaminated sand on pit walls
Tracer Test Results

- The rate of tracer transport was much greater in the oily zone compared to the nearby oil-free area.
- Preferential flow through the oil-contaminated sand by-passes most of the pore space, reducing adsorption and dispersion.
Yucca Mountain Project

- Support for DOE license application
- Geologic disposal of high-level radioactive waste studies
- Unsaturated-zone studies
Yucca Mountain Project
Unsaturated-Zone Hydrology

- Design and construct equipment for long-term monitoring
- Gas-flow characterization
- Transport through fractured and faulted volcanic rocks
- Estimation of infiltration rates in a desert environment
- Travel-time estimates
USGS Unsaturated-Zone Research Studies

- MTBE degradation in the unsaturated zone
- Estimating spatial variability of recharge with unsaturated-zone measurements
- Unsaturated-zone hydraulic conductivity measurements
- Unsaturated-zone flow theoretical models
MTBE Degradation in the Unsaturated Zone

- Potential sources of methyl tert-butyl ether (MTBE) in the unsaturated zone
  - Atmosphere
  - Leaking underground storage tanks
  - Ground water
  - Used motor oil
- MTBE degradation in unsaturated zone
  - Degradation products – tert-butyl alcohol (TBA)

MTBE to TBA Conversion in Lab Column
Sediments from a site in New Jersey

http://toxics.usgs.gov/highlights/mtbe.html
Estimating Spatial Variability Of Recharge with Unsaturated-Zone Measurements

- 48 sites in southern New Jersey
- Unsaturated-zone sediment samples
- Moisture-content data
- Estimates of conductivity and matric potential
- Median recharge – 29.1 centimeters per year
- 17 percent of the sites exceeded 250 centimeters per year
- Fundamental to understanding non-point source contaminant loading

http://water.usgs.gov/pubs/wri/wri024288/
Recharge Variability

![Graph showing the fraction of data in intervals for recharge (R), in centimeters per year.]

- Fractions for different recharge intervals:
  - < 0 (evapotranspiration)
  - 0 < R < 50
  - 50 < R < 100
  - 100 < R < 150
  - 150 < R < 200
  - 200 < R < 250
  - R > 250
Unsaturated-Zone Hydraulic Conductivity Measurements

- Steady-state centrifuge method
- Extends measurement range by at least three orders of magnitude
- Especially useful for low-permeability media

http://wwwrcamnl.wr.usgs.gov/uzf/lab.html
Unsaturated-Zone Flow: Theoretical Models

- Unsaturated flow in a centrifugal field
- Quantification of soil structure
- Flow under low-water-content conditions
- Preferential flow in soils, fractured rock, and layered media
- Representation of flow properties, hysteresis, and temperature effects
- Field-scale unsaturated-zone flow behavior – infiltration, recharge, redistribution

http://wwwrcamnl.wr.usgs.gov/uzf/theory.html
USGS Unsaturated-Zone Simulation Modes

- **AIR2D** – Air flow, air to or from a single borehole, steady-state flow field associated with vapor extraction
- **AIR3D** – Adaptation of MODFLOW, three dimensional air-flow, heterogeneous, anisotropic conditions, vapor-extraction remediation
- **R-UNSAT** – Reactive, multispecies transport, heterogeneous, variably-saturated porous media

http://nj.usgs.gov/toxics/models.html
USGS Unsaturated-Zone Simulation Modes

• SUTRA – 2D or 3D saturated-, unsaturated-, variable-density ground-water flow with solute or energy transport
  http://water.usgs.gov/nrp/gwsoftware/sutra.html

• VS2DI – Simulation of water, solute, and energy transport through variably saturated porous media
  http://water.usgs.gov/software/vs2di.html
Examples of Research on the Fate of Metals

• Mining related studies
  – Upper Arkansas River Toxics Project, CO
    http://toxics.usgs.gov/sites/upper_ark_page.html
  – Iron Mountain, CA

• Mercury contamination studies
  – National Assessment of Mercury in Aquatic Ecosystems
    http://toxics.usgs.gov/regional/mercury.html
  – Mercury Cycling in the Everglades, FL
    http://sofia.usgs.gov/projsubtopics/merc_cyc.html
Examples of Research on Metals

• Analytical methods development
  – Cation-exchange method for field speciation of hexavalent chromium
  – Ultra-low determination of metals in environmental materials
    http://wwwbrr.cr.usgs.gov/projects/SW_inorganic/