U.S.NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

3-D Subsurface Monitoring and Modeling Following Contamination Events

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OECD/NEA
Washington, DC

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
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Overview

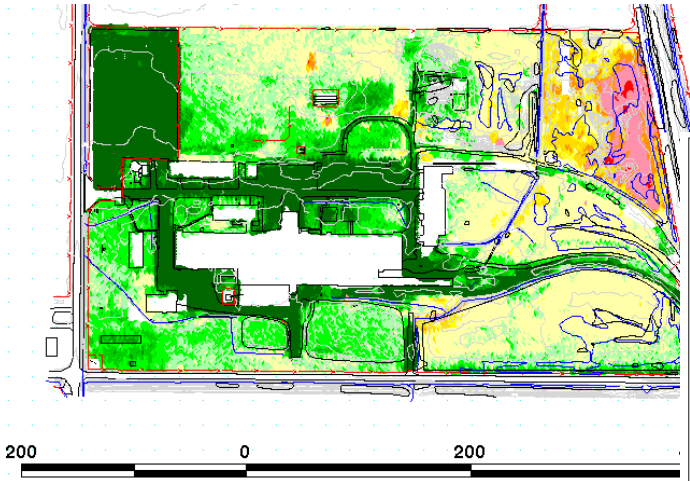
- Surface and Subsurface Survey Strategies
- Technical Issues for Subsurface Evaluation and Surveillance
- Develop Conceptual Site Model Using Historical & Field Data
- Bayesian Analyses to Reduce Uncertainties in Conceptual Site Models
- Formulate 3-D Probabilistic Models to Optimize Monitoring Locations and Sampling
- Utilize Monitoring Data to Select and Evaluate Ongoing Compliance or Remediation Alternatives
- Information Sources

2D Surface Survey to 3D Subsurface Survey Strategies

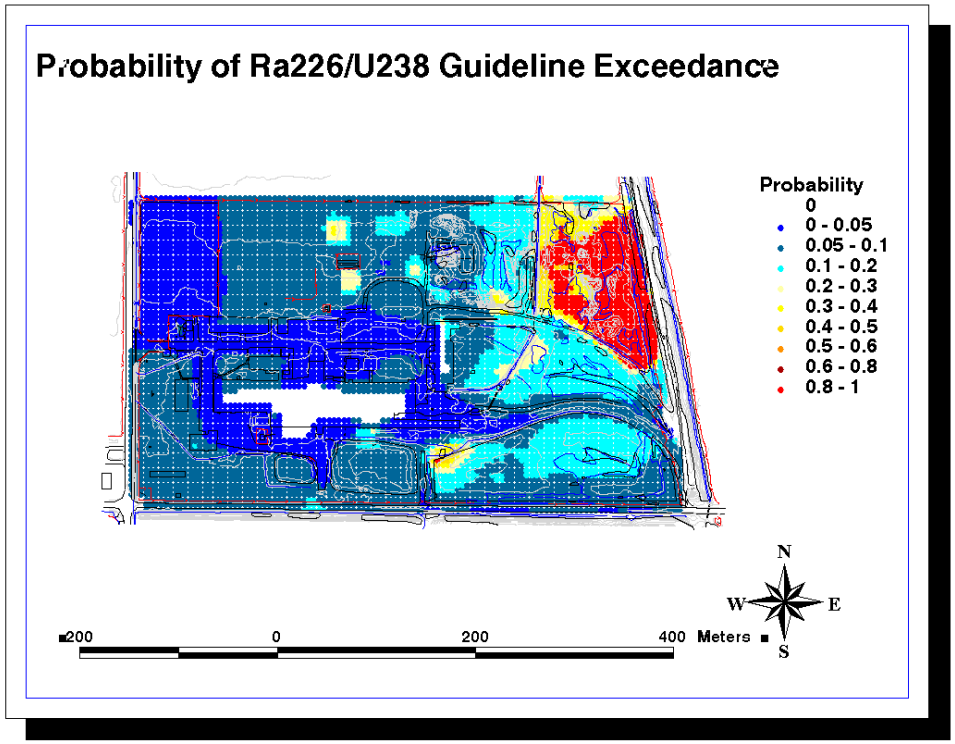
- Understand requirements of pending decisions
- Explicitly identify and manage uncertainties that could lead to decision errors
  - Sampling uncertainties -- MARSSIM (Aug 2000)
  - Analytical uncertainties -- MARLAP (Dec 2004)
  - Materials specific – MARSAME (Jan 2009)
  - MARSSIM update – In progress (???-2011)
  - Subsurface specific – MARSASS (???-????)
- Implementing the intent of "performance based" (surface/subsurface sampling & analysis)

Result Supports Early Decision-Making

Raw Walkover Results



Processed Results



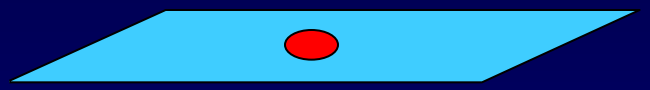
via Bob Johnson - ANL

via Bob Johnson - ANL

3 Types of Sampling Designs: 2d, 3d, and 3d Core

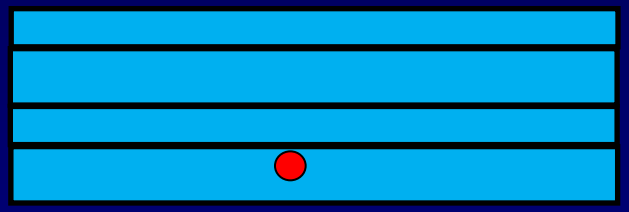
Based on whether there are multiple layers and whether the user wishes to core, the following broad scenarios are possible for a single sample.

2d



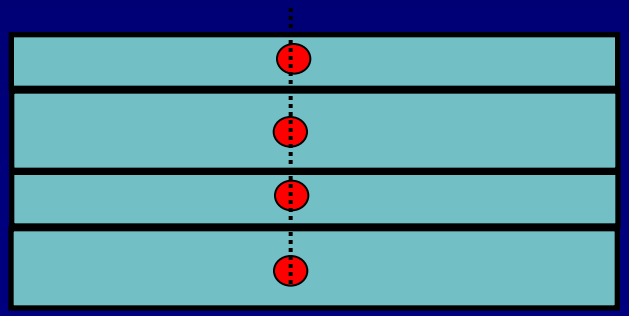
In a 2d application, the sample is represented within a single layer.

3d



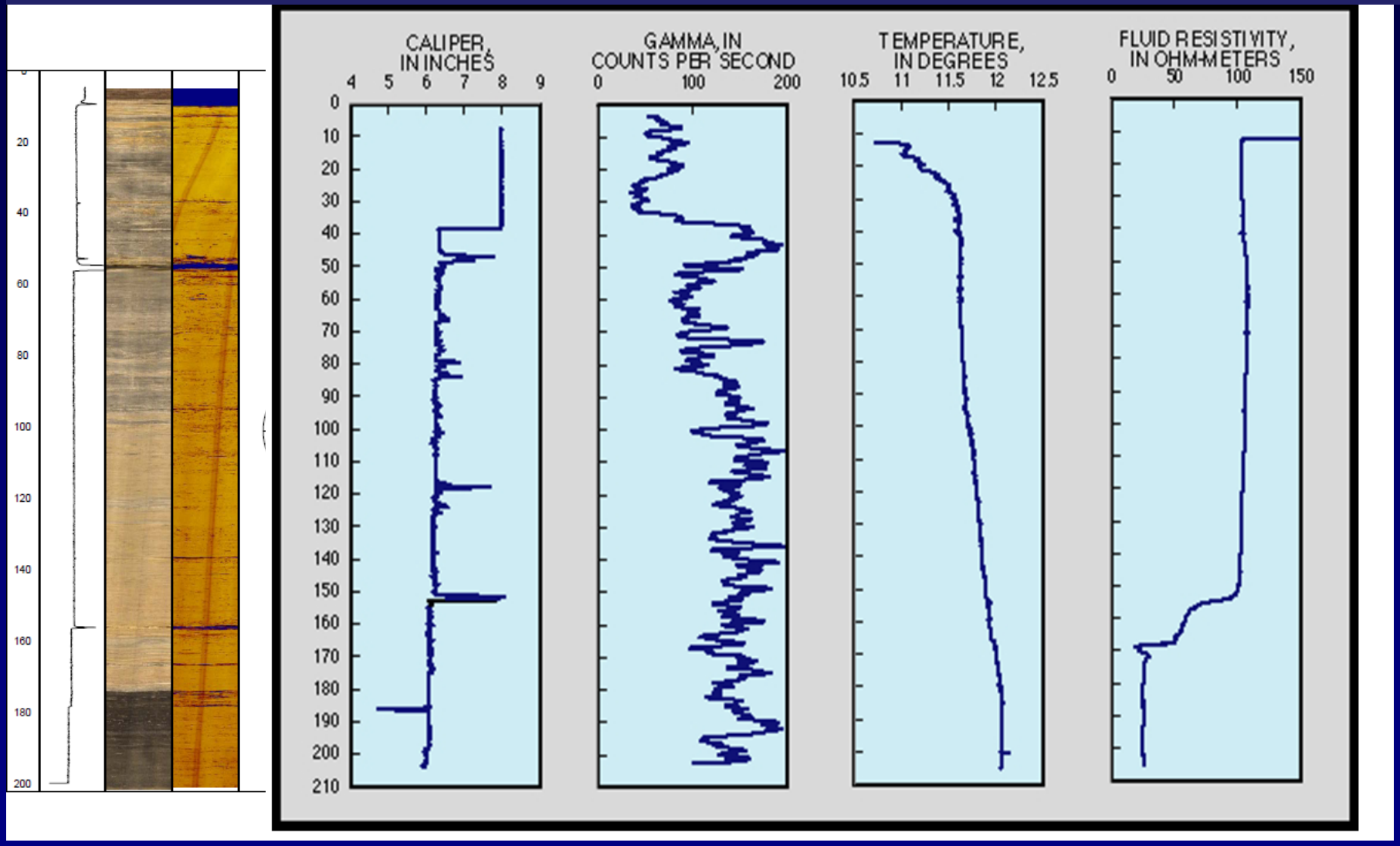
In a 3d application, the sample is located within a single layer at the depth of interest.

Core

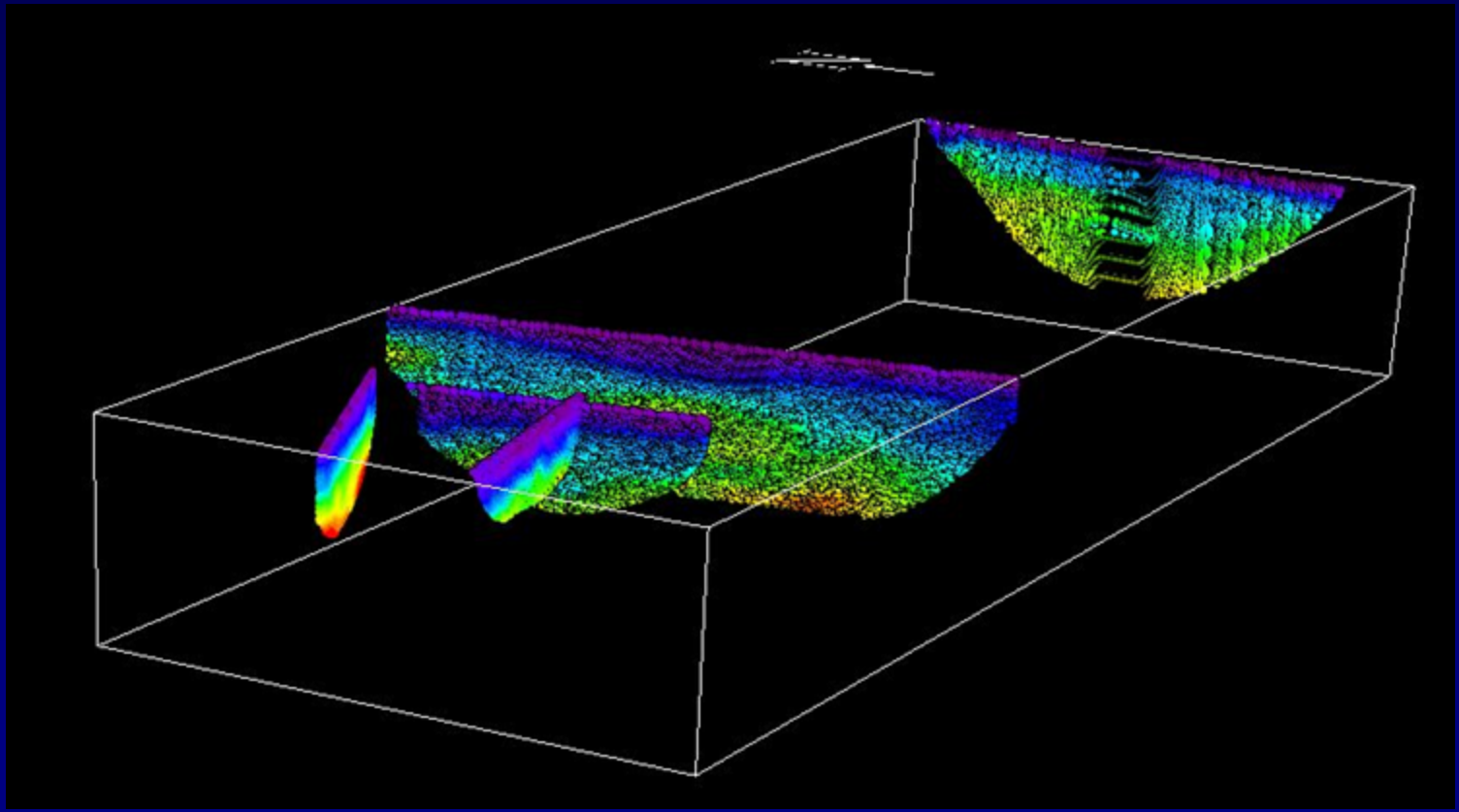


In a core application, the sample is located within a single layer at the depth of interest. Then all layers above and below are also sampled subject to layer geometries.

Composites of Geophysical Logs, Photographic, Gamma Counts, Temperature and Fluid Resistivity



Surveys are often done in Transects

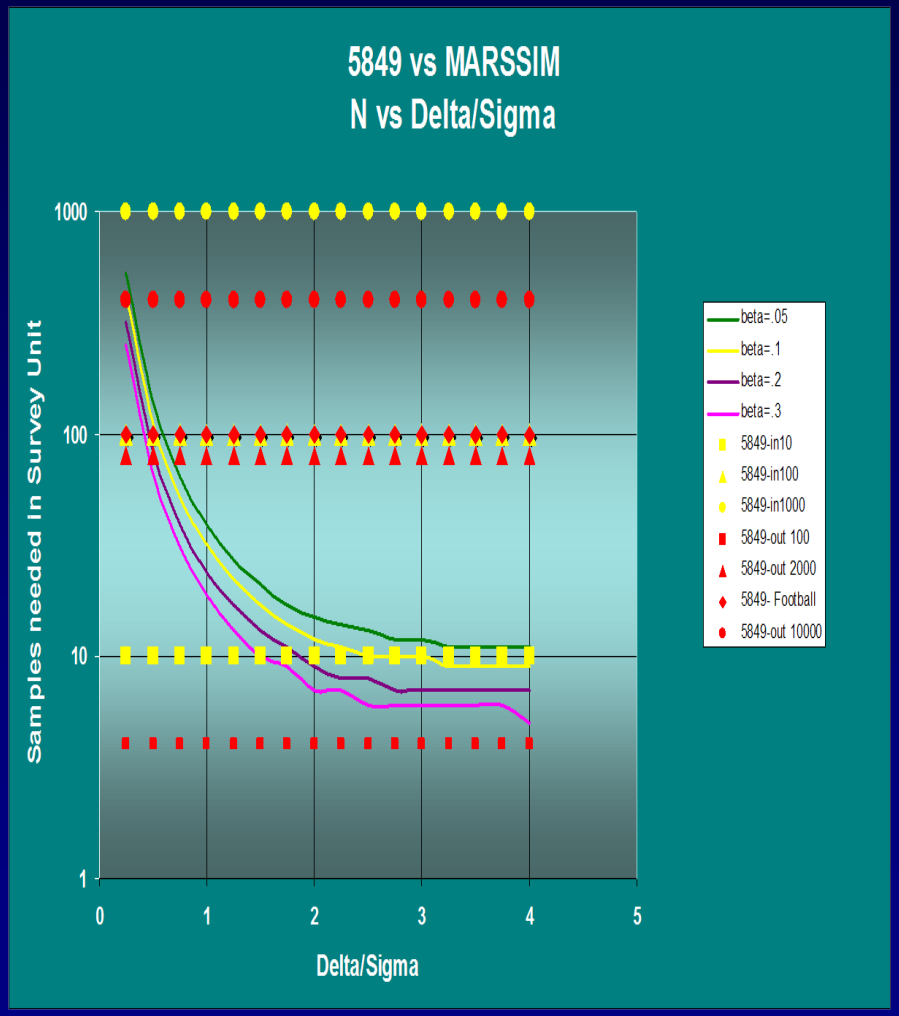


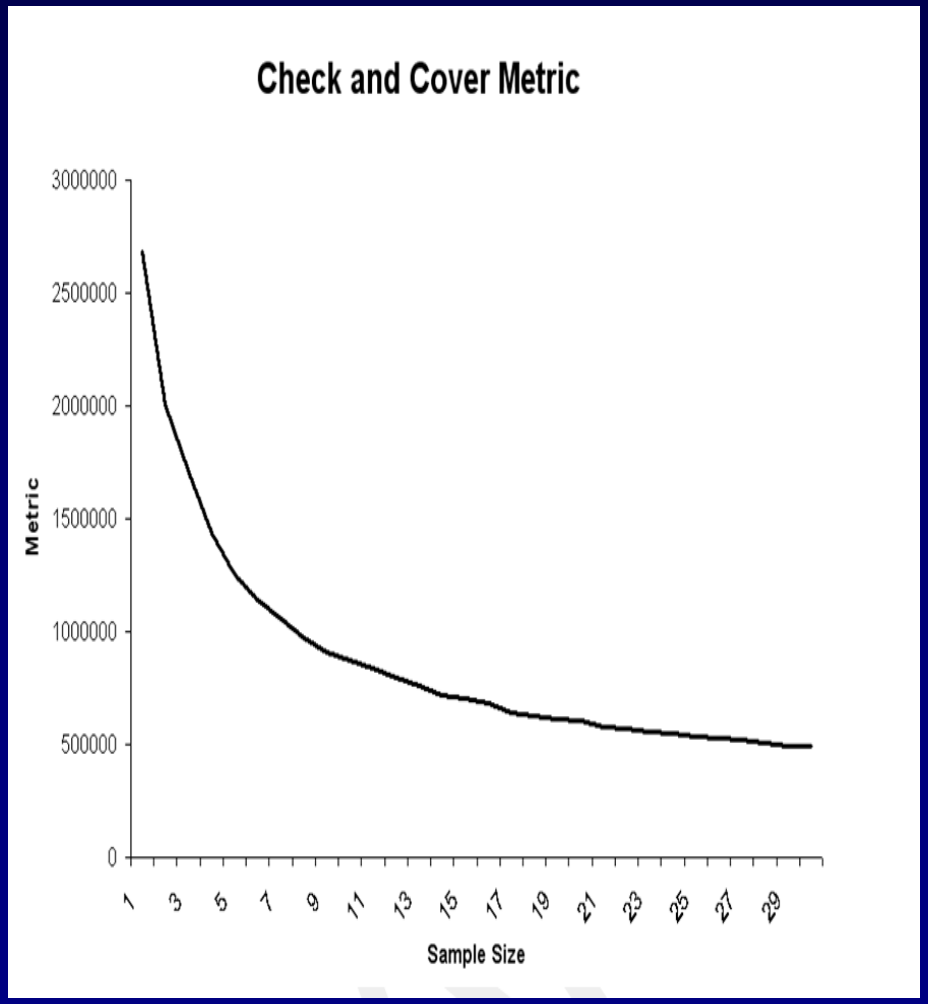
Surface vs. Subsurface

- Surface advantage
- Clear derivation of radiological criteria
- Measurements/sampling in place
- Scanning may provide comprehensive coverage

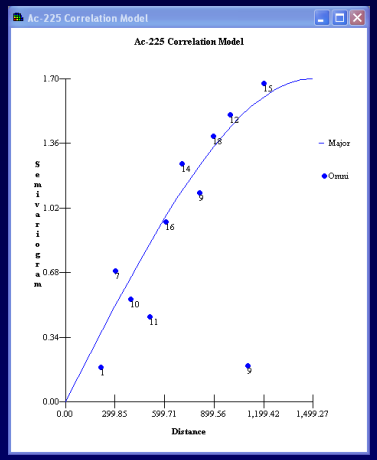
- Inaccessible heterogeneities
- Cautious derivation of radiological criteria
- Sampling more complex, expensive, time consuming & labor intensive
- Exhaustive scanning impossible

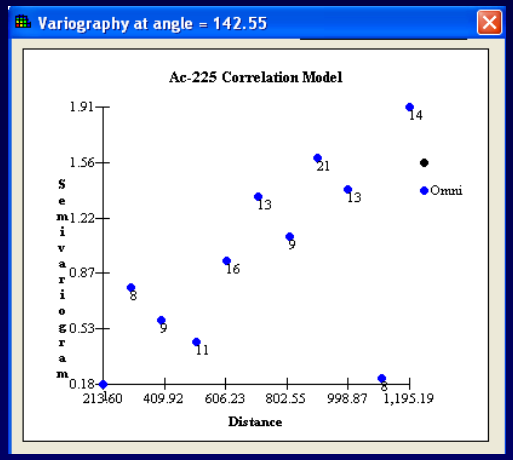
Number of Samples by Metric

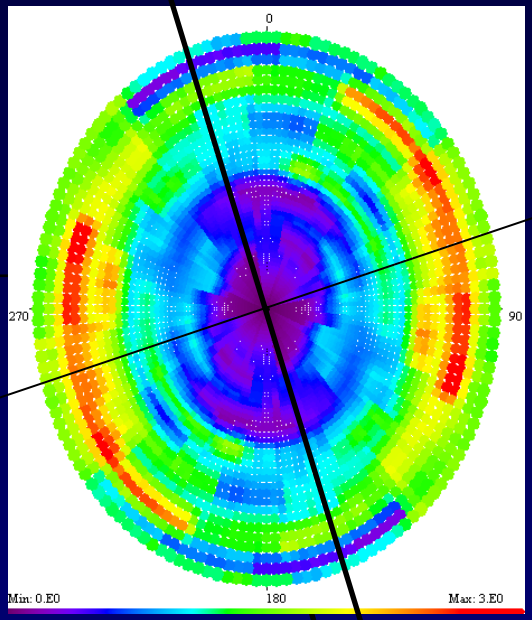


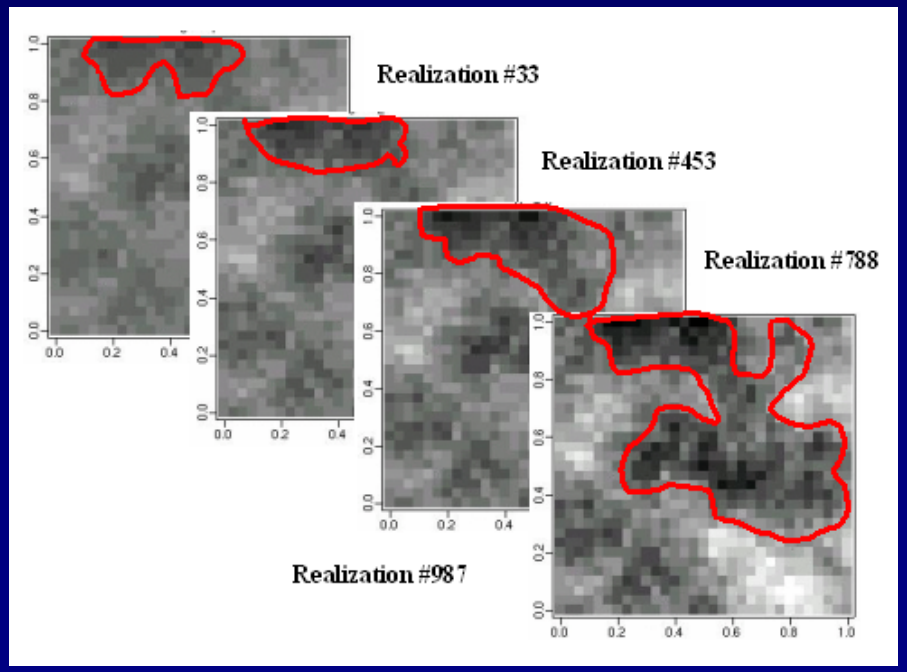


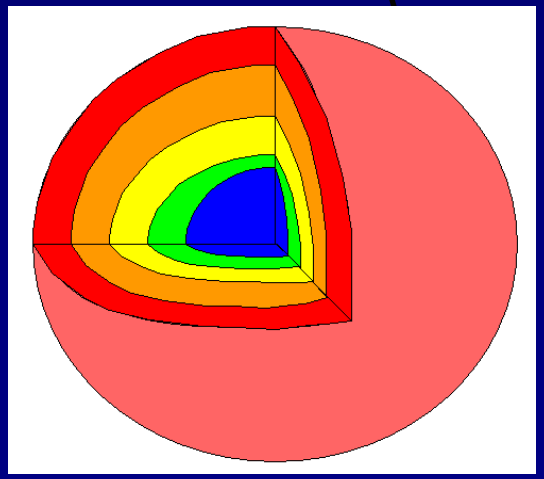
Correlation Modeling and Simulations











Case Study: Iterative Sampling

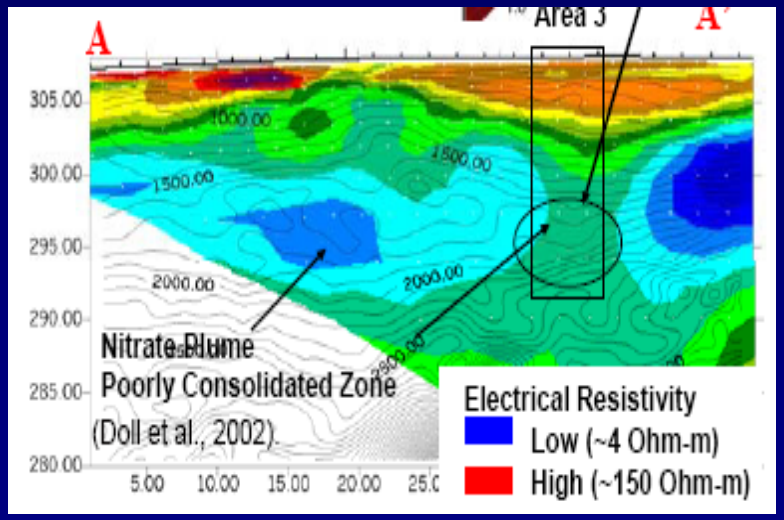
Depth

Samples	0	.6	1.2	1.8
0				
130				
260				
1260				

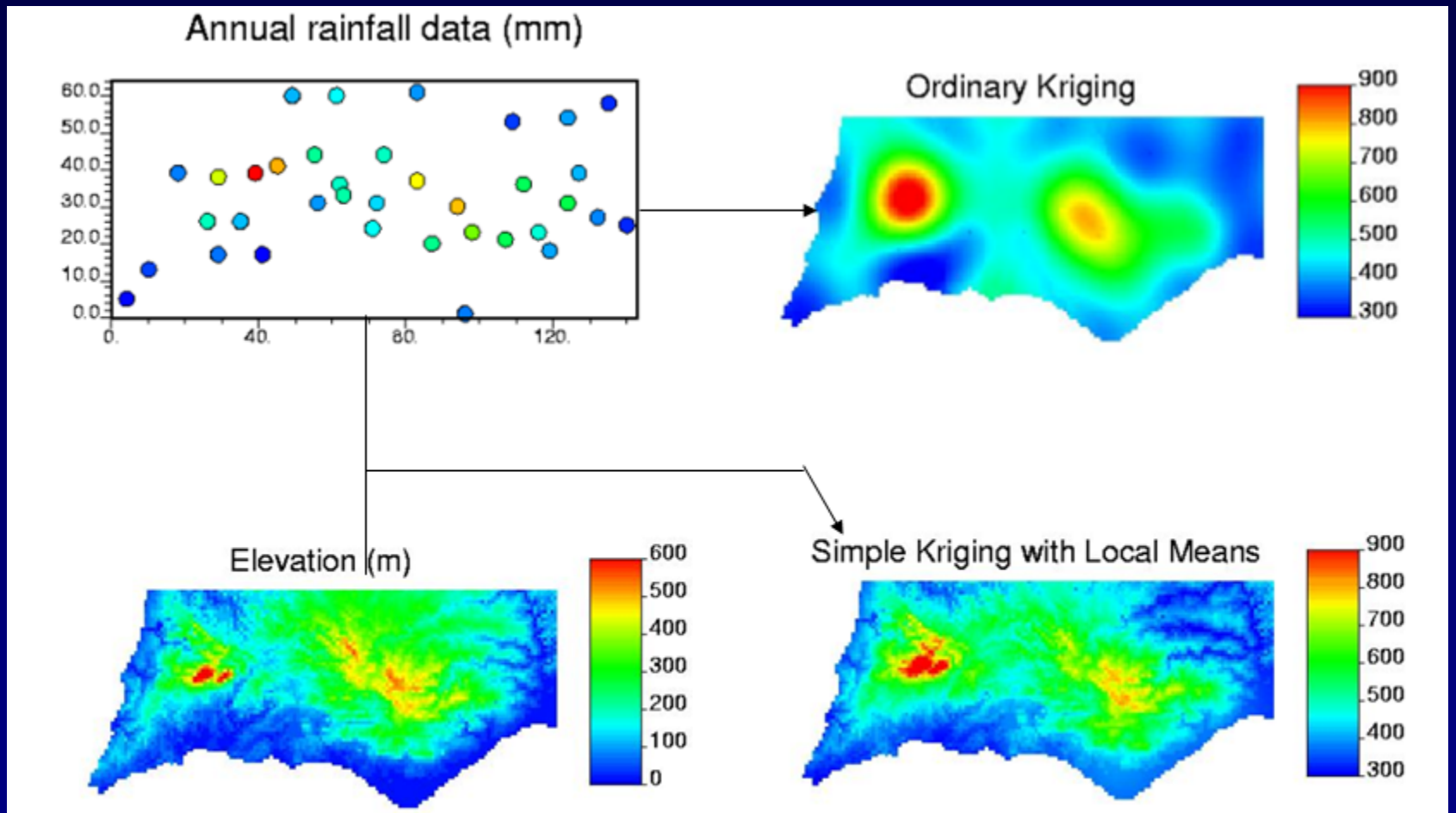
Secondary Information

Any other type of information (other than the primary direct measurements of interest) that may further support a spatial analysis.

- Field Detection Methods
- Radiological Count Data
- Geophysical Measurements
- Previous Sampling Efforts
- Conceptual Site Models
- Expert Knowledge
- Historical Records



Impact of Secondary Information



*Taken from Pierre Goovaerts' Presentation "Performance comparison of geostatistical algorithms for incorporating elevation into the mapping of precipitation"

MARSASS

Scope and focus:

- Introduce, describe or develop guidance and known methodologies for the proper use of historical data to assess potential subsurface residual activity.
- Recommend appropriate statistical techniques to determine optimum sampling locations.
- Minimize the number of samples and depth of penetration while achieving adequate information on potential subsurface contamination.
- Emphasize non-intrusive techniques.

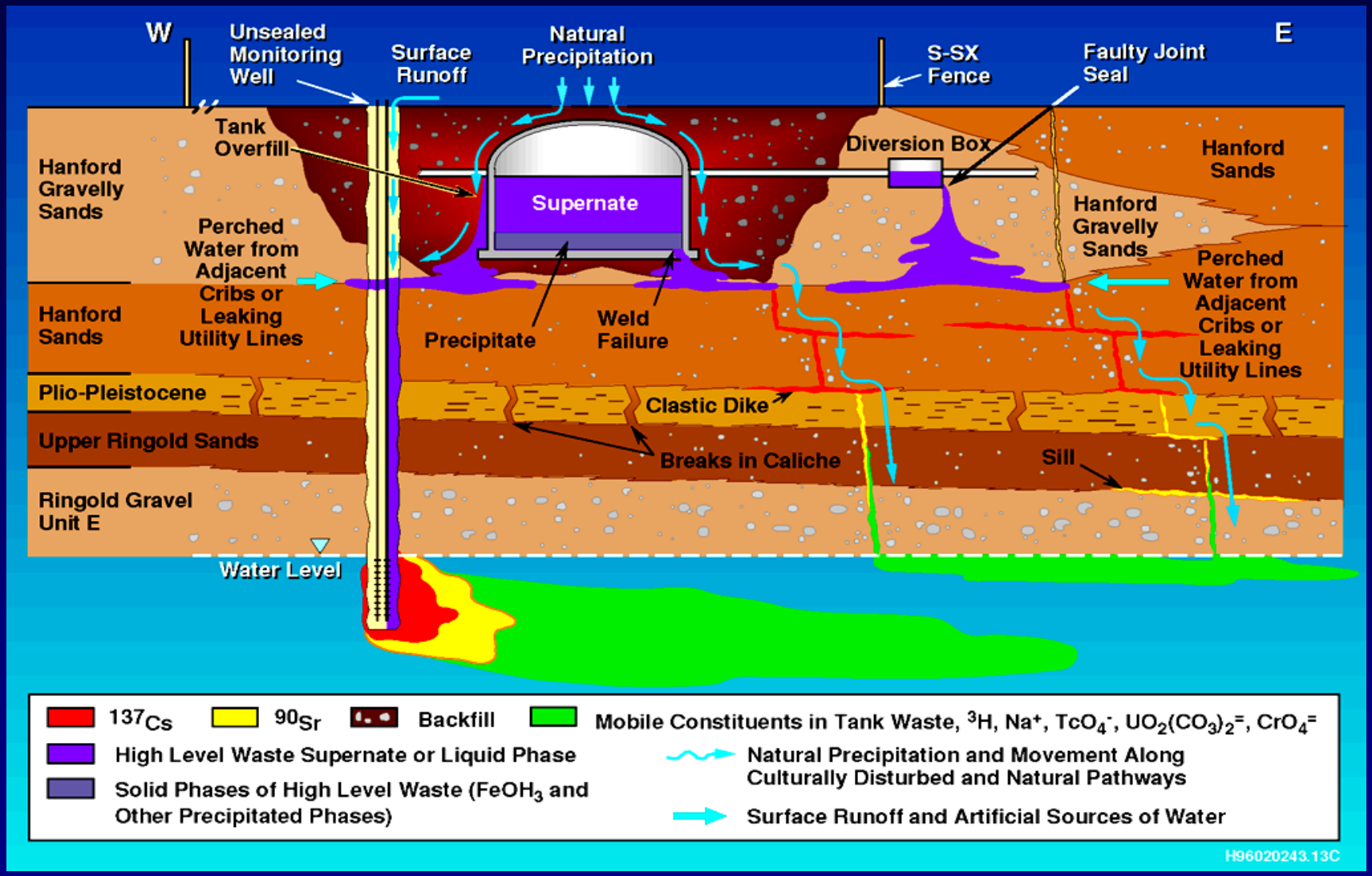
Multi-Agency Radiological Survey and Analysis for Subsurface Soil

MARSASS

Scope and focus - Continued:

- Provide case studies/examples demonstrating usefulness and benefits of using MARSASS methodologies ,e.g.
  - Significant reduction in cost
  - Appropriate level of sampling for decision making
  - Increase efficiency and save time
  - Confine sampling to proximity of contamination e.g. avoid unnecessary and premature contamination of potable aquifers.

Conceptual Model of Complex Site with Multiple Sources

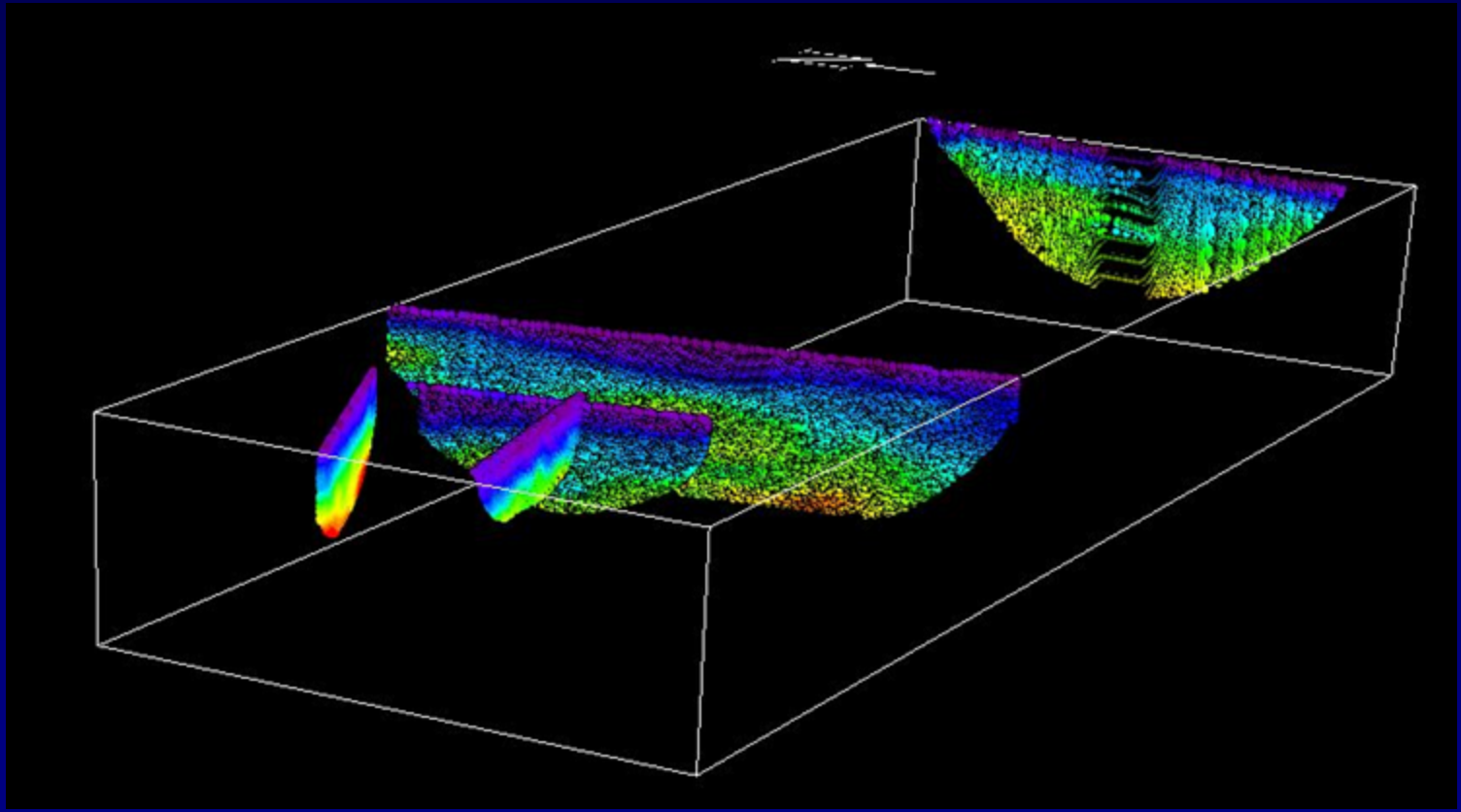


from Ward et al. (1997) after Caggiano et al. (1996)

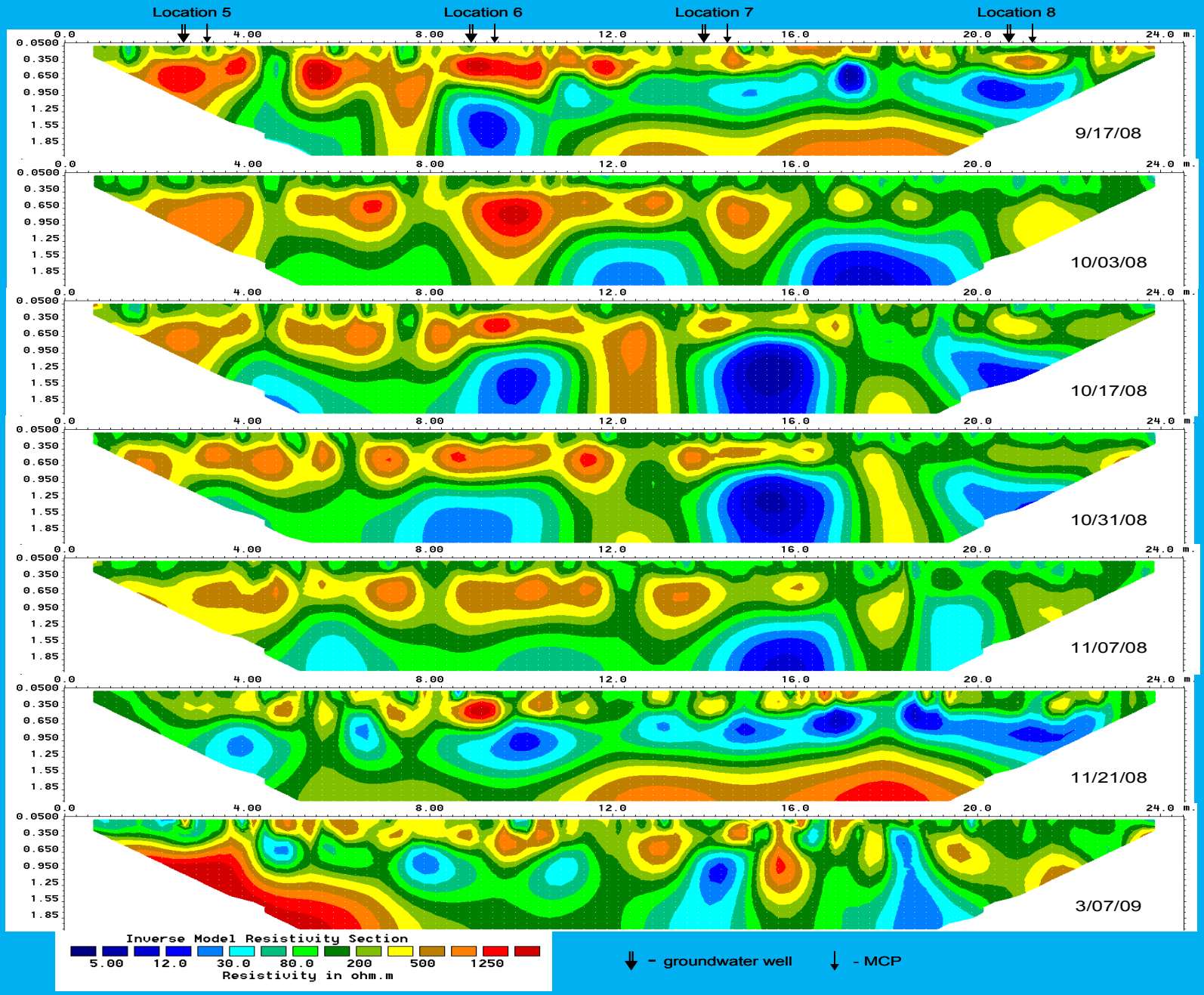
Information Needed to Develop Conceptual Site Hydrologic Model

- Natural and engineered features, structures, backfills and soil-rock interfaces, boundary conditions and time-dependent processes
- Potential sources of contaminant releases
- Regional and site hydrologic setting (perched water, aquifers, surface- water bodies, springs, wetlands and drainage systems)
- Local drinking water sources (ground- and surface-water sources)
- Existing ground-water wells and monitoring points onsite and offsite
- Depth to the water table and surface-water body elevations
- Historical details on contaminant releases
- Ground-water gradients, flow directions and velocities
- Transport processes (advection, dispersion, diffusion)

Recall : Surveys are often done in Transects

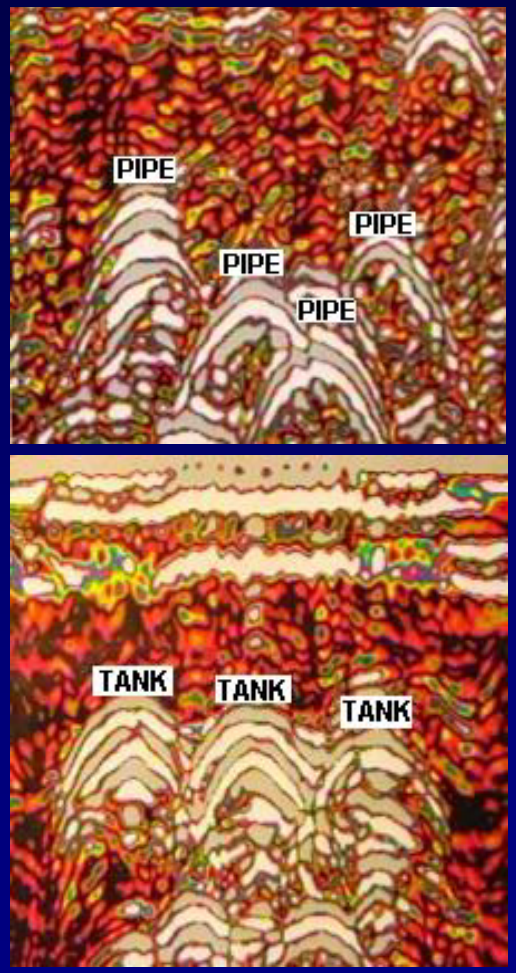


Electrical resistivity measured in a 2-m deep soil profile along a 24-m transect. Locations of ground-water wells and MCPs (multiple capacitance probes) are shown by arrows (from Pachepsky, 2010)



Anthropogenic Features for Consideration in Alternative Conceptual Site Models

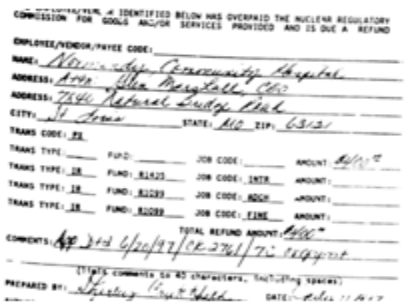
- Pathways for rapid spread of leaking contaminants
  - pipe or cable trenches
  - gravel backfill
- May drive contaminants in directions not predicted by contouring a few data points on a water-table map
- Local precipitation drainage (roof and storm drains)
- Sources of leaks
  - can inject large amounts of water into the vadose zone, sometimes creating perching
  - drive ground water and contaminants in directions not predicted based on water levels from scattered monitoring wells



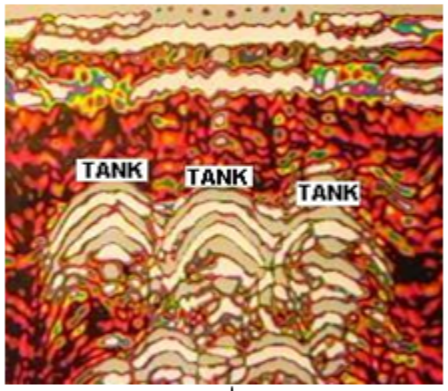
GPR Images

The Geobayesian Model

Historical Documents

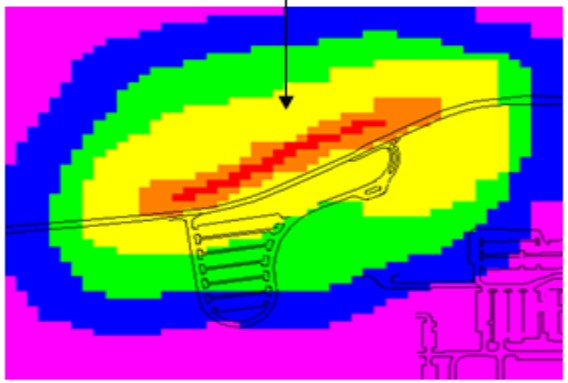


Geotechnical data



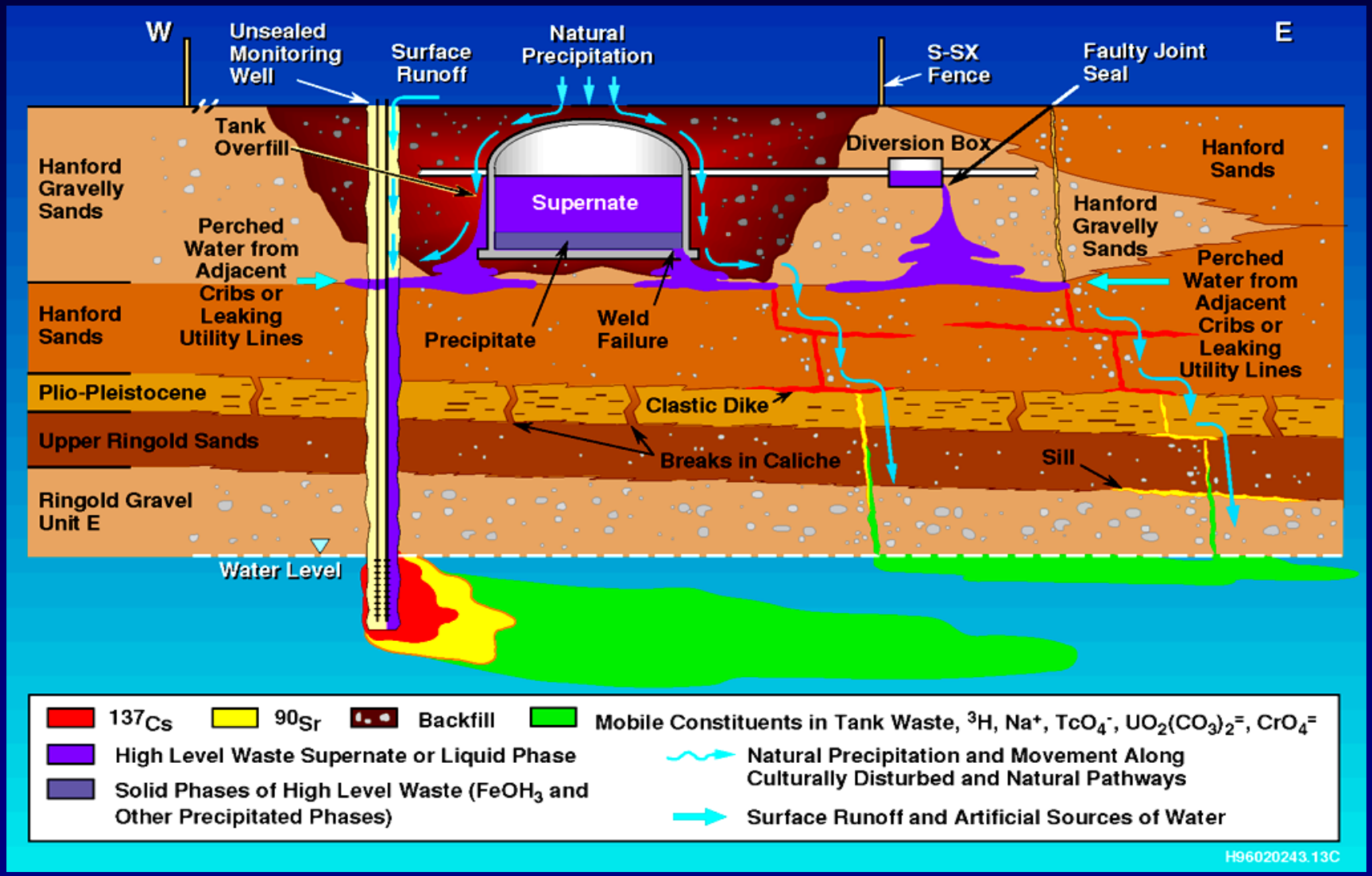
Previous data
(secondary or direct)

X	Y	Z	CAS	Names	Values	Detect
27273.89	23261.16	2.6	1234123	Chlordane	0.00015	
27273.89	23261.16	5.2	1234123	Chlordane	0.00027	
27273.89	23261.16	7.8	1234123	Chlordane	0.00046	
27273.89	23261.16	10.4	1234123	Chlordane	0.00045	
27273.89	23261.16	13	1234123	Chlordane	0.00028	
27273.89	23261.16	15.6	1234123	Chlordane	0.00012	
27273.89	23261.16	18.2	1234123	Chlordane	0.00004	
27273.89	23261.16	20.8	1234123	Chlordane	0	
27273.89	23261.16	23.4	1234123	Chlordane	0	
27273.89	23261.16	26	1234123	Chlordane	0	
27512.91	23260.99	2.6	1234123	Chlordane	0.46147	
27512.91	23260.99	5.2	1234123	Chlordane	0.69144	
27512.91	23260.99	7.8	1234123	Chlordane	0.73024	
27512.91	23260.99	10.4	1234123	Chlordane	0.38323	



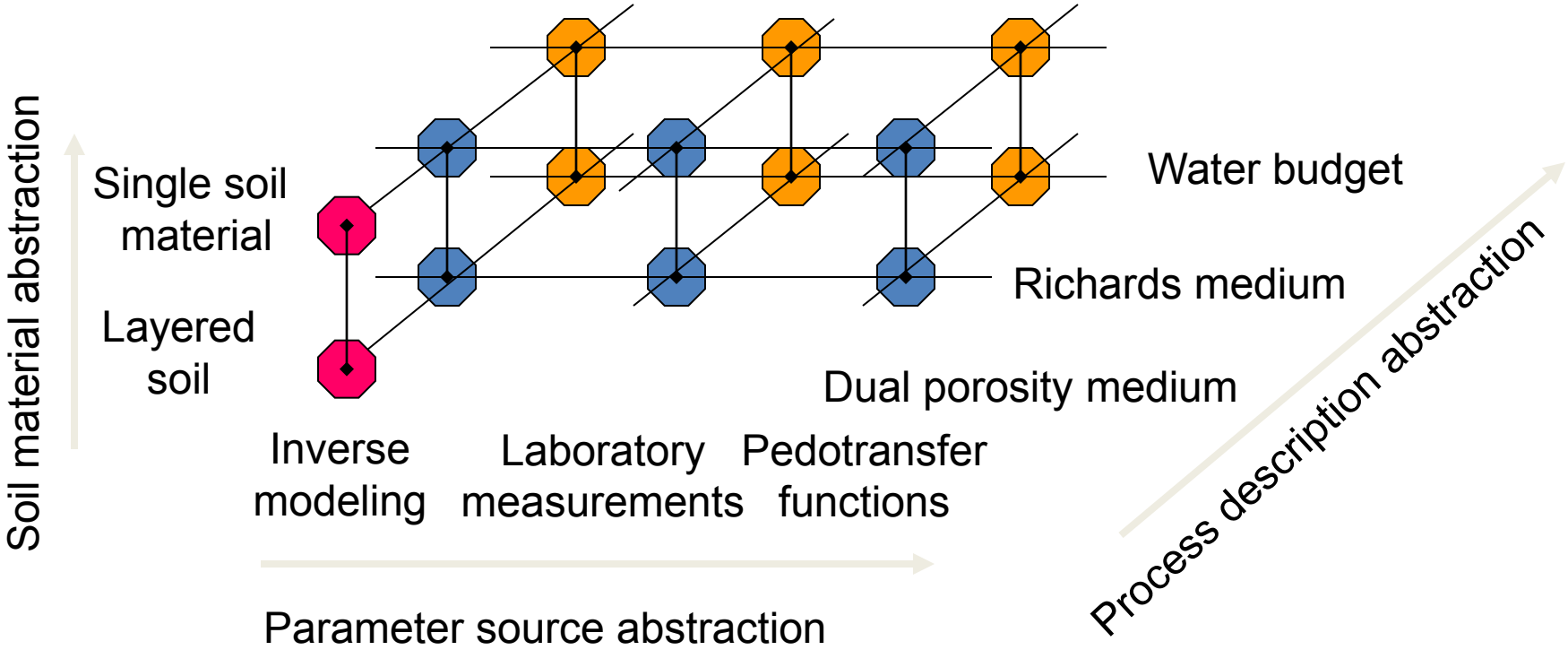
Probability of Exceedance

Conceptual Model of Complex Site with Multiple Sources



from Ward et al. (1997) after Caggiano et al. (1996)

Design of model abstraction via model boundary and behavior modification

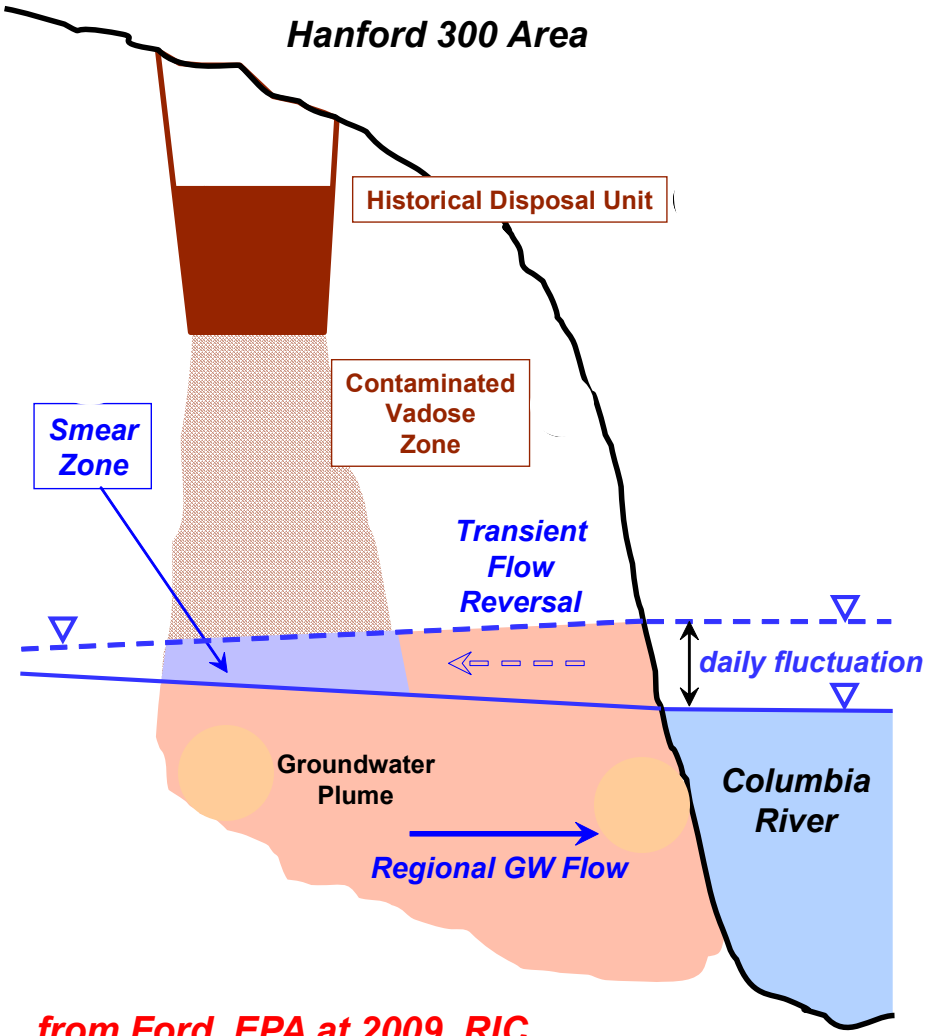


Computer codes

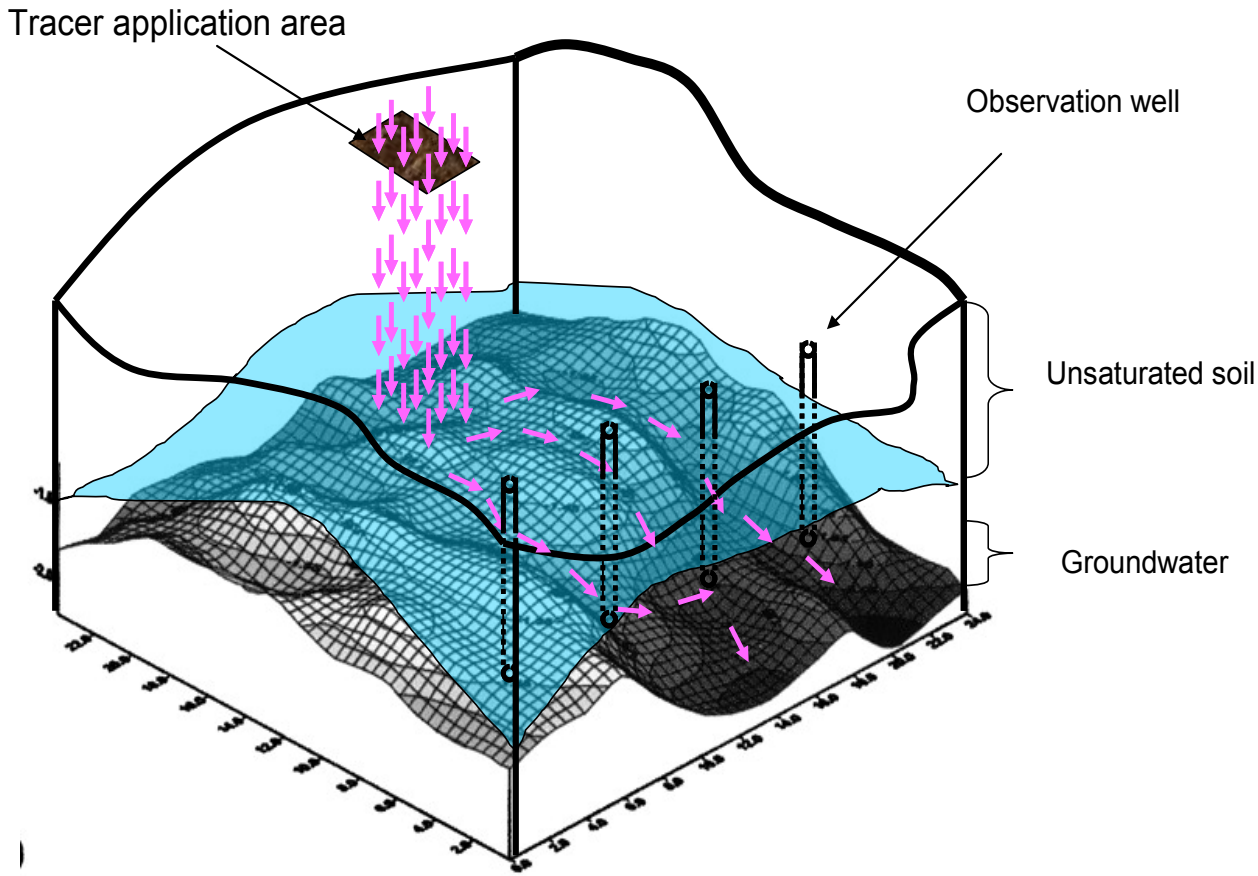
- **MACRO**
- **HYDRUS**
- **MWBUS (Model of Water Budget in Unsaturated Soil)**

Conceptual Site Model

- Simplified representation of the site with significant FEP's
- Select, organize and communicate information in 3-dimensional visualizations
- Subject to testing with new characterization and monitoring data

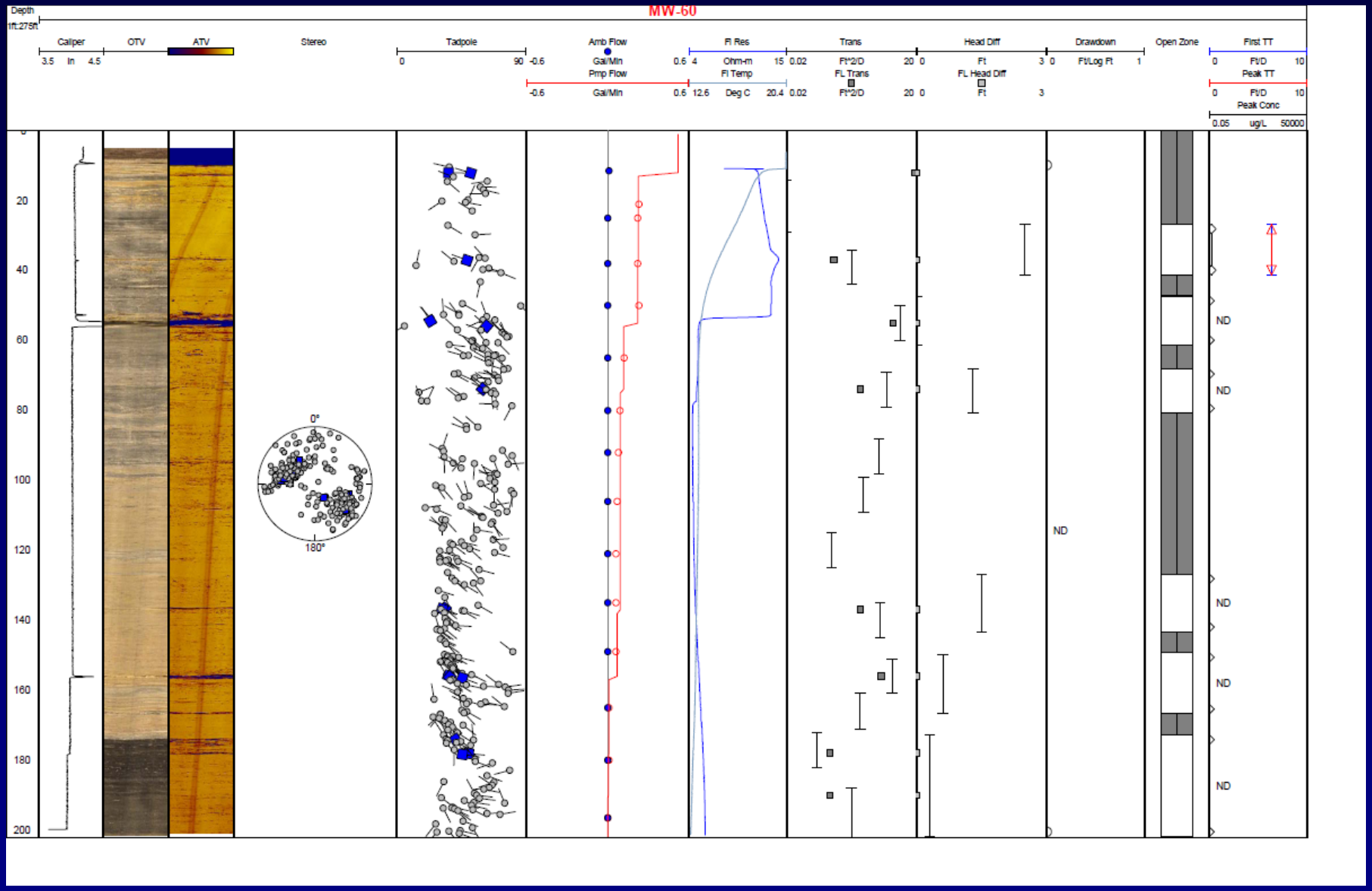


from Ford, EPA at 2009 RIC



Schematic of a tracer experiment used to validate (vertical and lateral) subsurface transport via performance conformation monitoring (from Pachepsky, 2010)

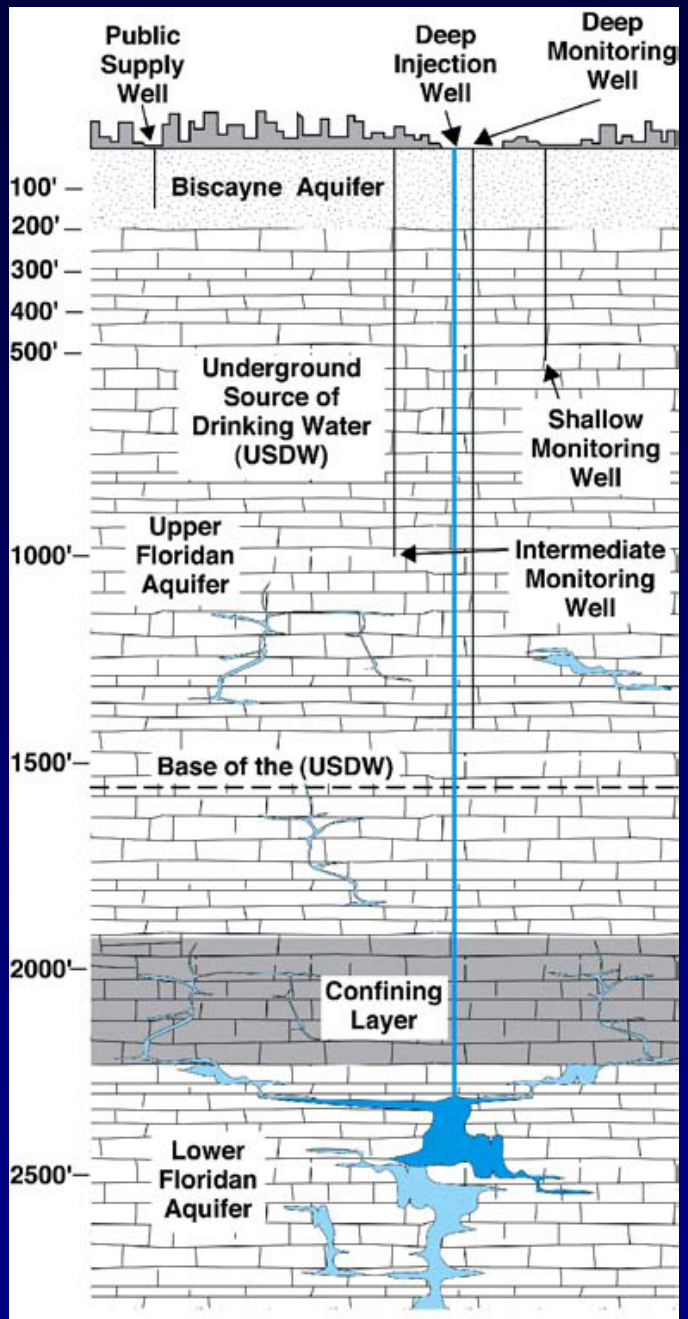
Composite of Geophysical Logs, Transmissivity and Hydraulic-Head Difference Estimates and Measurements & Tracer-Test Results for Test Well (from Williams, 2008)



Need for Bayesian Updating to Reduce Uncertainties in Conceptual Models

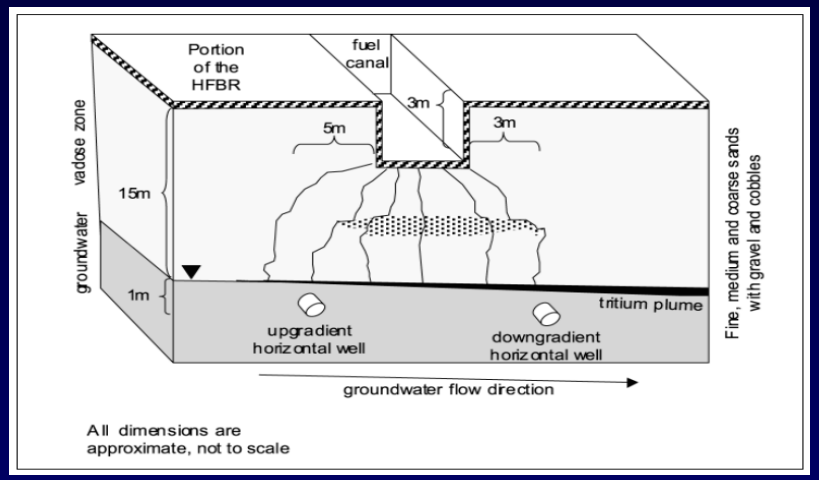
Sources:

- ✓ Incomplete knowledge of the subsurface system
- ✓ Measurement error in characterizing the system's features, events and processes (FEPs)
- ✓ Natural variability in the system's spatial properties, temporal events and transient external stresses
- ✓ Disparity in scales of sampling, monitoring and simulation relative to actual dimensions of the FEPs
- ✓ Parameter estimation
- ✓ Scenario definition



Hydrogeologic Cross Section in South Florida

Formulate 3-D Realistic Model to Evaluate Remediation Alternatives and Performance



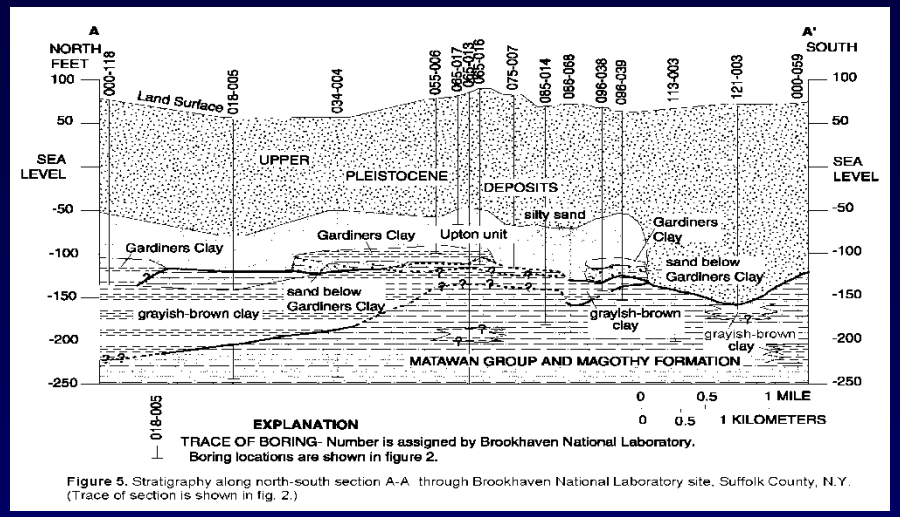
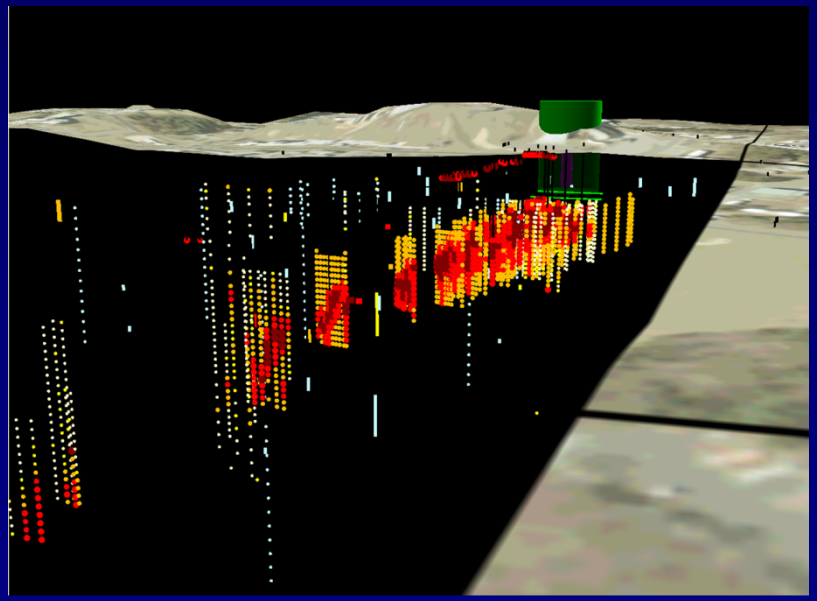


Figure 5. Stratigraphy along north-south section A-A' through Brookhaven National Laboratory site, Suffolk County, N.Y. (Trace of section is shown in fig. 2.)

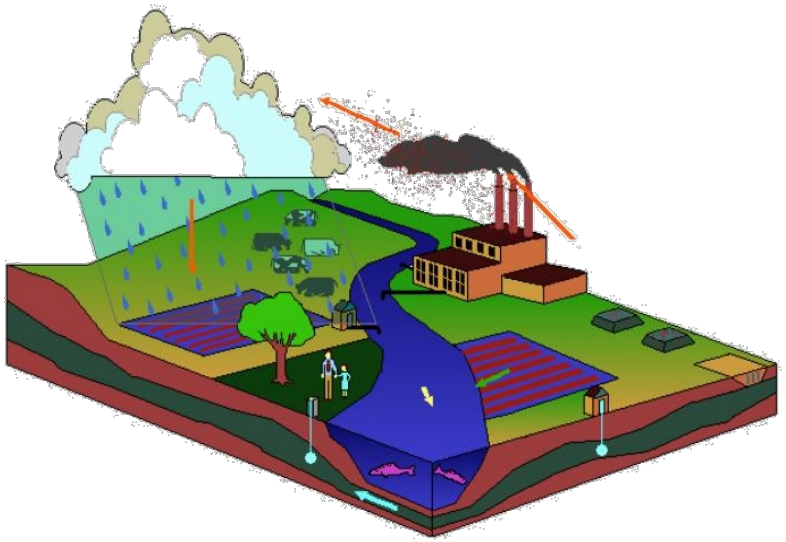
- Combine CSM with flow and transport details (e.g., influence of nearby pumping wells) to generate 3-D visualization of data
- Use flow and transport modeling to confirm CSM that reflects observed monitoring data
- Once validated, use flow and transport modeling to evaluate remediation alternatives



(from Price and others, 2007 NUREG/CR-6948)

Dose Assessment to Determine Need for Remediation

Decision to remediate based upon source and site characterization, monitoring and modeling



- ✓ Identify contaminant sources
- ✓ Are releases continuous or episodic?

- ✓ Soil and water sampling to estimate radiochemistry and mass flux
- ✓ Contaminant concentrations and properties

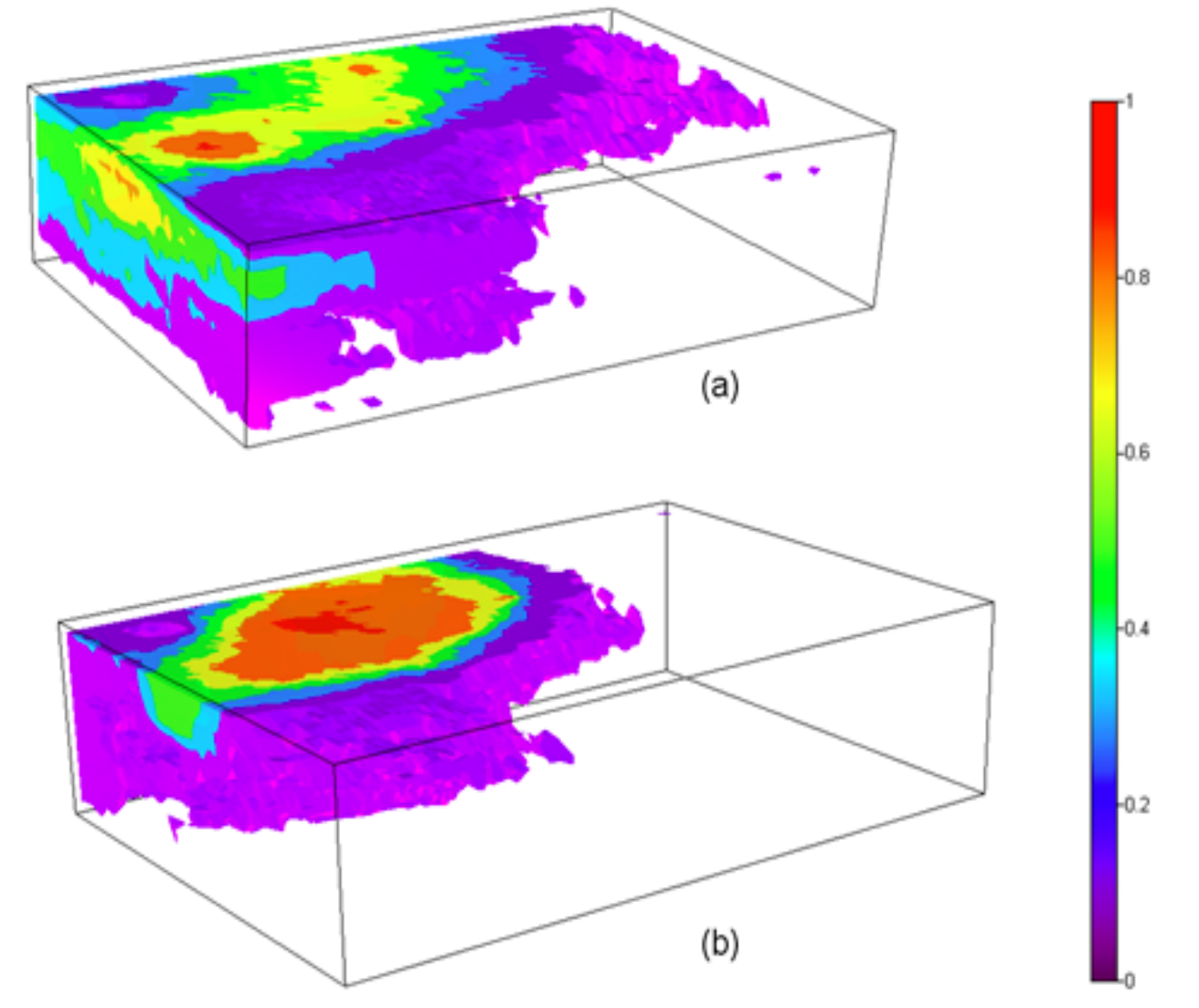
- ✓ Identify subsurface pathways from source to receptors
- ✓ Estimate attenuation and sorption of subsurface matrix
- ✓ Calculate dose to receptors and compare to dose criteria

❖ ***If Dose exceeds regulatory criteria consider the need for remediation***

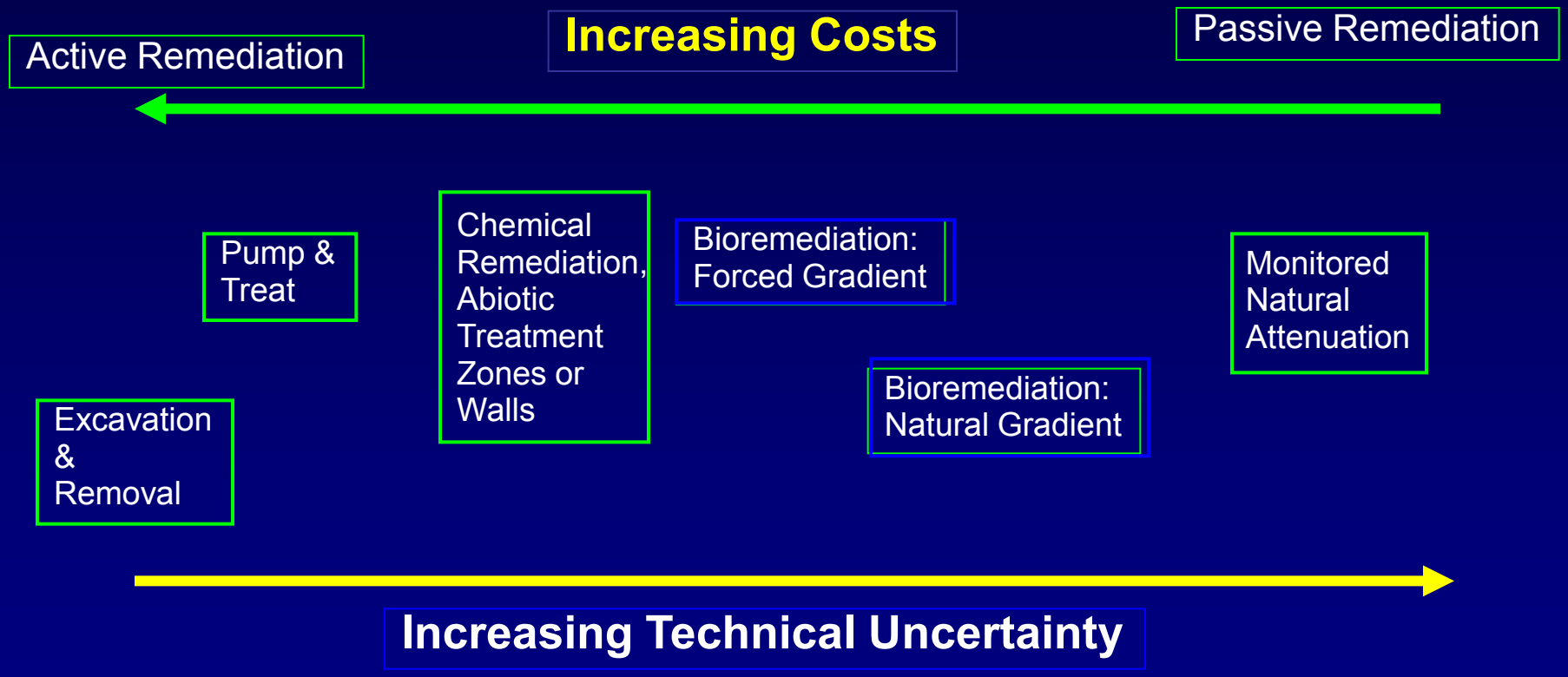
Impact of Multiple Characterization Techniques and Bayesian Analysis

Scoping phase remedial volume at 0.1 probability

Characterization phase volume at 0.1 probability.



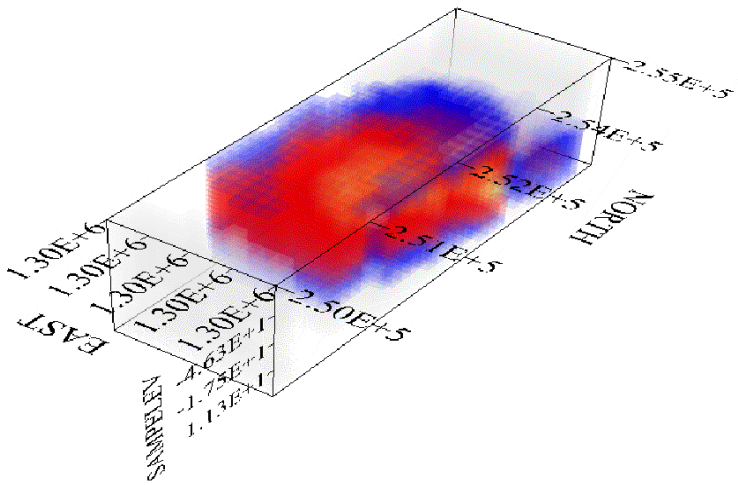
Range of Remediation Techniques

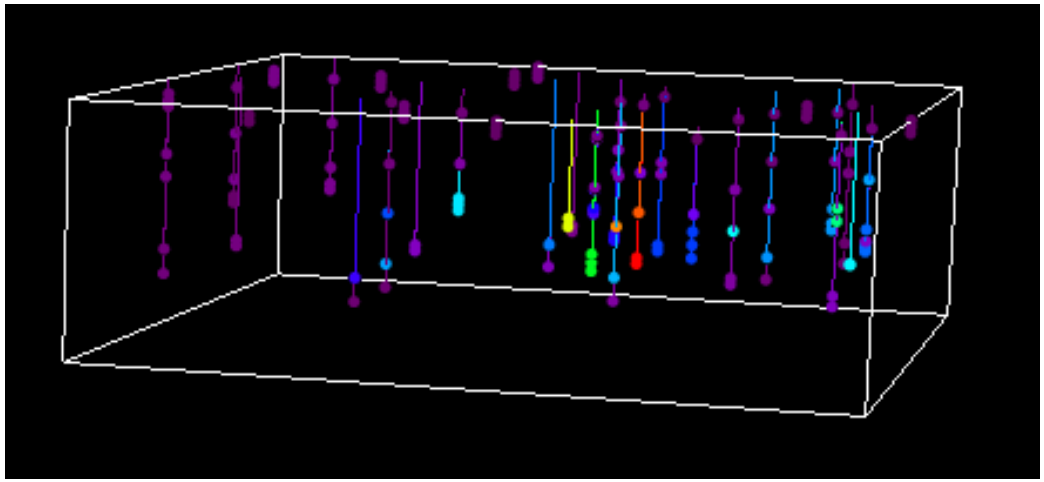


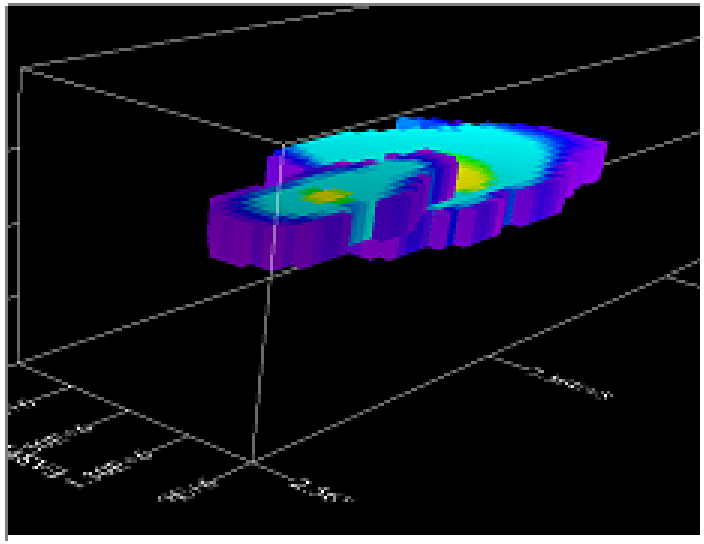
(after Long et al, 2008, NUREG/CR-6973)

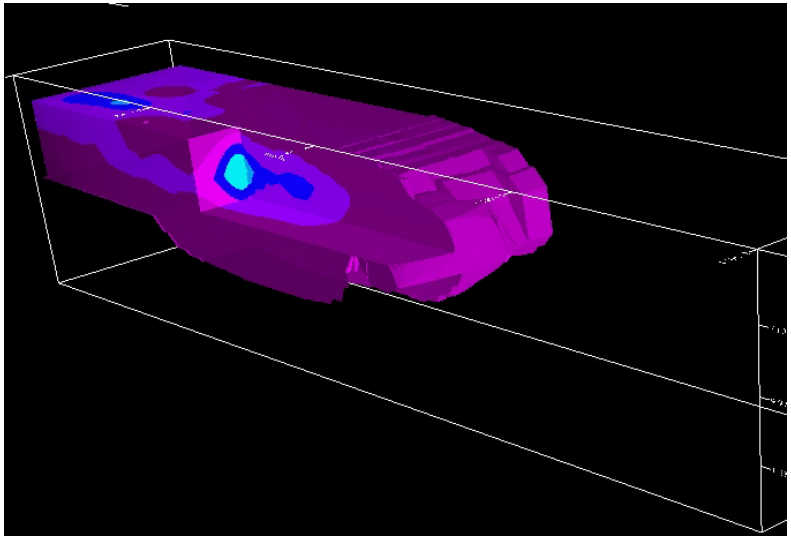
3D Visualization

True 3d Views: Points, Blocks, and Isosurfaces







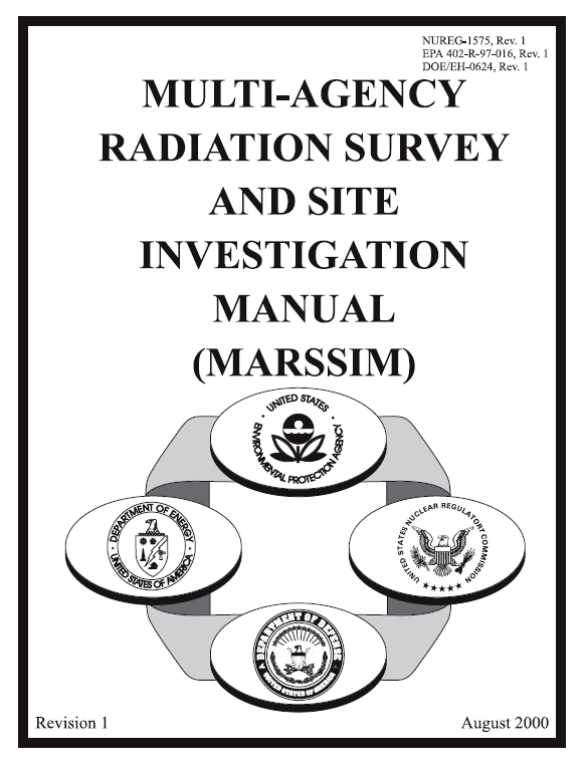


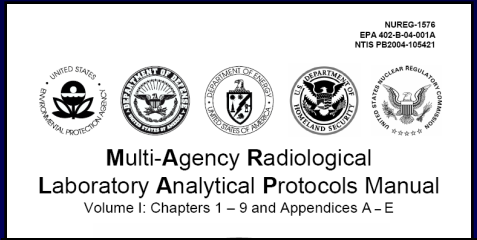
Subsurface Research Projects

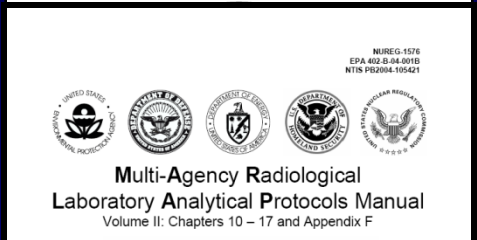
- Conceptual Model, Parameter & Scenario Uncertainty
- Model Abstraction
- Integrating Modeling and Monitoring
- Application of Remediation Strategies
- Subsurface Sampling Protocols – not funded

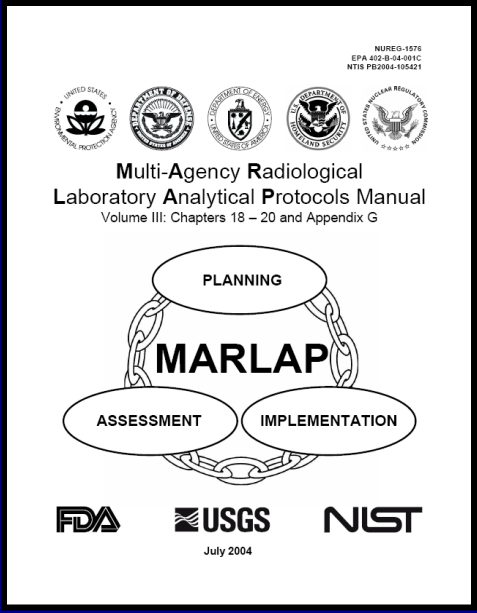
Information Sources

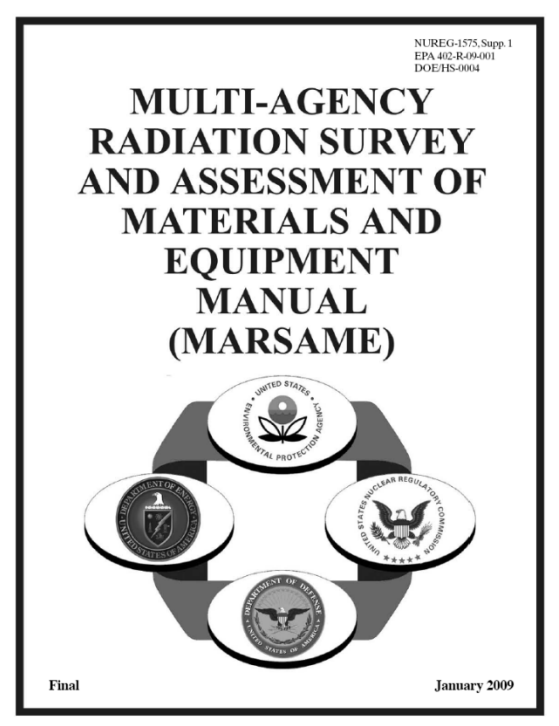
U.S. Federal Multi-Agency Consensus





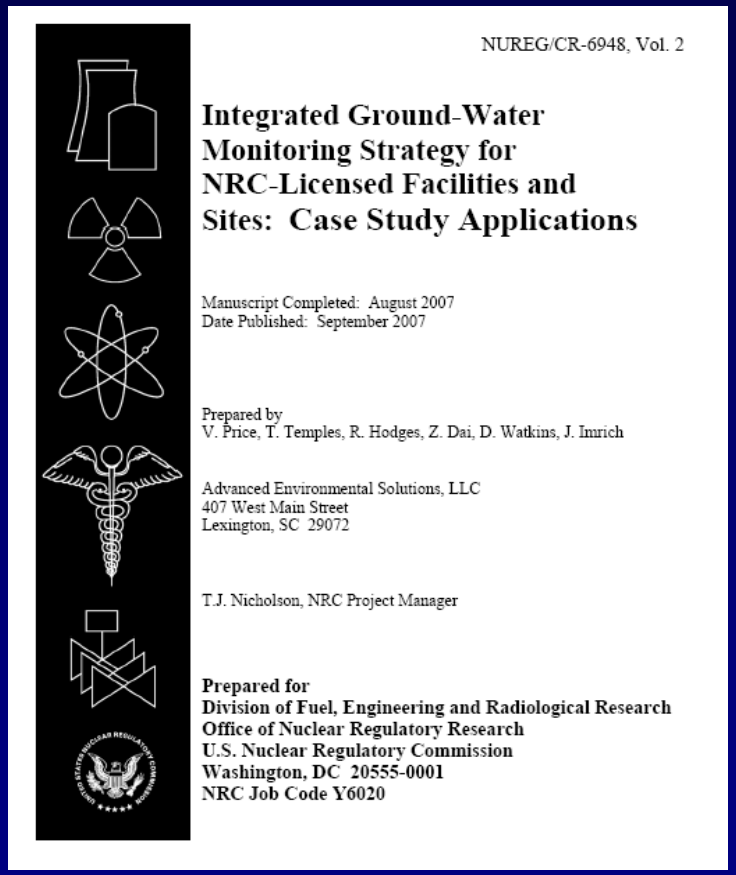






Information Source – NUREG/CR-6948

- Lessons-Learned for developing guidance on ground-water monitoring for NRC-licensed sites
- Case Studies which includes Brookhaven radionuclide plume remediation and monitoring
- **http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6948/v2/index.html**



NUREG/CR-6948, Vol. 2

Integrated Ground-Water Monitoring Strategy for NRC-Licensed Facilities and Sites: Case Study Applications

Manuscript Completed: August 2007
Date Published: September 2007

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Prepared for
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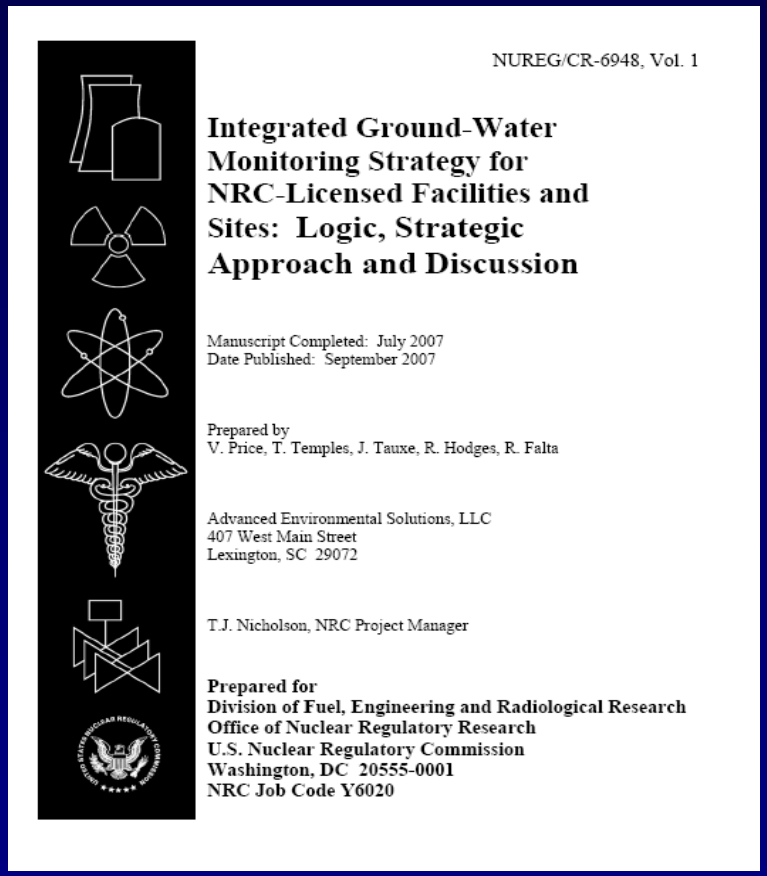
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code Y6020

Information Source – NUREG/CR-6948

- Technical bases for developing guidance on ground-water monitoring for NRC-licensed sites
- Systematic methodology to integrate monitoring with modeling
- **http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6948/v1/index.html**



NUREG/CR-6948, Vol. 1

Integrated Ground-Water Monitoring Strategy for NRC-Licensed Facilities and Sites: Logic, Strategic Approach and Discussion

Manuscript Completed: July 2007
Date Published: September 2007

Prepared by
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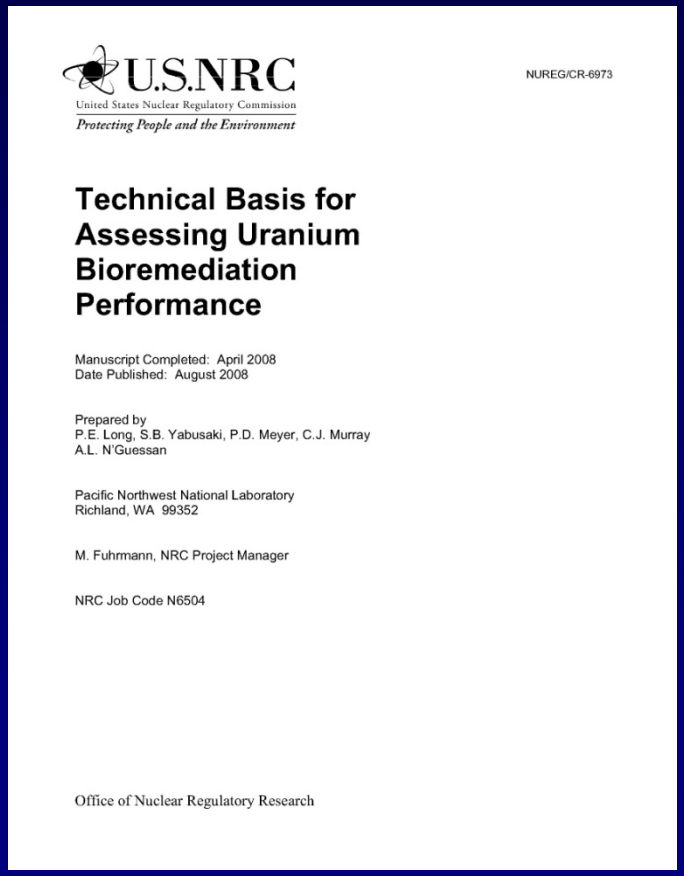
NRC Job Code Y6020

Information Source – NUREG/CR-6973

- Overview of *in situ* uranium bioremediation which identifies and prioritizes field performance indicators for evaluating its effectiveness.
- Performance indicators to be monitored and modeled are based on current biogeochemical understanding of uranium.
- Confirmation monitoring is vital to demonstrating long-term success of U-bioremediation and provides a significant assurance that regulatory goals will be met.
- http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6973/index.html



U.S.NRC
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Protecting People and the Environment

NUREG/CR-6973

Technical Basis for Assessing Uranium Bioremediation Performance

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Date Published: August 2008

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