Module 4

Where Does Uncertainty Come from When Making Restoration Decisions?
“As we know, there are known knowns. There are things we know we know. We also know there are known unknowns. That is to say we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know.”

Donald Rumsfeld, Feb. 12, 2002, Department of Defense news briefing
Experience Has Demonstrated That Cleanup Work Is Filled with Uncertainty

- Removed soils volumes always greater than those estimated during the design phase
- DOE Ohio experience:
  - Fernald, 817,500 yd$^3$ more soil than expected requiring off-site disposal
  - West Jefferson, three times as much soil as expected
  - Mound, twice as much soil as expected
- FUSRAP experience:
  - Wayne: estimated – 58,000 yd$^3$; revised – 110,000 yd$^3$; actual 96,000 yd$^3$
  - Middlesex: estimated – 24,000 yd$^3$; actual – 41,000 yd$^3$
- Complicates:
  - Program planning
  - Cost estimation
  - Remedial design and implementation
Uncertainty Arises from Complexity and Heterogeneity of Natural Systems Combined with the Sparseness of Characterizing Data

- Spatial heterogeneity is primary source of variability observed in environmental sample results
- Sample results can vary by orders of magnitude for proximal samples
- Historically the cost of collecting/analyzing samples has been significant, limiting data that are available
- The result: decision-making taking place in a fog of uncertainty
Decision Quality Only as Good as the Weakest Link in the Data Quality Chain

Each link represents a variable contributing toward the quality of the analytical result. All links in the data quality chain must be intact for data to be of decision-making quality!
Taking a Sample for Analysis

Population

Soil Core Sample

Lab Subsamples (Duplicates)

Field Subsample

Analytical Sample Prep

Analytical Sample Unit

Statistical Sampling
Sample Collection
Sample Handling

23.4567 ppm

GC Determination
Heterogeneity Causes Data Variability

• **Heterogeneity**: Variations in matrix properties
  – **Within-sample** micro-scale heterogeneity
  – **Short-scale, between-sample** heterogeneity (affects agreement between collocated samples)
  – **Large-scale, between-sample** heterogeneity (on scale of conventional distances between samples)
Within Sample Variability

Micro-scale, within sample jar: measured by lab duplicates (2 analytical subsamples taken from same sample jar)

Lab dup examples from actual site data. Population characteristic being measured = Pb conc

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Short-Scale Heterogeneity Can Be Significant: Arsenic in Samples from 3 Residential Yards

1 ft apart over 4 ft

As 129 221 61 39 14

Linear even spread over 6 ft

As 37 290 625 94

Same yard, 8 ft away from group to left & spread over 6 ft

As 27 29 45 34

Spread evenly over 7 ft

As 17 41 367 351 268

Same yard, 15 ft away from group to left & spread over 4 ft

As 29 24 79 120
Short-Scale Variability Can Be Significant: Explosives

Figure adapted from Jenkins (CRREL), 1996
Heterogeneity Overwhelms Variability from Different Analytical Techniques

Figure adapted from Jenkins (CRREL), 1996

September 12, 2012
Portsmouth Training
Variability at Highest Spatial Scale

Large-scale variability: differences in concentration at the scale of typical sampling design spacing; the kind of conc. variability traditional sampling designs are trying to find.
Historically Focus Has Been Analytical Quality, But…

- Emphasis on fixed laboratory analyses following well-defined protocols
- Analytical costs driven to a large degree by QC/QC requirements
- Result:
  - analytical error typically on order of 30% or less for replicate analyses
  - traditional laboratory data treated as “definitive”…but definitive about what?
The Biggest Cause of Misleading Data

Heterogeneity Rules!

You Can't Fool Mother Nature

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How Do We Reduce Decision Uncertainty?

• For analytical errors:
  – Switch to a better analytical technique
  – Improve QC on existing techniques

• For sample prep and handling errors:
  – Improve sample preparation

• For sampling uncertainty:
  – Collect samples from more locations
We can’t control the effects of uncertainty on our decisions if we don’t know where it is coming from.

Historically the cleanup business has focused resources on the wrong sources of data uncertainty.
Any Questions?