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Incremental Sampling Methods:

Current VSP Applications for Representative Soil Sampling

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2015 Environmental Data Quality Workshop (Portland, OR)

U.S. DEPARTMENT OF ENERGY

Full Disclosure

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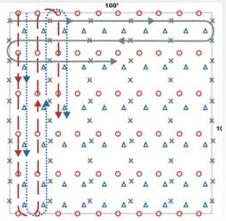
- I am a statistician
- Graduate thesis was on composite sampling
- I had many concerns about multi-increment sampling (MIS) when I was introduced to it in 2006
- Participated on the Interstate Technology & Regulatory Council (ITRC) committee that drafted guidance on the Incremental Sampling Methodology (ISM)
- Currently funded to integrate statistical sample design concepts into MIS/ISM in collaboration with the original developers (Cold Regions Research and Engineering Laboratory)
- I have no preference regarding the naming of a formalized compositing process



Outline

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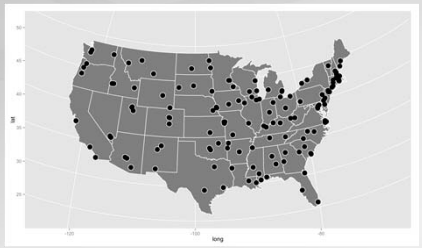
1) Simple example of representativeness



2) Review of Multi-Increment Sampling (MIS), Incremental Sampling Method (ISM), and composite sampling

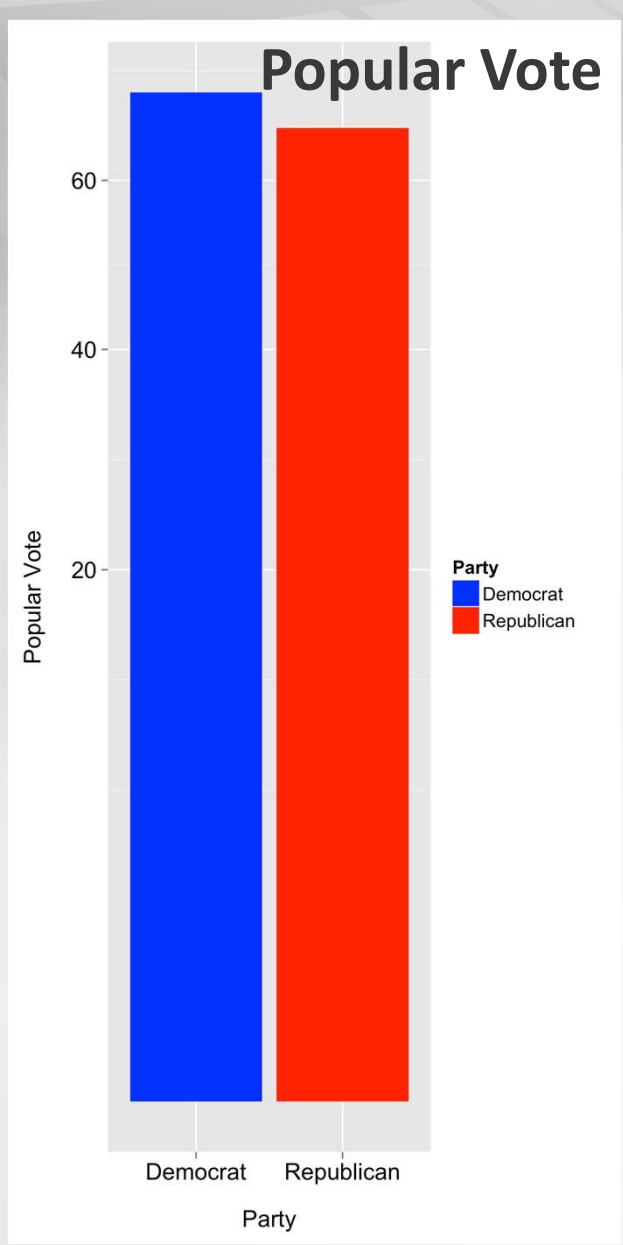
Representative
Reproducible
Randomized

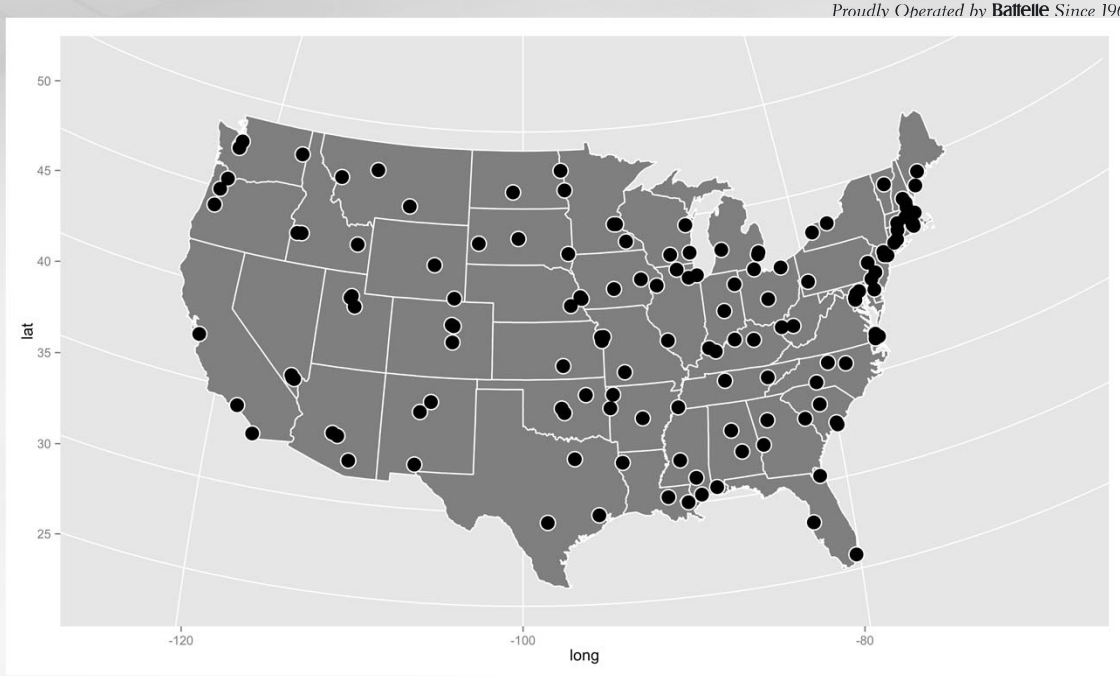
3) Background of Visual Sample Plan and MIS/ISM

VSP 7
Visual Sample Plan

4) Field demonstration of statistically driven ISM designs

Decision Units & Presidential Elections





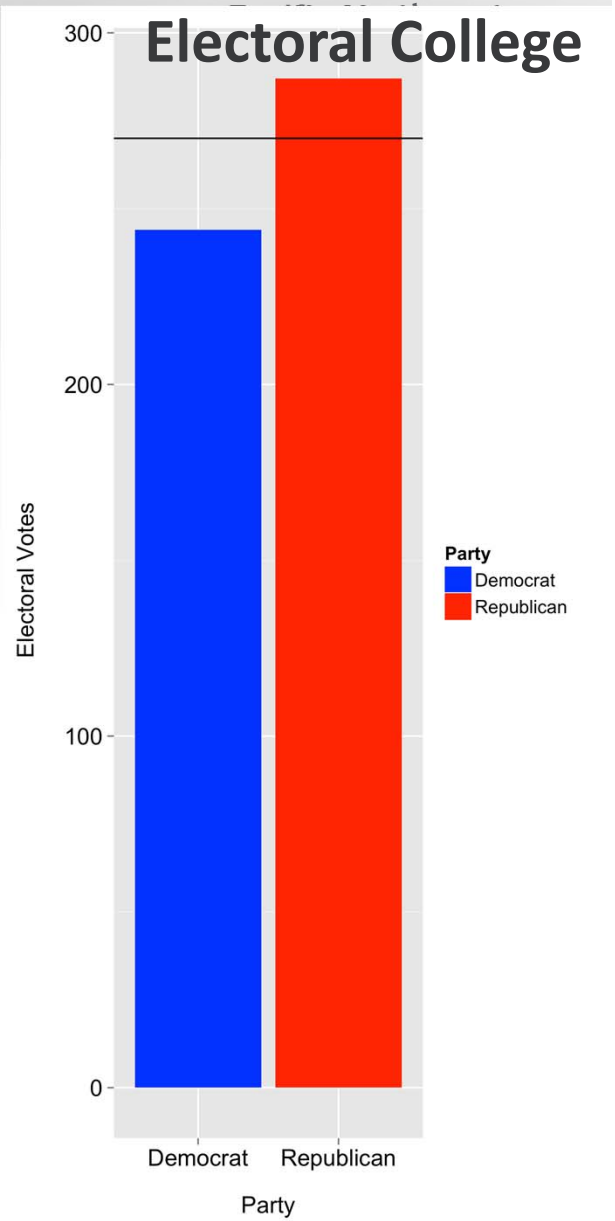
- Random by state sample: Polled 144 people
- Democratic candidate has 52% of the vote
- Thus, the democratic candidate is the most likely to win
- 5% standard error

Decision Units & Presidential Elections

But elections are not decided by the popular vote.

Now what do we do?

We have sampled 3 people for every state. We can estimate which way each state will go and tally up the electoral votes.



Decision Units & Presidential Elections

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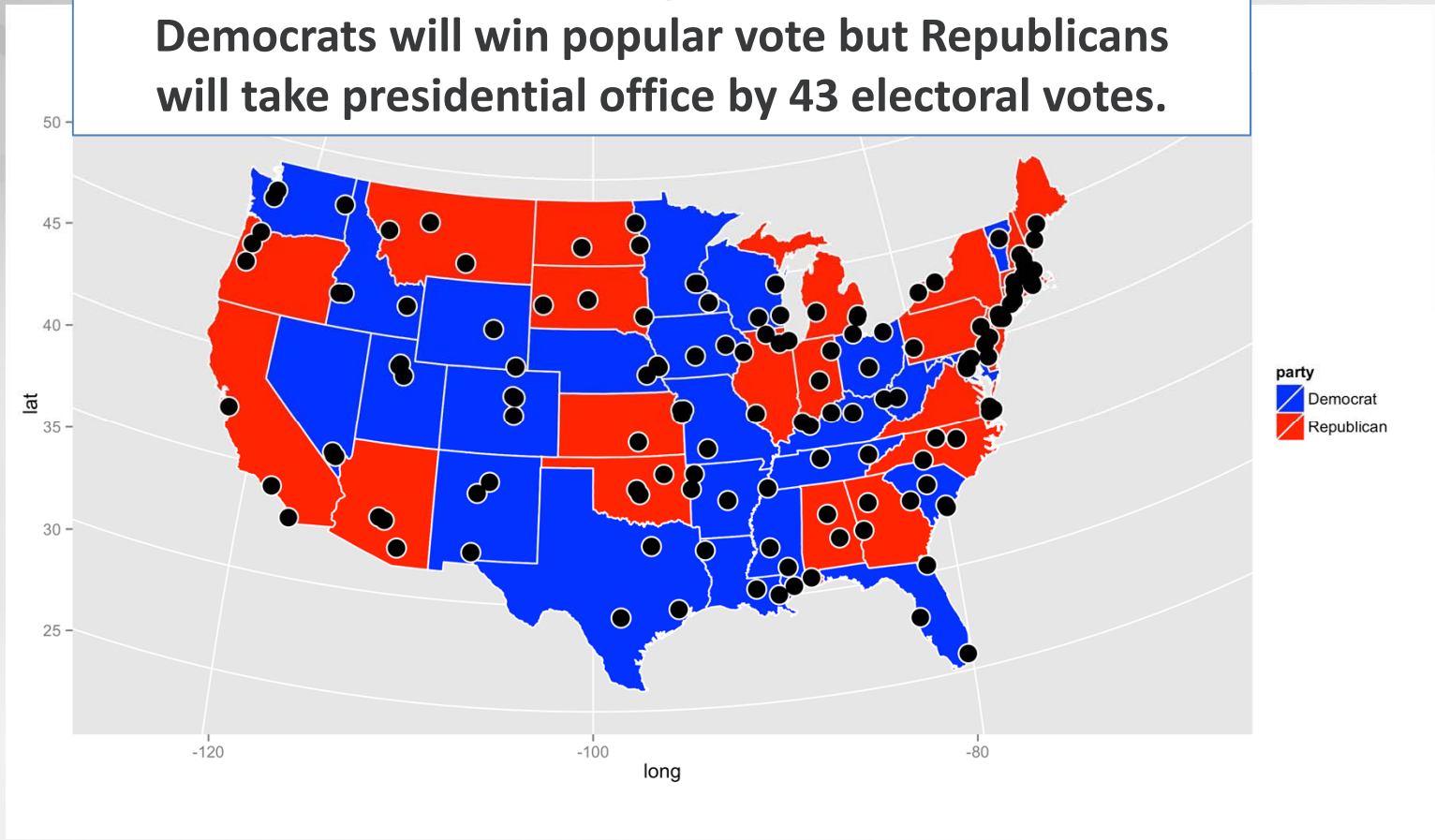
Breaking News!
Democrats will win popular vote but Republicans will take presidential office by 43 electoral votes.



- Do you feel comfortable making a decision for each state based on 3 samples?

What is Incremental Sampling?

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- **Environmental Sampling Goal:**

  Obtain representative data for decision making on a study area

- Incremental sampling is the process of establishing pertinent decision units and then collecting multiple increment samples that are

  Representative
  Reproducible
  Randomized

- ISM forces the conversation about “representativeness”
  - One sample from 2 acres most likely is not representative of the 2 acres
  - Too much grouping/compositing may underrepresent/dilute elevated regions within a wide area

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Tons of Soil
3 mg/kg DNT

Representativeness:

Field Sample

Collection to

Lab Analysis

Solvent Extraction 0.03 mg DNT

100 µL of solvent analyzed

DOE Funded Design Development

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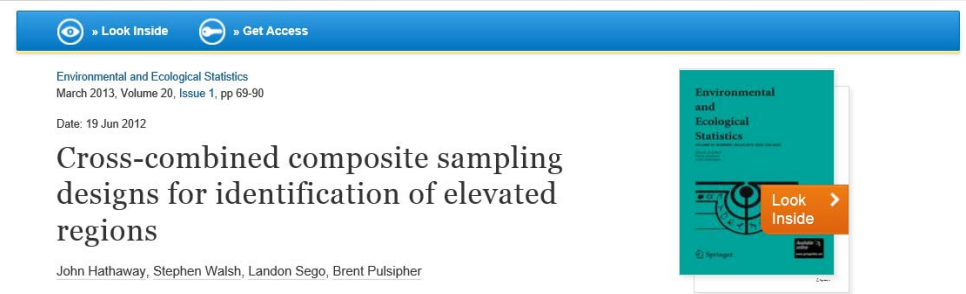
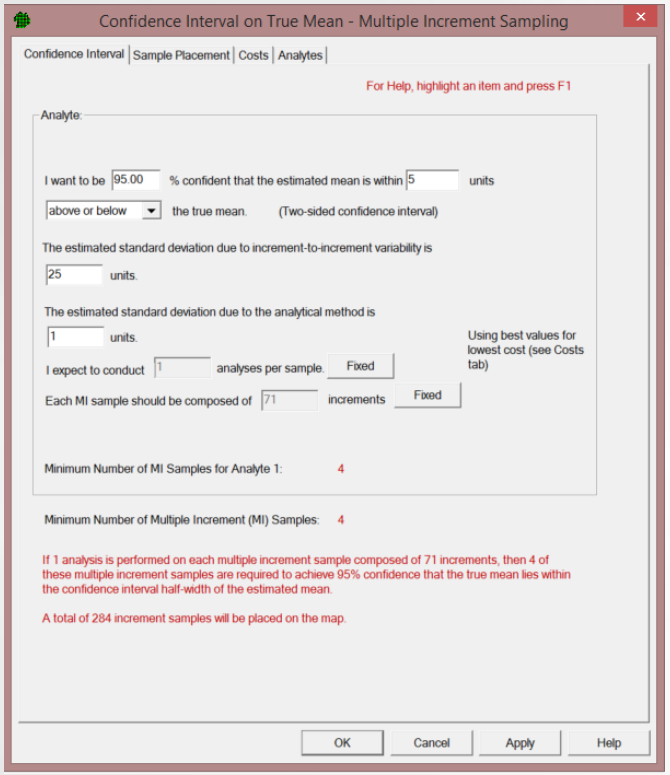
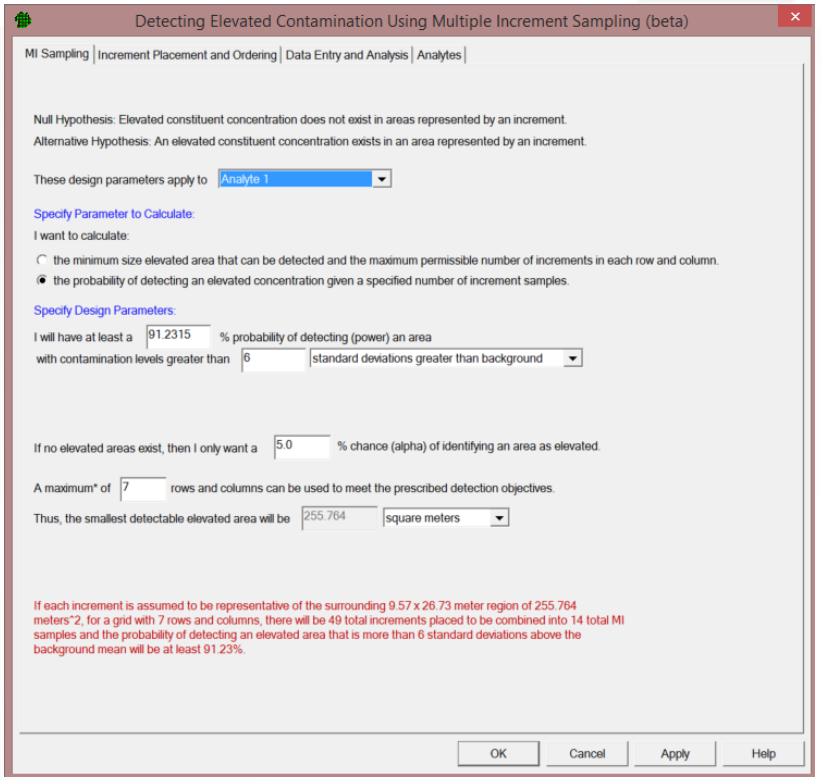
- Methods development research and integration into VSP (2008-2012)







Technical Description: Aligned ISM Sampling Designs

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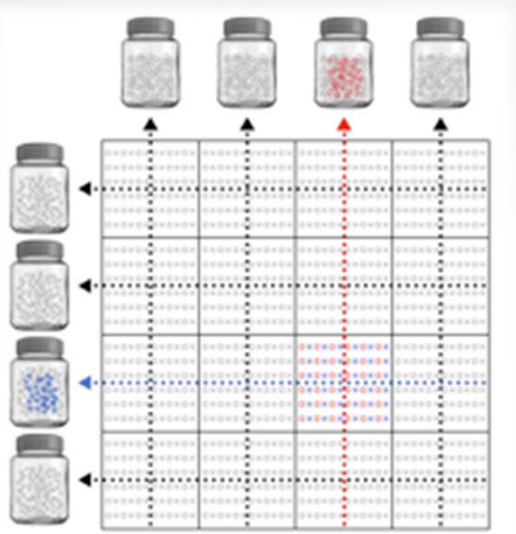
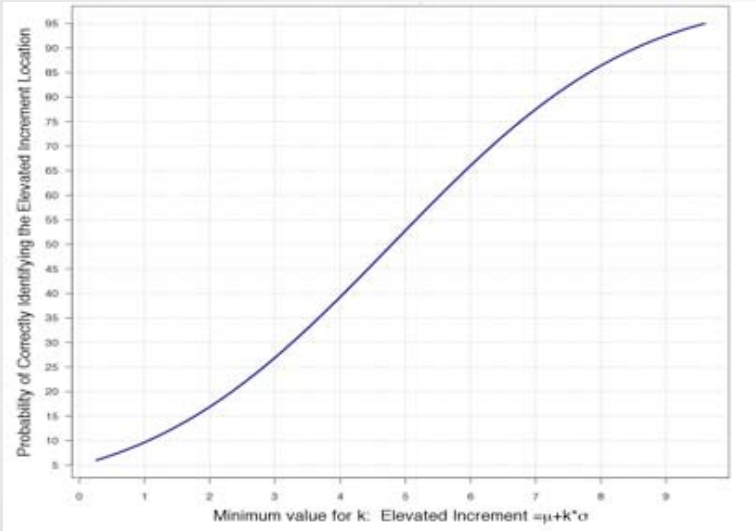
- The Aligned MI design -- The ability to collect a reduced number of ISM samples over large areas while still preserving information about the spatial distribution of the contaminant
- PNNL developed the theoretical model to quantify the probability that a single elevated grid cell could be identified using a pre-defined "row" and "column" ISM sampling configuration





$$k = 0.5\sqrt{r + c + 2}\,(Z_{1-\alpha} - Z_{1-\pi})$$

r number of rows
c number of columns
k # of standard deviations above background.
$(Z_{1-\alpha} - Z_{1-\pi})$ Type I & II Error

Technical Description:
ISM Designs for Decisions on Mean

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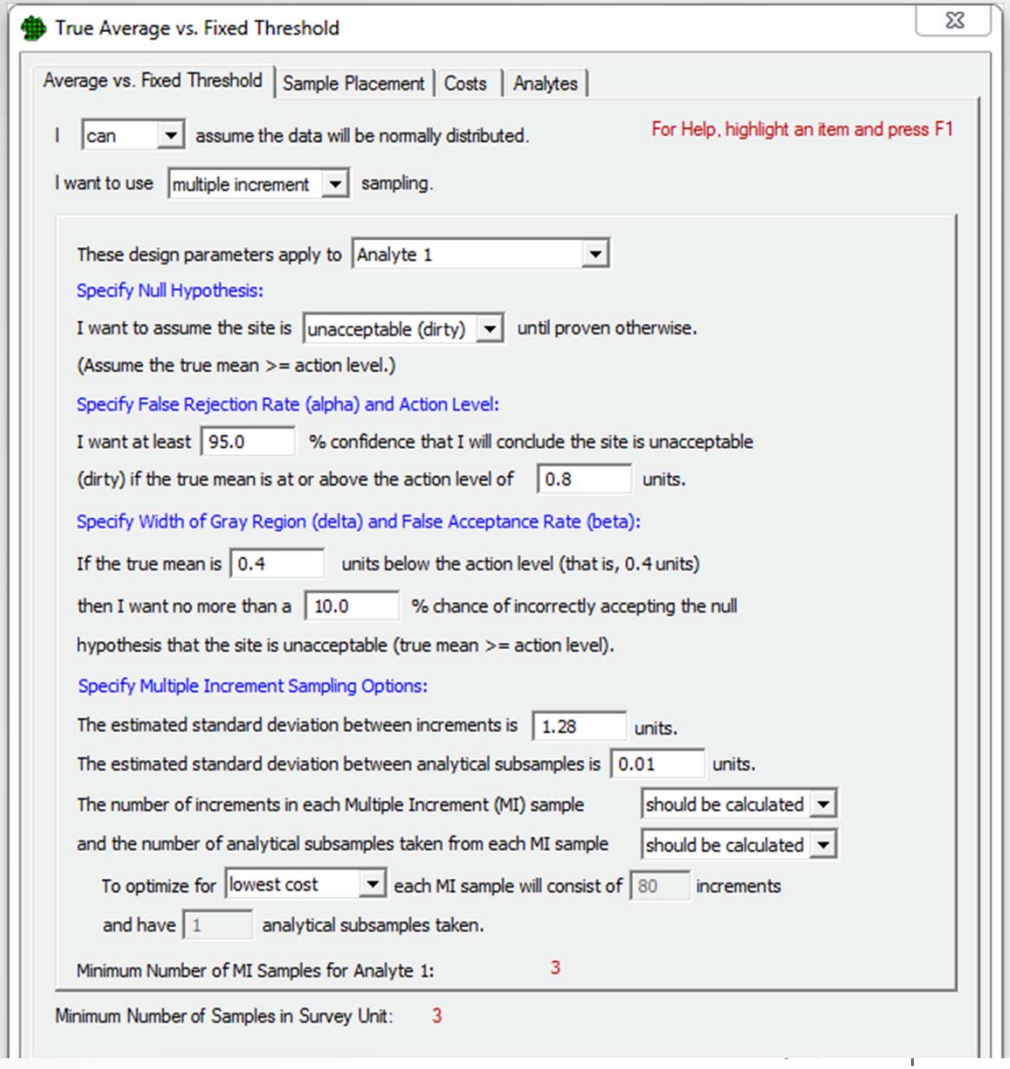
- Provide a **site specific DQO-based** answer to **how many increments** should be combined in each ISM sample and **how many ISM samples** should be taken within a wide area decision unit (DU)

- Three designs for mean based DQOs
  - Compare to a threshold
  - Construct a confidence interval
  - Compare to background

- Methods adapted from published paper (Rholf, 1996)



Technical Description: Wide Area ISM Designs

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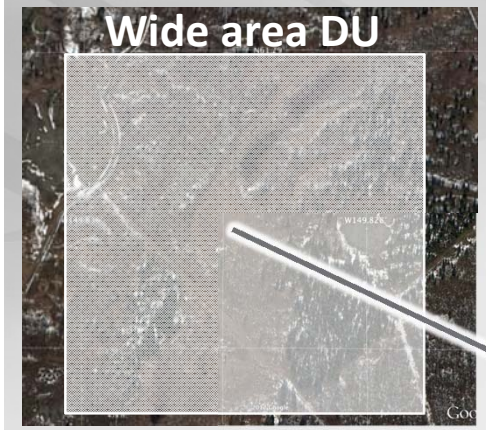


Very large DUs restrict usability of current full DU ISM samples

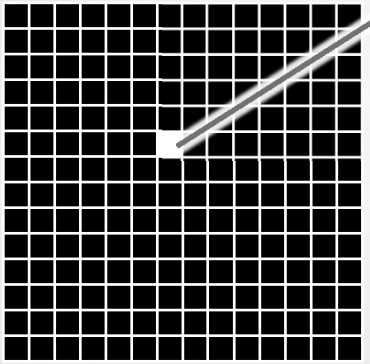
Data Quality Objectives (DQO)

DU mean decisions:
VSP tools use traditional statistical sample size equations adapted to ISM to define how many ISM should be collected and the number of increments to include in each.

VSP 7 Visual Sample Plan

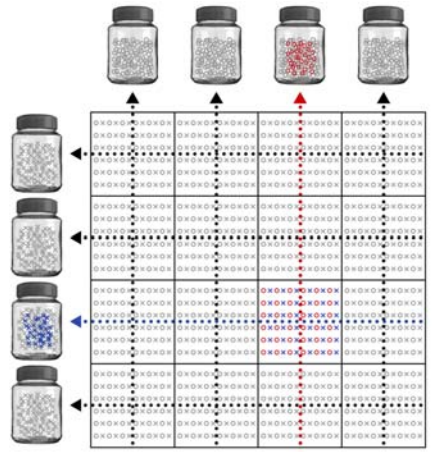
Statistical sampling designs can leverage small sampling units to make inference to the wide area DUs

~Hundreds of 1/4 acre sampling units



Collecting hundreds of ISM samples is cost prohibitive

Dispersion decisions:



ESTCP Funded Demonstration Project

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- Demonstrate the integration of statistically based ISM designs within VSP that incorporate ISM/MIS methods previously demonstrated under SERDP/ESTCP for wide area applications (2013-2016)

http://prod.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminants-on-Ranges/Identifying-and-Evaluating-Sources/ER-201329

Technical Approach

2014 – Statistical Sampling Validation within Wide Area DUs

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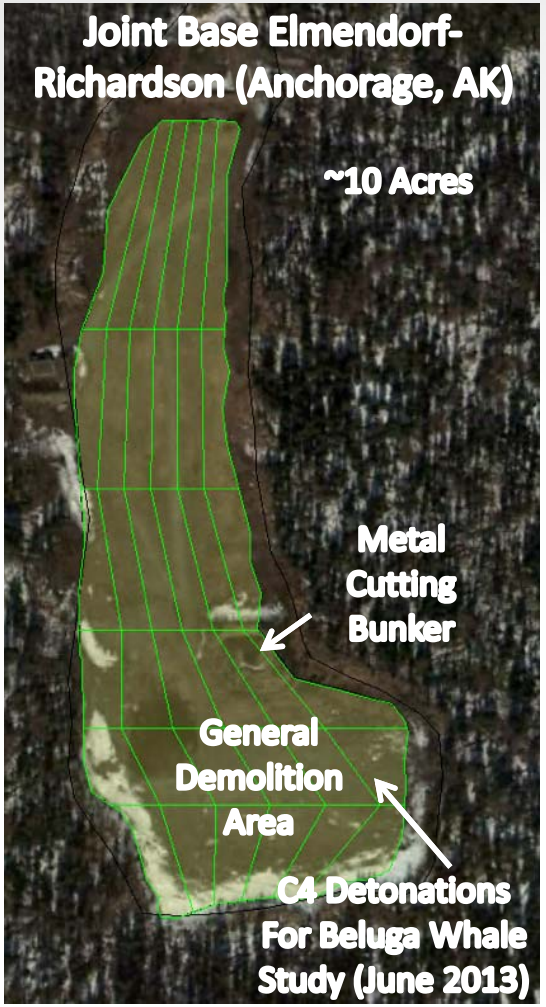

Technical Approach

2013 – Statistical Sampling Validation within Small Area DUs

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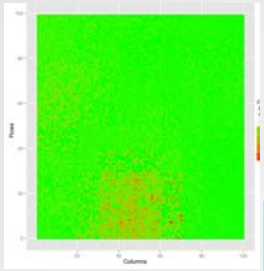
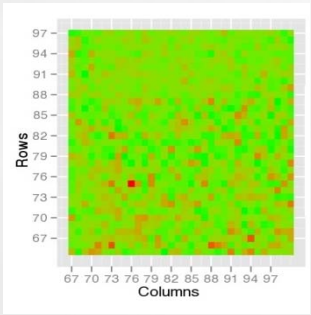
- Compare mean estimates from VSP designs to traditional ISM designs
- Validate robustness of aligned ISM assumptions

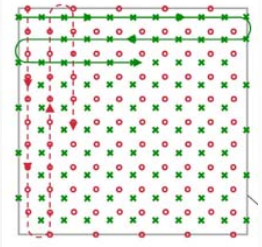
Two DU Scenarios



DU 1



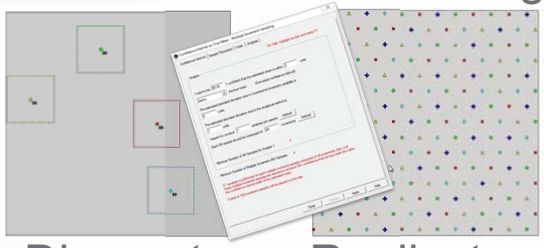
DU 2



Traditional ISM
100 increments

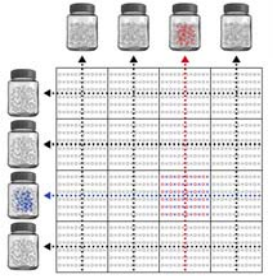
Four Design Scenarios

VSP Mean Estimation Design



Disparate Replicate

>400 laboratory analyses during phase 2



Aligned ISM
10 x 10 grid

Alaskan Training Ranges
Donnelly Training Area

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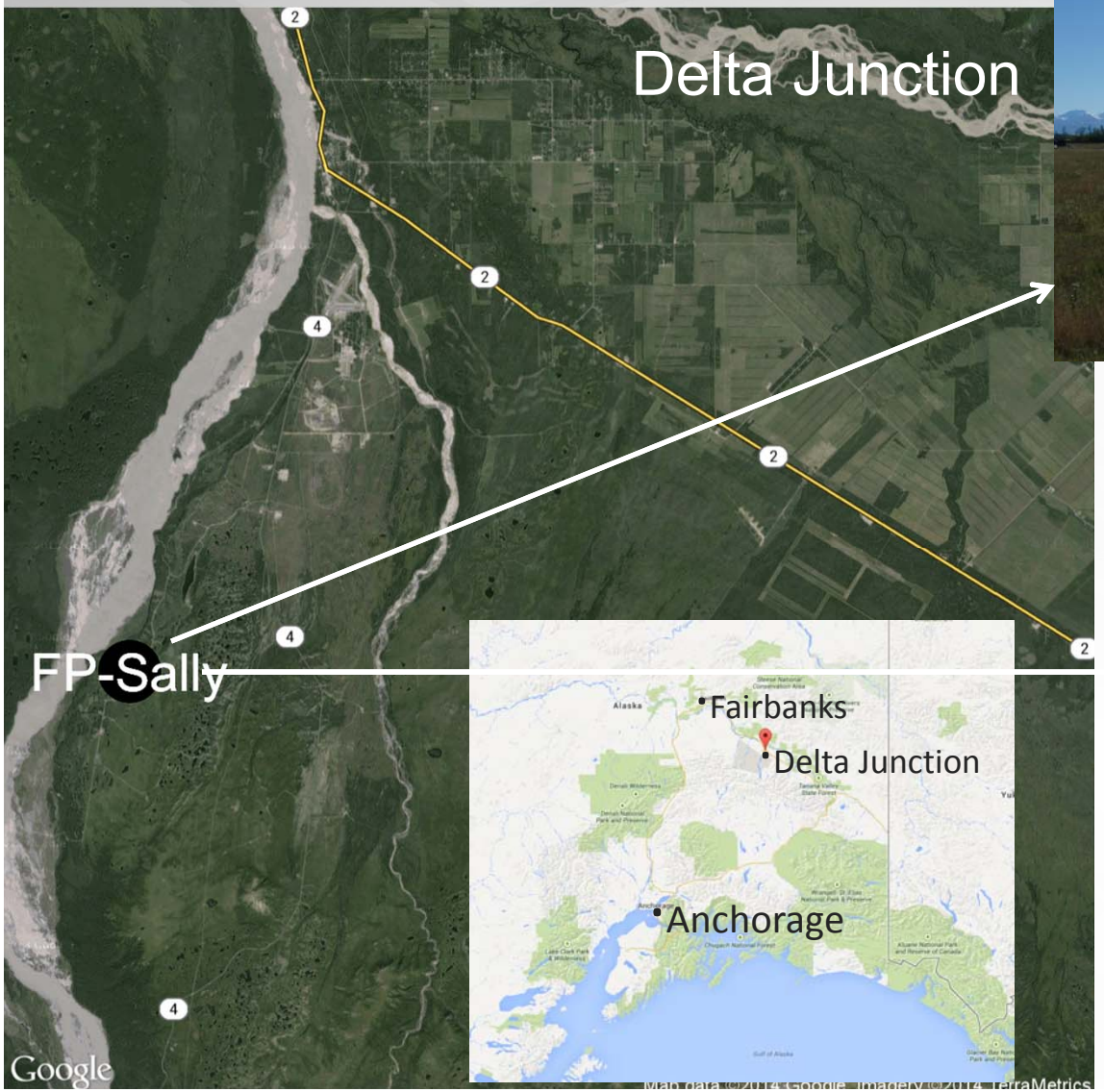

Contaminants of Concern

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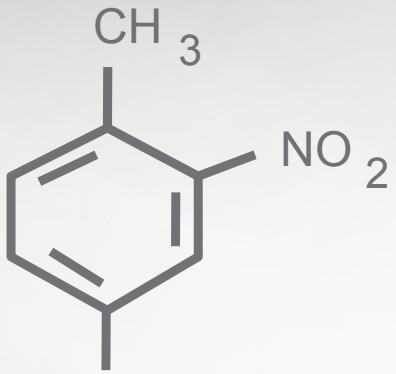
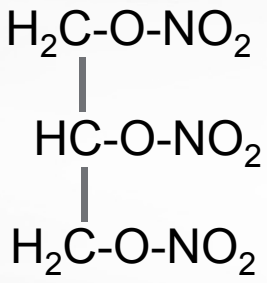
105-mm Howitzer

Fibers 0.4 to 7.5 mm long containing 2,4-DNT

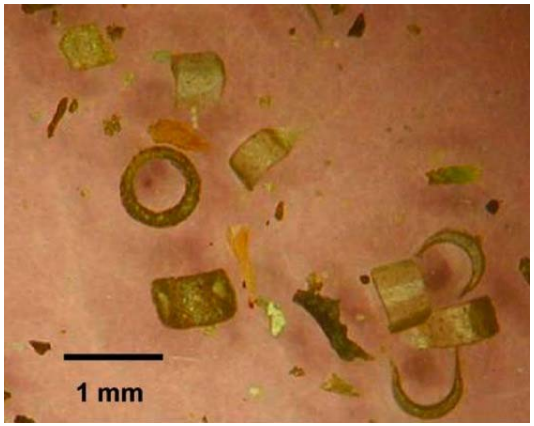


2,4-Dinitrotoluene (2,4-DNT)



Nitroglycerin (NG)

120-mm Mortar



Rings and fragments containing NG

Solid Residues of Propellants at Firing Points

Alaskan Training Ranges
Donnelly Training Area

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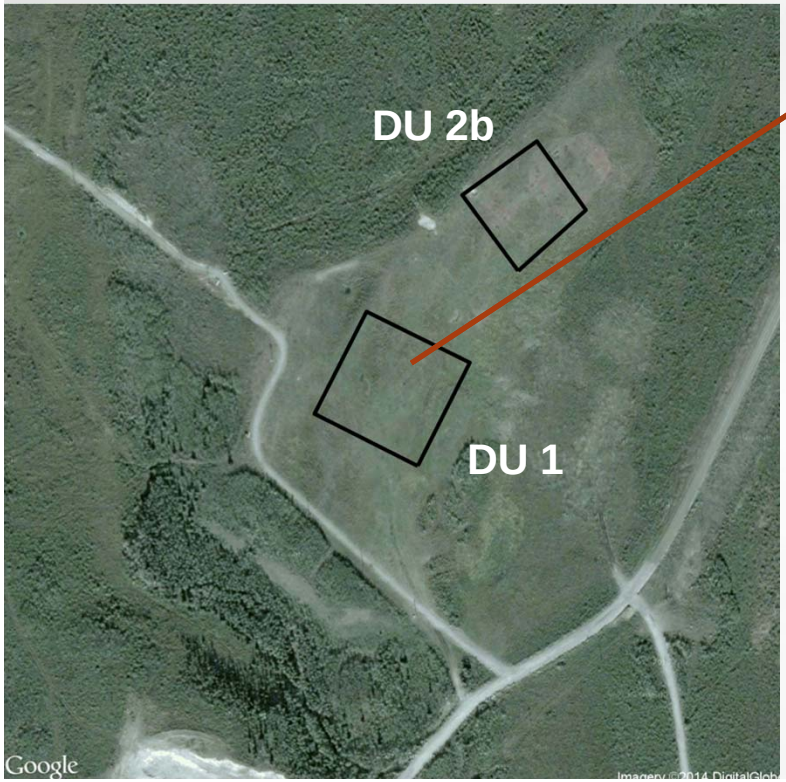
- **DU 1 matches historical footprint**
- **DU 2b shifted northeast and resized (80 x 80 m.)**

- FP Sally chosen due to potential for localized high concentration of 2,4-DNT in DU 1
- Historical ISM samples show some highly variable observations



Month-Year	2,4-DNT	NG
July-2003	1.1, 0.14, 0.45, 3.7, 1.8, 1.6	not detected
June-2005	3.4, 4.7, 3.2	not detected
July-2007	2.1, 1.5, 5.4	0.7, 0.7, 0.8
September-2007	**3.3, 2.4, 44**	0.9, 0.9, 1.2
May-2008	2.6, 3.9, 3.1	0.8, 3.2, 1.1
September-2008	3.1, 1.3, 2.4	0.8, 0.7, 0.9
July-2009	1.5, 1.2, 1.7	1.0, 0.7. 1.4
September-2012	**0.80, 0.75, 8.0**	0.7, 0.4, 0.4

Donnelly Training Area
DU-1 FP-Sally

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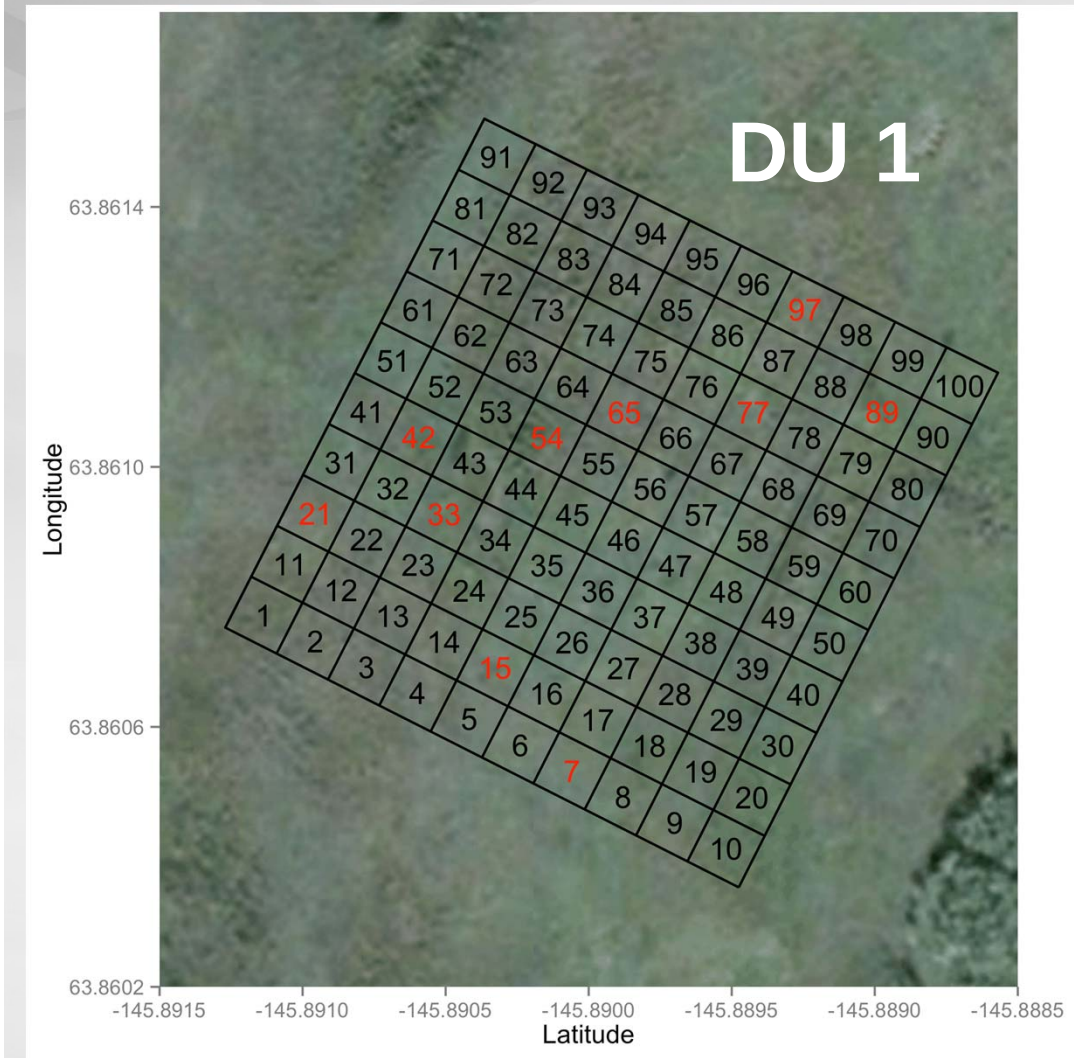

- **Super Cells colored red**
- **> 23,000 increments collected**
- **>200 of ISM samples collected**

Method 8330B Sample Prep

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Performance Assessment

$$\frac{\left(number\ of\ columns \times Row_i + number\ of\ rows \times Column_j\right)}{number\ of\ columns + number\ of\ rows} = Cell_{ij}\ test\ statistic$$

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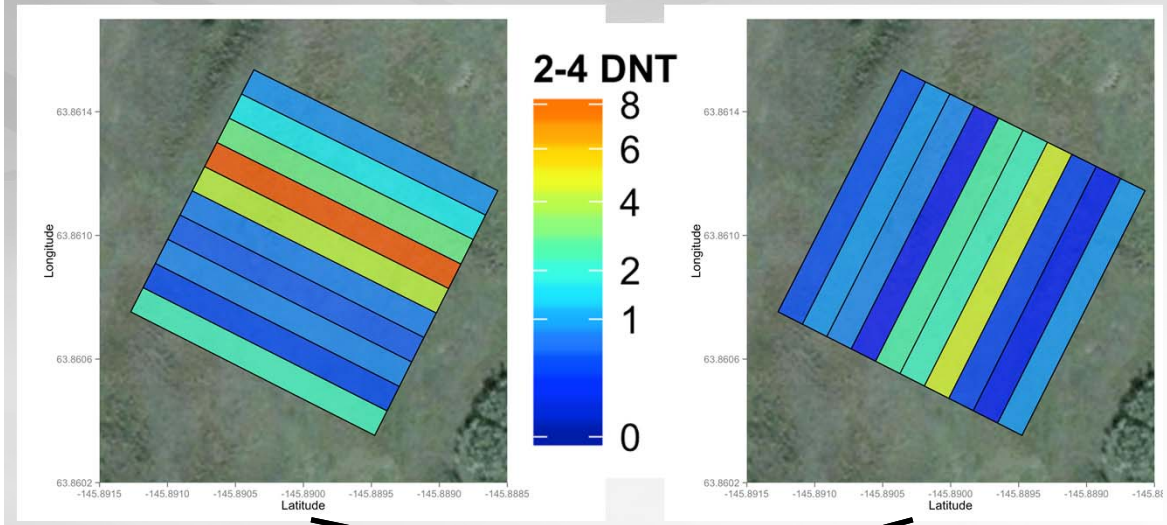
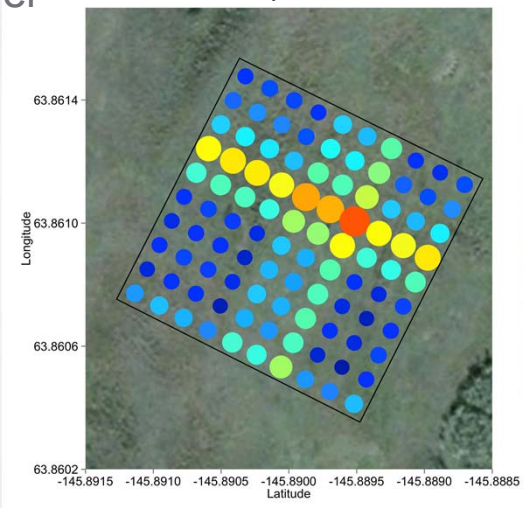
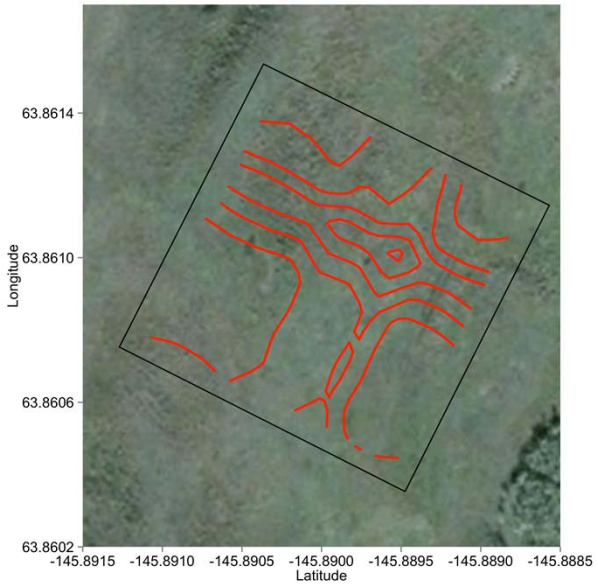


- **Develop elevated cells contour map from row and column ISM**

Calculate cell level test statistics



Develop elevated region contour map



Performance Assessment

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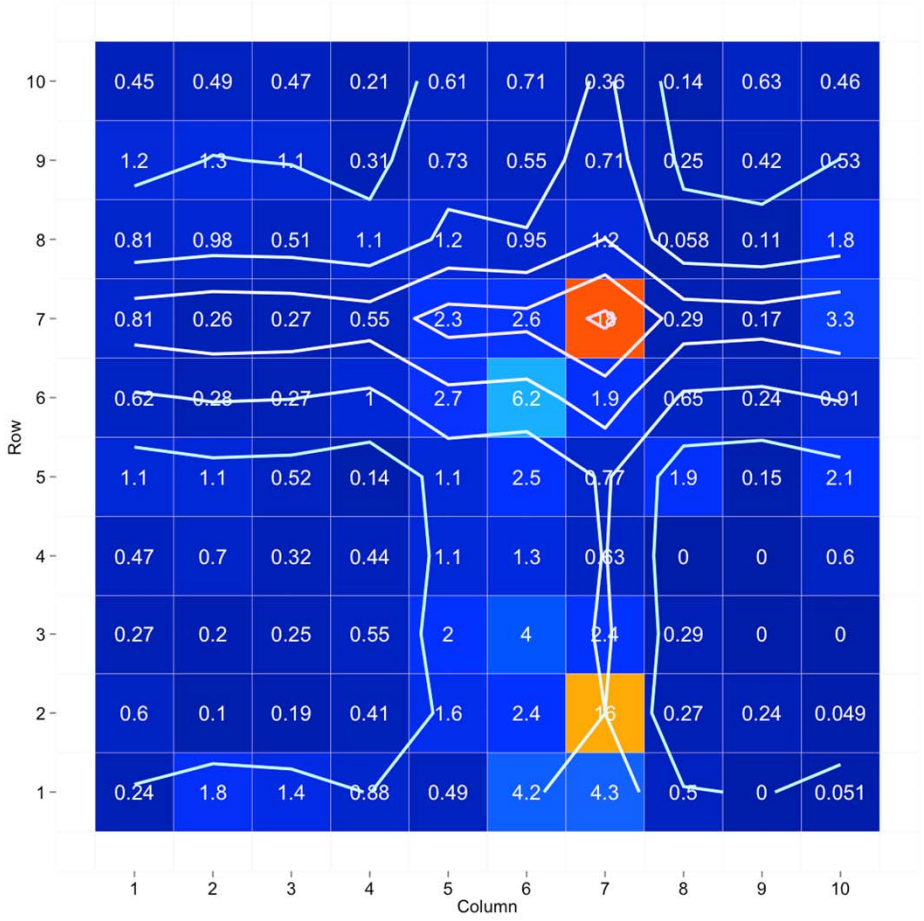

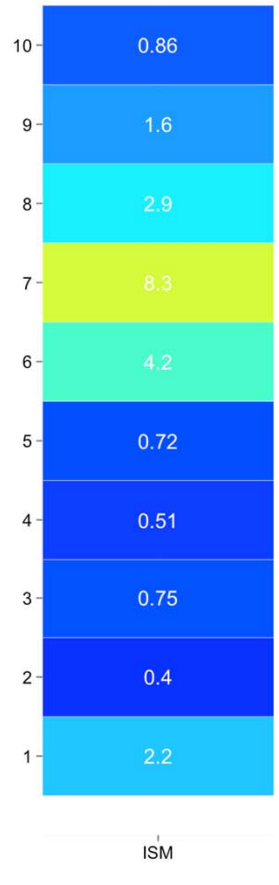

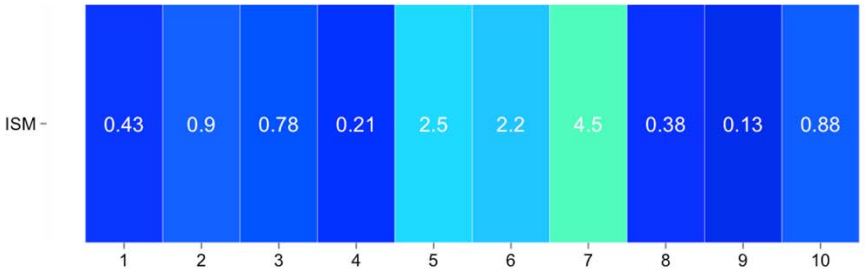

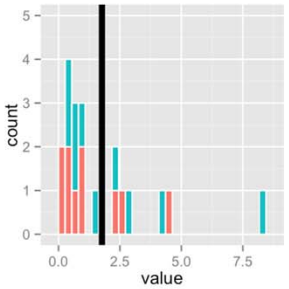

- **Row/Column ISM**
  - **Contour estimates**
  - **Mean estimate of 1.8 mg/kg 2-4 DNT**
- **Cell level ISM**
  - **Colored grid cells**
  - **Mean estimate of 1.3 mg/kg 2-4 DNT**

Mean and spatial mapping align

Performance Assessment

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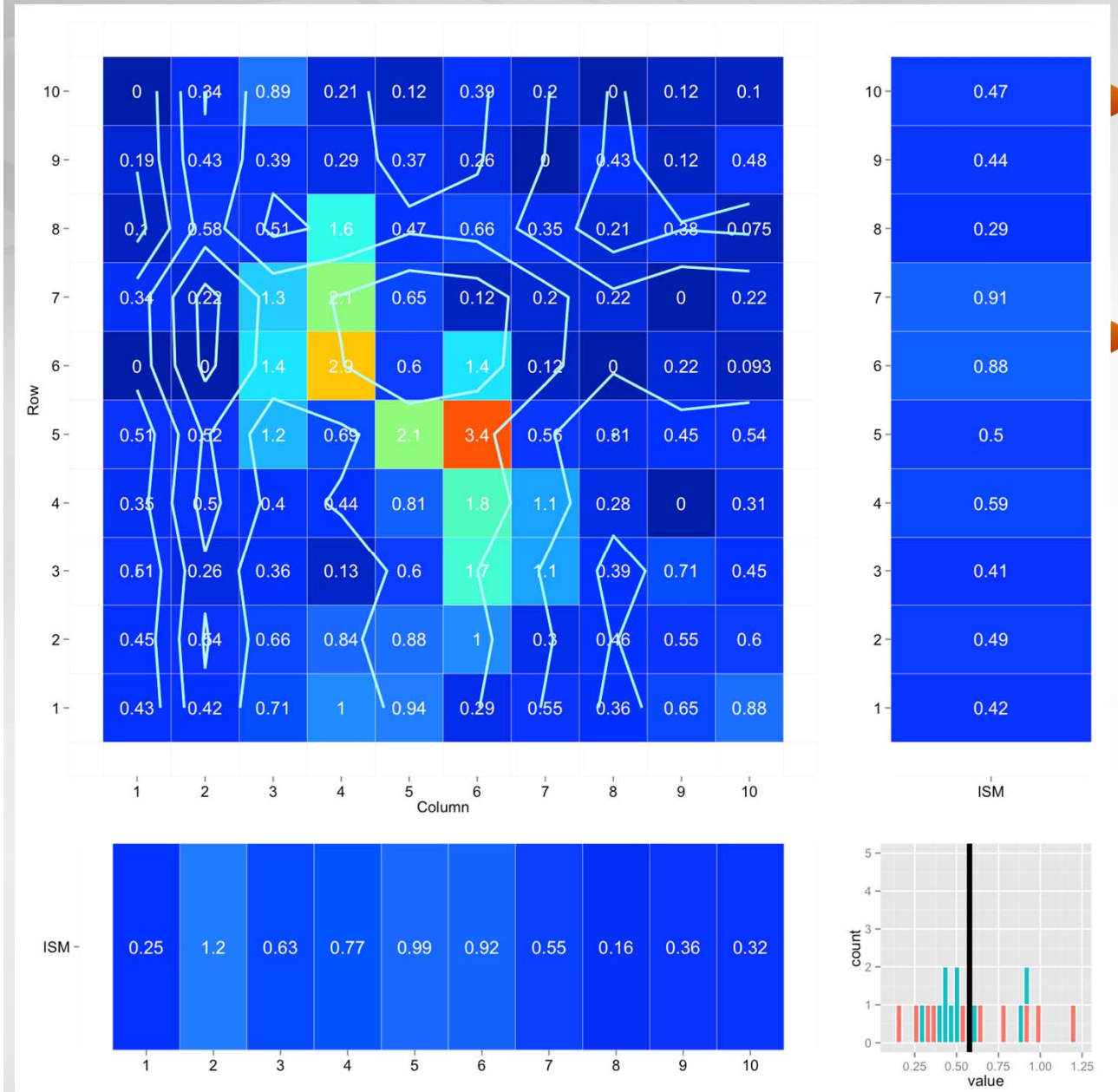

- **Row/Column ISM**
  - **Contour estimates**
  - **Mean estimate of 0.6 mg/kg NG**
- **Cell level ISM**
  - **Colored grid cells**
  - **Mean estimate of 0.6 mg/kg NG**

Mean and spatial mapping align

Performance Assessment

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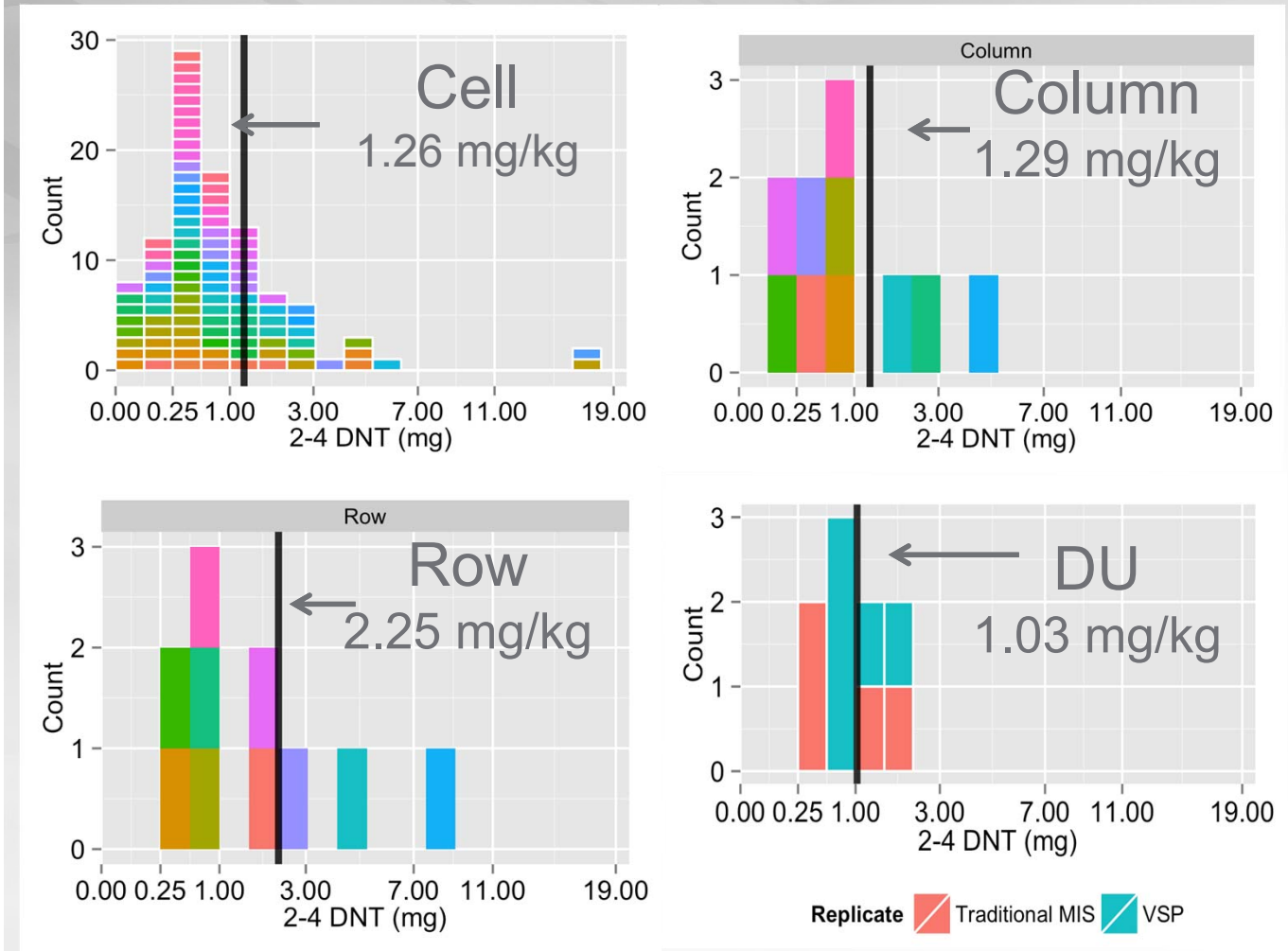

FP-Sally, DU 1: 2-4 DNT

- **DU mean estimates are consistent across ISM methods**
- **"True" mean is 1.5 mg/kg for 2-4 DNT**

Conclusions

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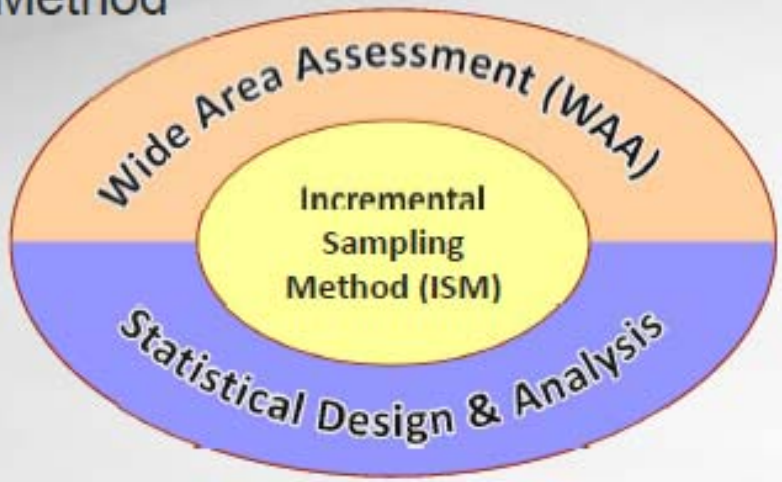
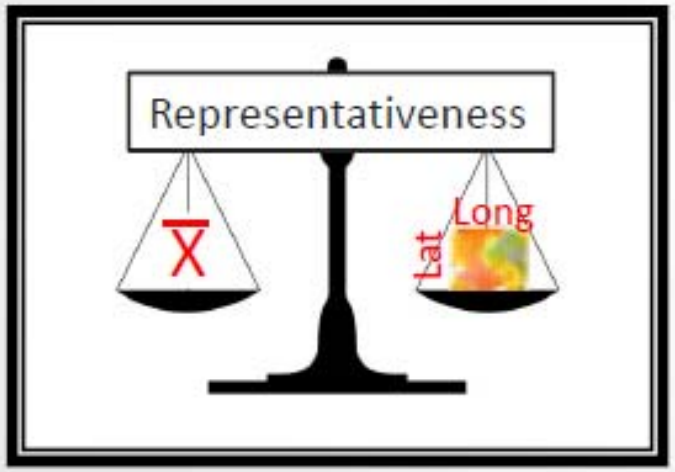
- Statistically based sample designs need to be more tightly incorporated into the Incremental Sampling Method



- Dialogue between ISM "devotees" and discrete sampling "devotees" needs to continue



- We need to strike a better balance between spatial extent and mean estimation