TETRA TECH

Uranium Mine Waste Mapping at Riley Pass, SD using Gamma Radiation and XRF Field Surveys

Presented By

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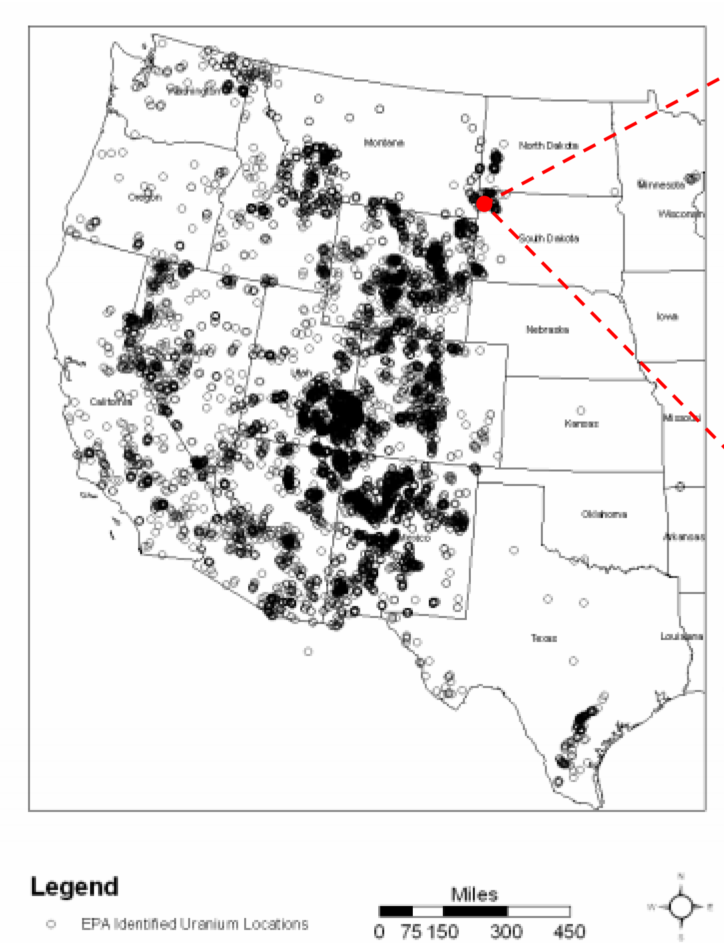
Case Study Overview

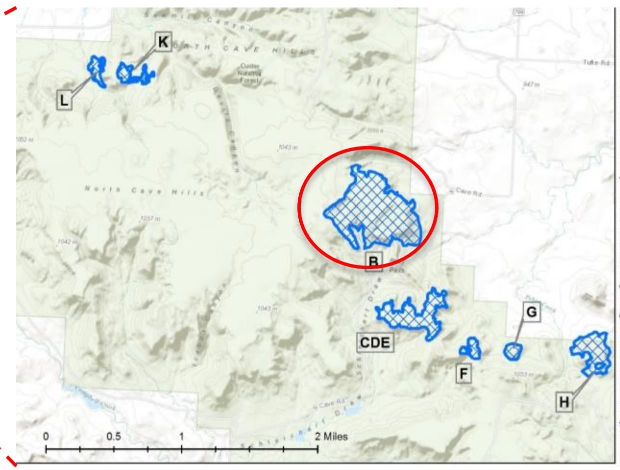
- Objectives
- Legacy Uranium Mining in US
- Site Background
- Data Acquisition/ Methodology
- Results

Presentation Objectives

- Present sampling design approach methodology for characterizing surface soils at Riley Pass abandoned uranium mine.
- Demonstrate use of XRF and gamma surveys.
- Present soil concentration mapping techniques and results.
- Present results of cost savings analysis of using the techniques described in this study.

Western U.S. Uranium Locations from the EPA Uranium Location Database (EPA 2006)



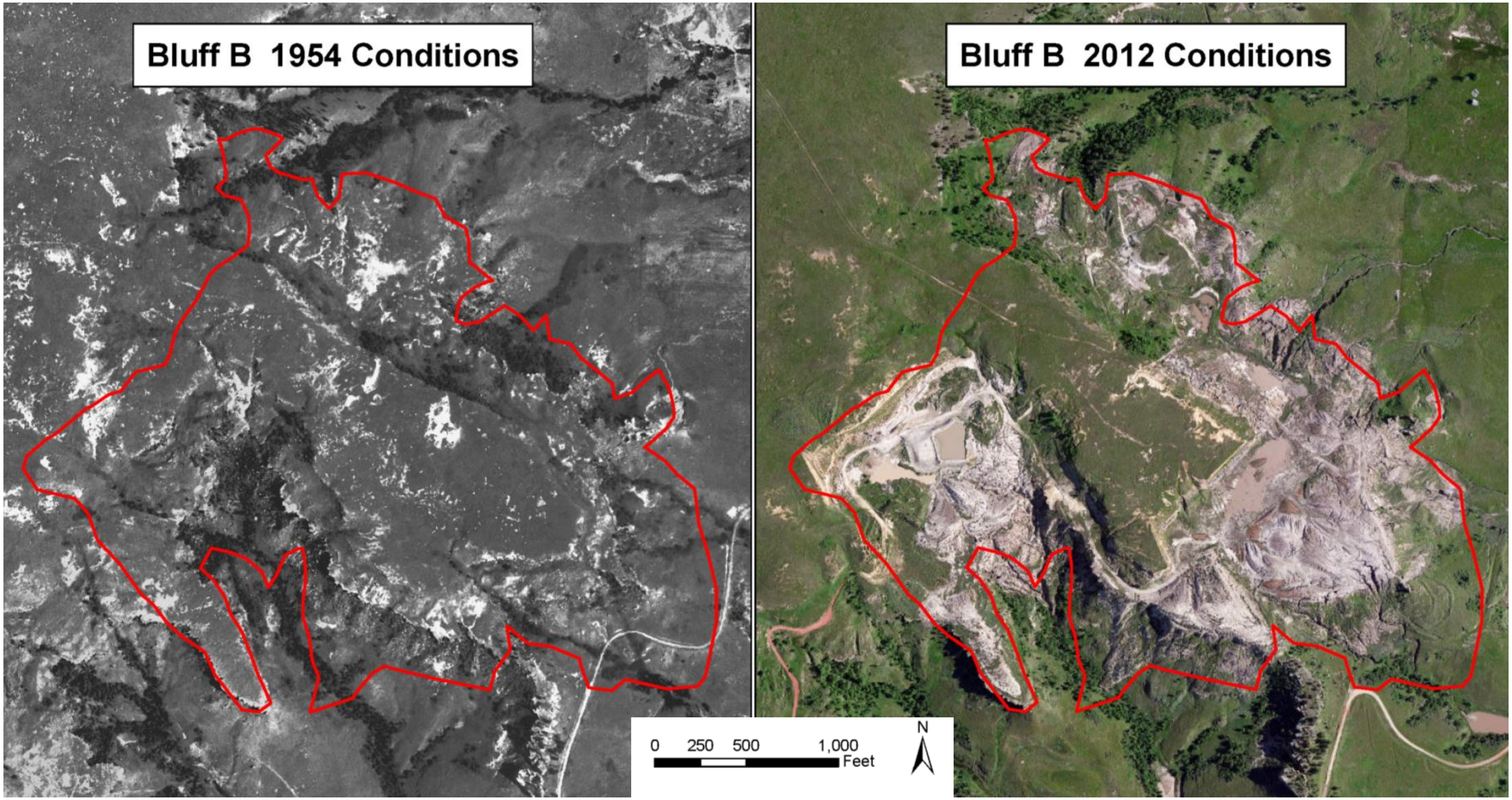


Study Area	Surface Area (acres)	Surface Area (ft^2)	Original Characterization Date	Reclamation Status
Bluff A	6.03	262,449	2009	Not Reclaimed
Bluff B	153	6,667,729	2012	Not Reclaimed
Bluff CDE	48.0	2,092,884	2012	Not Reclaimed
Bluff F	7.54	328,346	2009	Partially Reclaimed
Bluff G	3.78	164,744	2012	Partially Reclaimed
Bluff H	33.7	1,466,553	2012	Not Reclaimed
Bluff I	30.8	1,342,509	2009	Partially Reclaimed
Bluff J	8.75	381,150	2009	Reclaimed
Bluff K	10.6	460,892	2009	Reclaimed
Bluff L	15.03	654,707	2009	Not Reclaimed
All Bluffs	317	13,821,963	-	-

Riley Pass – Site Background

- 1950 - 1964: Strip Mining
- 1965 - 1989: Erosion and sedimentation controls implemented.
- 1991: Environmental evaluation performed
- 1996: CERCLA (Superfund) Authorisation
  - In 1996, the Custer National Forest began working at the Riley Pass site under their Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authority.
  - Non-Time Critical
- 1999 - Present: Site Investigations and Removal Action
  - Tronox Bankruptcy Settlement

Historical Imagery



Historic

Portable Burner Used near Buffalo, SD

Current

TETRA TECH

ASMR 2009 Follow-up

ASSESSMENT OF ENVIRONMENTAL IMPACTS NEAR ABANDONED URANIUM MINES WITHIN THE CAVE HILLS AND SLIM BUTTES COMPLEXES, CUSTER NATIONAL FOREST, SOUTH DAKOTA[1]

J.J. Stone[2] and L.D. Stetler

Abstract: Prospecting and mining of uraniferous lignite in the Tertiary Fort Union formation occurred from 1954 through 1967 in northwestern South Dakota. Activity was centered on US Forest Service land and abandoned mine sites received limited reclamation. Subsequent erosion and transport of mine waste has resulted in environmental impacts to soil and water resources down gradient of the mine sites. Through US-EPA Region 8 funding, a Joint Venture Agreement between the USDA-Forest Service Northern Region and the South Dakota School of Mines and Technology (SDSM&T) has been established to evaluate environmental impacts from uranium mining to soil, water, and air resources occurring on private lands surrounding the Cave Hills and Slim Buttes complexes within Custer National Forest. Results from this impact study indicate historical mining activities have caused degradation of regional ecological and environmental resources through the transport and deposition of sediments and spoils containing elevated concentrations of arsenic and uranium. Within the watershed downgradient of the North Cave Hills, surface water concentrations of arsenic and uranium exceeded established background concentrations within 27 km of stream length below the abandoned mines. Sediment results suggest secondary arsenic and uranium mineral phases were typically limited to the upper depths of drainage sediments. Results show that 14 watersheds were potentially impacted by sediment transport from previous mining activity. The most impacted area was the Upper Pete's Creek drainage below Bluff B where two U samples were 3× and 4× established background. Groundwater results indicate that metals and radionuclides were natural components of the groundwater systems. Results of the surface dust study indicate the general ubiquity of target analytes in the soils around the North Cave Hills. All metals concentrations in the surface dust were decreasing or below background levels within 15 km from the mine sites.

Additional Key Words: uranium mining impacts, wind dust transport, groundwater, surface water, sediments

[1] Paper was presented at the 2009 National Meeting of the American Society of Mining and Reclamation, Billings, MT, ***Revitalizing the Environment: Proven Solutions and Innovative Approaches*** May 30 – June 5, 2009. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] Dr. James Stone, PE, Associate Professor, Department of Civil and Environmental Engineering, South Dakota School of Mines and Technology, Rapid City, SD 57701, Dr. Larry Stetler, Associate Professor, Department of Geology and Geological Engineering, South Dakota School of Mines and Technology, Rapid City, SD 57701.

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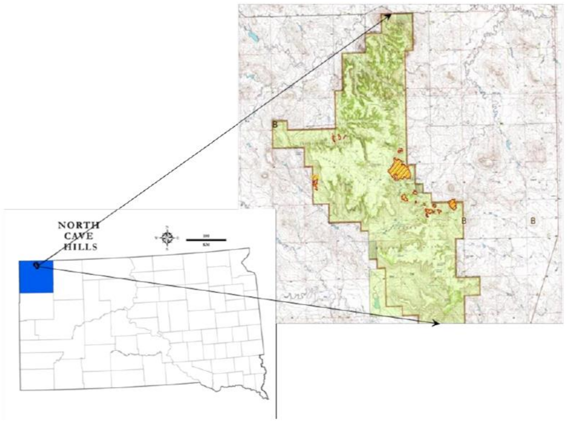


- *Focused on Cave Hills and Slim Butte Complexes*
- *Evaluated environmental impacts to soil and water resources down gradient of mine site.*
- *Soil, water, and air resources on private lands.*
- *Results*
  - *Degradation of regional ecological and environmental resources through transport and deposition of sediments and spoils containing elevated arsenic and uranium.*
  - *SW concentrations above background within 27 km of stream length below the abandoned mines.*
  - *14 watersheds impacted by sediment transport from previous mining activity.*
  - *All metals concentrations in the surface dust were decreasing or below background within 15 km from the mine sites.*

Non-Time Critical Removal Action

- Engineering Evaluation/ Cost Analysis
  - Risk Assessment
  - Identified Removal Action
- Risk Assessment
  - Identified cleanup values for a number of COPCs.
    - The proposed cleanup values are to be protective of human health and environment.
    - Cleanup values should result in site-associated risks below 1×10^{-4} and usually below 1×10^{-5} in total, summed across COPCs and all exposure pathways.

Characterization Needed

- Cancer risk drivers – (As and Ra-226) in soil
- Detailed spatial extent of contamination based on the DCGLs:
    - Arsenic: 142 mg/kg
    - Molybdenum: 2,775 mg/kg
    - U-238: 42.8 pCi/g
    - U-234: 44.6 pCi/g
    - U-235: 2.03 pCi/g
    - Ra-226: 30.0 pCi/g
    - Th-230: 39.8 pCi/g
- Determine sampling techniques
    - Conventional soil sampling with laboratory analysis
    - In situ measurements

Characterization Techniques

Gamma Radiation Survey




XRF Field Survey

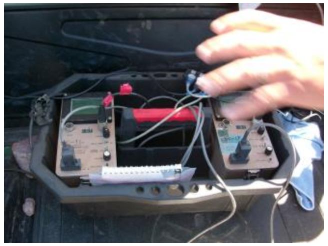

Mobile Gamma Scanning Systems

Ludlum 2350-1 Datalogger

44-10 NaI Scintillator

WAAS Enabled GPS Units

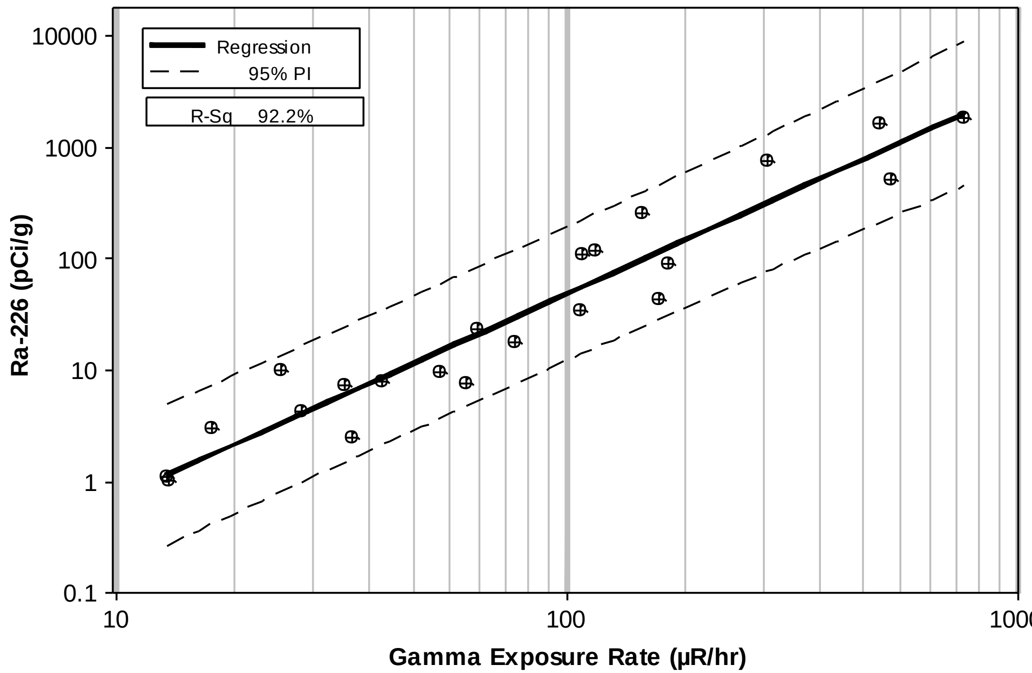
Scanning Software



Gamma/Ra-226 Correlation

MARSSIM Guidance Approach

Multi-Agency Workgroup



Methods in Johnson et. al (2006)

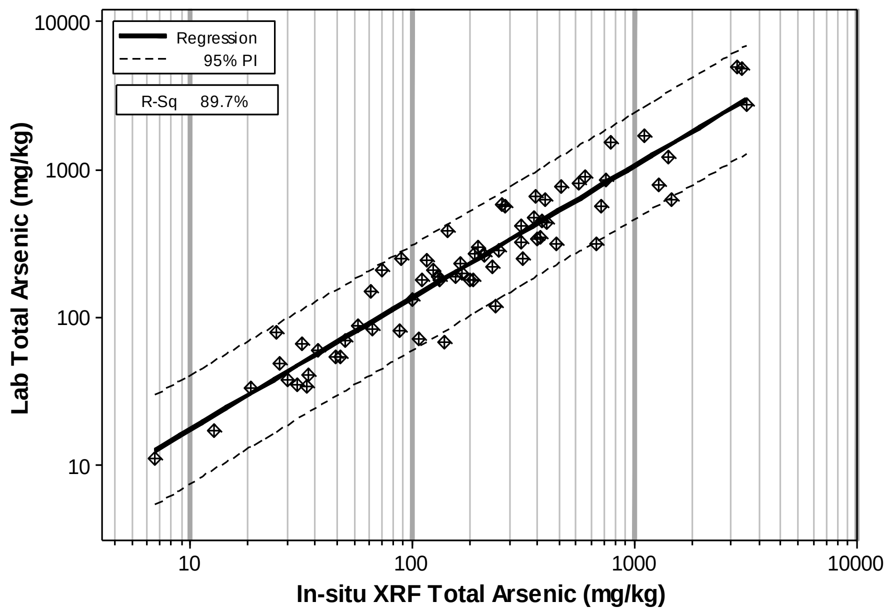
$$\text{Lab Ra} - 226 = 10^{-1.979+1.835\ log_{10}(Gamma)}$$

Where:

Lab Ra-226 = lab. soil Ra-226 concentration (pCi/g).

Gamma = Gamma exposure rate measurement (µR/hr)

XRF Field Survey



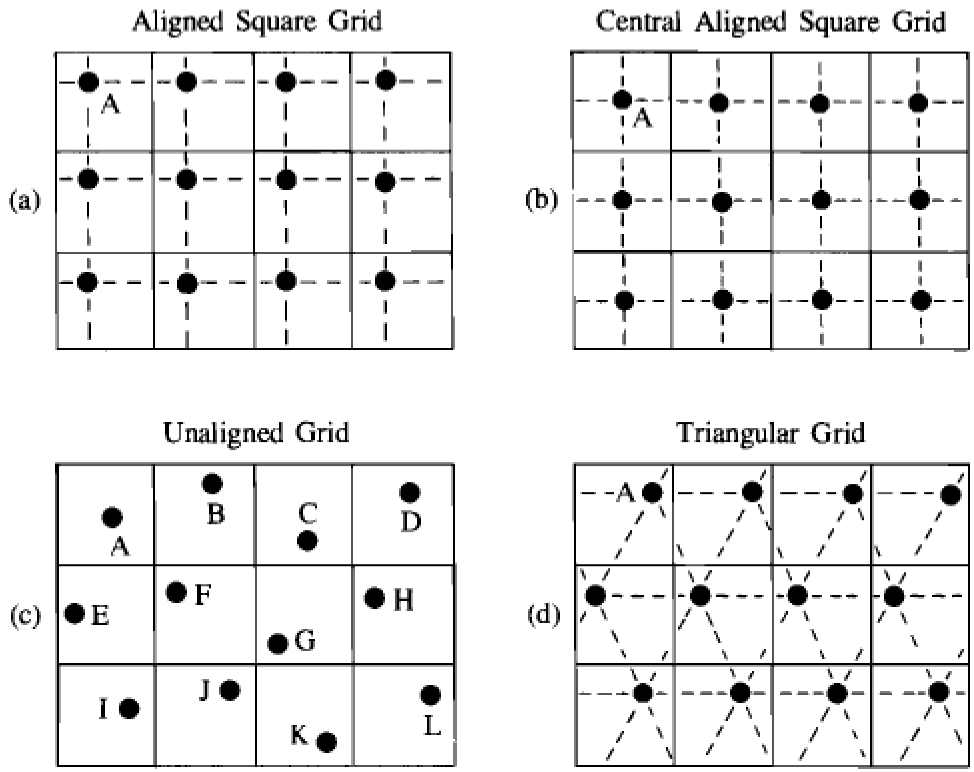
$$Lab\ Arsenic\ = 10^{0.352+0.891log_{10}(\text{XRF Arsenic})}$$

Where:

Lab Arsenic= laboratory reported arsenic concentration in surface soil (mg/kg).

XRF Arsenic = XRF measured arsenic concentration in surface soil (mg/kg).

Systematic Sampling

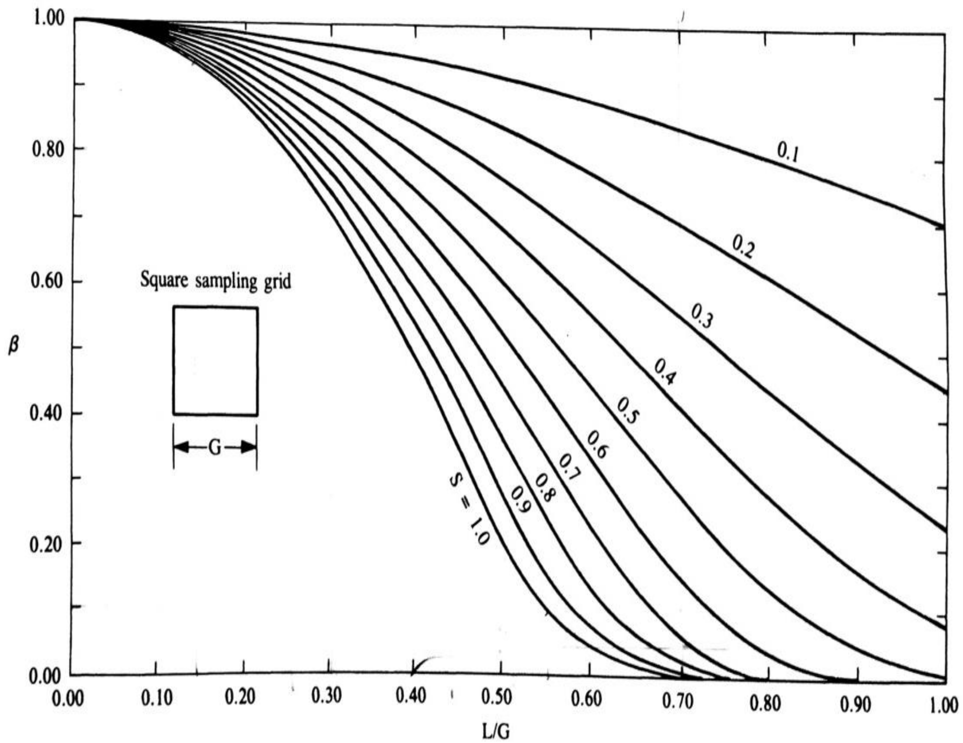


Grid spacing to use to have a specified probability of detecting a hot spot of a certain size?

Definition:

- Hot spot is area exceeding cleanup standard

Hot Spot Location Technique



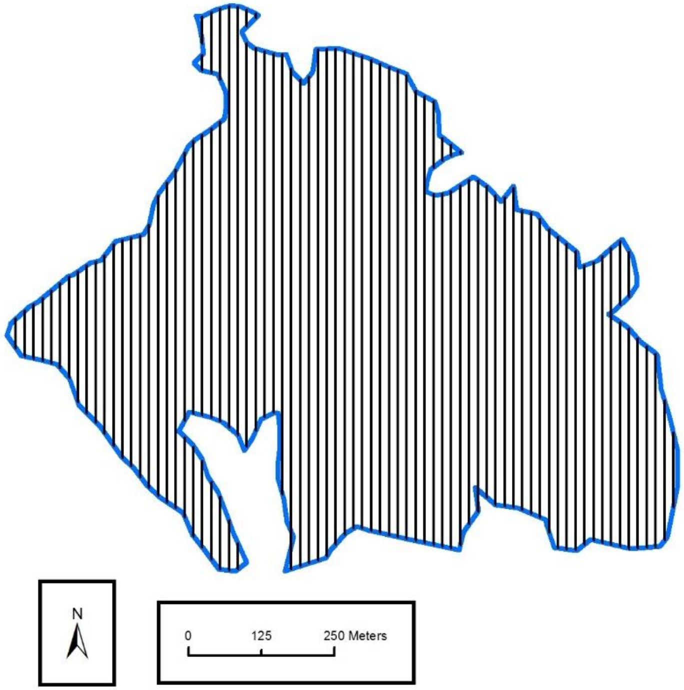
(Gilbert 1987)

How to determine grid spacing (G) ?

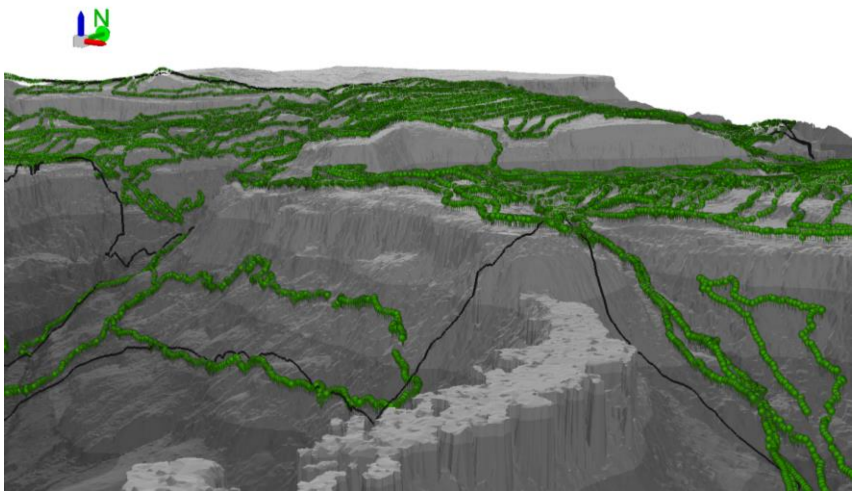
1. Specify L (semi-major axis) and S (shape factor).
2. Specify β = probability of missing the hot spot that you are willing to live with.
3. Use the appropriate charts from Gilbert to find the value of L/G. From this you get G.

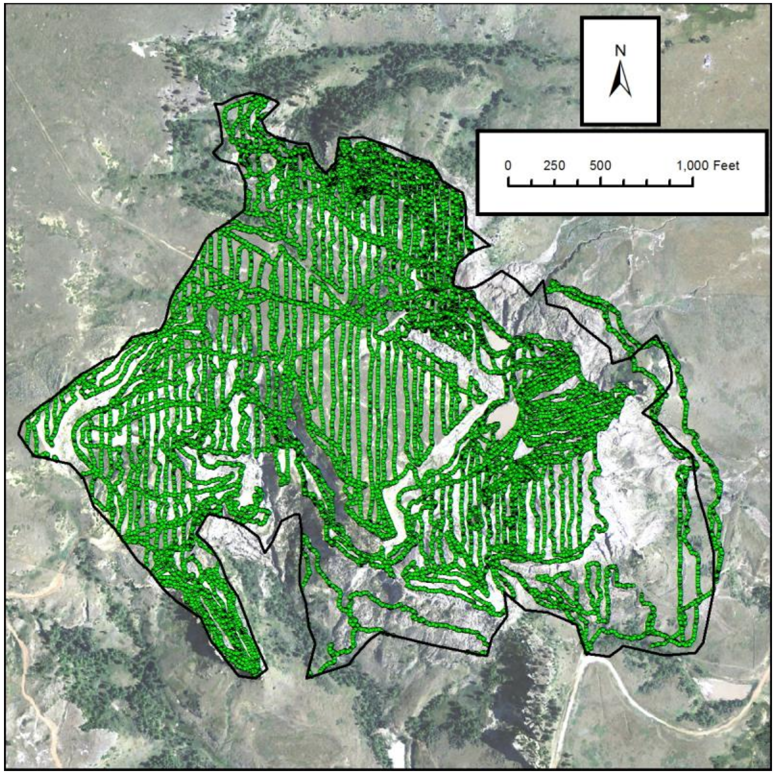
Identifying Hot Spots of Contamination for Radium-226

- Hot Spot Size
  - 18 m (circle)
- Probability of Finding Hot Spot
  - 1 - β = 95 percent
- Resulting Grid Size
  - G = 15 m



Gamma Survey– Bluff B

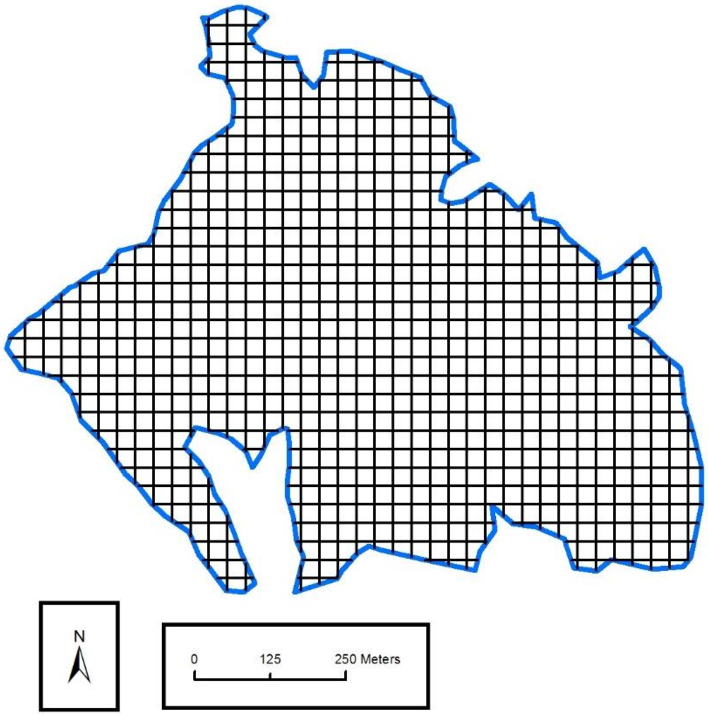




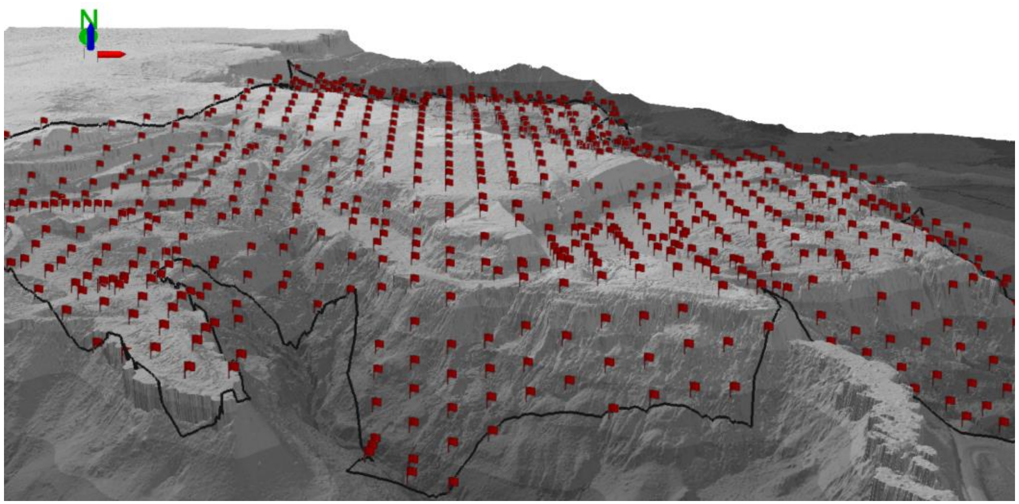
67,000+ Samples on 15 m grid spacing

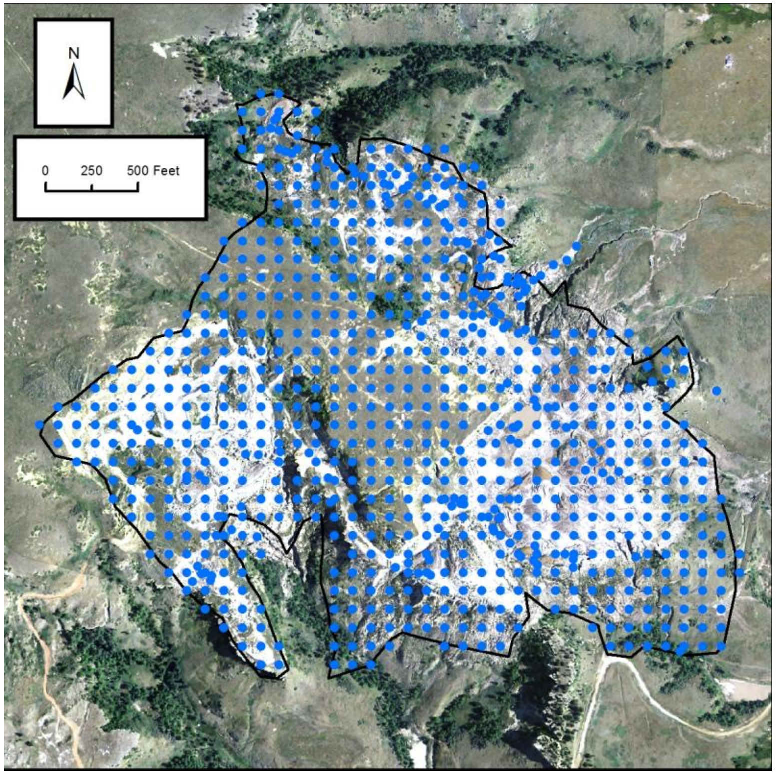
Identifying Hot Spots of Contamination for Arsenic

- Hot Spot Size
  - L = 36 m (circular)
- Probability of Finding Hot Spot
  - $1 - \beta = 95$ percent
- Resulting Grid Size
  - G = 30 m



XRF Field Survey – Bluff B





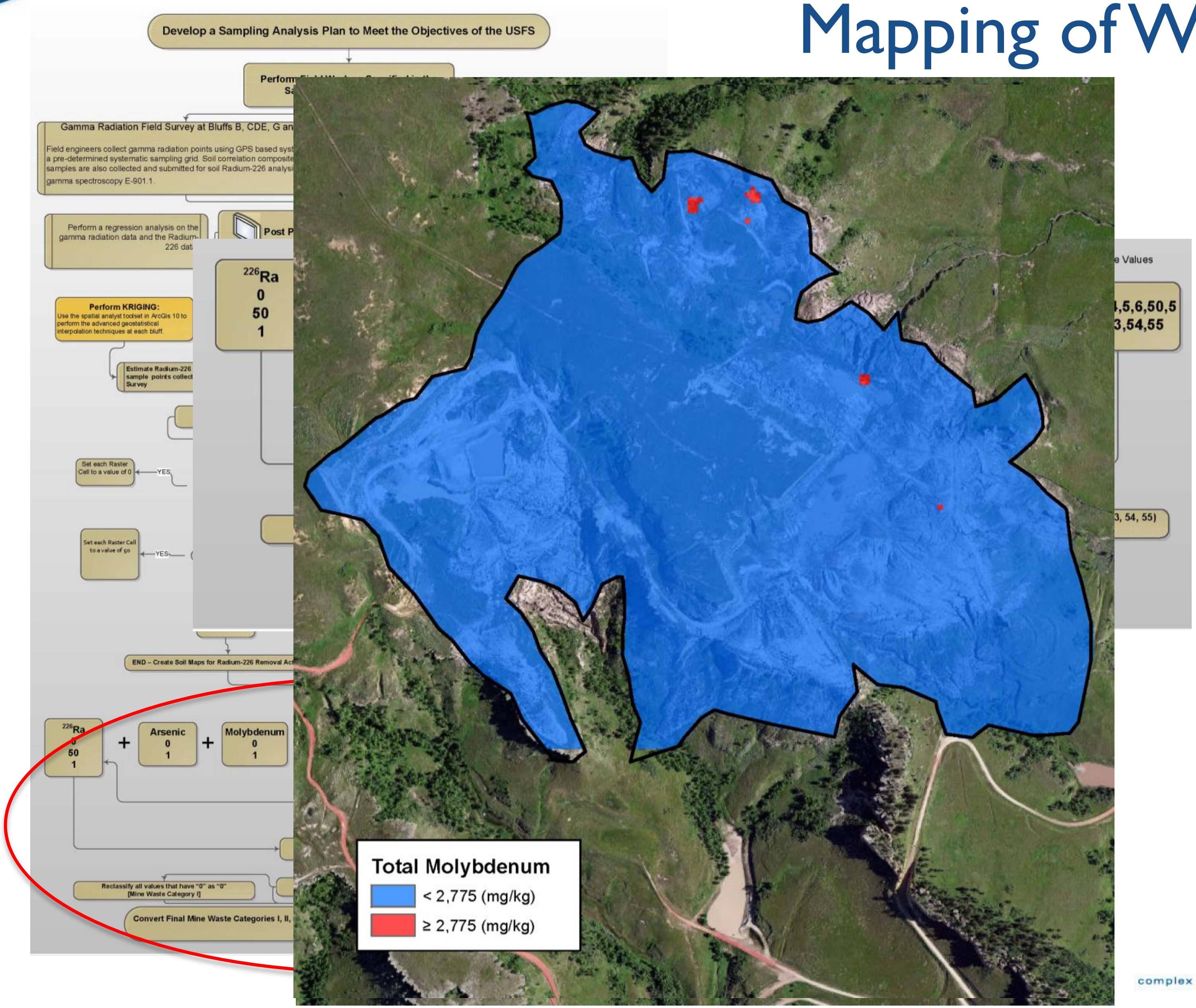
800+ Samples on 30 m grid spacing

Previous Mine Waste Categorization

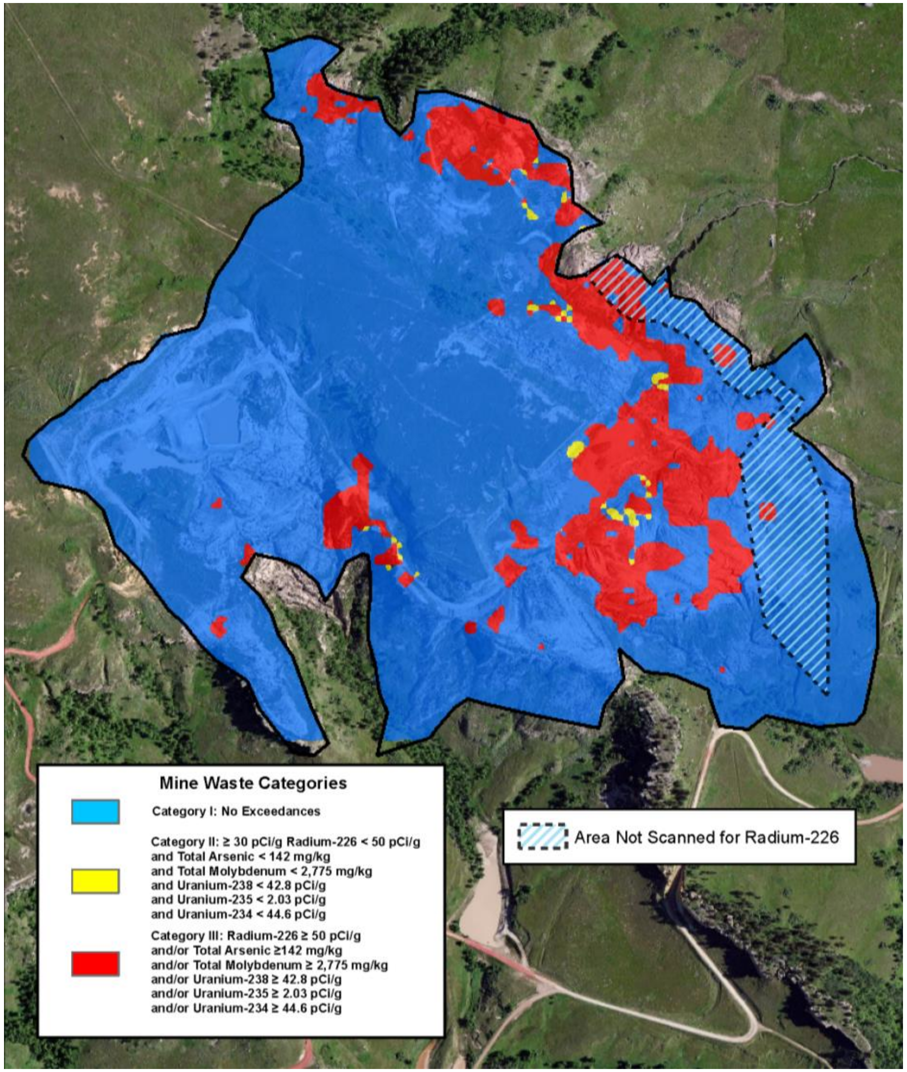
Category	^{226}Ra Activity	Total Arsenic Concentration	Total Molybdenum* Concentration	^{238}U** Activity	^{235}U** Activity	^{234}U** Activity	Removal Action Goal
Category I	< 30 pCi/g***	and < 142 mg/kg+	and < 2,775 mg/kg	and < 42.8 pCi/g	and < 2.03 pCi/g	and < 44.6 pCi/g	Vegetate/stabilize where/if necessary
Category II	≥ 30 pCi/g; <50 pCi/g	and < 142 mg/kg	and < 2,775 mg/kg	and < 42.8 pCi/g	and <2.03 pCi/g	and < 44.6 pCi/g	Mitigate to bring average soil ^{226}Ra activity down to less than or equal to 30 pCi/g
Category III	≥ 50 pCi/g	and/or ≥ 142 mg/kg	and/or ≥ 2,775 mg/kg	and/or ≥ 42.8 pCi/g	and/or ≥ 2.03 pCi/g	and/or ≥ 44.6 pCi/g	Excavate and place in a designed repository

*Total Molybdenum concentration criteria is based on Table 5-3 of Appendix D of the EE/CA
**The Uranium decay series isotopes activities for 238U, 235U, and 234U are based on Table 5-4 from Appendix D of the EE/CA.
***pCi/g = picocuries per gram
+mg/kg = milligrams per kilograms

Mapping of Waste



Categorization Results



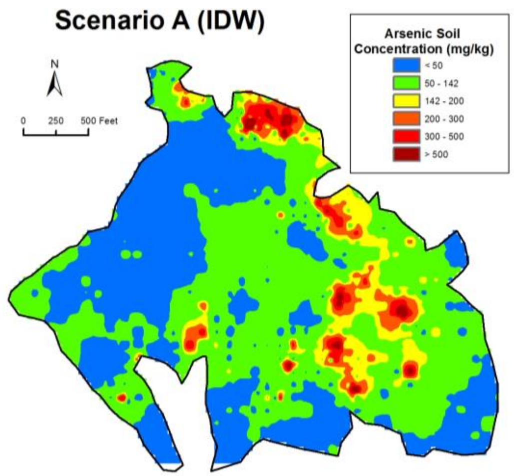
Proposed Mine Waste Categorization

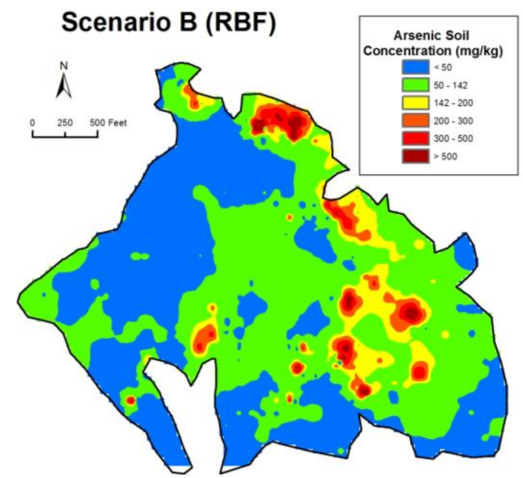
- Arsenic and Ra-226 only?
- Detailed Evaluation showing that arsenic and Ra-226 cleanup values can be used as a surrogate for uranium and molybdenum.
- Clean up areas
  - Arsenic = 142 mg/kg
  - Ra-226 = 30 pCi/g

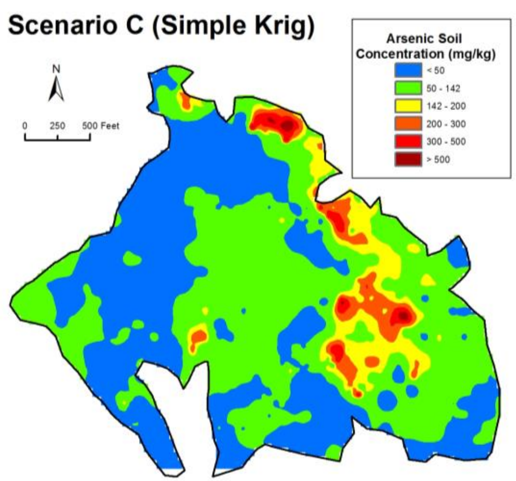
Soil Mapping

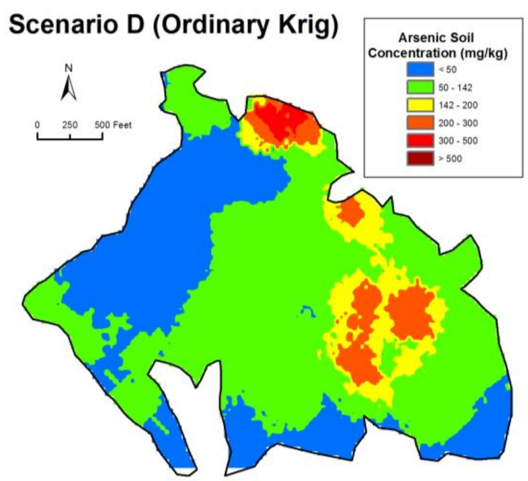
- Goals
  - Generate the most accurate possible surface from existing sample data.
- Geostatistical Analyst tool in ArcGIS
- Evaluate a number of scenarios and geostatistical and deterministic methods:
  - Kriging (Simple, Ordinary, Universal)
  - Inverse Distance Weighted (IDW), Radial Basis Functions (RBF)

Bluff B Arsenic Scenarios

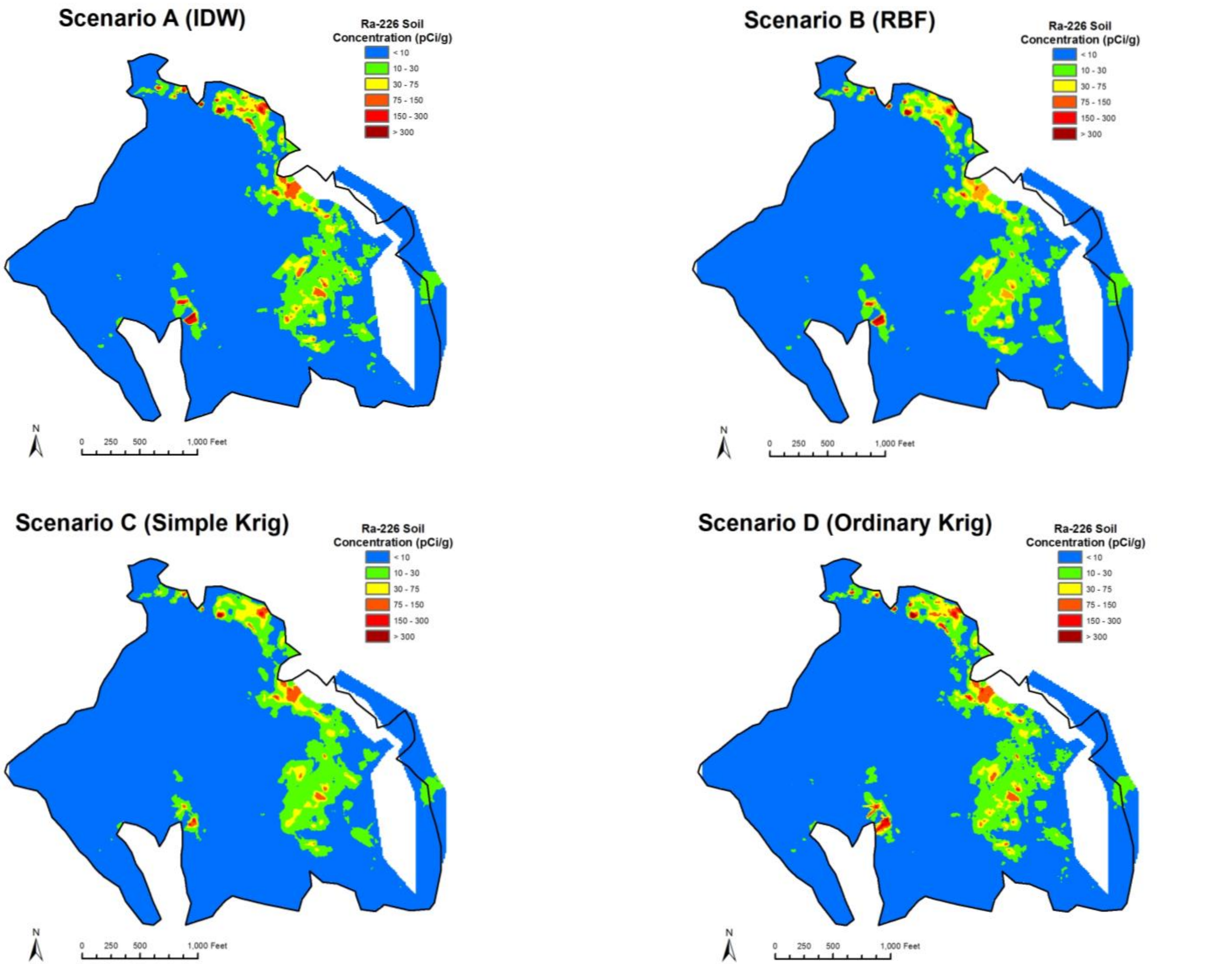




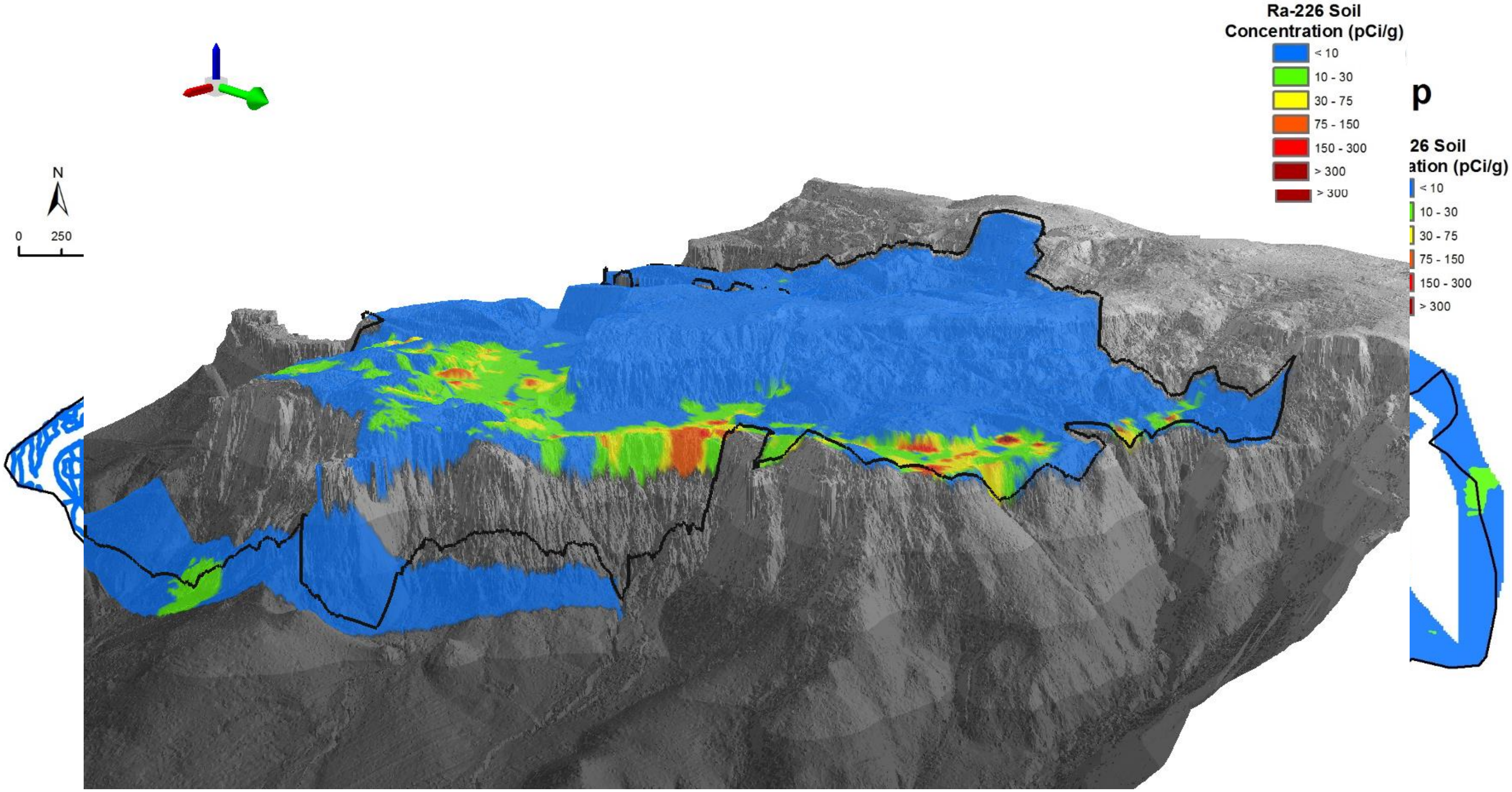




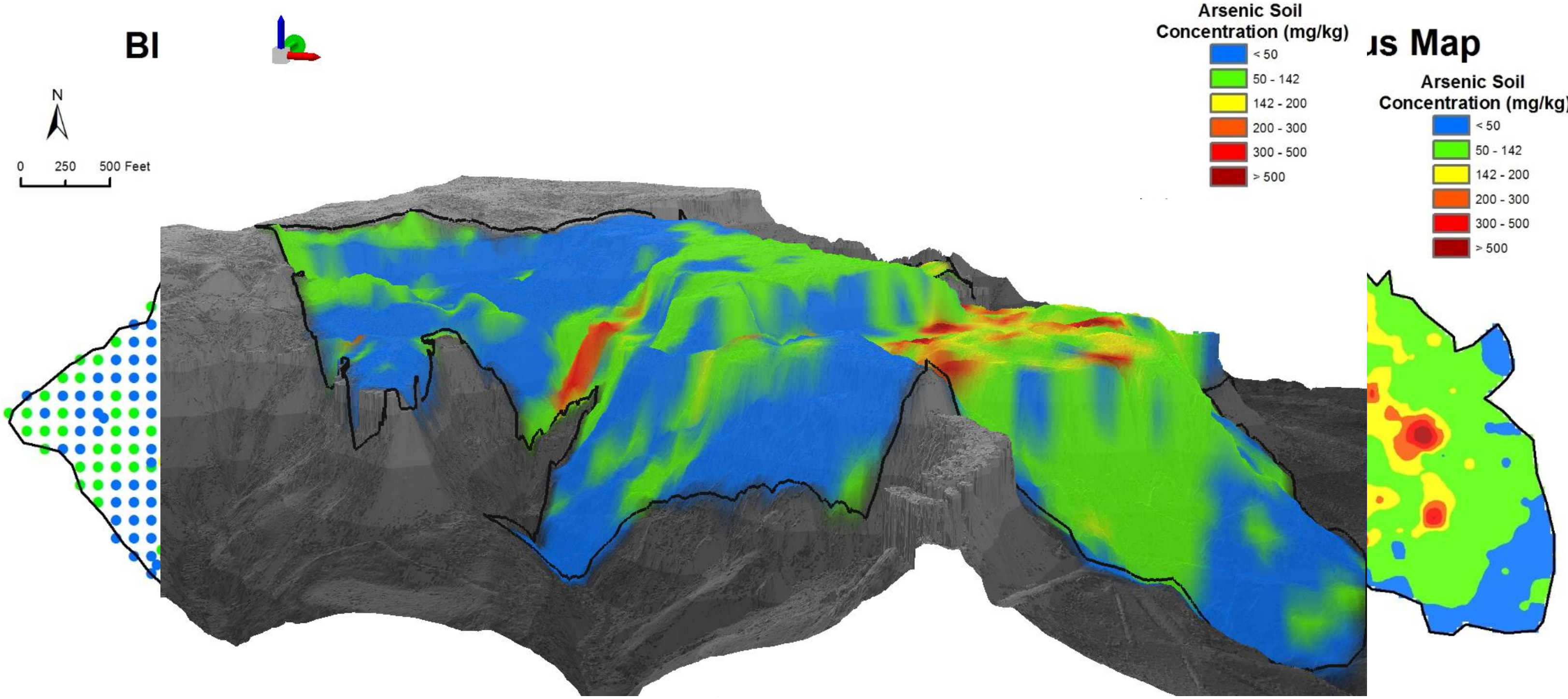
Bluff B Ra-226 Scenarios



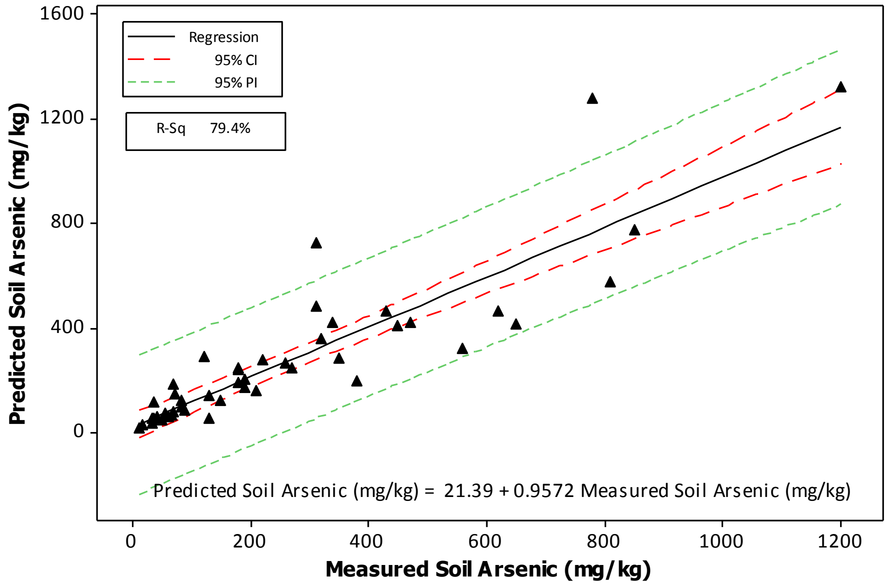
Radium-226 Mapping



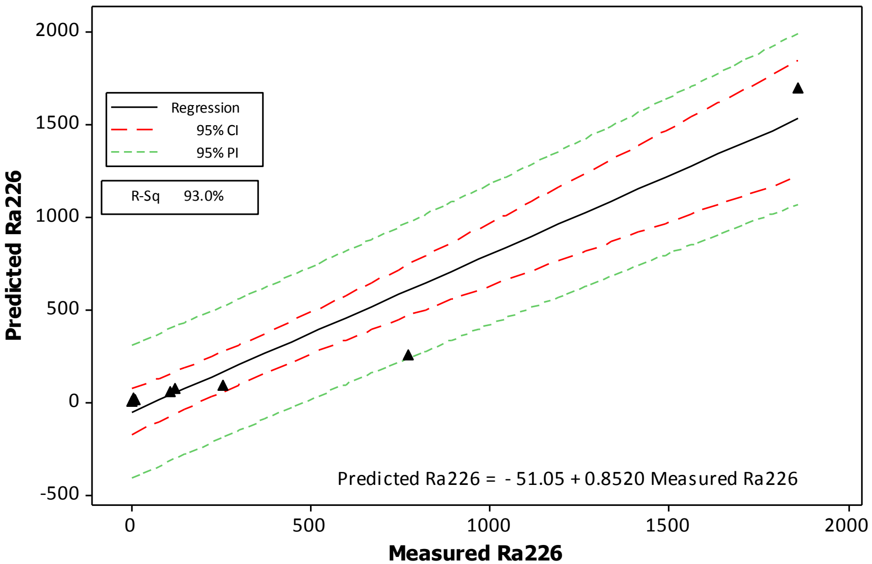
Arsenic Mapping



Soil Sample Validation

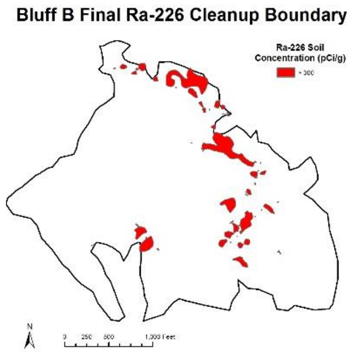


*These soil samples were not used in development of models.
*Therefore, a good indicator of how these models predict true conditions on the ground.



Final Cleanup Removal Areas

Ra-226 ≥ 30 pCi/g   Arsenic ≥ 142 mg/kg



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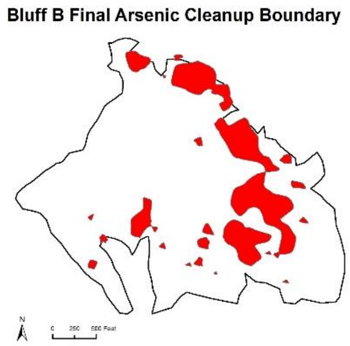

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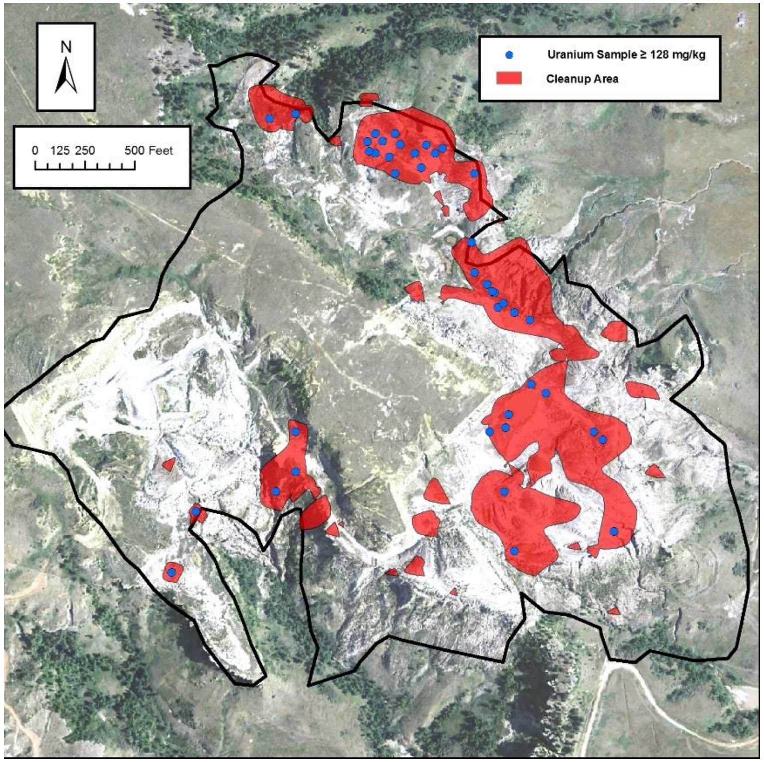
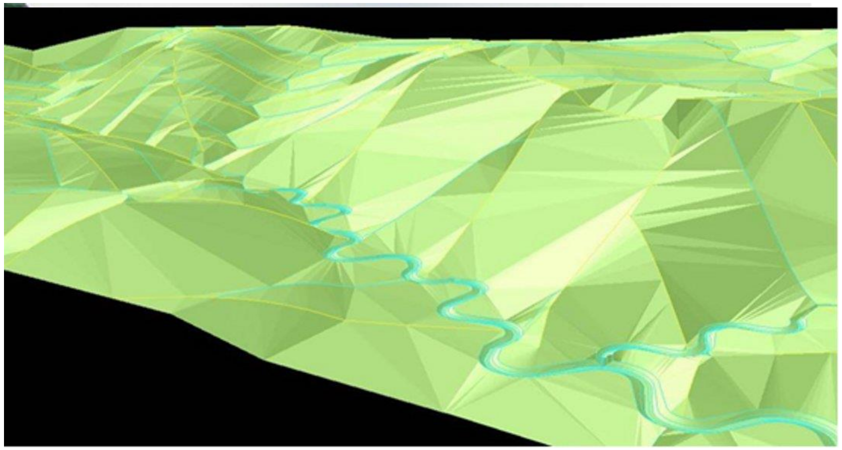


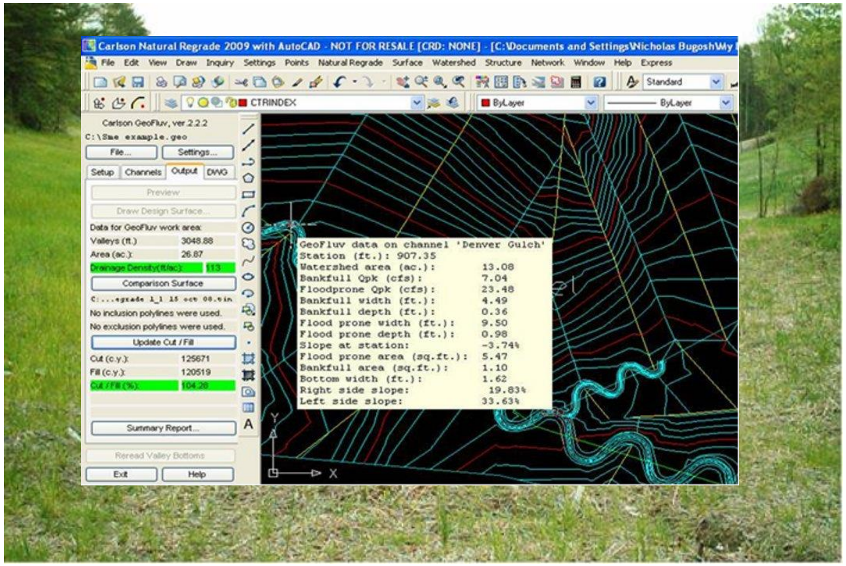
Study Area	Total Area (acres)	Cleanup Area (acres)	Percentage of Area
Bluff B	153	25.4	17%

Reclamation Approach- Soils Removal

Landform Design

- Natural Regrade software from GeoFluv.
- Goals:
  - Geotechnical stability
  - Surface water management
  - Long term stability of geomorphology
  - Aesthetics



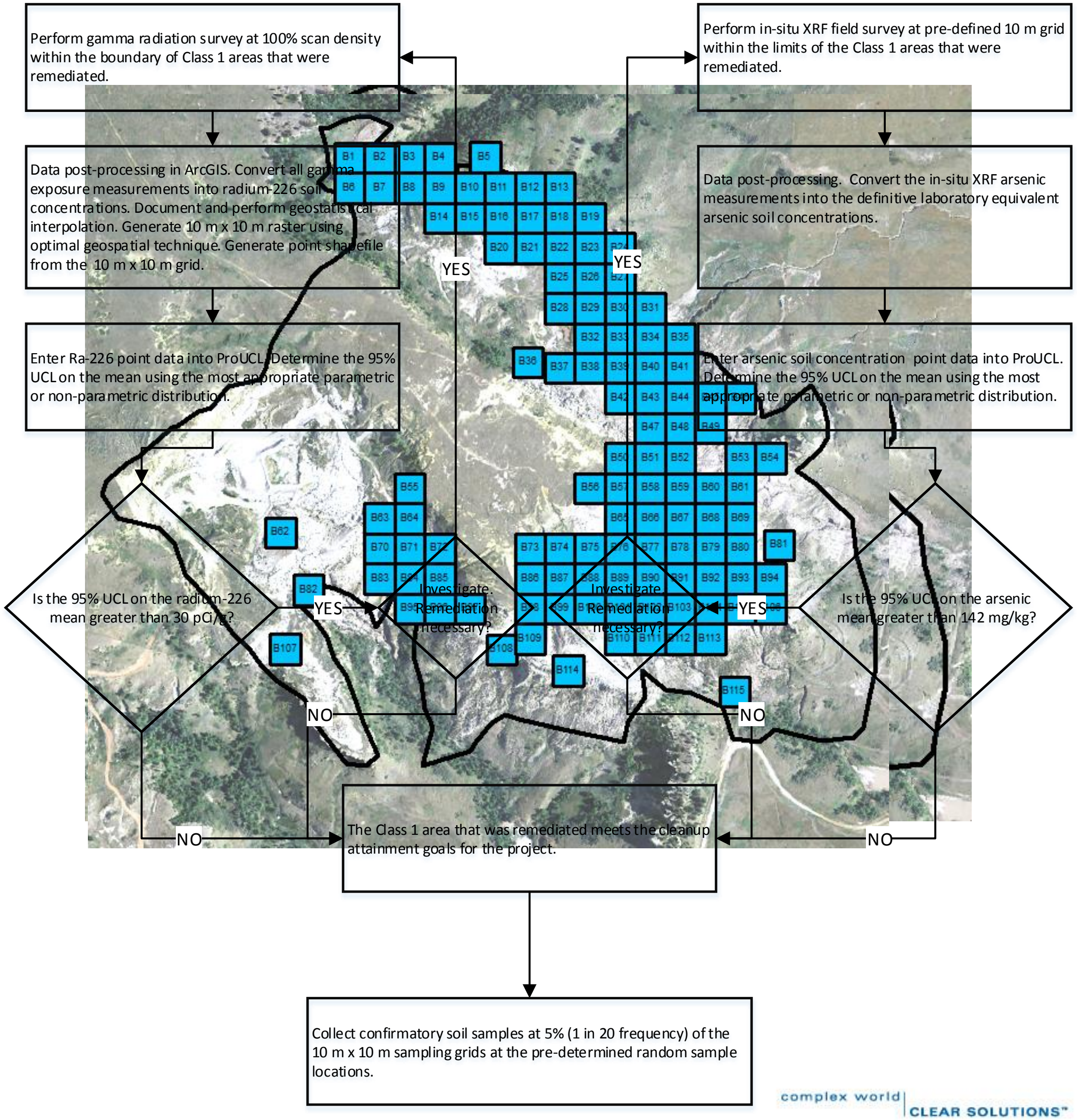


GeoFluv™

Carlson®

Cleanup Verification Survey/Final Status Survey

- Data Quality Objective Process
- MARSSIM Approach
  - Survey Units
  - Statistical Testing
    - Sign Test
    - Wilcoxon Rank-Sum
- EPA Approach
  - Statistical Testing
    - 95% UCL on mean



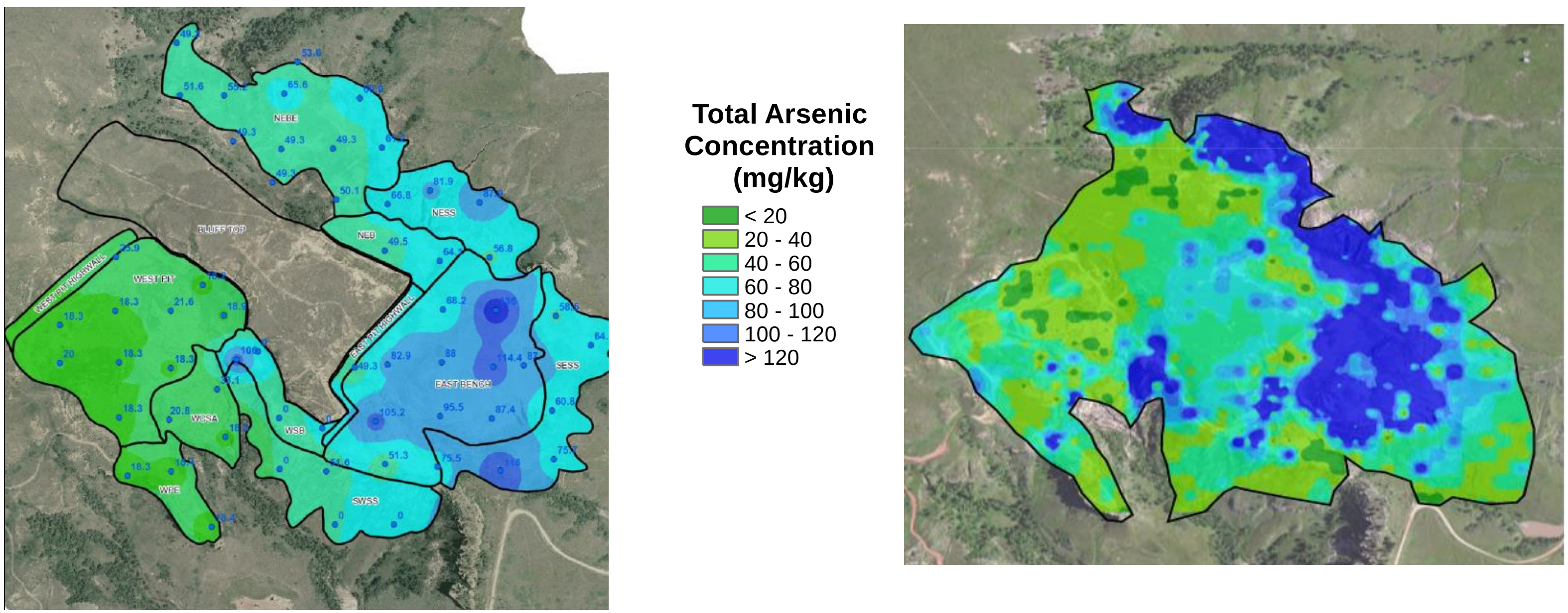
Hot Spot Analysis on Previous Study

Previous Study (2008)

- 100 meter grid size
- 95% Probability of Finding 110 meter circular hot spot of arsenic

Tetra Tech Study (2012)

- 30 meter grid size
- 95% Probability of Finding 36 meter circular hot spot of arsenic



Cost Savings Analysis

Survey Method	# of C_A Samples	# of C_I Samples	Double Sampling Method Cost (US$)	Conventional Method (US$)	Project Savings Factor
XRF	69	804	$22,017	$97,284	4.4
Gamma Survey	22	5,988	$12,964	$1,083,828	84

Total Cost of Project (Double Sampling): ~**$35,000**

Total Cost of Project (Conventional Sampling): ~**$1.1 million**

Total Project Savings Factor: 34

Conclusions

- Sampling design approach methodology is an important component that should be considered carefully for site characterization.
- XRF field surveys and gamma radiation surveys are cost effective tools for characterization at abandoned uranium mines.
- A total project savings factor of 34 was calculated for this study.

Questions?

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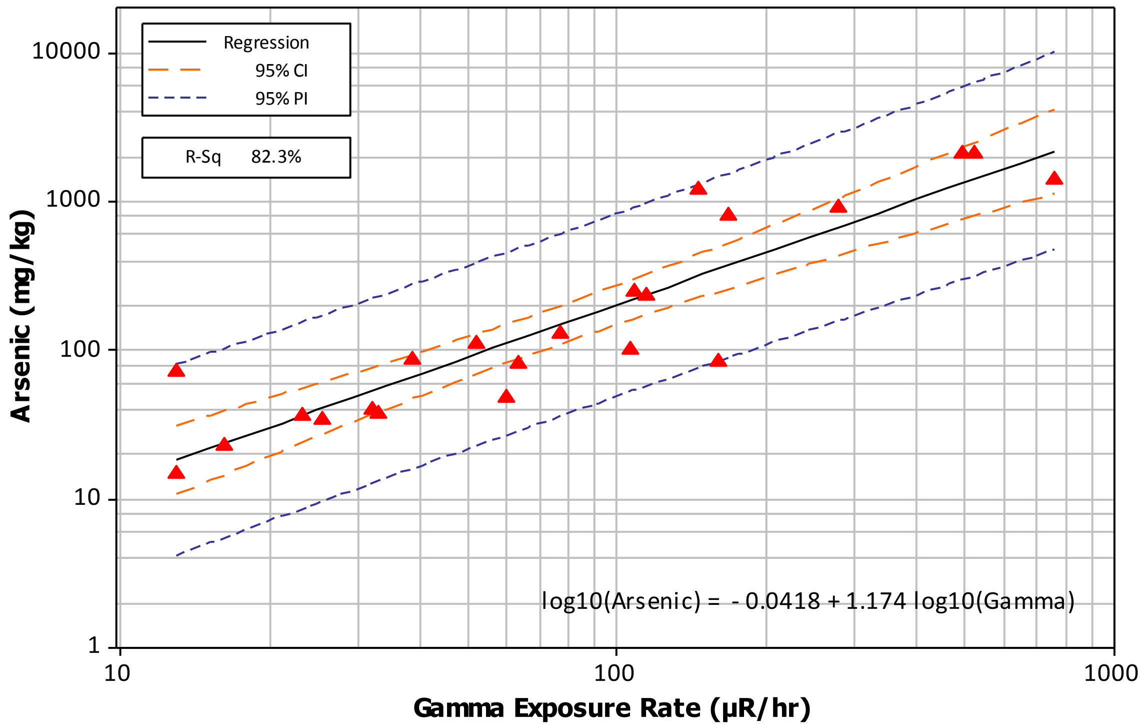
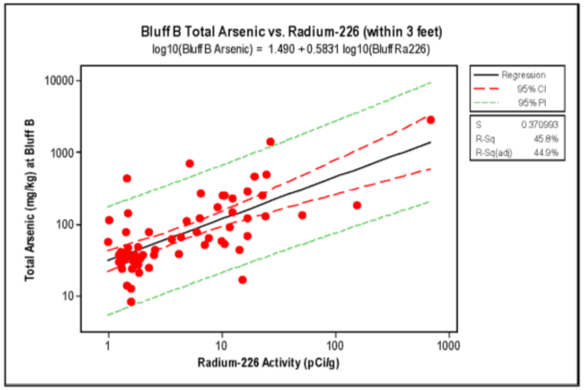
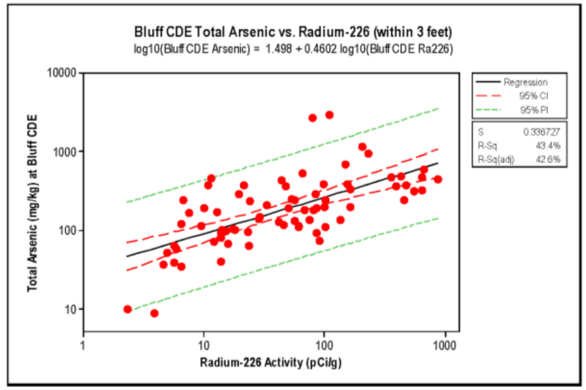
Arsenic and Radium Correlation

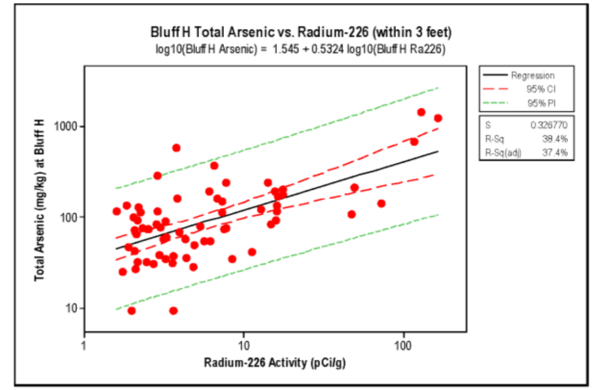
2009 & 2012 Combined



Arsenic and Radium Correlation (cont…)







Location	X-Value	Y-Value	R	R^2
Bluff B	^{226}Ra Activity (pCi/g*)	Total Arsenic (mg/kg**)	0.83	0.69
	$\log_{10}$ ^{226}Ra Activity (pCi/g)	$\log_{10}$ Total Arsenic (mg/kg)	0.68	0.46
Bluff CDE	^{226}Ra Activity (pCi/g)	Total Arsenic (mg/kg)	0.19	0.04
	$\log_{10}$ ^{226}Ra Activity (pCi/g)	$\log_{10}$ Total Arsenic (mg/kg)	0.66	0.43
Bluff G	^{226}Ra Activity (pCi/g)	Total Arsenic (mg/kg)	0.76	0.58
	$\log_{10}$ ^{226}Ra Activity (pCi/g)	$\log_{10}$ Total Arsenic (mg/kg)	0.90	0.82
Bluff H	^{226}Ra Activity (pCi/g)	Total Arsenic (mg/kg)	0.85	0.73
	$\log_{10}$ ^{226}Ra Activity (pCi/g)	$\log_{10}$ Total Arsenic (mg/kg)	0.62	0.38

*pCi/g = picocuries per gram
**mg/kg = milligrams per kilogram

Need to characterize arsenic and Ra-226 separately