Tronox Bluff Waste Characterization Report

Riley Pass Abandoned Uranium Mines Site
North Cave Hills, Harding County, South Dakota

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Tetra Tech Project No. 114-551083

Task 3.1 on Federal Task Order #AG-0355-D-12-0021; GSA contract #GS-1 OF-02081

June 27, 2013

EXECUTIVE SUMMARY

In October and November 2012, Tetra Tech Inc. (Tetra Tech) completed site assessment field work as part of the 2012 Tronox Bluff waste characterization program at the Riley Pass Abandoned Uranium Mines Site (Site) Tronox Bluffs located in the North Cave Hills in South Dakota. Tetra Tech field personnel performed the waste characterization field work between October 23 and November 4, 2012. The purpose of this site assessment was to determine the magnitude and spatial distribution of surface soils contamination on the site, as well as identify areas to be addressed based on remediation goals set by the United States Forest Service (USFS) in its Tronox Bluff Action Memorandum (2007 Action Memorandum). The results and findings of this site assessment will help guide removal design and management of contaminated materials at the Tronox Bluffs. The Site is located in the Custer National Forest north of Buffalo, South Dakota, and south of Bowman, North Dakota. A site location map is shown in Figure ES-1.

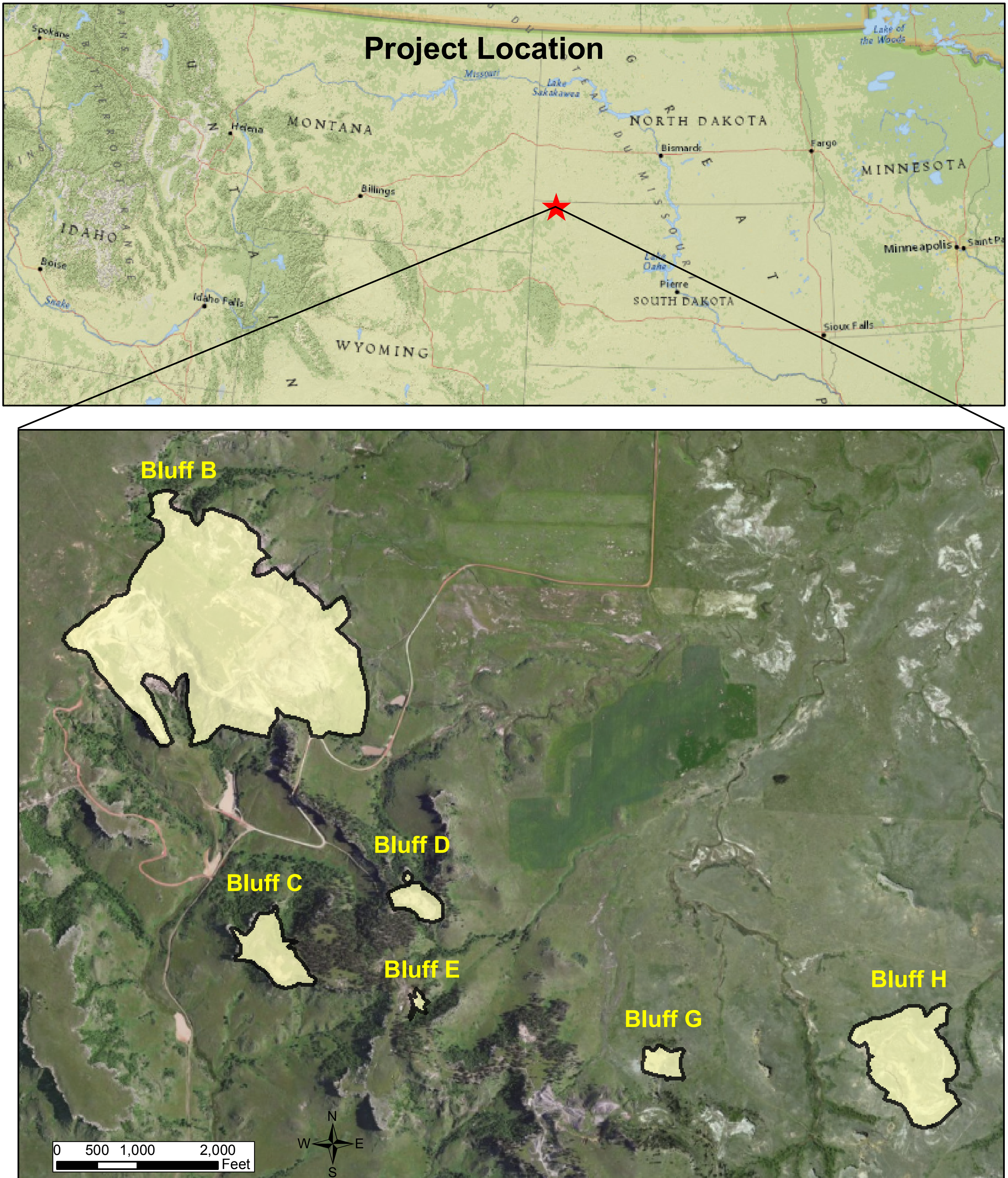
Mining activities that occurred during the 1950s and early 1960s at the North Cave Hills in Harding County, South Dakota, are a significant part of South Dakota's uranium mining history. Under the General Mining Laws, per the Atomic Energy Act of 1946 and Public Law 357, unrestricted strip mining took place within the North Cave Hills during this time. The strip mining involved the removal of uranium-bearing lignite coal beds, with no requirements for environmental restoration or for establishing post-mining responsibility (USFS, 2006). Overall, approximately 1,000 acres of land were disturbed by these mining processes. A section of this disturbed land includes the Riley Pass Abandoned Uranium Mines Site. The Riley Pass Uranium Mine consists of 250 acres of disturbed land distributed across 12 bluffs or buttes. The bluffs at the Site have been delineated as either "Tronox" or "Non-Tronox," relating each bluff to the potentially responsible party (PRP). This report evaluates the waste characterization data collected only at the Tronox Bluffs (Tronox Worldwide, LLC [Tronox], a corporate successor to Kermac).

Based on the 2012 waste characterization, all of the original Tronox Bluff boundaries were revised to some degree, with the exception of Bluff B. The most significant changes to the boundaries were made to Bluffs C, D, and E. Additional characterization sampling was performed outside the original limits as part of a contract modification from the USFS; the revised bluff boundaries were merged into one larger boundary and are herein referred to as Bluff CDE (previously known as Bluffs C, D, and E). Table ES-1 shows the original and revised boundary area for each of the Tronox Bluffs. Figure ES-2 shows the original and revised boundary delineation changes.

Table ES-1. Summary of Revised Tronox Bluffs Boundaries

Bluff Boundary	Original Area (acres)	Rev. Bluff Boundary	Revised Area (acres)	Percent Increase
Bluff B	153	Bluff B	153	0
Bluff C	11.3	Bluff CDE	48.1	179
Bluff D	5.02			
Bluff E	0.935			
Bluff G	3.78	Bluff G[1]	7.1	88
Bluff H	29.8	Bluff H	31.8	7
Total	**204**	**ALL**	**240**	**18**

[1] There is a sandstone area of 1.2 acres at Bluff G where limited sampling was performed due to lack of available soil. The physical boundary was added to the figures for Bluff G, where applicable. Based on the XRF field survey IDW maps it appears the sandstone is above action limits; however, this area was not actually sampled by XRF due to lack of soil. The sandstone area was identified on the maps and this is included in the waste area estimates. During field sampling, a small outcrop of natural radiation was observed on the west side of the sandstone area that should also be noted during reclamation. Tetra Tech included this area in the removal action maps in the likelihood there is some small volumes of contaminated soil layer present. The 1.2 acre Bluff G sandstone area is included within the revised area value.



Legend:

Original USFS Bluff Boundary

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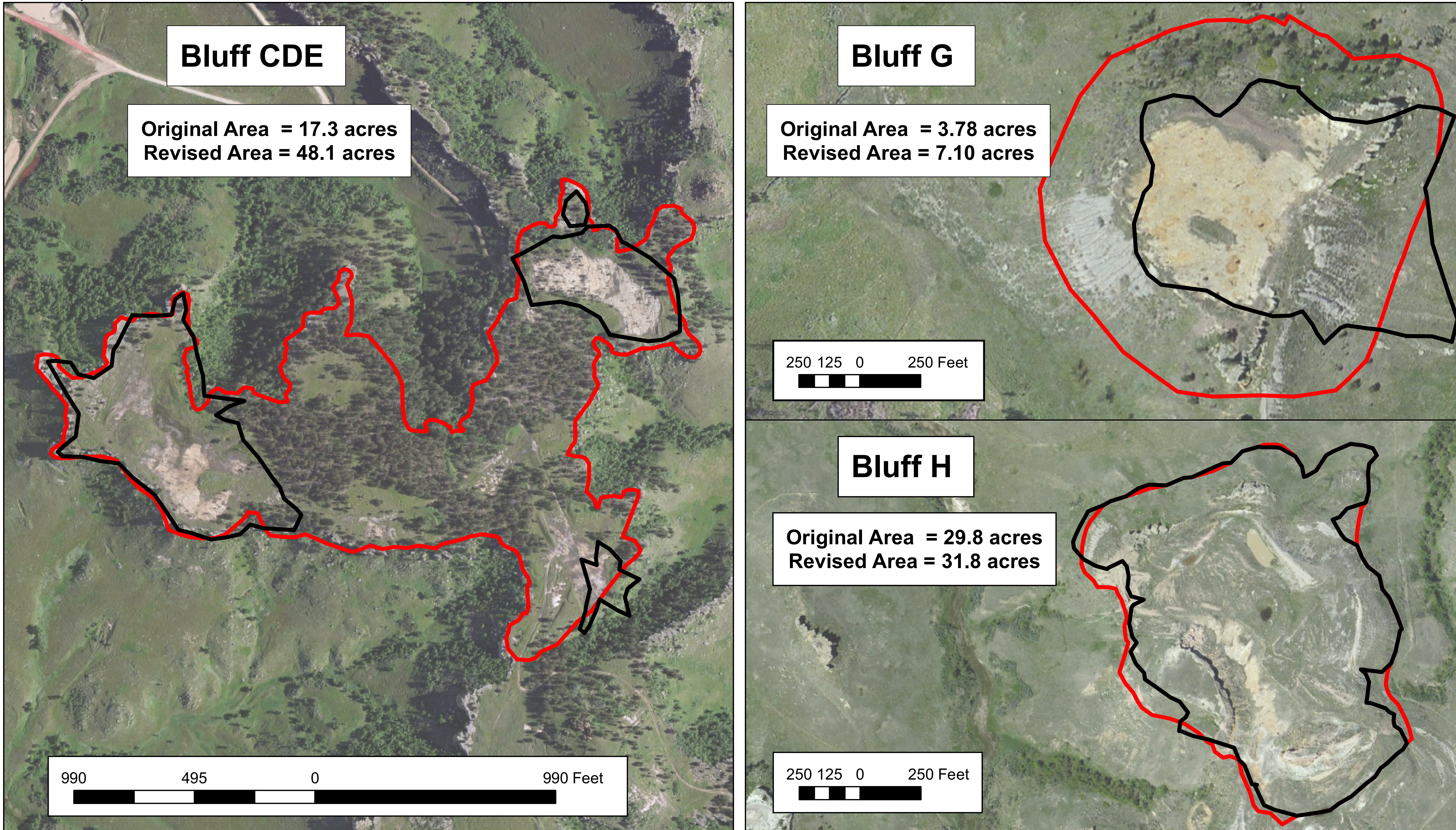
Riley Pass Tronox Bluffs
Site Location Map

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure ES-1
Location:	Harding County, South Dakota	June, 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Original USFS Tronox Bluff Boundary

2012 Revised Tronox Bluff Boundary

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Revised Tronox Bluff Boundary Delineation

3 Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure ES-2
Location: HARDING COUNTY COUNTY, SD	May 2013	

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The waste characterization program employed double sampling techniques to identify removal areas based on site-specific soil cleanup criteria for radium-226 (^{226}Ra) activity, total arsenic concentration, total molybdenum concentration, ^{238}U activity, ^{235}U activity, and ^{234}U activity in surface soils. Double sampling is more cost-effective when compared to simple random or grid soil sampling (Gilbert, 1987) and can be more effective at identifying isolated areas of contamination. The first double sampling method was the gamma radiation survey used to predict soil ^{226}Ra activity in surface soils. It was determined that a high correlation exists between gamma radiation and ^{226}Ra (R=0.96) at the Site, and the results indicate that soil ^{226}Ra activity can be estimated to a definitive level by directly converting from the gamma radiation survey data.

The second double sampling technique utilized during the waste characterization program was an X-ray fluorescence (XRF) field survey, conducted to predict total arsenic, total molybdenum, and natural uranium soil concentrations from *in-situ* field XRF measurements. Field XRF has been previously used at the Site and is more cost-effective than random or grid-based soil sampling. It was determined that a high correlation exists between total arsenic (R=0.95), natural uranium (R=0.98) and total molybdenum (R=0.96) and *in-situ* XRF measurements, and therefore total arsenic, uranium, and molybdenum concentrations in surface soils can be estimated to a definitive level using the XRF field survey data.

It should be noted that the correlations developed in this study apply to a specific model of XRF. Therefore, additional characterization studies or future verification work should employ the same model of XRF or newer if possible; otherwise a new correlation may need to be developed. The field data collection activities and evaluation included the following elements: 1) An XRF field survey which involved the collection of 1,350 *in-situ* XRF measurements and 69 soil confirmation samples; 2) a gamma radiation survey which involved the collection of more than 167,000 individual gamma exposure rate measurements and 11 soil correlation plot samples; 3) collection of 25 sediment samples from a variety of sediment ponds within or adjacent to the affected area; 4) evaluation of erosion impacts and vegetation status within certain of the bluff areas; 5) estimation of the areal extent of contaminated soils; 6) comparison to a previous studies performed using similar methods by different consultants; and 7) leachability analysis using the synthetic precipitation leaching procedure (SPLP) of the XRF soil confirmation samples.

An estimated 88.6 percent of the total bluff areas had surface soil ^{226}Ra activity that fell below the soil cleanup value of 30 pCi/g. Table ES-2 provides the summary of estimated removal areas based strictly on the soil ^{226}Ra activity criteria described above. Bluff CDE has the highest percentage by area and total surface area of ^{226}Ra contamination, followed by Bluff G. The majority of the surface soils at Bluff B and Bluff H were below the soil ^{226}Ra activity criteria of 30 pCi/g.

Table ES-2. Summary of Tronox Bluff Soil Areas Contaminated by ^{226}Ra

Location	Removal Area Acres by ^{226}Ra			Percent* of Bluff that is Removal Area by ^{226}Ra		
	< 30 pCi/g**	≥ 30 and < 50 pCi/g	≥ 50 pCi/g	< 30 pCi/g	≥ 30 and < 50 pCi/g	≥ 50 pCi/g
Bluff B	137	2.18	2.89	90	1.4	1.9
Bluff CDE	27.6	5.48	14.5	58	12	30
Bluff G	6.16	0.36	0.57	87	5.0	8.0
Bluff H	31.2	0.43	0.17	98	1.4	0.53
All Bluffs	**202**	**8**	**18**	**88.6**	**3.5**	**7.9**

* Percent based on total area scanned; some of Bluff B was not scanned due to safety reasons (10.91 acres/7.1%)
**pCi/g = picocuries per gram

The XRF field survey results were used to estimate the total arsenic concentration, natural uranium concentration and total molybdenum concentration in the surface soils at the Tronox Bluffs. The natural uranium soil activity was then converted into soil activities for each of the isotopes assuming that ^{238}U and ^{234}U each make up 48.9 percent of the total soil activity in natural uranium and that ^{235}U makes up 2.25 percent of the total soil activity in natural uranium. These conversions were predicated on the assumption that the uranium ore deposits analyzed at the Site are in secular equilibrium between ^{238}U and its decay products; this assumption was based on the analysis presented in Section 2.4 of Appendix D of the EE/CA (USFS, 2006). The surfaces were mapped using the IDW interpolation method on the point estimates. Table ES-3 provides a summary of the removal action areas based on the XRF field survey data. Similar to the ^{226}Ra criteria, Bluff CDE has the highest overall area (27 acres) of soils exceeding at least one of the contaminants of concern identified from the XRF field survey waste characterization data, followed by Bluff B (21 acres). Overall, 26 percent of the total area of surface soils at the Tronox Bluffs exceeded the risk protective levels identified of at least one of contaminants of concern.

Table ES-3. Summary of Removal Action Areas by XRF Field Survey Data at Tronox Bluffs

Location	Total Bluff Area (Acres)	< 142 mg/kg* As and <2,775 mg/kg Mo and < 42.8 pCi/g** ^{238}U and <2.03 pCi/g ^{235}U and <44.6 pCi/g ^{234}U		≥ 142 mg/kg As and/or ≥2,775 mg/kg Mo and/or ≥ 42.8 pCi/g ^{238}U and/or ≥2.03 pCi/g ^{235}U and/or ≥44.6 pCi/g ^{234}U	
	Acres	Acres	Percent	Acres	Percent
Bluff B	153	132	86	21	14
Bluff CDE	48	20	42	27	58
Bluff G	7.1	1.8	26	5.2	74
Bluff H	32	22	69	9.7	31
All Tronox Bluffs	**240**	**176**	**74**	**63**	**26**

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

The primary objective of the waste characterization collection activities is to identify areas of the Site that meet removal action requirements set forth by the USFS. Tetra Tech interprets the mine waste removal area Criteria 1 categories as follows:

1. Category I (based on ^{226}Ra and total arsenic, total molybdenum, ^{238}U, ^{235}U, ^{234}U): All surface soils that do not exceed the risk-protective ^{226}Ra activity of 30 pCi/g and do not exceed any of the risk-protective levels identified for: total arsenic concentration (142 mg/kg), total molybdenum concentration (2,775 mg/kg), ^{238}U activity (42.8 pCi/g), ^{235}U activity (2.03 pCi/g), or ^{234}U activity (44.6 pCi/g).

2. Category II (based on ^{226}Ra and total arsenic, total molybdenum, ^{238}U, ^{235}U, ^{234}U): All surface soils that are greater than or equal to the risk-protective ^{226}Ra activity of 30 pCi/g but fall below a ^{226}Ra activity of 50 pCi/g and do not exceed any of the risk-protective levels identified for: total arsenic concentration (142 mg/kg), total molybdenum concentration (2,775 mg/kg), ^{238}U activity (42.8 pCi/g), ^{235}U activity (2.03 pCi/g), or ^{234}U activity (44.6 pCi/g)

3. Category III (based on ^{226}Ra and total arsenic, total molybdenum, ^{238}U, ^{235}U, ^{234}U): All surface soils that are greater than or equal to the risk protective ^{226}Ra activity of 50 pCi/g and are greater than or equal to at least one of the risk-protective levels identified for: total arsenic concentration (142 mg/kg), total molybdenum concentration (2,775 mg/kg), ^{238}U activity (42.8 pCi/g), ^{235}U activity (2.03 pCi/g), or ^{234}U activity (44.6 pCi/g)

The soil removal areas for the bluffs based on ^{226}Ra activity and the XRF field survey data are summarized in Table ES-1 and Table ES-2, respectively. These areas were then classified and combined using the map algebra feature of *ArcMap10* ©; after the initial step, the final removal raster at each bluff was converted into a polygon and smoothed using the Polynomial Algorithm with Exponential Kernal (*paek algorithm)* function. The final areas based on the mine removal categories are provided in Table ES-4.

Table ES-4. Summary of Tronox Bluff Soil Areas Contaminated by Mine Waste Category

Location	Total Bluff Area Analyzed (Acres)	Category I: No Exceedances: < 30 pCi/g ^{226}Ra and < 142 mg/kg As and < 2,775 mg/kg Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U		Category II: ≥ 30 pCi/g and < 50 pCi/g ^{226}Ra and < 142 mg/kg As and < 2,775 mg/kg Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U		Category III: ≥ 50 pCi/g ^{226}Ra and/or ≥ 142 mg/kg As and/or ≥ 2,775 mg/kg Mo &/or ≥ 42.8 pCi/g ^{238}U and/or ≥ 2.03 pCi/g ^{235}U and/or ≥ 44.6 pCi/g ^{234}U	
	Acres	Acres	Percent	Acres	Percent	Acres	Percent
Bluff B	153	130	85.4	0.684	0.45	21.5	14
Bluff CDE	46.5	17.7	38	0.99	2.1	27.8	60
Bluff G	6.99	1.83	26	0.0	0.0	5.17	74
Bluff H	31.6	21.9	69.3	0.051	0.2	9.67	31
All Tronox Bluffs	**238**	**172**	**72**	**1.7**	**0.70**	**64.4**	**27**

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

The results of this analysis showed that 172 acres of the total 238 acres analyzed (72 percent) were classified as Category I; an estimated 1.7 acres or (0.7 percent) were classified as Category II; and an estimated 64.4 acres of the total 240 acres (27 percent) were classified as Category III. The mine waste category maps for Bluff B, Bluff CDE, Bluff G, and Bluff H are shown in Figure ES-3 through Figure ES-6, respectively.

An analysis was performed to estimate the volumes for Category I, Category II, and Category III mine waste materials throughout the Site. This approach utilized a combination of 1954 imagery and LIDAR data points provided to Tetra Tech by the USFS. A combination of methods was used to calculate the volumes of spoils at Bluff B, Bluff G, and Bluff H. The results of the test pit sampling were used to estimate the volume of mine waste materials at Bluff CDE. The results of the volume analysis resulted in an estimated 2,089,868 yd^3 of Category I material (no exceedances) that is pushed off the sides of the bluffs, an estimated 15,488 yd^3 of Category II materials, and an estimated 853,750 yd^3 of Category III materials. Table ES-5 summarizes the results mine waste volume estimation analysis.

Table ES-5. Mine Waste Volume Estimation

Location	Mine Waste Category I Materials (yd^3)	Mine Waste Category II Materials (yd^3)	Mine Waste Category III Materials (yd^3)	Total Materials (yd^3)
Bluff B	1,623,530	4,892	280,090	1,908,512
Bluff H	438118	1,013	260,381	699,513
Bluff G	28,220	0	44,175	72,395
Bluff CDE	0	9,583	269,104	269,104
Total	**2,089,868**	**15,488**	**853,750**	**2,949,524**

*yd^3 = cubic yards

The 2007 Action Memorandum specifies that a separate set of criteria (defined as Action Memorandum Category 2) for classifying mine waste removal areas are applicable to Tronox Bluffs C, D, and E and are listed below:

- **No Reclamation:** In areas where minimal overburden was historically present, vegetation has stabilized the soil and no significant erosion is evident.
- **Stabilization and Vegetate:** In areas where active significant erosion is occurring due to poor vegetative cover.
- **Excavation and Consolidation:** In areas immediately adjacent to road 3130 where materials associated with historic mining activities exceed Criteria 1 Category II soil ^{226}Ra activity.

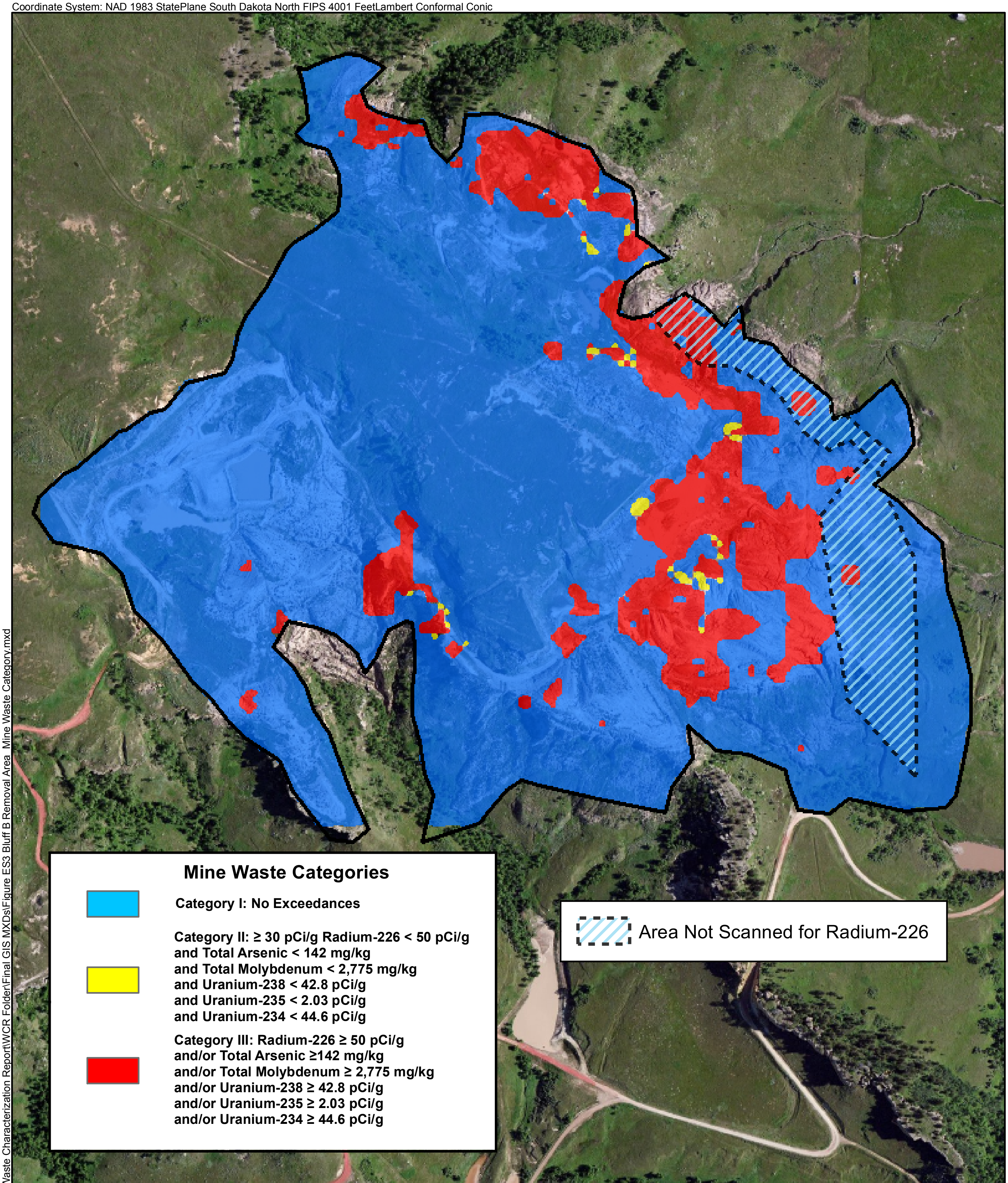
A detailed survey of the vegetation and soil conditions at Bluffs C, D, and E was performed by a KC Harvey reclamation scientist. Full details of this survey are found in Appendix O, including site photos, GIS mapping and comments. Areas were identified according to 2007 Action Memorandum Criteria 2 classification, discussed above. Figure ES-7 displays the classification of Bluff CDE according to Criteria 2. This figure does not include any Criteria 1 classification and is based entirely on the visual observations of the vegetation and soil conditions.

In general, there is no significant erosion observable at Bluff CDE; however, the Criteria "Stabilize and Vegetate" was further refined to "Cap and Vegetate" to include areas that will require a borrow soil cover and vegetation. The areas to be capped and vegetated include bare sandstone areas with a shallow layer of contaminated soil or areas with little to no vegetation present. Areas identified for "Excavation and Consolidation" include tailings piles and identified contaminated soils. The 2007 Action Memorandum specifies that the areas to be considered for excavation and consolidation are those locations on or immediately adjacent to Road 3130 where the soil exceeds Criteria 1 Category II soil ^{226}Ra activity.

The waste characterization data collected at Bluff CDE demonstrates that a large portion of the bluff exceeds Criteria 1 Category II and III cleanup levels. When 2007 Action Memorandum Criteria 2 category areas for "Cap and Vegetate" are overlaid on Criteria 2 mapping, all areas identified for "Cap and Vegetate" fall within areas of Criteria 2 Category III exceedances, as shown in Figure ES-8.

Due to the high levels of arsenic, uranium and ^{226}Ra present at Bluff CDE, it is recommended to apply the Criteria 1 waste characterization scheme in determining what removal actions should be taken at Bluff CDE.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 FeetLambert Conformal Conic



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure ES3 Bluff B Removal Area Mine Waste Category.mxd

Legend:

Bluff B Boundary

0 130 260 520 Feet

N

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Bluff B- Removal Action Areas and Mine Waste Category Map

3 Revision

Project: Riley Pass Tronox Bluffs

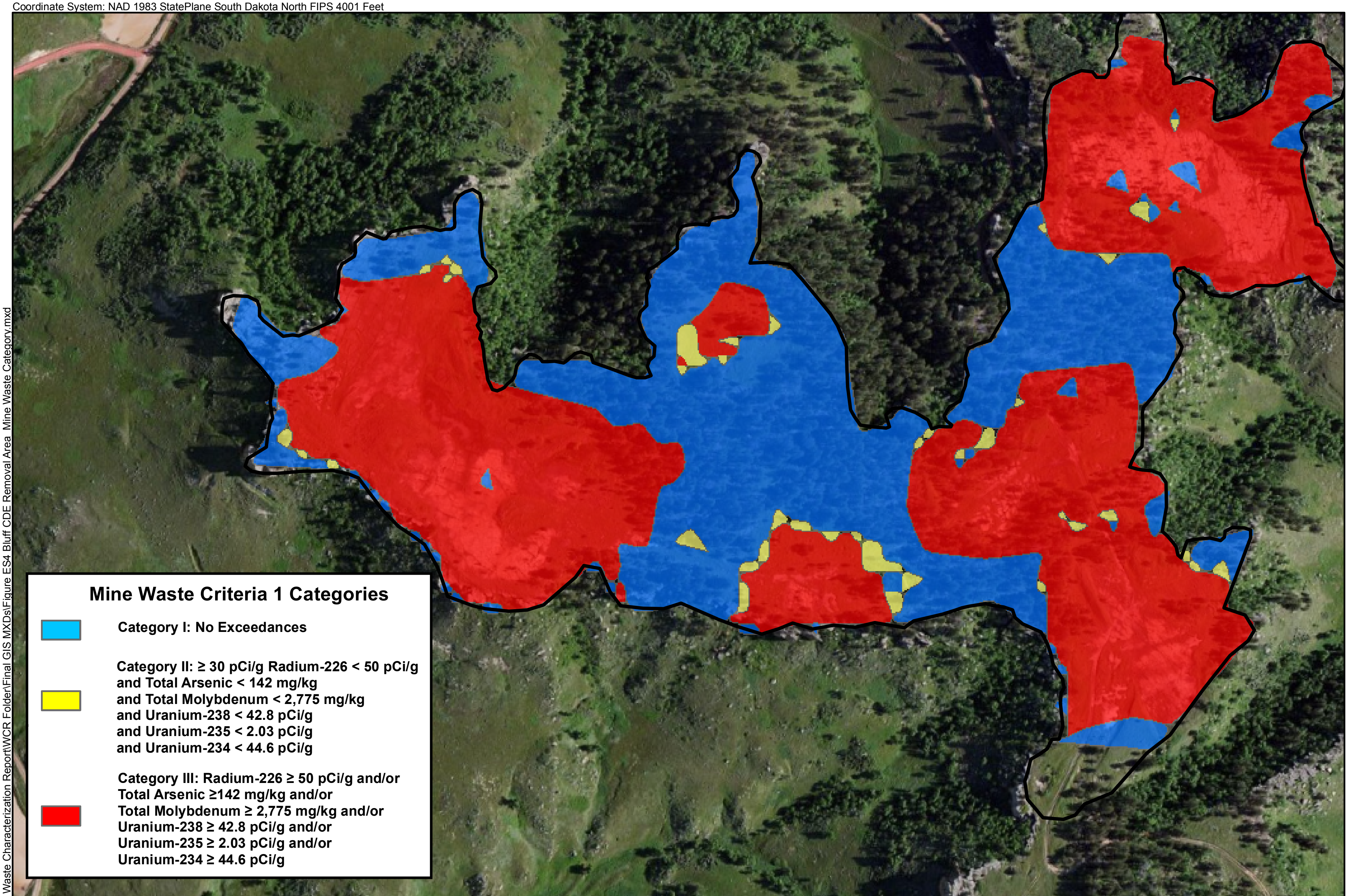
Project no.: 114-551083

Location: Harding County, South Dakota

June 2013

Figure ES-3

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff CDE Boundary

N

0 125 250 500 Feet

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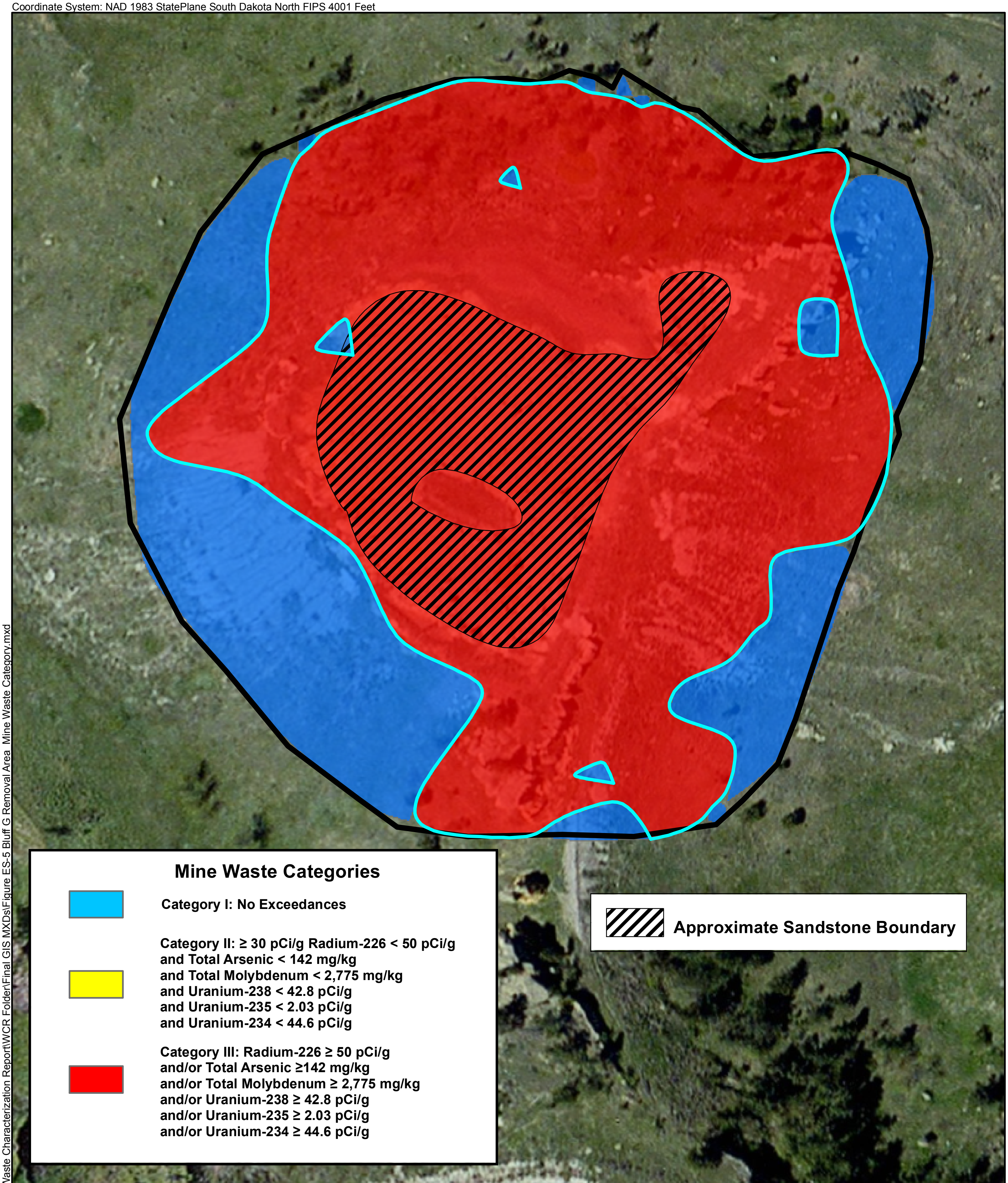
Bluff CDE- Removal Action Areas and Mine Waste Criteria 1 Category Map

3 Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure ES-4
Location:	Harding County, South Dakota	June, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure ES4 Bluff CDE Removal Area Mine Waste Category.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff G Boundary

0 25 50 100 Feet

N

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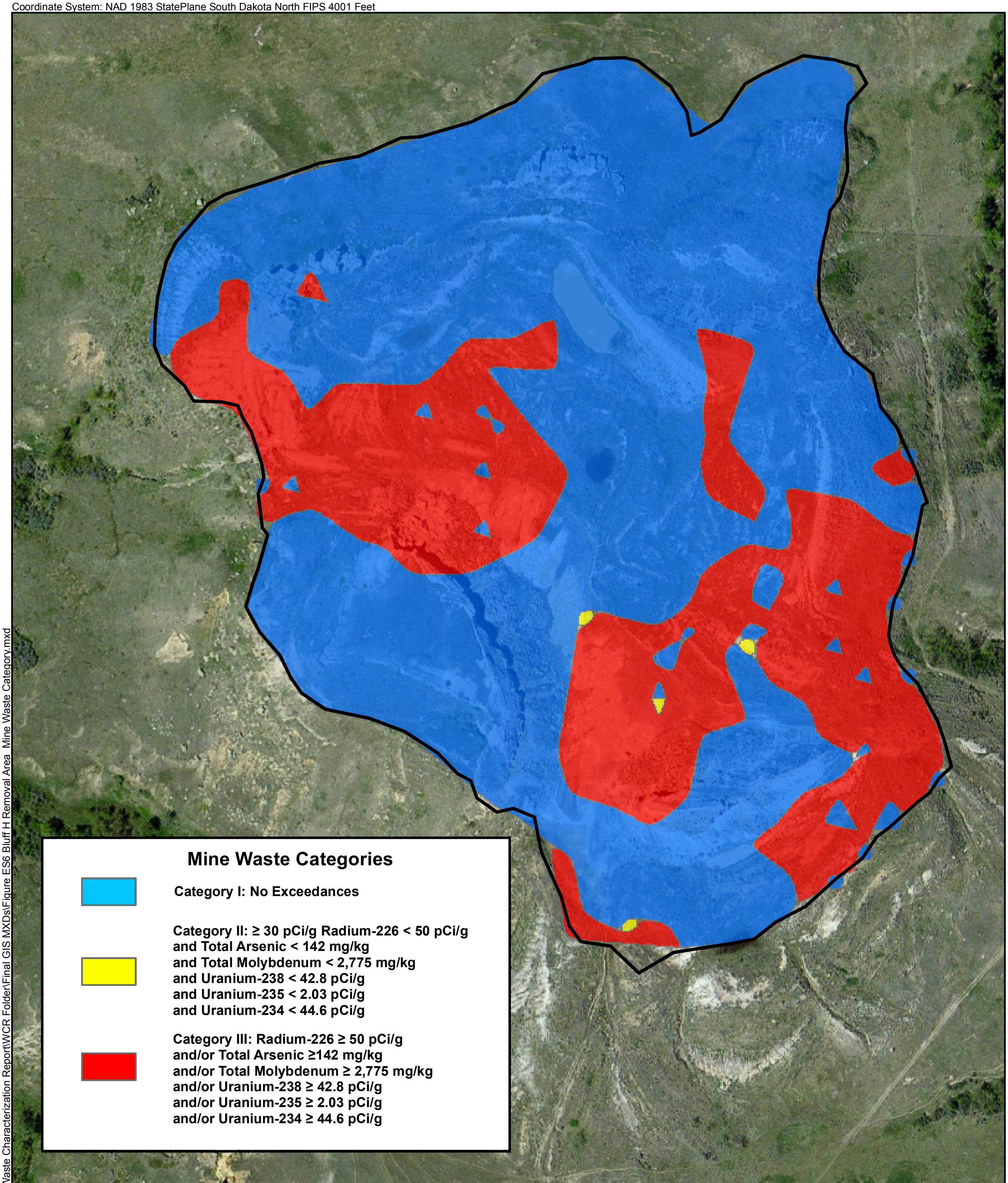
Bluff G- Removal Action Areas and Mine Waste Category Map

3 Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure ES-5
Location:	Harding County, South Dakota	June, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure ES-5 Bluff G Removal Area Mine Waste Category.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff H Boundary

0 75 150 300 Feet

N

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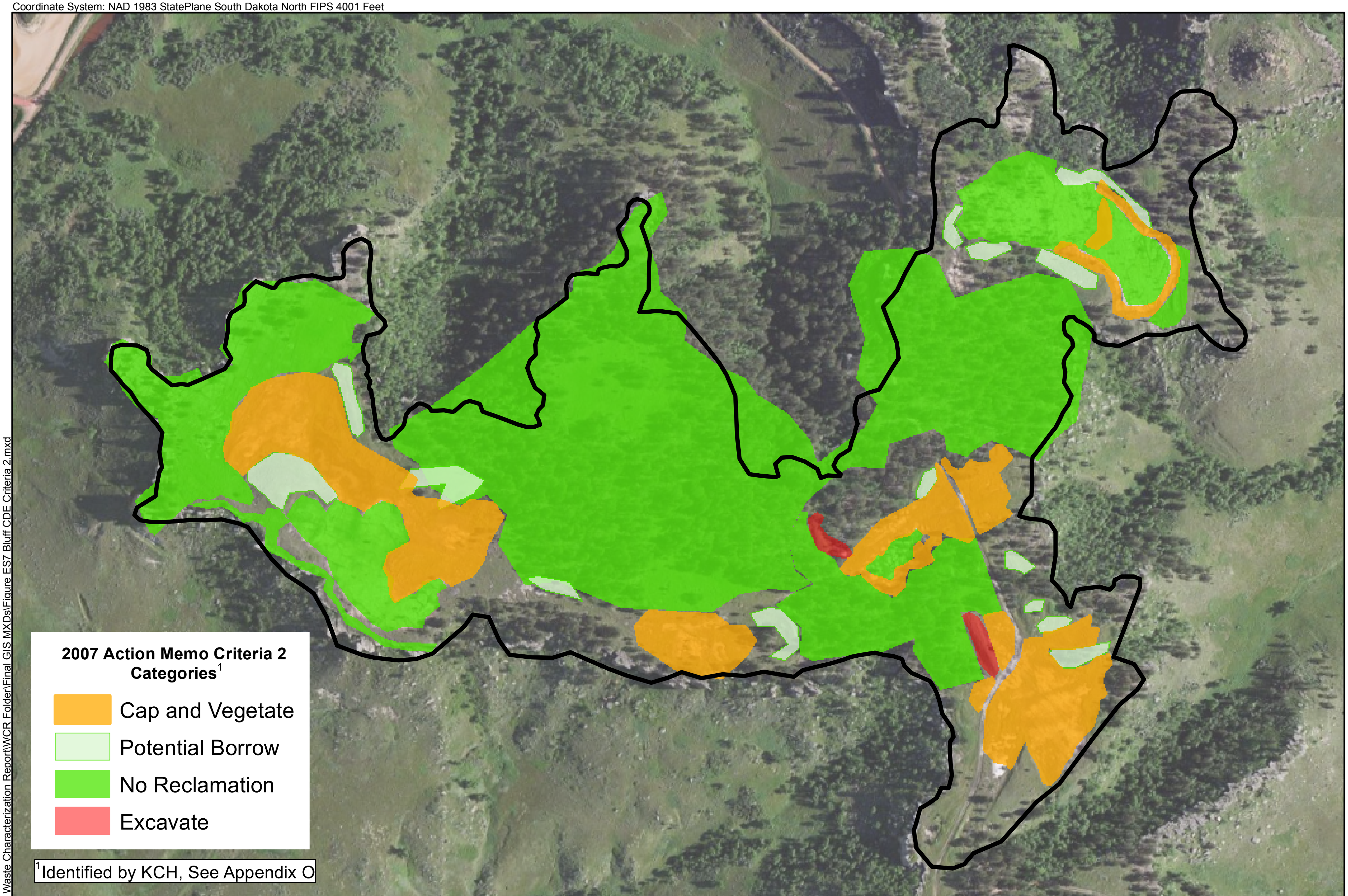
Bluff H- Removal Action Areas and Mine Waste Category Map

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure ES-6
Location:	Harding County, South Dakota	June, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure ES6 Bluff H Removal Area Mine Waste Category.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff CDE Boundary

0 125 250 500 Feet

N

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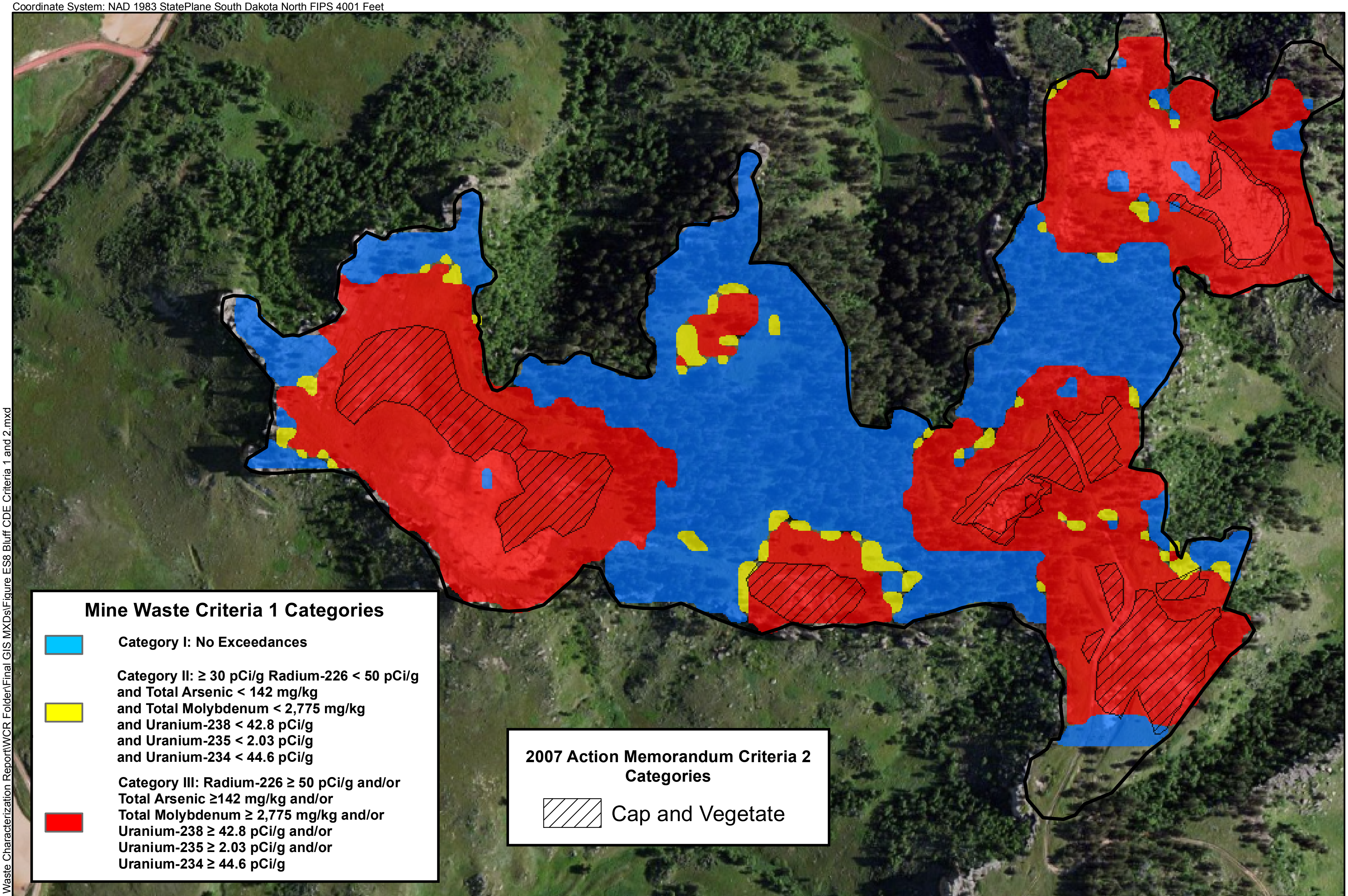
Bluff CDE- Criteria 2
Classification Map

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure ES-7	
Location: Harding County, South Dakota	June, 2013		

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure ES7 Bluff CDE Criteria 2.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff CDE Boundary

N

0 125 250 500 Feet

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Bluff CDE- Criteria 1 and 2
Classification Map

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure ES-8
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1.0 INTRODUCTION

This Waste Characterization Report (WCR) presents the results of field activities conducted to characterize the existing physical, radiochemical, and environmental conditions at the Riley Pass Abandoned Uranium Mines site (referred to herein as the Site) located in the North Cave Hills area of the Custer National Forest in northwest South Dakota. These activities were conducted as part of the 2012 Tronox Bluff waste characterization program, performed by Tetra Tech, Inc. (Tetra Tech) under contract with the United States Forest Service (USFS), to provide collection of field data to meet the requirements of the 2007 USFS Tronox Bluff Action Memorandum (2007 Action Memorandum) (USFS, 2007) as authorized by section 104 (42 U.S.C. 9604) of the Comprehensive, Environmental, Response, Compensation, and Liability Act (CERCLA). The 2012 field activities were conducted to characterize surface soils at Bluffs B, C, D, E, G, and H, in addition to the sediment ponds at the Site. Waste characterization and the WCR were completed as part of Task 3.1 on Federal Task Order Contract #AG-0355-D-12-0021 against GSA contract #GS-1 OF-02081. The intent of waste characterization is to determine waste types and locations for use in ongoing reclamation design work being completed by the USFS and Tetra Tech.

1.1 Purpose

The purpose of this report is to document the data and information collected by Tetra Tech during the 2012 Tronox Bluffs waste characterization program at the Site in October and early November 2012. The field data and information collected as part of the program are used to characterize the Site and are presented within this report. These field data will be used in the development of a series of engineering design, revegetation, operations, monitoring, and maintenance plans as part of the final Tronox removal action engineering design process.

The USFS approved a non-time critical removal action at the Tronox Bluffs as stated in the 2007 Action Memorandum. A combination of alternative actions that were presented in the Engineering Evaluation and Cost Analysis (EE/CA) (USFS, 2006) will be implemented at the Tronox Bluffs after field data evaluation has been performed. This waste characterization program was designed to collect the information required to identify the extent of areas requiring removal action.

The waste characterization field activities were performed under a USFS approved Sampling and Analysis Plan (SAP) (Tetra Tech, 2012a), which was prepared in compliance with the Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP) and is included as Appendix A.

The field characterization activities included the following:

- Collect field data using approved mine waste characterization tools to identify and evaluate the areal extent of total arsenic concentration, total molybdenum concentration, natural uranium concentration, uranium-238 (^{238}U) activity, uranium-235 (^{235}U) activity, uranium-234 (^{234}U) activity, and radium-226 (^{226}Ra) activity in surface soils at Tronox Bluffs, B, C, D, E, G, and H.

- Perform a preliminary characterization of mine wastes and agronomic properties of eight sediment ponds within the project vicinity.

- Perform and document a visual survey of vegetation, erosion, overburden, and surface conditions within Bluffs C, D, and E, in order to further define the extent to which reclamation efforts will be required.

- Collect and analyze soil samples at USFS-specified locations at Bluff B to determine if erionite is present in road surfacing materials previously placed onsite. Erionite is a naturally-occurring fibrous mineral that has similar properties to asbestos.

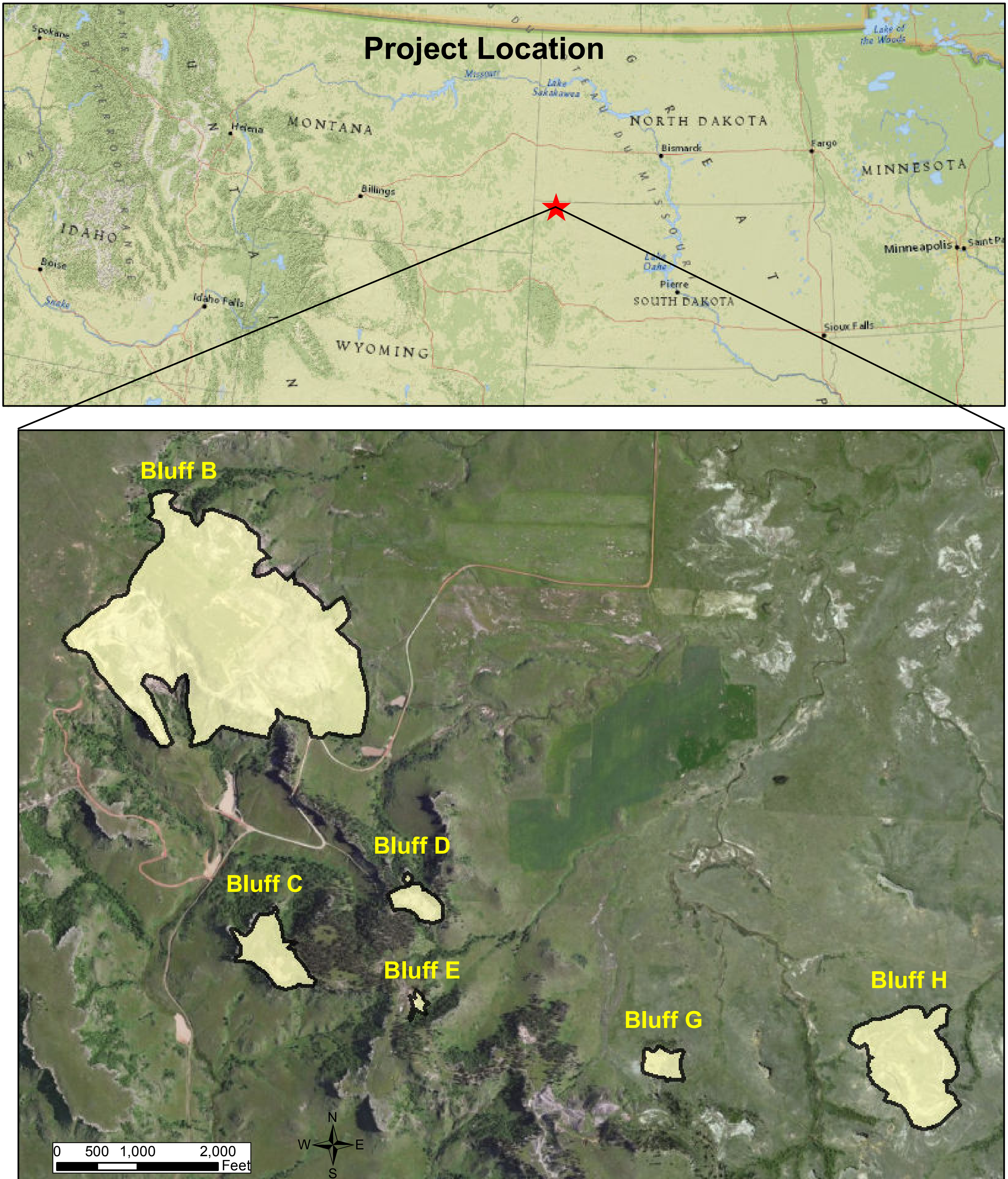
- Perform a preliminary contaminant leachability analysis by collecting and analyzing soil samples at each bluff using U.S. Environmental Protection Agency (EPA) Synthetic Precipitation Leaching Procedure (EPA, 1994).

- Perform test pit subsurface sampling and LIDAR surface versus historic air photography evaluations to provide an overall depth of mine waste contamination allowing for quantity estimates of mine waste material volumes.

1.2 Project Setting

The Site is part of the North Cave Hills area located in the Sioux Ranger District, Custer National Forest in Harding County, South Dakota, falling within Region 1 of the USFS. The Site is approximately 25 miles north of Buffalo, South Dakota. The nearest town is Ludlow, South Dakota, which lies 5 miles to the east. A small fraction of the Site is situated on private land (USFS, 2007).

For the purposes of this study, the Site includes the Tronox Bluffs B, C, D, E, G, and H. The physical boundaries of these bluff areas were delineated by the USFS and provided to Tetra Tech. In addition to the bluff areas, site characterization activities were also performed at several sediment ponds within the project vicinity. The Tronox Bluffs are located in parts of Township 22 North and Range 5 East. The location of the Site and the original Tronox Bluff boundaries are illustrated in Figure 1-1.



Legend:

Original USFS Bluff Boundary

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Riley Pass Tronox Bluffs
Site Location Map

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 1-1
Location:	Harding County, South Dakota	June, 2013	

1.3 Site Background

Mining activities occurred during the 1950s and early 1960s at the North Cave Hills in Harding County, South Dakota. This time period was of significant importance with regards to the uranium mining history of South Dakota. The first commercial deposit of uranium in South Dakota was discovered in Craven Canyon by Jerry G. Brennan (Page and Reddan, 1952); the second commercial deposit was found in the North and South Cave Hills of Harding County. In 1954, the Atomic Energy Commission planned to fly radiometric surveys over the Slim Buttes; due to adverse weather, the pilots changed course and flew over the Cave Hills, recording significant radiological anomalies (Curtiss, 1955).

Under the General Mining Laws, per the Atomic Energy Act of 1946 and Public Law 357, unrestricted strip mining took place within the North Cave Hills during the 1950s and 1960s. The strip mining involved the removal of uranium-bearing lignite coal beds, with no requirements for environmental restoration or for establishing post-mining responsibility (USFS, 2006). Overall, approximately 1,000 acres of land were disturbed by these mining processes.

The geology of Harding County consists of generally flat-lying sediments that are folded and faulted in several areas. The flat-topped, steep-sided sandstone buttes in the North Cave Hills tower to heights of several hundred feet over the gently undulating uplands (Curtiss, 1955). The North Cave Hills possess a lower sandstone layer that is 39 to 100 feet thick, yellow-brown, fine- to medium-grained, massive, slightly cemented with lime, and cross-bedded; a thin bed of impure lignite overlies basal sandstone (Curtiss, 1955). Uraniferous lignites are generally lower grade, comparable to uraniferous shales; however, when uraniferous lignites are burned, uranium is concentrated in the ash; a situation observed in multiple areas within the Tronox Bluff boundaries. Figure 1-2 displays a portable burner used for burning the lignite at a site near Buffalo, South Dakota. The Site includes many abandoned lignite strip mines located on relatively flat areas along the top of buttes. Mining features at the site include bluffs, overburden piles (spoils), hazardous openings created by soil piping/erosion, and highwalls. Figure 1-3 shows the result of the ashy material being pushed off the top of bluffs onto the side slopes. Samples of spoils materials have been characterized as sandy clay and clayey sand. The bluffs are located primarily within the Sioux District of Custer National Forest and a small fraction of the site is situated on private land.

The climate in the area is classified as continental, marked by cold winters and hot summers with large fluctuations in daily and seasonal temperatures (USFS, 2006). The region is semi-arid, precipitation is irregular, and droughts are commonplace. The primary land uses in the Site region are livestock grazing under USFS permits, hunting, hiking, camping, ATV/motorcycle use, and Native American spiritual activities. The altitude within the area of investigation ranges between 3,100 feet and 3,400 feet above mean sea level (amsl). The North Cave Hills area serves as the headwaters of the south and north forks of the Grand River, which flows into the Missouri River at Mobridge, South Dakota.

In 1964, the Forest Service noted that overburden from one of the claims mined by Kermac Nuclear Fuels (Kermac) had been transported through the forest boundary fence, causing significant disturbance on the adjacent owner’s land and destroying a section of the fence (USFS, 2007).

The USFS estimates the Site consists of 250 acres of disturbed land distributed across 12 bluffs or buttes. The bluffs at the Site have been delineated as either “Tronox” or “Non-Tronox,” relating each bluff to the potentially responsible party (PRP). This report evaluates the waste characterization data collected only at locations where Tronox [Tronox Worldwide, LLC (Tronox), a corporate successor to Kermac] is the identified PRP. These areas are referred to in this report as the Tronox Bluffs.

The 2007 Action Memorandum indicates that the conditions at the Site present an imminent and substantial endangerment to human health and the environment, due to the presence of elevated soil concentrations of metals and radionuclides. The purpose of the 2007 Action Memorandum was to document approval of the selected non-time-critical removal action remedy. The conditions specified meet the criteria for initiating a Removal Action under 40 Code of Federal Regulations (CFR) Section 300.415 (b)(2) of the National Contingency Plan (NCP). Executive Order 12580 and 7 CFR 2.60(a)(39) delegates Removal Action Authority to the USFS because the hazardous source is on National Forest System Lands.

Figure 1-2. Portable Burner at site near Buffalo, South Dakota (USDA[1], 1964)

[1]U.S. Department of Agriculture

Figure 1-3. Result of Strip Mining Activities in the North Cave Hills (USDA, 1964)

1.4 Tronox Bluff Boundary Delineation

The 2012 Tronox Bluff waste characterization sampling program includes the areas within Tronox Bluffs B, C, D, E, G, and H, which were based on the original boundaries provided to Tetra Tech by the USFS. After the field work was initiated as part of the waste characterization program, Tetra Tech analyzed 2012 data and determined that the original boundaries established in the EE/CA did not entirely reflect the actual areal extent of mine waste contamination or mine disturbance at each of the Tronox Bluffs. The data collection activities performed by Tetra Tech used immediate real-time screening tools such as x-ray fluorescence (XRF) and gamma radiation detection systems, allowing mine waste to be mapped in the field and waste locations and bluff boundaries to be further refined after Tetra Tech processed and analyzed the data. The revised boundaries were developed using a combination of total arsenic concentration, total molybdenum concentration, ^{226}Ra activity, ^{238}U activity, ^{235}U activity, and ^{234}U activity observed in the surface soil characterization data in conjunction with natural boundaries, field observations, and aerial imagery.

All of the original Tronox Bluff boundaries were revised to some degree, with the exception of Bluff B. The most significant changes to the boundaries were made to Bluffs C, D, and E. Additional characterization sampling was performed outside the original limits as part of a USFS contract modification; the revised bluff boundaries were merged into one larger boundary and are herein referred to as Bluff CDE (previously known as Bluffs C, D, and E). Table 1-1 shows the original and revised boundary areas of the Tronox Bluffs.

Table 1-1. Summary of Revised Tronox Bluff Boundary Areas

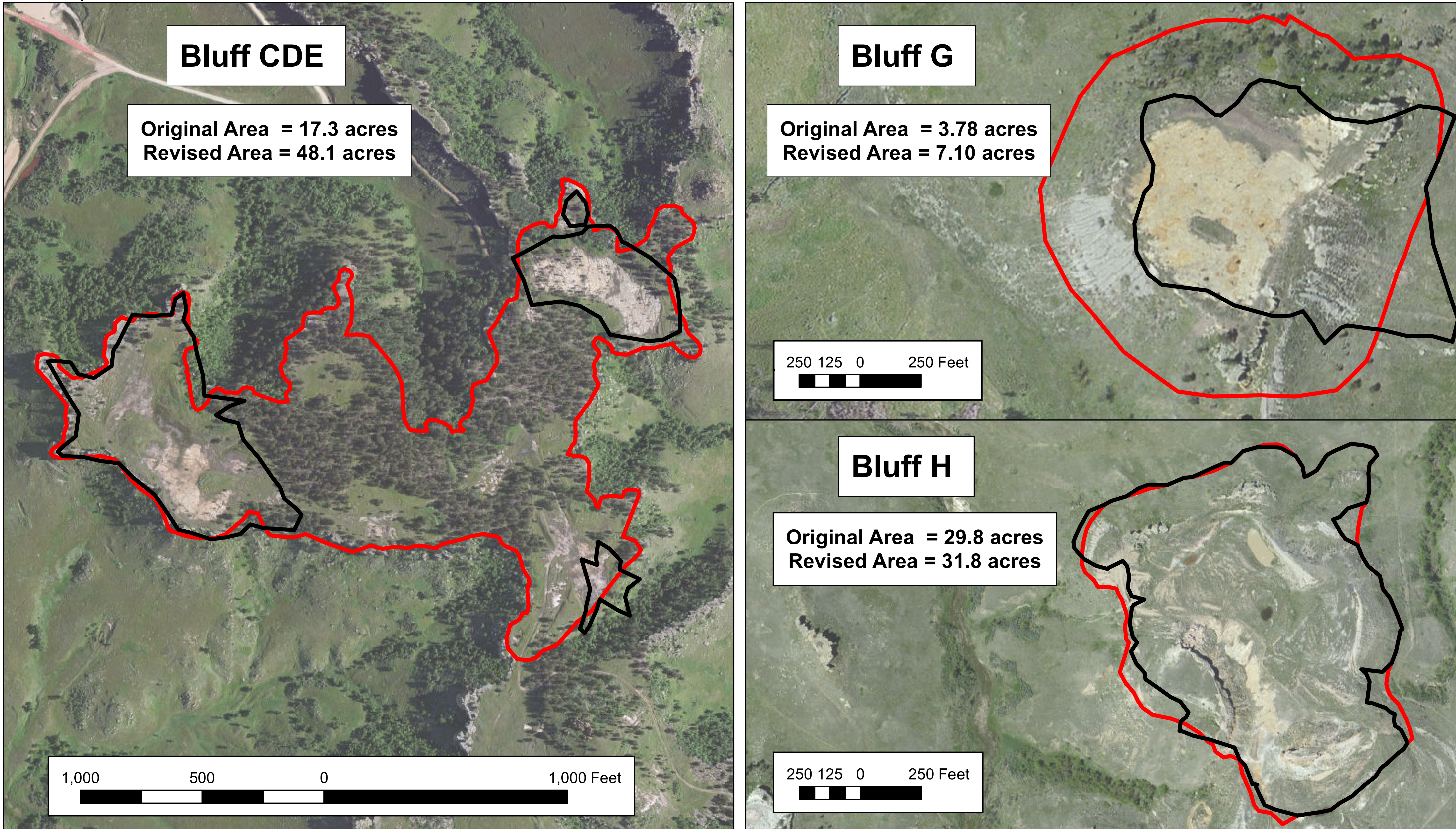
Bluff Boundary	Original Area (acres)	Rev. Bluff Boundary	Revised Area (acres)	Percent Increase
Bluff B	153	Bluff B	153	0
Bluff C	11.3	Bluff CDE	48.1	179
Bluff D	5.02			
Bluff E	0.935			
Bluff G	3.78	Bluff G[1]	7.1	88
Bluff H	29.8	Bluff H	31.8	7
Total	**204**	**ALL**	**240**	**18**

[1] There is a sandstone area of 1.2 acres at Bluff G where limited sampling was performed due to lack of available soil. The physical boundary was added to the figures for Bluff G, where applicable. Based on the XRF field survey IDW maps it appears the sandstone is above action limits; however, this area was not actually sampled by XRF due to lack of soil. The sandstone area was identified on the maps and this is included in the waste area estimates. During field sampling, a small outcrop of natural radiation was observed on the west side of the sandstone area that should also be noted during reclamation. Tetra Tech included this area in the removal action maps in the likelihood there is some small volumes of contaminated soil layer present. The 1.2-acre Bluff G sandstone area is included within the revised area value.

The revised boundaries, compared to the original boundaries for the Tronox Bluffs, are shown in Figure 1-4. The total combined area of the original Bluff C, D, and E boundaries was 17.3 acres; the revised boundary now referred to as Bluff CDE covers 48.1 acres (increase of 179 percent). The boundary delineation for Bluff G was increased from 3.78 acres to 7.1 acres (increase of 88 percent), and the boundary delineation for Bluff H was increased from 29.8 acres to 31.8 acres (increase of 7 percent). Overall, the revised boundary area of the Tronox Bluffs increased from 204 acres to 240 acres (increase of 18 percent).

The USFS provided Tetra Tech with georeferenced aerial imagery from 1954. Figure 1-5 through Figure 1-8 compare the 1954 and 2012 aerial imagery for the areas of Bluffs B, CDE, G, and H, respectively. This comparison provided Tetra Tech information on the pre-mining conditions at each of the bluffs.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Original USFS Tronox Bluff Boundary

2012 Revised Tronox Bluff Boundary

N

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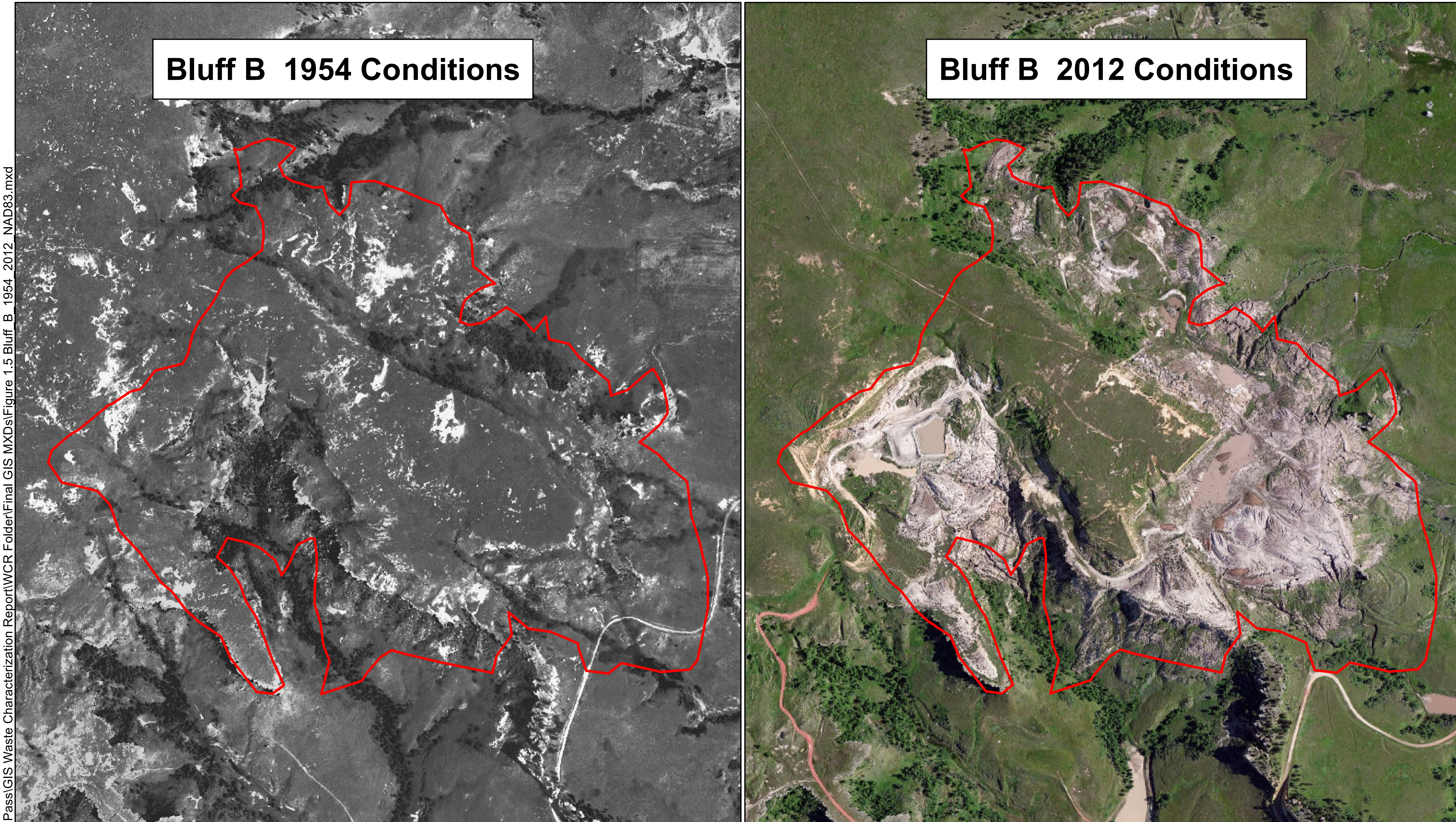
Revised Tronox Bluff Boundary Delineation

3 Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 1-4
Location: HARDING COUNTY COUNTY, SD	May 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 1.4 Bluff_Boundary_Changes_NAD83.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Revised 2012 Tronox Bluff Boundary

0 250 500 1,000 Feet

N

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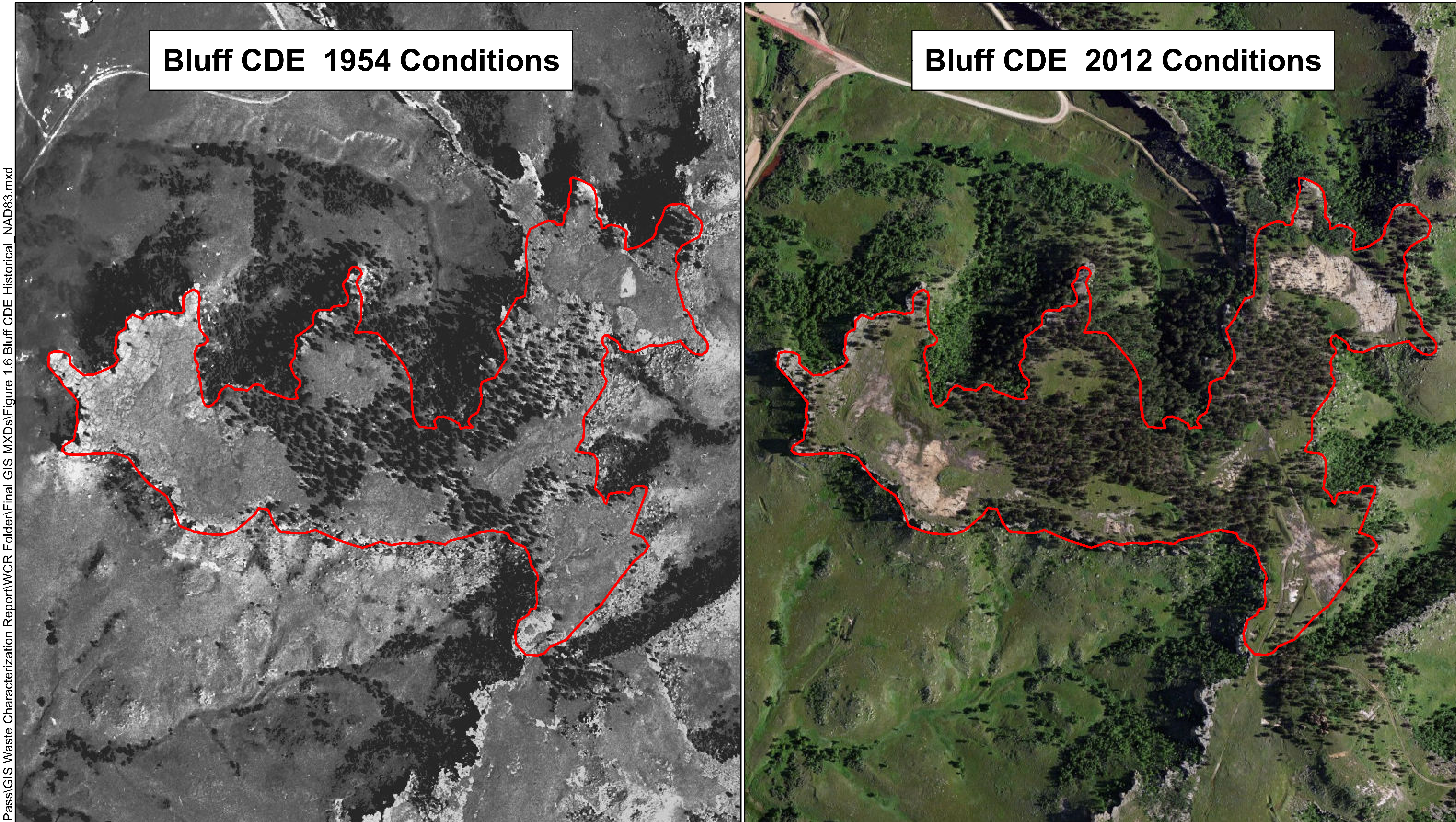
Bluff B Historical Conditions 1954 v. 2012 Aerial Imagery		3 Revision
Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 1-5
Location: HARDING COUNTY COUNTY, SD	May, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 1.5 Bluff_B_1954_2012_NAD83.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Revised 2012 Tronox Bluff Boundary

0 125 250 500
Feet

N

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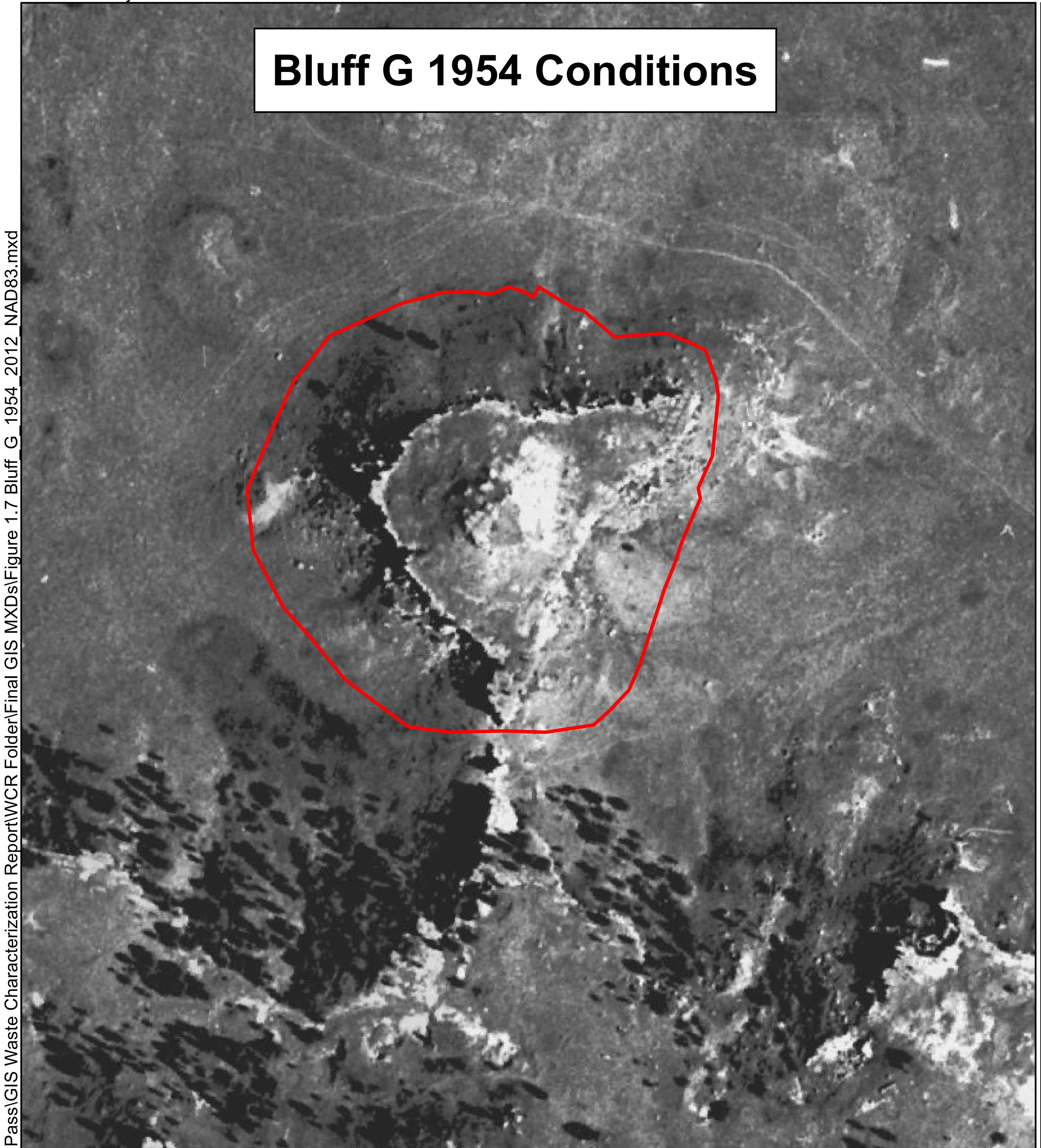
Bluff CDE Historical Conditions
1954 v. 2012 Aerial Imagery

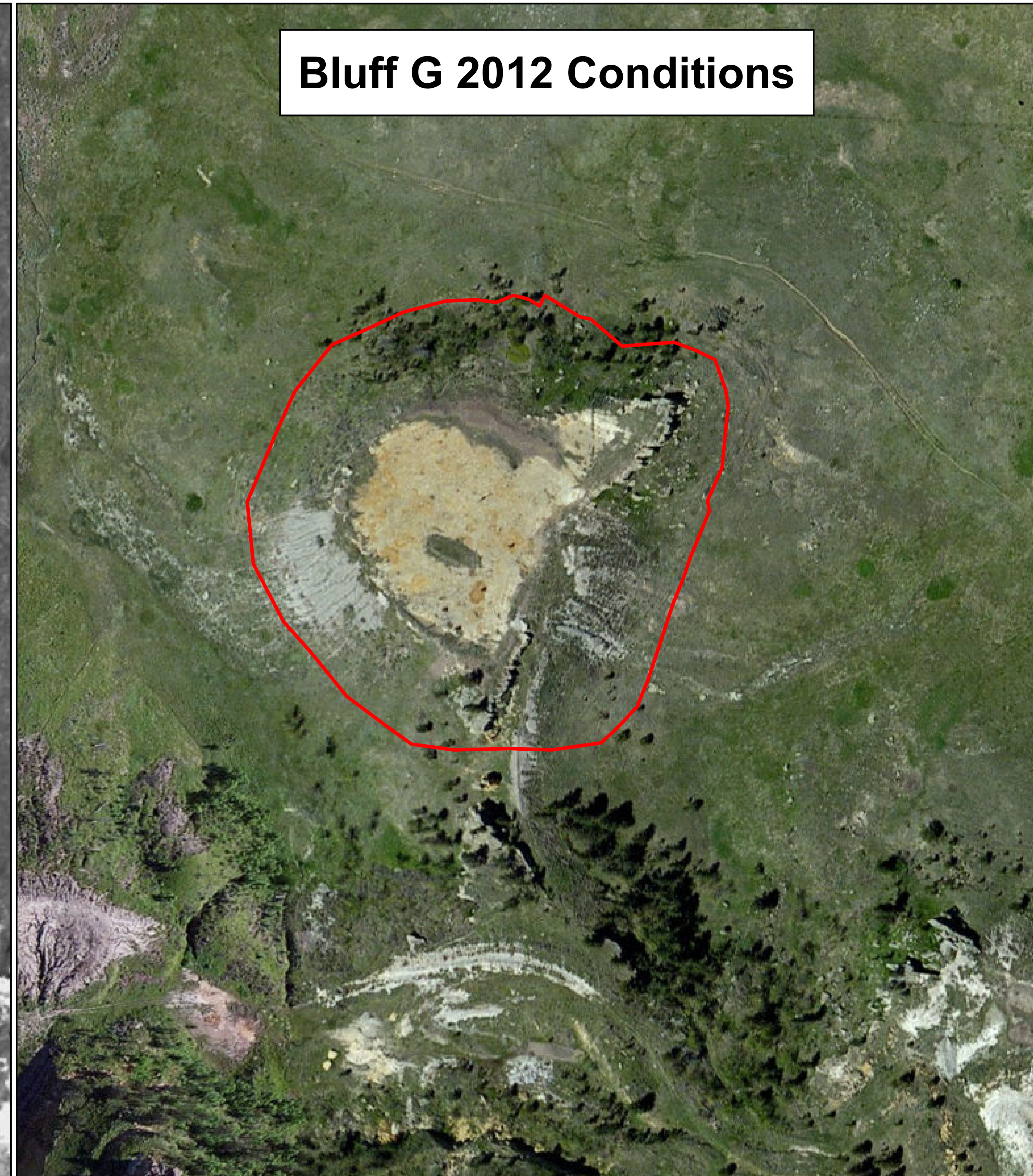
3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 1-6
Location: HARDING COUNTY COUNTY, SD	May, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 1.6 Bluff CDE Historical_NAD83.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet





Legend:

Revised 2012 Tronox Bluff Boundary

0 75 150 300 Feet

N

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Bluff G Historical Conditions
1954 v. 2012 Aerial Imagery

3 Revision

Project: Riley Pass Tronox Bluffs

Project no.: 114-551083

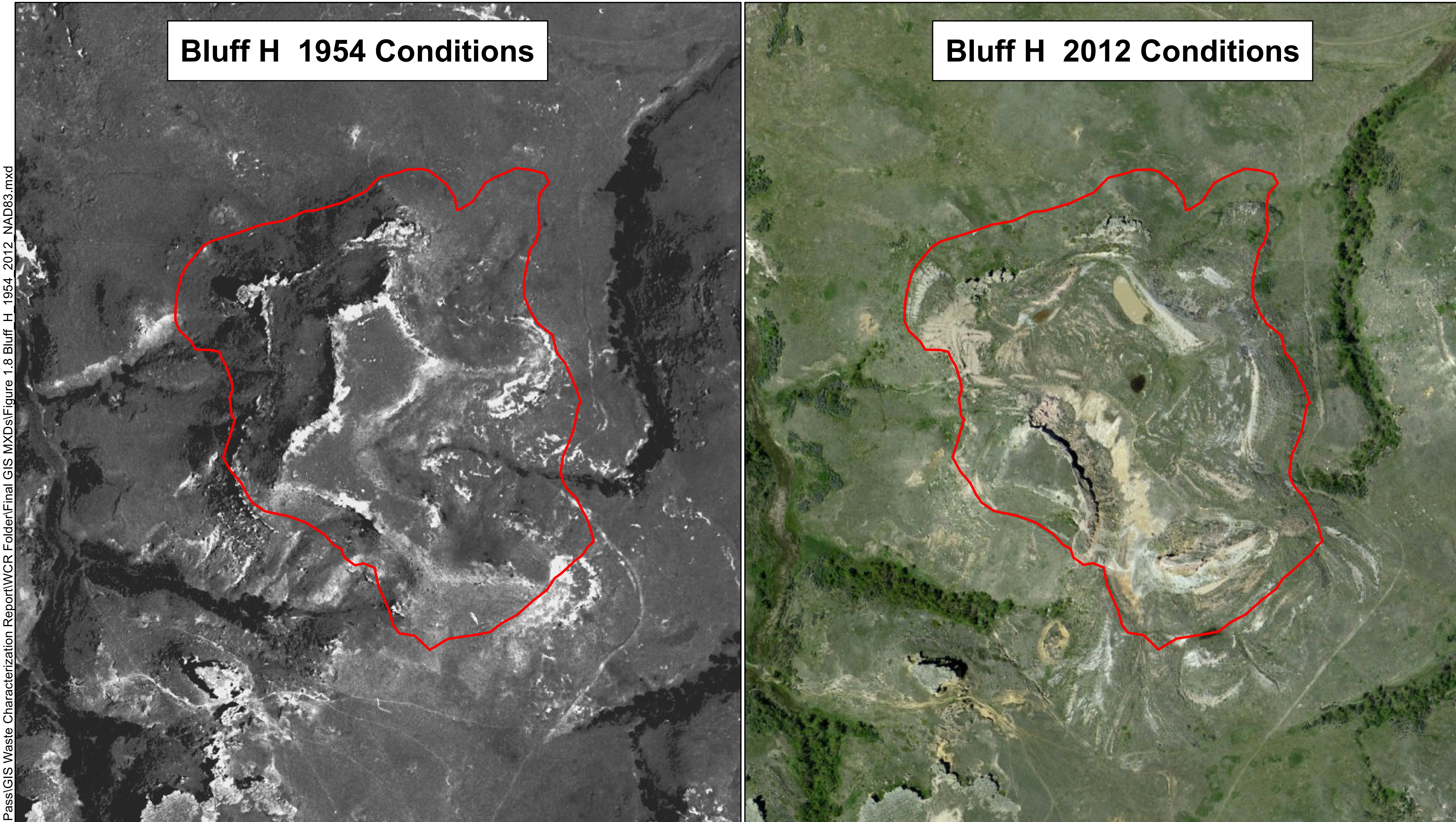
Location: HARDING COUNTY COUNTY, SD

May, 2013

Figure 1-7

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 1.7 Bluff_G_1954_2012_NAD83.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff H Boundary

0 125 250 500 Feet

N

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Bluff H - Revised Boundary
1954 v. 2012 Aerial Imagery

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 1-8	
Location: HARDING COUNTY COUNTY, SD	May, 2013		

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 1.8 Bluff_H_1954_2012_NAD83.mxd

1.5 Previous Site Investigations

A number of investigations and studies have been performed at the Riley Pass and the North and South Cave Hills complexes. Many of these studies have reported elevated metals and radionuclide soil concentrations at the bluff areas at the Site (USFS, 2006). Table 1-2 shows a list of the previous investigative actions taken by various entities within the recent past.

Table 1-2. Brief Summary of Recent Federal Government Investigations at the Site

Date	Action	Consultant/Agency
1999 to 2002	Site investigation and EE/CA	USFS and Pioneer Technical Services
2002	Public notice warning signs were posted	USFS
2004	Human Health and Environmental Risk Assessment	Portage Environmental Incorporated
2004	Time Critical Removal Action memorandum for sediment ponds and Schleichart Reservoir	USFS
2005	Draft Final EE/CA released for public review	USFS, Pioneer Technical Services, and Portage Environmental
	Public meetings, public notices, and public comments	
2006	USFS came to agreement with South Dakota (SD) DENR* on the ARARs** to be included in Final EE/CA	USFS / SD DENR
2006	Final EE/CA released	USFS, Pioneer Technical Services, and Portage Environmental
2007	Final Report: North Cave Hills Abandoned Uranium Mines Impact Investigation.	South Dakota School of Mines and Technology and Oglala Lakota College
2007	Tronox Bluffs Action Memorandum	USFS
2008	2007 End-Of-Year Completion Report Riley Pass Uranium Mines Site	AECOM/Tronox
2009	Riley Pass Uranium Mines Site XRF and Gamma Surveys Report (Non-Tronox)	USFS/MSE[†]
2010	Non-Tronox Bluffs Action Memorandum	USFS
2010	Verification SAP developed	MSE
2011	MSE, Tetra Tech, and USFS begin verification sampling on Bluff J, K	Tetra Tech, MSE, USFS
2012	Tetra Tech and USFS begin verification sampling on Bluff I and Bluff F	Tetra Tech, USFS
2013	Tronox Bluffs Waste characterization	Tetra Tech, KC Harvey, USFS

*DENR = Department of Environment and Natural Resources
**ARAR = Applicable or Relevant and Appropriate Requirements
[†]MSE = Millennium Science and Engineering

1.6 Report Organization

This report presents the data and information collected during the waste characterization activities, and is organized as follows:

- Section 1.0 provides the introduction, purpose, project setting, site background, boundary delineation, and lists previous site investigations.
- Section 2.0 presents the data collection objectives related to the removal action cleanup criteria.
- Section 3.0 presents the data collection activities and quality assurance/quality control (QA/QC) procedures.
- Section 4.0 presents the results of the gamma radiation soil correlation analysis and the *in-situ* XRF correlation analysis.
- Section 5.0 presents the waste characterization results and volume estimation.
- Section 6.0 presents the contaminant leachability results.
- Section 7.0 presents a comparative analysis of the data collected during the present study and historical site investigations.
- Section 8.0 presents the conclusions and recommendations resulting from the waste characterization study.

2.0 WASTE CHARACTERIZATION DATA COLLECTION OBJECTIVES

In accordance with the proposed remedy specified in the 2007 Action Memorandum, Tetra Tech performed field data collection involving a gamma radiation survey, an XRF field survey, test pit sampling, erionite sampling, and sediment sampling. This section provides a description of the waste characterization data collection objectives.

2.1 Data Collection Objectives

Tetra Tech developed the SAP to document the environmental data collection procedures to be conducted as part of the 2012 Tronox Bluffs waste characterization program in support of the engineering removal action engineering design. The objectives were to characterize the physical, chemical, and radiological conditions of surface soils at each of the Tronox Bluffs included in the study. This information will be utilized by Tetra Tech and the USFS in ongoing reclamation design.

The criteria used to measure the precision, accuracy, representativeness, comparability, and completeness of the data acquired during the waste characterization program are described in the SAP. The assessment of data usability and data quality validation for this project is explained in Section 3.6.

The following waste characterization data collection objectives and activities are as follows:

1. **Gamma Radiation Survey:** The purpose of the gamma radiation survey was to characterize the spatial distributions of gamma radiation from surface soils within the boundaries of the Tronox Bluffs. The gamma exposure rates were then correlated with the soil ^{226}Ra activity and radiation dose rates and mapped for each bluff. As specified in the 2007 Action Memorandum, spatial interpolation techniques were used to divide the Site into grid cells to identify the existing average soil ^{226}Ra activity. This information was used to identify the areal extent of removal action boundaries based on the soil reclamation criteria for the Site.

2. ***In-Situ* XRF Field Survey:** The purpose of the *in-situ* XRF field survey was to characterize the spatial distributions of *in-situ* XRF metals concentrations in surface soils within the boundaries of the Tronox Bluffs. The *in-situ* XRF metal concentrations were correlated to select metals concentrations determined via laboratory confirmation soil sample analyses. Spatial interpolation techniques were used to divide the Site into appropriate grid cells to identify the existing average total arsenic concentration, total molybdenum concentration, natural uranium concentration, ^{238}U activity, ^{235}U activity, ^{234}U activity in the surface soils. This information was used to identify the areal extent of removal action boundaries based on the soil reclamation criteria for the Site.

3. **Test Pit Sampling:** The purpose of the test pit sampling was to estimate the vertical extent of the mine-affected materials. The test pit sampling was performed only at Bluff CDE due to access restrictions.

4. **Erionite Sampling:** The purpose of the erionite sampling was to identify the presence of the naturally occurring zeolite mineral that may have been used as a road surface material within the boundary of Bluff B.

5. **Sediment Sampling:** The purpose of sampling within the sediment ponds was to characterize the physical and chemical characteristics of the sediment with respect to removal action criteria and agronomic properties to evaluate potential options for disposal or use as reclamation cover materials.

In addition to waste characterization data collection activities, the SAP specified that erosion and vegetation surveys were to be performed at Bluff CDE. Observations were performed to evaluate vegetative conditions at all disturbed areas for evidence of active erosion and/or soil stability. This information will be used to determine the type and extent of soil reclamation recommended for the bluffs.

Another objective was to develop a revised delineation of the bluff boundaries, as discussed in Section 1.4 of this report. These new boundaries were based on field data, natural boundaries, visual observations, and aerial imagery. Scanned copies of the waste characterization team's field logbooks and XRF sampling summary sheets are provided in Appendix B.

2.2 Removal Action Cleanup Criteria

According to the USFS, the environmental conditions at the Site present an imminent and substantial endangerment to human health and the environment due to the presence of elevated soil concentrations of radionuclides and heavy metals (USFS, 2007, 2010). These hazardous substances, as defined in section 101(14) of CERCLA, include arsenic, molybdenum, thorium, uranium, and ^{226}Ra. These conditions meet the criteria for initiating a Removal Action under 40 CFR Section 300.415 (b)(2) of the NCP Executive Order 12580 and 7 CFR 2.60(a)(39) delegates Removal Action authority to the USFS, when the potential for release is on or from National Forest System lands. The proposed action determined by the USFS is to contain, consolidate, stabilize, and vegetate contaminated soil, spoils, and sediment associated with historic mining activities within the Tronox Bluffs at the Site.

As stated in the Human Health and Ecological Risk Assessment in the EE/CA, arsenic is the primary human health risk driver, with the carcinogenic risk from radionuclides approximately an order of magnitude less than that for arsenic (EE/CA Appendix D, page 3-16). The USFS defined specific risk-protective criteria for specific bluffs that will be met in the implementation of the Removal Action in its 2007 Action Memorandum. They defined these as Criteria 1, applicable to Bluff B, G, and H and Criteria 2 that is applicable to Bluffs C, D, and E.

Section 2.2.1 discusses the criteria set forth in the Action Memo (USFS, 2007) for Bluffs B, G, and H. Section 2.2.2 presents the criteria set forth in the 2007 Action Memorandum for Bluffs C, D, and E. Finally, Section 2.2.3 presents how Tetra Tech interprets and presents the waste characterization data in this WCR.

2.2.1 2007 Action Memo Criteria 1: Applicable to Bluffs B, G, and H

The 2007 Action Memorandum specifies that Criteria 1 is applicable to Bluffs B, G, and H and the sediment ponds, and Criteria 2 is applicable to Bluffs C, D, and E. These criteria define the reclamation and materials handling requirements for these bluffs, where there is demonstrable disturbance attributable to the past surface mining activities. Measurements to affirm these criteria, as stated in the 2007 Action Memorandum, will be based on surface gamma radiation readings. However, as noted above, total arsenic needed to be characterized separately by conducting the XRF field survey. The following three Criteria 1 categories are described in the Action Memorandum as follows:

- **Category I:** Material with less than or equal to 30 picocuries per gram (pCi/g) soil ^{226}Ra activity. These areas will be left undisturbed to the extent practical. However, if the materials are poorly vegetated and active significant erosion occurs, they will be addressed by grading or compaction or otherwise stabilized and revegetated.

- **Category II:** Materials with soil ^{226}Ra activity greater than or equal to 30 pCi/g, but less than 50 pCi/g. In areas where these bluffs meet this criteria, mitigation efforts will be implemented to bring the average soil ^{226}Ra activity down to less than or equal to 30 pCi/g by any practical combination.

- **Category III:** Materials with greater than or equal to 50 pCi/g of soil ^{226}Ra activity. Materials in this category will be excavated and placed in a designated disposal repository.

2.2.2 2007 Action Memo Criteria 2: Applicable to Bluffs C, D, and E

The 2007 Action Memorandum specifies that Criteria 2 are applicable to Tronox Bluffs C, D, and E and are listed below:

- **No Reclamation:** In areas where minimal overburden was historically present, vegetation has stabilized the soil and no significant erosion is evident.

- **Stabilization and Vegetate:** In areas where active significant erosion is occurring due to poor vegetative cover.

- **Excavation and Consolidation**: In areas immediately adjacent to Road 3130 where materials associated with historic mining activities exceed Criteria 1 Category II soil 226Ra activity.

2.2.3 Interpretation of Criteria for Waste Characterization Purposes

There is contradictory language written in USFS 2007 and 2010 Action Removal Memoranda, as discussed below.

Based on the sampling and measurements completed at that time, the 2007 Action Memorandum states in Section IV.A1, "…a direct correlation exists between arsenic and ^{226}Ra concentrations, therefore cleanup of the Project area to a risk protective ^{226}Ra concentration will result in arsenic concentrations that, when combined with the risk associated with ^{226}Ra will be protective of human health and potential environmental receptors. In addition, using ^{226}Ra as the direct clean-up guideline will allow for direct quantifiable measurements to be made in the field during the course of removal action."

The 2010 Action Memorandum states in Section B.V.A.1, "Measurement to confirm attainment of these criteria will be based on surface gamma radiation readings and correlated to ^{226}Ra and arsenic concentrations and will be based on block averaging or another method." However, the same memorandum states in Section B.V.A.1.e, "Because there is not a direct correlation between ^{226}Ra and arsenic concentrations, x-ray diffraction equipment will be used to verify arsenic concentrations using a grid system."

These variations make it difficult to interpret the mine waste categories at the Site; therefore, Tetra Tech, in consultation with the USFS On Scene Coordinator (OSC), has developed an interpretation of the soil reclamation criteria using the primary human health constituents of concern identified in the 2007 Action Memorandum, 2010 Action Memorandum, and EE/CA Appendix D Human Health Risk Assessment: total arsenic, total molybdenum, ^{238}U, ^{235}U, ^{234}U, and ^{226}Ra. The waste characterization data collected as part of the XRF field survey were used to categorize the Site based on total arsenic concentration, total molybdenum concentration, ^{238}U activity, ^{235}U activity, and ^{234}U activity in the surface soils. Similarly, the waste characterization data that was collected as part of the gamma radiation survey were used to categorize the site specifically based on soil ^{226}Ra activity. After the bluffs were characterized based on point data, advanced spatial interpolation and geostatistical techniques were applied to the data sets to map bluffs and identify soil remediation attainment areas that exceeded the cleanup standard based on each contaminant's site specific concentration criteria. The merging of all contaminant criteria into a universal mine waste category scheme was conducted using map algebra and raster processing in *ArcMap10©* to develop mine waste characterization maps that can be used during the reclamation design phase. The site-specific relationship between total arsenic concentration and ^{226}Ra activity is discussed further in Section 4.1.4.

Tetra Tech utilized the *in-situ* XRF field survey to characterize the Site for total arsenic concentration, total molybdenum concentration, ^{238}U activity, ^{235}U activity, and ^{234}U activity in the surface soils. The soil reclamation criteria at the Site for total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U are based on the less than 142 mg/kg soil cleanup goal from the 2007 Action Memorandum and 2,775 mg/kg, 42.8 pCi/g, 2.03 pCi/g, and 44.6 pCi/g site-specific risk-based preliminary cleanup goals, respectively, from the Final Human Health and Ecological Risk Assessment for the Riley Pass Uranium Mines (Appendix D, EE/CA) (USFS, 2006). The molybdenum risk-based level was selected from the site-specific level in EE/CA Appendix D Table 5-3 and the uranium isotope risk levels were based on EE/CA Appendix D Table 5-4 RBCs for permit holder with 10 percent beef ingestion from Site. For the purposes of this study, each bluff was categorized using the following definitions for existing average total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U concentrations/activities:

1. Surface soils that do not exceed the risk-protective total arsenic concentration of 142 mg/kg and that do not exceed total molybdenum concentration of 2,775 mg/kg and that do not exceed radionuclide activities for ^{238}U, ^{235}U, and ^{234}U of 42.8 pCi/g, 2.03 pCi/g, and 44.5 pCi/g, respectively.

2. Surface soils that are greater than or equal to the risk-protective total arsenic concentration of 142 mg/kg or that exceed total molybdenum concentration of 2,775 mg/kg or that exceed soil radionuclide activities for ^{238}U, ^{235}U, and ^{234}U of 42.8 pCi/g, 2.03 pCi/g, and 44.5 pCi/g, respectively.

Similar criteria applicable to Bluffs B, G, and H presented in the 2007 Action Memorandum were utilized to categorize each of the bluffs using the existing average soil ^{226}Ra activity established during the gamma radiation survey as follows:

1. Surface soils that do not exceed the risk-protective soil ^{226}Ra activity of 30 pCi/g.

2. Surface soils that are greater than or equal to the risk-protective soil ^{226}Ra activity of 30 pCi/g, but fall below a ^{226}Ra concentration of 50 pCi/g.

3. Surface soils that are greater than or equal to the risk-protective soil ^{226}Ra activity of 50 pCi/g.

The primary objective of the waste characterization collection activities is to identify areas of the Site that meet removal action requirements set forth by the USFS in the 2007 Action Memorandum and site-specific risk-based preliminary cleanup goals from the Final Human Health and Ecological Risk Assessment (Appendix D, EE/CA) (USFS, 2006). Tetra Tech interprets the mine waste removal area Criteria 1 categories as follows:

1. **Category I (based on ^{226}Ra and total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U):** All surface soils that do not exceed the risk-protective ^{226}Ra activity of 30 pCi/g and do not exceed any of the risk-protective levels identified for: total arsenic concentration (142 mg/kg), total molybdenum concentration (2,775 mg/kg), ^{238}U activity (42.8 pCi/g), ^{235}U activity (2.03 pCi/g), or ^{234}U activity (44.6 pCi/g).

2. **Category II (based on ^{226}Ra and total arsenic, total molybdenum, ^{238}U, ^{235}U, ^{234}U):** All surface soils that are greater than or equal to the risk-protective ^{226}Ra activity of 30 pCi/g, but fall below a ^{226}Ra concentration of 50 pCi/g and do not exceed any of the risk-protective levels identified for: total arsenic concentration (142 mg/kg), total molybdenum concentration (2,775 mg/kg), ^{238}U activity (42.8 pCi/g), ^{235}U activity (2.03 pCi/g), or ^{234}U activity (44.6 pCi/g).

3. **Category III (based on ^{226}Ra and total arsenic, total molybdenum, ^{238}U, ^{235}U, ^{234}U):** All surface soils that are greater than or equal to a soil ^{226}Ra activity of 50 pCi/g and are greater than or equal to at least one of the risk-protective levels identified for: total arsenic concentration (142 mg/kg), total molybdenum concentration (2,775 mg/kg), ^{238}U soil activity (42.8 pCi/g), ^{235}U soil activity (2.03 pCi/g), or ^{234}U soil activity (44.6 pCi/g).

The three Criteria 1 categories using total arsenic, total molybdenum, soil ^{226}Ra, ^{238}U, ^{235}U, and ^{234}U activity were combined and applied to each of the Tronox Bluffs. These categories were not applied to materials sampled in the sediment ponds due to a small number of samples collected and generally low metals levels within those samples. The results of the mine waste characterization are provided in Section 5.0.

Selenium and thorium were not mapped or included in the mine waste categorization criteria. Selenium was not measured with the XRF for all samples; however, it was analyzed in the 69 XRF soil confirmation samples and the highest value measured (110 mg/kg) was over 2,000 mg/kg less than the site-specific human health risk assessment (HHRA) presented in Table 5-3 of Appendix D of the EE/CA (USFS, 2006). Additionally, thorium analysis was not in the original scope of work presented to the USFS and, therefore, was not analyzed in any of the composite soil correlation samples or XRF soil correlation samples.

Tetra Tech, in consultation with the USFS OSC, has included total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U for removal action for Category I through Category III, based on criteria from the 2010 Action Memorandum and from the Human Health and Ecological Risk Assessment. The intent of including these additional criteria is to ensure, based on current data and best available science, that the removal actions adequately address human health concerns as defined in the Final Human Health and Ecological Risk Assessment for the Riley Pass Uranium Mines, which is EE/CA Appendix D (USFS, 2006). For purposes of this WCR, criteria listed in Table 2-1 were also applied to Bluff CDE.

Table 2-1. Criteria 1 - Applicable to Bluffs B, G, and H and Addressed in Implementation of the Removal Action

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

The EE/CA and 2007 Action Memorandum were based on sampling and measurements completed at that time. In the 2007 Action Memorandum, it was stated that a direct correlation existed between soil ^{226}Ra activity and total arsenic concentrations at the Site; therefore, only ^{226}Ra was addressed in categorizing Criteria 1 materials (USFS, 2007). However, further site characterization work completed for the Non-Tronox bluffs (USFS, 2010) and for this WCR has shown that the ^{226}Ra and arsenic are not always directly correlated. The total arsenic levels at the Site are now addressed in the SAP by including the addition of *in-situ* XRF field measurements of total arsenic and other heavy metals. For the purposes of the 2012 Tronox bluffs sampling and this WCR, both the 2007 Action Memorandum and the 2010 USFS Non-Tronox Bluff Action Memorandum (2010 Action Memorandum) criteria are used. The site-specific relationship between ^{226}Ra activity and other metals based on 2012 sampling is also discussed further in Section 4.1.4 of this WCR.

3.0 DATA COLLECTION AND QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES

This section presents the data collection procedures and the QA/QC protocols performed as part of the 2012 Tronox Bluff waste characterization program. The data collection procedures included a gamma radiation survey, an XRF field survey, test pit sampling, sediment sampling, and erionite sampling.

3.1 Gamma Radiation Survey Methods

This section describes the gamma radiation survey procedures and results related to the QA/QC procedures.

3.1.1 Gamma Survey Sampling Method

The purpose of the gamma radiation survey is to characterize the spatial distributions of gamma radiation exposure rates emanating from surface soils within the boundaries of the Tronox Bluffs. The gamma exposure rates were mapped using proprietary software and correlated with gamma dose rates and ^{226}Ra activity in the surface soils. The gamma survey technology and correlation procedures used for this study are efficient tools used to spatially characterize the distribution of gamma exposure rates and the associated soil ^{226}Ra activity within the surface soils at each bluff.

The gamma survey was performed in accordance with procedures outlined in the SAP (Tetra Tech, 2012a). Tetra Tech field engineers used backpack-mounted mobile gamma survey systems. The mobile gamma survey systems consist of Global Positioning Systems (GPS) receivers and gamma radiation detectors using proprietary software developed by Tetra Tech (2006). The survey was conducted in a manner that allowed for rapid gamma scanning and simultaneous geospatial data acquisition; data were recorded approximately every second. The GPS units utilize the Wide Area Augmentation System (WAAS), providing GPS signal correction to enhance position accuracy within ±2 meters.

Gamma exposure rate surveys for this project were performed using an unshielded Ludlum 44-10 sodium iodide (NaI) scintillation detector, which is comprised of a 2-inch by 2-inch NaI crystal and photomultiplier tube. The NaI detector was paired to a Ludlum 2350-1 data logger and a GPS unit linked to a computer that utilizes data recording software on a backpack-mounted unit. Gamma radiation detection instruments are factory-calibrated. Each member of the gamma survey field crew was trained and experienced in radiation protection measurement techniques. The entire gamma survey was performed using backpack mounted systems with the detector at a height of 3 feet above the ground surface. The results of QA/QC procedures for the gamma radiation survey are discussed in Section 3.1.3.

In accordance with the 2007 Action Memorandum, a systematic square grid sampling method was used to verify the extent of contamination at each of the Tronox Bluffs for the WCR. Overall, the gamma radiation survey collection activities met the requirements set forth in the SAP. The SAP specified a scan transect width of 50 feet; this was maintained by field personnel on the bluffs where terrain and personnel safety allowed. The results of the gamma radiation survey are presented in Section 5.0.

3.1.2 Gamma Correlation Methods

Given a strong relationship between gamma exposure rates and soil ^{226}Ra activity at a site, statistical correlations can be developed and used to estimate the soil ^{226}Ra activity across the site using the data collected from the gamma survey (Whicker et al., 2008). Tetra Tech performed gamma exposure rate and ^{226}Ra soil correlation analyses during the gamma radiation survey, following the methods described in Johnson (2006) and outlined in the SAP (Tetra Tech, 2012a). The results of the gamma correlation analyses are presented in Section 4.1.

A total of 11 soil correlation sample plots (10 meters [m] by 10 m grids) were selected by field personnel as part of the gamma radiation survey. The plots were selected after the range of gamma exposure rates for the Site had been determined during the gamma survey, such that the selected plots would cover the range of gamma exposure rates that were recorded during the survey. Within each soil correlation plot, a total of nine soil sub-samples were collected to a depth of 15 centimeters (cm) and composited into a single sample presumed to be representative of the average soil ^{226}Ra activity for each 100 square meter (m^2) plot.

The composite soil samples were submitted to ALS Laboratory in Fort Collins, Colorado for analysis of ^{226}Ra by gamma spectroscopy after drying, homogenizing, canning, and equilibration using the EPA Method E901.1 (Modified). Soil correlation samples were also submitted for analyses of total metals, as shown in Table 3-1.

Table 3-1. Gamma Soil Correlation Sample Laboratory Analysis Methods

Analyte	CAS-NO	Reported Units	Prep Method	Analytical Method
^{226}Ra	13982-63-3	pCi/g*	PAI 739 Rev 10	Gamma Spec (E901.1)
Arsenic	7440-38-2	µg/kg**	Method 3050B	Method 6020A
Cadmium	7440-43-9	µg/kg	Method 3050B	Method 6020A
Copper	7440-50-8	µg/kg	Method 3050B	Method 6020A
Lead	7439-92-1	µg/kg	Method 3050B	Method 6020A
Molybdenum	7439-98-7	µg/kg	Method 3050B	Method 6020A
Uranium	7440-61-1	µg/kg	Method 3050B	Method 6020A
Zinc	7440-66-6	µg/kg	Method 3050B	Method 6020A

*pCi/g = picocuries per gram
**µg/kg = micrograms per kilogram

3.1.3 Gamma Survey Quality Assurance/Quality Control Results

All radiological characterization projects conducted by Tetra Tech incorporate specific data QA/QC protocols. In general, QA includes qualitative factors that provide confidence in the results, while QC involves quantitative, field evidence that supports the validity of results. This section presents the results of the QA/QC program for the 2012 Tronox Bluff waste characterization program. The SAP (Tetra Tech, 2012a) describes the QA/QC methods and procedures that were to be followed as protocol for the program.

Tetra Tech utilized GPS-based gamma scanning systems with automated electronic data acquisition software to perform the gamma radiation survey at the Tronox Bluffs. The gamma survey procedures discussed in the SAP were followed closely during the characterization work.

These survey procedures are widely used and represent accepted techniques for characterization of gamma radiation at abandoned uranium mining sites. This type of technology allows for a large amount of radiological data to be collected during the survey. Each detector and rate meter was calibrated by the manufacturer (Ludlum) with a ^{137}Cs source per manufacturer suggested requirements. The factory calibration documents for each of the radiation detectors used during the gamma radiation survey are included as Appendix C.

Prior to commencement (pre-survey) of the gamma radiation survey, QC measurements were performed at an indoor location for each NaI detector with the potential for use during the survey. The same QC procedure was performed again after completion (post-survey) of the field survey, but only on the instruments actually used during the survey. The purpose of this assessment was to quantify the consistency of readings between radiation detectors under controlled conditions before and after the gamma radiation survey. The instrument QC measurements included a static background reading and a radioactive source check (^{137}Cs) reading at the same indoor location.

In some cases, individual radiation detector systems will read slightly different gamma exposure rates under the same conditions due to variations within each system. By identifying systems with the most similar readings, field engineers may select specific sets of instruments to be used during a study, reducing variability in the final data set. Small differences in measurement geometry relative to isotropic, mono-energetic photons from a ^{137}Cs point source are believed to be responsible for some unusually large differences in check source readings between some detectors. Ludlum reports that there are normally small differences in the internal mounting geometry of individual NaI crystals. There can be large distance/angular response differences in NaI counting efficiency for a ^{137}Cs point source, especially when the source is placed in close proximity to the detector (Ogundare et al., 2008).

QC data collected, as noted above, should follow normal statistical distributions due to common instrument measurement error. The results of the pre-survey and post-survey measurements indicate that the detector systems utilized during the survey presented normal distributions of background and source check readings for both the pre-survey and post-survey measurements. The applicable frequency histograms for each detector system are shown in Figure 3-1 and Figure 3-2. The top row shows the pre-survey histograms and the bottom row shows the post-survey histograms; summary statistics are shown to the right of the histograms. The results of the pre-survey and post-survey instrument QC analysis indicated that the instruments used in the survey met the objectives of Tetra Tech’s QA/QC program; therefore, the field data collected should be considered valid, and the data included in the final project database are considered to be of the highest quality/reliability. A detailed analysis of results of the pre-survey and post-survey QC measurements is provided in Appendix D.

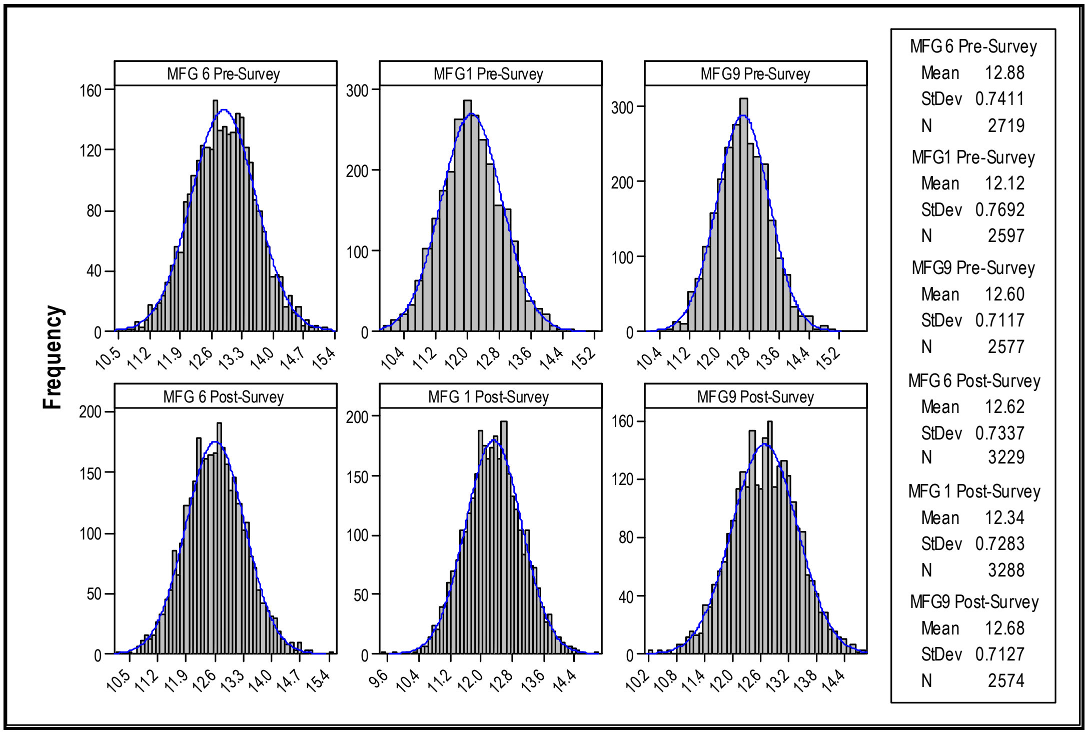


Figure 3-1. Frequency Histograms for Controlled Indoor Background Radiation Pre-Survey and Post-Survey QC Measurements

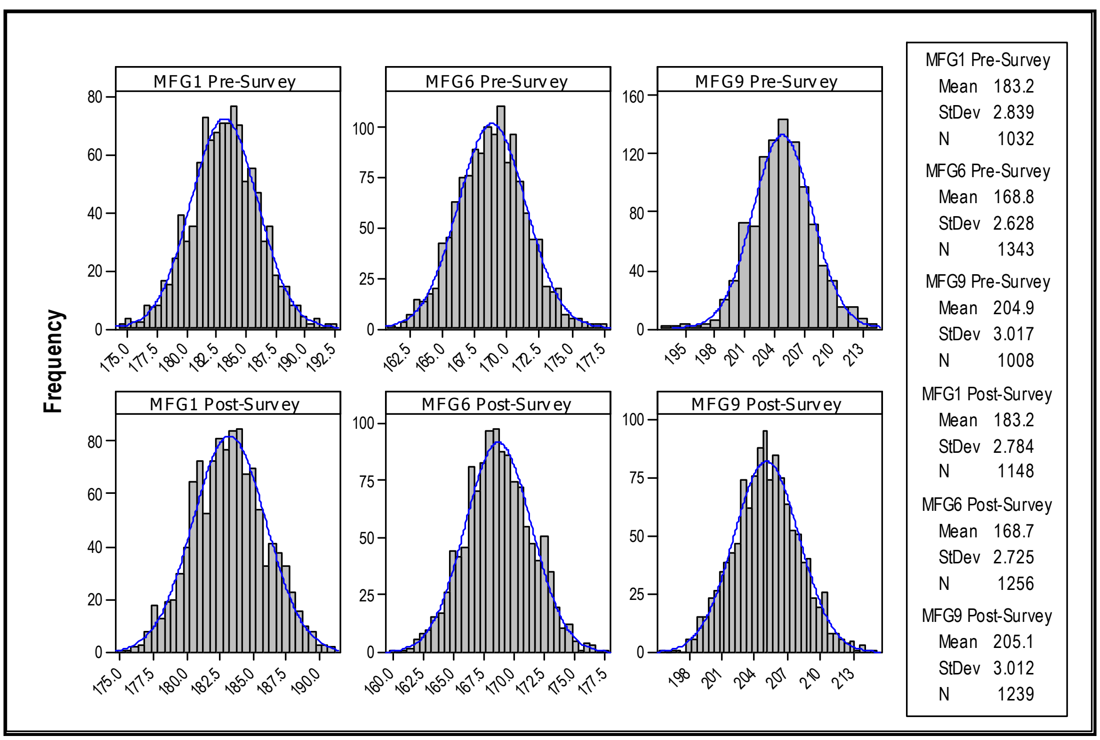


Figure 3-2. Frequency Histograms for Controlled Indoor ^{137}Cs Source Pre-Survey and Post-Survey QC Measurements

In addition to the controlled indoor pre-survey and post-survey instrument QC measurements discussed above, sets of individual, background, and field strip QC measurements were collected at a designated location in the field before and after each day of scanning. Under the QA program, factory-calibrated instruments must also meet on-site field test criteria. Data developed using any of the field-qualified instruments are then interchangeable, allowing instrument substitution if needed.

Field check requirements are as follows:

- For normally distributed data, 99 percent of all measurements are expected to fall within ±3 standard deviations of the mean. Background, field strip, and check source standard deviation values are recalculated twice daily throughout the project. Any instrument with a QC measurement result falling outside ±3 standard deviations from the mean of all QC measurements on the field check control chart require investigation. A detector that exceeds control limits on any QC check (background, field strip, or source check) is replaced with a pre-qualified spare detector and sent back to the manufacturer for evaluation, repair, and calibration.

- QC measurements, including a background check, a source check, and a field strip check, are performed twice daily during the work for each scanning system in use. The daily field strip check, during which data are collected along the same 10 m strip morning and evening, provides an indication of total measurement uncertainty for the system.

The Ludlum 2350-1 datalogger employs a calibration factor to internally convert detector counts per minute to a gamma exposure rate. The calculated exposure rate, directly proportional to the measured count rate, is transmitted by the data logger to the scanning system portable computer. No record of count rate is retained by the system, but count rate can be calculated using the instrument-specific calibration factor.

Daily count rate variations within these limits are functions of several possible variables, including exact placement of detector systems during daily checks and recent variations in barometric pressure (affecting radon daughter concentrations in air and soil). The low detector count rates at very low background gamma exposure rates also contribute significantly to variability. Differences in detector internal characteristics, including minor NaI detector crystal issues or photomultiplier tube optical interface variations, can also affect NaI detector readings.

Daily QA/QC checks were performed by field personnel before and after scanning activities. The systems functioned properly during the waste characterization work, and no instruments were substituted. The results of the background, field strip, and the ^{137}Cs source check are provided in Appendix D. The results indicate that the instrument QC results fell within the acceptable ranges and, therefore, the preliminary field data collected during the gamma radiation survey are considered valid and have been incorporated in the final project database. A detailed presentation and analysis of the gamma radiation survey QA/QC data is included in Appendix D.

3.2 XRF Field Survey Methods

This section describes the XRF field survey procedures and results of the XRF field survey QA/QC program.

3.2.1 Field XRF Measurement and Laboratory Correlation Methods

In-situ XRF measurements were collected at each of the Tronox Bluffs following a systematic square grid sampling approach in accordance with the SAP and as recommended by the 2007 Action Memorandum. *In-situ* XRF measurements were collected on a pre-designed 100-foot grid system. Using hot spot location techniques outlined in “EPA Methods for Evaluating the Attainment of Cleanup Standards Volume 1: Soils and Solid Media” (1989) and in Gilbert (1987), the selected systematic grid size of 100-feet corresponds to a specified probability of either identifying the presence or absence of a hot spot. A “hot spot” refers to highly contaminated local area or any sample that exceeds the cleanup standard for a specified contaminant (EPA, 1989). Using the 100-foot square grid specified in the SAP, field engineers had a 95 percent probability of finding all circular hot spots of 60-feet or greater diameter within each bluff region. This probability of finding a circular hot spot was calculated using the methodology presented by Gilbert (1987) and EPA (1989). Field personnel performed additional judgment sampling after hot spots were located in the field, further increasing the probability of mapping hot spots.

Soil confirmation samples were co-located at *in-situ* XRF sample locations at a frequency of 1 in 20 samples. The confirmation samples were sent to ALS Laboratory in Fort Collins, Colorado to analyze total metals via atomic emission spectrometry (Table 3-2). In addition to metals analysis, the soil confirmation samples were also evaluated for soluble metals content using the Synthetic Precipitation Leaching Procedure (SPLP) (EPA, 1994). SPLP is a standard method used to determine the mobility of organic and inorganic constituents present in both liquid and solid matrices. SPLP utilizes a mildly acidic extraction solution (prepared from 60:40 w/w sulfuric-nitric acid) adjusted to a pH of 5.0 ±0.05 consistent with the pH of natural precipitation in the western United States. SPLP uses a solution:solid ratio of 20:1 with rotary agitation for 18 ±2 hours followed by filtration through a 0.6 to 0.8 micrometer (µm) pore-size filter. The filtered leachate is then analyzed for dissolved metals using inductively coupled plasma mass spectrometry (ICP-MS). The SPLP analysis methods are provided in Table 3-3. The results of the contaminant leachability analysis at each bluff are presented in Section 6.0.

The *in-situ* XRF measurements were then correlated to the laboratory results for several metals through regression analysis, as described in Section 4.2. The sampling approach and methods are described in more detail in the SAP (Appendix A). The XRF sample locations are discussed in the *in-situ* XRF correlation analysis section (Section 4.2.1). The final ALS laboratory reports of the metals analysis for the XRF soil confirmation samples are provided in Appendix E.

The *in-situ* XRF measurements were collected throughout the Tronox Bluffs using a portable Niton XRF 900 Xlt spectrum analyzer. The field portable XRF procedures were performed as described in the SAP in accordance with EPA Method 6200 – Field Portable X-ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment (EPA, 2007). The Niton XRF utilizes an X-ray tube to irradiate soil samples. The source X-rays excite electrons in the sample (EPA, 2007) dislodging electrons from atomic shells and creating vacancies. The vacancies are filled by the ray spectra as they cascade down to fill the inner shell vacancies. This allows the XRF instrument to identify elements present based on the unique spectra emitted and to estimate soil concentrations based on emitted flux.

Table 3-2. XRF Confirmation Soil Sample Laboratory Analysis Methods (Metals)

Analyte	CAS-NO	Reported Units	Prep Method	Analytical Method
Arsenic	7440-38-2	µg/kg*	Method 3050B	Method 6020A
Cadmium	7440-43-9	µg/kg	Method 3050B	Method 6020A
Copper	7440-50-8	µg/kg	Method 3050B	Method 6020A
Lead	7439-92-1	µg/kg	Method 3050B	Method 6020A
Molybdenum	7439-98-7	µg/kg	Method 3050B	Method 6020A
Selenium	77872-49-2	µg/kg	Method 3050B	Method 6020A
Uranium	7440-61-1	µg/kg	Method 3050B	Method 6020A
Zinc	7440-66-6	µg/kg	Method 3050B	Method 6020A

*µg/kg = micrograms per kilogram

Table 3-3. XRF Confirmation Soil Sample Laboratory Analysis Methods (SPLP)

Analyte	CAS-NO	Reported Units	Prep Method	Analytical Method
Arsenic	7440-38-2	µg/L*	Method 3010A	Method 6020A
Cadmium	7440-43-9	µg/L	Method 3010A	Method 6020A
Chromium	7440-47-3	µg/L	Method 3010A	Method 6020A
Copper	7440-50-8	µg/L	Method 3010A	Method 6020A
Iron	7439-89-6	µg/L	Method 3010A	Method 6020A
Lead	7439-92-1	µg/L	Method 3010A	Method 6020A
Manganese	7439-96-5	µg/L	Method 3010A	Method 6020A
Molybdenum	7439-98-7	µg/L	Method 3010A	Method 6020A
Selenium	7782-49-2	µg/L	Method 3010A	Method 6020A
Thallium	7440-28-0	µg/L	Method 3010A	Method 6020A
Uranium	7440-61-1	µg/L	Method 3010A	Method 6020A
Vanadium	7440-62-2	µg/L	Method 3010A	Method 6020A
Zinc	7440-66-6	µg/L	Method 3010A	Method 6020A

*µg/L = micrograms per liter

The correlations developed in this study are specifically applied to this model of XRF. Additional characterization studies or future verification work should employ the same model of XRF or newer; otherwise, a new correlation should be developed if a different instrument is used. Field personnel used Trimble Geoexplorer® 6000 Handheld GPS systems to note collection locations. The accuracy of the data points collected with these systems after post-processing was sub-meter (less than one meter). Tetra Tech will submit sample location data to the USFS with project GIS data. All field data were entered daily into a database. Additional *in-situ* XRF measurements were made beyond the predetermined systematic grid sampling locations when elevated arsenic was observed or if spoils or other mine waste were evident.

EPA Method 6200 Part 9.7 provides comparability analysis requirements for XRF analysis. The comparability of the XRF analysis can be quantified by submitting XRF-analyzed samples for analysis at a laboratory. Two major conditions must be met before applying a simple linear regression model to the data set. The first condition notes that the dependent variable (y, laboratory data) must have an approximately normal distribution for each value of the independent variable (x, XRF data). The second condition notes that the response variable must increase by a constant increment for each increment of the independent variable. In order to evaluate whether the laboratory data conform to a normal distribution, it is important to measure the errors or residuals. Residuals are the difference between the observed value of the dependent variable and the predicted value; every data pair from the regression model has a residual.

The least squares regression method is used to approximate the linear mathematical function that describes the relationship between the laboratory reported analyte (response) and the field XRF *in-situ* measurement value (predictor).

EPA Method 6200 states that at least 1 in 20 of the XRF samples must be submitted to a laboratory for confirmatory analysis. This condition was met during this project. Samples were submitted to ALS Laboratories in Fort Collins, Colorado. A total of 69 surface soil samples were analyzed per SW 846 for arsenic, cadmium, copper, lead, molybdenum, and zinc. EPA Method 6200 states that a linear regression analysis using a least squares fit shall be applied to correlate the *in-situ* XRF measurements and the corresponding laboratory soil confirmation samples. If the range of concentrations observed in the soil samples varies by more than one order of magnitude, it is recommended that a logarithmic transformation of the data occur prior to performing the least squares regression analysis. The results of the regression analyses are provided in Section 4.2. A summary explaining the process utilized to select an appropriate model for each of the metals analyzed is provided in Appendix F.

3.2.2 XRF Field Survey Quality Assurance/Quality Control Results

Standard reference materials contain certified concentrations of metals in soil or sediment. As part of the QC process for the field XRF instruments, soil standards from the National Institute of Standards and Technology (NIST) were applied on a daily basis by field personnel. Additionally, daily system checks, as recommended by Niton, and duplicate field measurements were performed to assess the accuracy and consistency of XRF instruments. Results from the XRF QC procedures are presented in Appendix G.

The XRF detector was turned on 15 minutes prior to field use, as recommended by Niton. A calibration system check was also performed on XRF instruments prior to field use and according to manufacturer specifications. The results of the calibration checks were recorded by the field engineer and are in Appendix G. All daily system checks were within Niton's acceptable values. Additional QA/QC measures included the analyses of field sample duplicates and soil blanks to determine precision and accuracy of the field XRF data measurements. Reference measurements, with the instrument placed in a lead box, were performed for 15 minutes daily.

3.3 Test Pit Sampling Methods

Field geologists performed the test pit sampling described in the SAP (Tetra Tech, 2012a). A total of 22 samples were collected from nine test pit locations using a backhoe. Per the SAP, test pits were excavated to a minimum 4-foot depth. The test pit samples were sent to ALS Laboratories for analysis of radium-226, total arsenic, total molybdenum, and natural uranium as shown in Table 3-4. The results of the test pit sampling are discussed in Section 5.7. The test pit sample laboratory reports are provided in Appendix P.

Table 3-4. Test Pit Sample Laboratory Analysis Methods

Analyte	CAS-NO	Reported Units	Prep Method	Analytical Method
^{226}Ra	13982-63-3	pCi/g*	PAI 739 Rev 10	Gamma Spec (E901.1)
Arsenic	7440-38-2	µg/kg**	Method 3050B	Method 6020A
Molybdenum	7439-98-7	µg/kg	Method 3050B	Method 6020A
Uranium	7440-61-1	µg/kg	Method 3050B	Method 6020A

*pCi/g = picocuries per gram

**µg/kg = micrograms per kilogram

3.4 Sediment Pond Sampling Methods

Field personnel performed the sediment pond sampling as prescribed in the SAP (Tetra Tech, 2012a). A total of 23 samples were collected from eight ponds, including two duplicate samples, for a total of 25 laboratory samples. The SAP specified that a minimum of three samples should be collected from each pond; however, only two samples were collected from pond SP5 given its small size compared to the other sediment ponds. Table 3-5 shows the metals analyte list for the sediment samples. Agronomic testing methods, shown in Table 3-6, were performed on the sediment samples. The results of sediment pond sampling are discussed in Section 5.7. The final sediment sample laboratory reports are provided in Appendix H.

Table 3-5. Sediment Pond Sample Laboratory Analysis Methods

Analyte	CAS-NO	Reported Units	Prep Method	Analytical Method
Arsenic	7440-38-2	µg/kg*	Method 3050B	Method 6020A
Cadmium	7440-43-9	µg/kg	Method 3050B	Method 6020A
Copper	7440-50-8	µg/kg	Method 3050B	Method 6020A
Lead	7439-92-1	µg/kg	Method 3050B	Method 6020A
Molybdenum	7439-98-7	µg/kg	Method 3050B	Method 6020A
Uranium	7440-61-1	µg/kg	Method 3050B	Method 6020A
Zinc	7440-66-6	µg/kg	Method 3050B	Method 6020A

*µg/kg = micrograms per kilogram

Table 3-6. Argronomic Methods Table

Analyte	Purpose	Reported Units	Method	Reference
pH	General fertility assessment and potential indicator of acid generation	Standard Units	1:1 soil:water	Watson and Brown, 1998
Electrical Conductivity (EC)	Soil salinity indicator	dS/m*	1:1 soil:water	Dahnke and Whitney, 1988
Nitrate-nitrogen (NO_3-N)	Fertility assessment	ppm**	Water extraction / cadmium reduction	Carson, 1980
Phosphorus	Fertility assessment	ppm	Olsen bicarbonate / Method 6010B	Kuo, 1996
Potassium (extractable)	Fertility assessment	ppm	Ammonium acetate extraction / Method 6010B	USDA, 1954
Soluble cations (Ca, Mg, Na, K)	Salinity assessment and used to calculate both ESP and SAR	me/L***	Saturation paste extract / Method 6010B	USDA, 1954
Sodium Adsorption Ratio (SAR)	Indicator of soil salinity and sodium infiltration hazard	-------	Calculation	USDA, 1954
Exchangeable sodium percentage (ESP)	Related to SAR and is an indicator of sodium infiltration hazard	percent	Calculation	USDA, 1954
Gypsum Requirement	Provides an estimate of the amount of gypsum for sodic soil reclamation	tons/acre	Standard calcium addition	USDA, 1954

*dS/m = deciSiemens per meter
**ppm = parts per million
***me/L = milliequivalent per liter

3.5 Erionite Sampling Methods

The naturally occurring fibrous zeolite mineral erionite was likely present in road surfacing materials placed in areas of Bluff B throughout the Site history. Prior testing of the nearby Craig Pass gravel pit, the likely source for this road surfacing material, indicated both non-detect and trace levels of erionite. In addition to the waste characterization program sampling activities, bulk samples of Bluff B road surfacing materials were sampled and submitted to Reservoirs Environmental, Inc. laboratory in Denver, Colorado for analysis of erionite. The results of the erionite sampling are discussed in Section 5.9. The final erionite laboratory reports are provided in Appendix I.

3.6 Data Usability Assessment

The laboratory data generated from analysis of all soil and sediment samples for metals and ^{226}Ra were assessed for precision, accuracy, representativeness, comparability and completeness (PARCC) parameters (ALS, 2012). Acceptable precision and accuracy were attained, and properly designed sampling techniques and handling protocols provided adequate representativeness. The use of standardized EPA methods of analysis and reporting allows for sufficient comparability of results. Data qualifiers were based on EPA guidance (EPA, 2004; ALS, 2012). Very few data were noted by ALS as qualified, and no data for this project were rejected. Therefore, 100 percent completeness was achieved. The data generated as part of the

Tronox Bluff waste characterization program are judged to have met the SAP performance criteria (Tetra Tech, 2012a) and are useable for this waste characterization study and the removal action design. A detailed summary of the data validation is included in Appendix J.

The gamma survey included a comprehensive data QA/QC program to provide confidence in the results obtained by field personnel and ensure the data may be deemed reliable. Appendix D provides a detailed evaluation and analysis of the gamma radiation survey QA/QC results performed as part of the waste characterization program. The results of the QA/QC analysis indicate that the gamma exposure rate data are acceptable, and all of the scan data collected are incorporated in the final project database. Similarly, a detailed analysis of the XRF QA/QC results is included in Appendix G.

3.7 Deviations from the Sampling and Analysis Plan

Some minor deviations from the SAP included the following items:

- Addition of leachability analysis (SPLP) of the XRF soil confirmation samples.
- The field survey characterization performed at Bluff CDE was outside of the original boundaries presented in the SAP.
- Addition of total molybdenum and uranium isotope risk based levels to the mine waste categorization was not included in the SAP. The cleanup criteria for these contaminants were based on the human health and ecological risk assessment as described in Section 2.2.3 (USFS, 2006).

4.0 SOIL CORRELATION ANALYSIS AND RESULTS

This section presents the results of the gamma radiation survey and XRF field survey correlation analyses Tetra Tech conducted as part of the 2012 Tronox Bluff waste characterization program.

4.1 Gamma Radiation Correlation Analysis

Efficient and cost-effective characterization of uranium mining sites involves the measurement of gamma exposure rates over large sections of the area of interest, correlated to a limited set of soil ^{226}Ra activity. Past approaches include recording individual gamma measurements and soil samples using systematic grid patterns (Whicker, 2008). This approach is prescribed in guidance from the U.S. Nuclear Regulatory Commission (NRC) in Regulatory Guide 4.14 for uranium mills. Similarly, more recent guidance included in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (NRC, 2000) also suggests a grid-based sampling approach. In contrast, the gamma survey technology used at the Riley Pass site delivers an increase in the size of the measurement data set, providing a more detailed view of the extent and location of significant contamination while also developing useful estimates of soil ^{226}Ra activity.

The latter is feasible given a reasonably reliable relationship between gamma exposure rates and soil ^{226}Ra activity under field conditions, which is generally the case (Johnson et al., 2006; Whicker et al., 2008). Statistical correlations were developed for the Site and are considered in the following sections. The correlation techniques presented in this study allow the gamma exposure data to be converted into both soil ^{226}Ra activity and radiation dose rates for the areas of interest. Spatial interpolation techniques were applied to estimate these parameters in areas that were not directly evaluated.

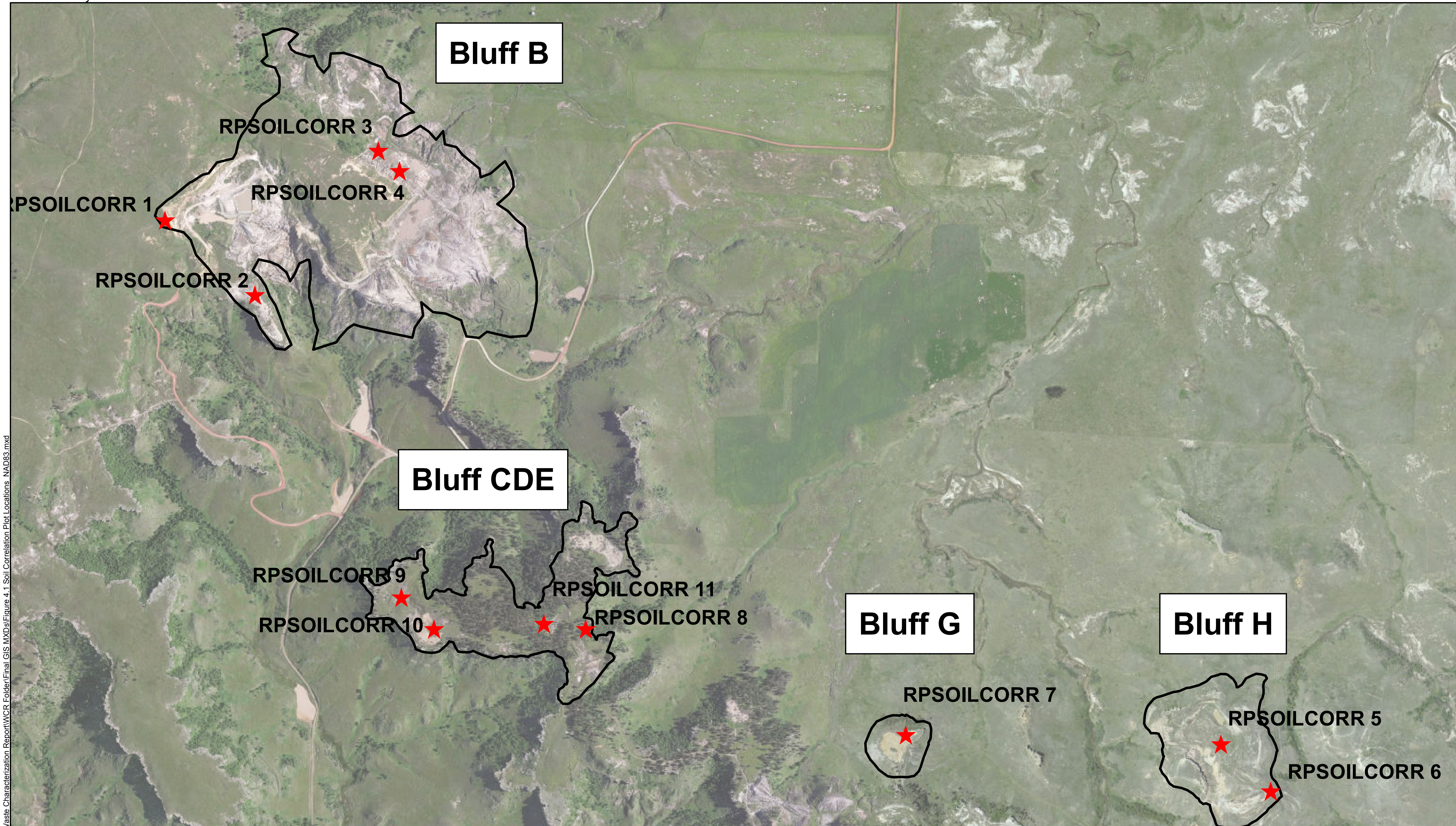
A total of 11 soil correlation plots were developed by field engineers during the 2012 Tronox Bluff waste characterization program. Table 4-1 provides the soil correlation plot identification numbers (IDs) and the geographic coordinates for each sample location. Soil correlation samples were collected from each of the Tronox Bluffs as shown in Figure 4-1. The soil correlation plot sampling methods were performed as described in Section 3.1.2 and in accordance with the SAP.

Copies of the final ALS laboratory reports for the metals and ^{226}Ra analyses performed on the surface soil correlation plot samples are provided in Appendix K. The soil correlation plot ^{226}Ra and metal correlation analyses and results are included in Appendix L.

Table 4-1. Soil Correlation Plot GPS Locations (WGS84)

Soil Correlation Plot ID	Latitude- North	Longitude-West
RPSOILCORR 1	45.846245000	-103.487318333
RPSOILCORR 2	45.844325000	-103.483718333
RPSOILCORR 3	45.848376667	-103.479173333
RPSOILCORR 4	45.847855000	-103.478316667
RPSOILCORR 5	45.833278333	-103.445520000
RPSOILCORR 6	45.832058333	-103.443506667
RPSOILCORR 7	45.833161667	-103.457751667
RPSOILCORR 8	45.835665000	-103.470331667
RPSOILCORR 9	45.836303333	-103.477531667
RPSOILCORR 10	45.835490000	-103.476208333
RPSOILCORR 11	45.835755000	-103.471960000

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:
★ **Soil Correlation Plot Locations**
Revised 2012 Tronox Bluff Boundary

0 375 750 1,500 Feet

N

Issued by:
TETRA TECH
3801 Automation Way, Suite 100
Fort Collins, Colorado 80525
(970) 223-9600 (970) 223-7171 fax

Tronox Bluff
Soil Correlation Plot Locations

Revision 3

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 4-1
Location: HARDING COUNTY COUNTY, SD	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 4.1 Soil Correlation Plot Locations_NAD83.mxd

4.1.1 Gamma Exposure Rate and Bicron Dose Rate Correlation

A NaI detector/Bicron dose rate instrument cross-calibration analysis was performed as part of the gamma radiation survey. The purpose of the Bicron cross-calibration is to normalize the data to a common basis for comparison at a later date in the event that different gamma exposure rate detectors are employed. The NaI detectors exhibit energy dependency or varying count rates with differences in detected gamma ray energies. In contrast, a system such as a high pressure ionization chamber (HPIC) or a Bicron Micro-Rem meter shows little or no energy dependency. The Bicron Micro-Rem radiation monitor is a lightweight, portable survey meter that is used for gamma radiation detection and reads the absorbed dose rate directly. The meter used for this survey is effective over the gamma energy range typically important during a uranium facility study between 40 kilo electron volts (KeV) and 1.3 mega electron volts (MeV).

The dose rate cross-calibration is performed as specified in Whicker (2008) and in accordance with the SAP. This procedure involves the collection of static measurements within the soil correlation grid areas discussed in Section 3.1.2. Approximately 10 to 20 readings are collected within a 100 m^2 grid location; then the average Bicron dose rate within the grid location is calculated and correlated against the average NaI gamma exposure rate within the same area. The resulting paired NaI/Bicron dose data are analyzed via the linear regression least squares method to enable conversion of NaI data-based gamma survey data to the Bicron dose rate equivalent. Table 4-2 provides a summary of the mean gamma exposure rates and dose rates collected for the NaI/Bicron cross calibration analysis.

Table 4-2. Summary of Mean NaI Gamma Exposure Rate and Mean Bicron Dose Rate

Correlation Plot ID	Mean NaI Gamma Exposure Rate (µR/hr*)	Mean Bicron Dose Rate (µrem/hr**)
RPSOILCORR1	12.9	6.81
RPSOILCORR2	16.2	8.63
RPSOILCORR3	59.8	30.9
RPSOILCORR4	32.1	14.3
RPSOILCORR5	23.2	10.7
RPSOILCORR6	146	76.7
RPSOILCORR7	493	283
RPSOILCORR8	114	54.0
RPSOILCORR9	759	406
RPSOILCORR10	108	45.0
RPSOILCORR11	277	139

*µR/hr = micro roentgens per hour
**µrem/hr = microrem per hour

Using the 11 pairs of data, a least squares linear regression analysis was conducted. The Pearson correlation coefficient (R) was 0.998 with a p-value of 0.0 ($p<0.01$), indicating there is a strong relationship between the NaI gamma exposure rates and the Bicron dose rates. The model was determined to be statistically significant ($p<0.01$) and the coefficient of determination (R^2) value was 99.7 percent. The slope of the fitted line was calculated at 0.55 and the y-intercept is -3.962. The lowest measured gamma exposure rate at the Site is 8.71 μR/hr, so the equation will not result in negative estimates when converting gamma exposure rates to dose rates. Figure 4-2 shows the fitted line plot for the cross-calibration analysis with the 95 percent confidence interval. A residual analysis was performed on the simple linear regression model. The residuals were standardized and plotted on a normal probability plot. Overall, the points fell within the acceptable range of -3 to +3 standard deviations and followed the straight line shown on Figure 4-3.

Based on the results of the regression model parameters and the standardized residuals analysis, the model is assumed to be valid and can be used successfully to predict radiation dose rates at the Site by converting from gamma exposure rate measurements. The following equation shows the relationship between the dose rate and gamma exposure rate:

Equation 1: $$\boldsymbol{Dose\ Rate}\left(\frac{mRem}{hour}\right) = \mathbf{0.55}\left[\boldsymbol{Gamma\ Exposure}\left(\mu\frac{R}{hr}\right)\right] - \mathbf{3.962}$$

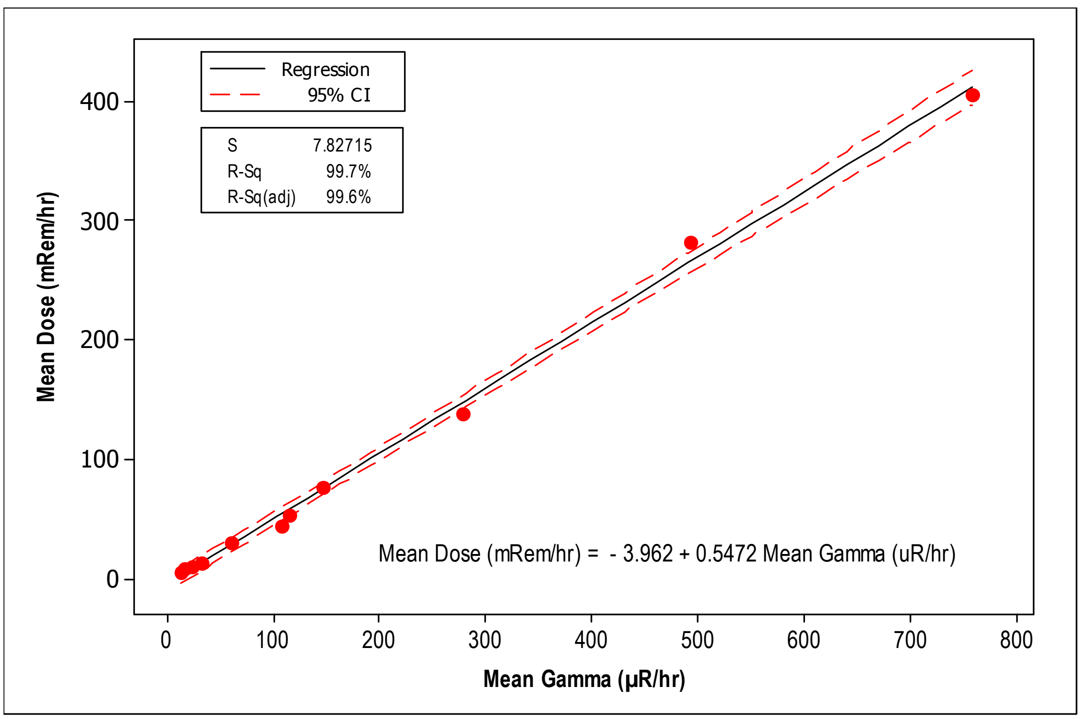


Figure 4-2. Gamma Exposure Rate versus Dose Rate Linear Regression Model with 95 percent Confidence Interval

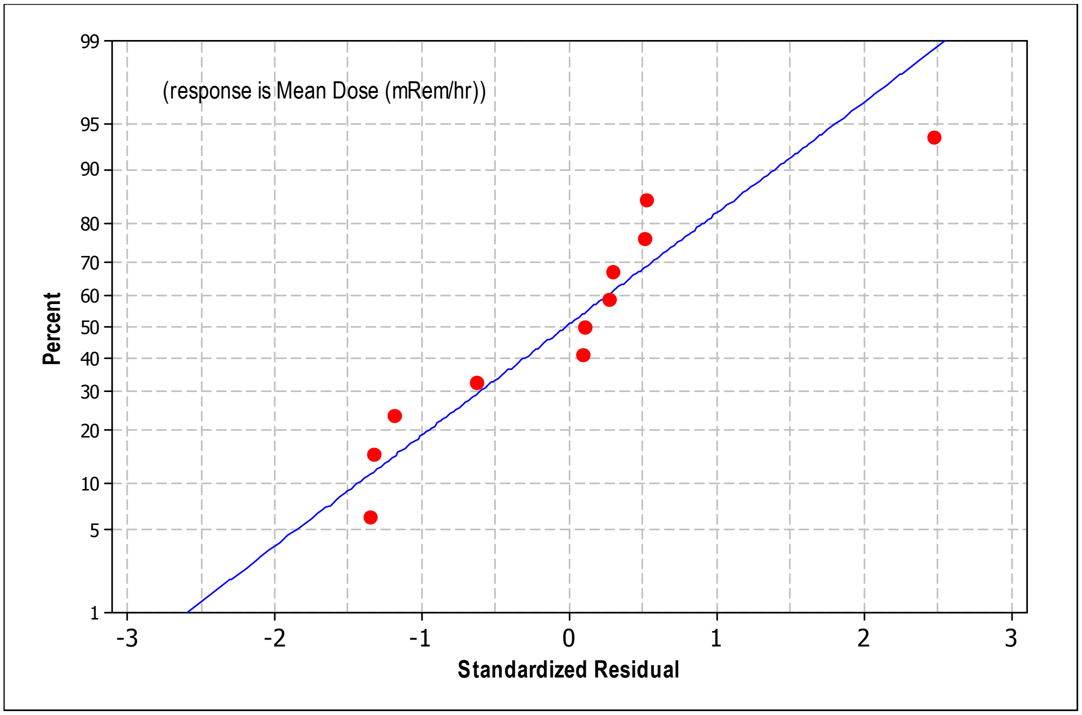


Figure 4-3. Normal Probability Plot of Standardized Residuals of NaI/Bicron Cross Calibration Linear Regression Model

4.1.2 Gamma Exposure Rate and Soil ^{226}Ra Correlation

The 11 soil correlation plot locations that were collected at the Tronox Bluffs are provided in Figure 4-1; soil aliquot samples were collected in accordance with procedures discussed in Section 3.1.2 and in accordance with the SAP. The soil samples were submitted to ALS Laboratory in Fort Collins, Colorado to be analyzed for ^{226}Ra by gamma spectroscopy and for additional metals.

In addition to the 2012 soil correlation plots, 11 correlation plots were sampled during the 2009 Non-Tronox radiological study. The 2009 and the 2012 correlation plots were performed using the same procedures and laboratory analysis. The ranges of soil ^{226}Ra activity differed between the two sampling events. Therefore, a detailed analysis evaluating the individual sample sets and the combined sample sets (2009, 2012, and 2009/2012) was performed. Tetra Tech evaluated nine different regression models; a discussion of the different scenarios and analyses are provided in Appendix L. Table 4-3 provides the raw correlation data used in the final regression model.

Table 4-3. Summary of Soil Correlation Data – 2009 and 2012 Data Sets

Correlation ID	Sampling Event	Gamma Exposure Rate (µR/hr*)	^{226}Ra (pCi/g**)
RPSOILCORR1	2012	12.9	1.08
RPSOILCORR2	2012	16.2	3.02
RPSOILCORR3	2012	59.8	7.5
RPSOILCORR4	2012	32.1	7.2
RPSOILCORR5	2012	23.2	9.9
RPSOILCORR6	2012	146	257
RPSOILCORR7	2012	493	1670
RPSOILCORR8	2012	115	119
RPSOILCORR9	2012	759	1,860
RPSOILCORR10	2012	108	108
RPSOILCORR11	2012	277	772
RPC-1	2009	38.7	7.9
RPC-2	2009	13.0	1.0
RPC-3	2009	25.6	4.3
RPC-4	2009	33.2	2.5
RPC-5	2009	63.2	23.1
RPC-6	2009	160	43.0
RPC-7	2009	522	524
RPC-8	2009	107	34.7
RPC-9	2009	76.6	17.9
RPC-10	2009	168	91.1
RPC-11	2009	52.0	9.5

*µR/hr = micro-Roentgen per hour
** pCi/g = picocuries per gram

After careful consideration, the regression model selected was Scenario 9. This scenario combined data sets from both the 2009 and 2012 soil correlation sampling events as shown in the table above. Both the gamma exposure rates and soil ^{226}Ra data were log-transformed and a linear regression analysis was performed. The resulting model has an R^2 of 0.922 and is shown in Figure 4-4. An analysis was performed on the residuals of the model; the standardized residuals follow a normal distribution as shown in Figure 4-5.

Based on the results of the regression model parameters and the standardized residuals analysis, the model is assumed to be valid and can be successfully used to predict soil ^{226}Ra activity at the Site using the gamma exposure rates. Using this final regression model, the corresponding gamma exposure rates were 76.5 µR/hr and 101 µR/hr, for soil ^{226}Ra activity of 30 pCi/g and 50 pCi/g, respectively.

The following linear equation shows the relationship between the soil ^{226}Ra activity and gamma exposure rates:

Equation 2: $$\log_{10}\left(Ra^{226}\,(pCi/g)\right) = -1.979 + 1.835\,\log_{10}\left(Gamma(\mu R/hr)\right)$$

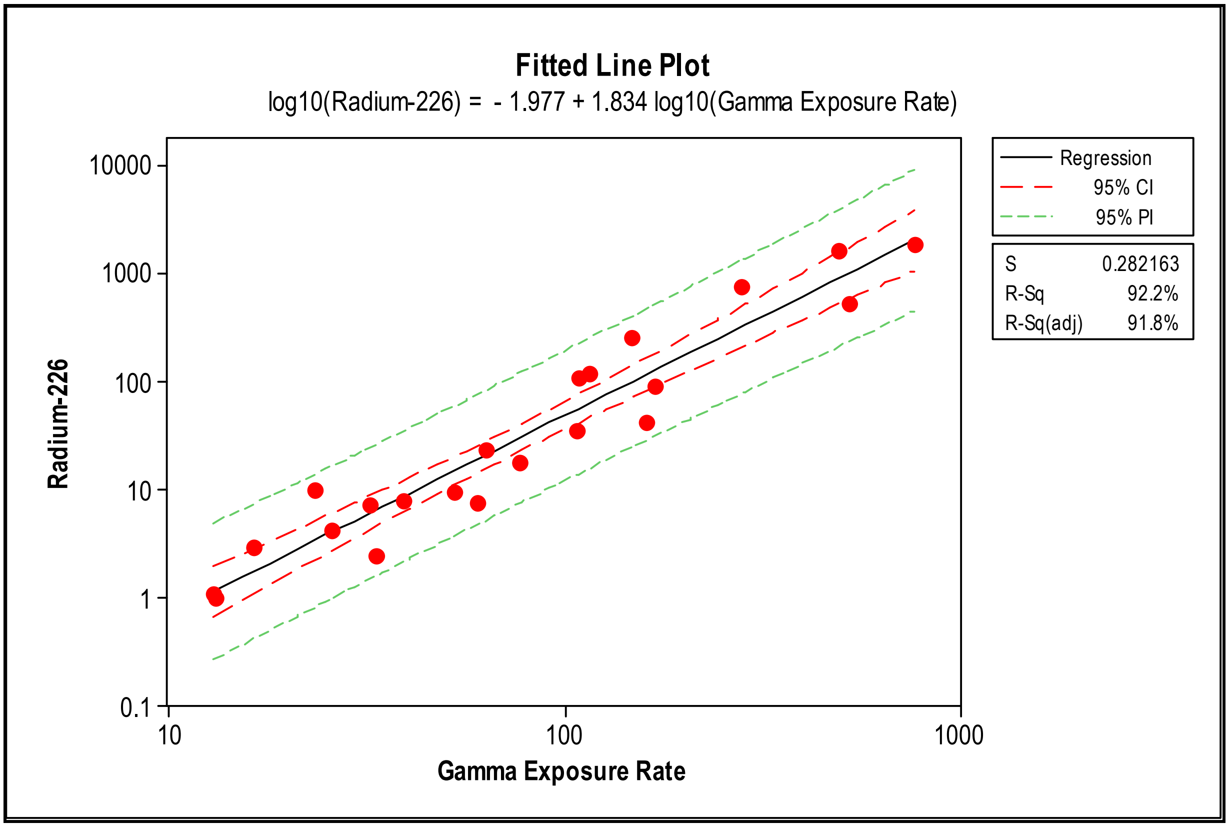


Figure 4-4. Gamma Exposure Rates versus Soil ^{226}Ra Concentrations-Linear Regression Model

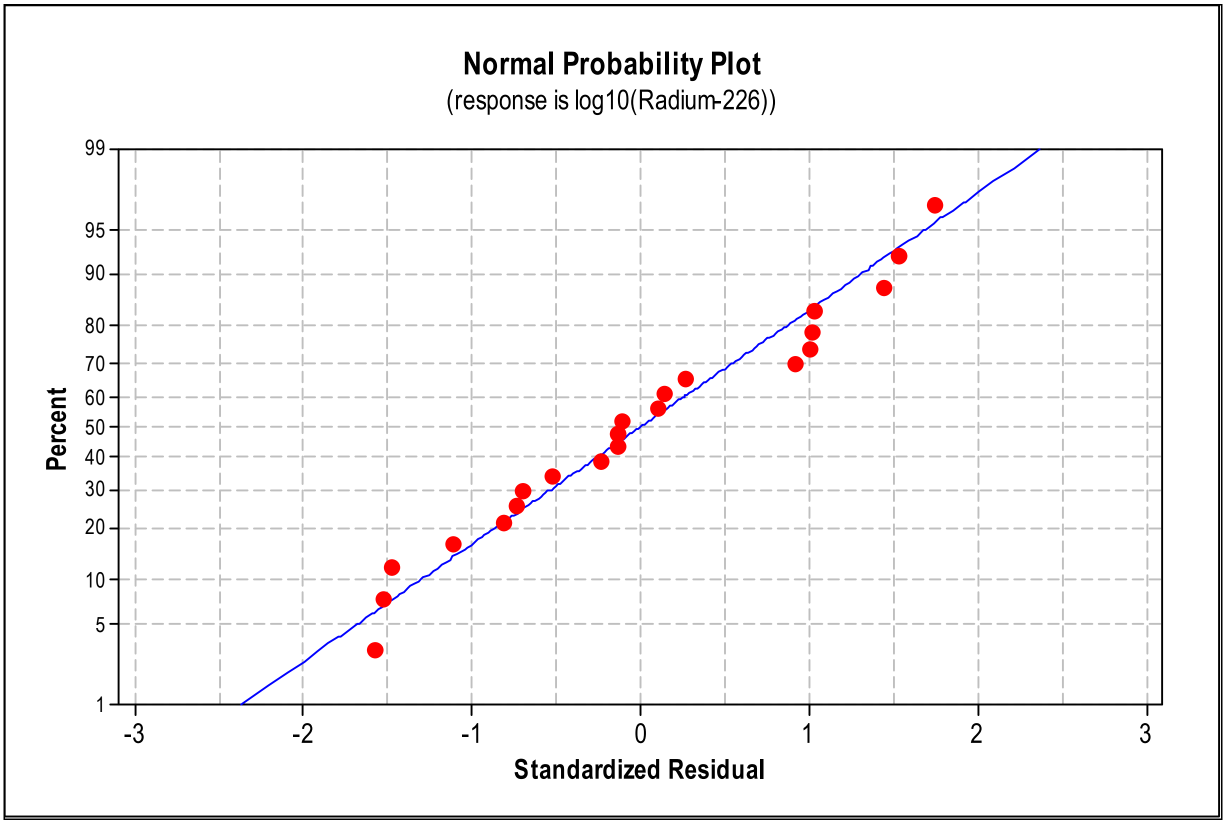


Figure 4-5. Normal Probability Plot of Standardized Residuals of Final ^{226}Ra/Gamma Regression Model

4.1.3 Gamma Exposure Rate and Metals Correlation Results

The soil correlation plot samples were analyzed primarily for ^{226}Ra, the results of which are presented in the previous section. Metals testing were performed on the soil correlation plot samples. A total of 11 samples were submitted to ALS Laboratory in Fort Collins, Colorado and analyzed for the following total metals: arsenic, cadmium, copper, lead, molybdenum, uranium, and zinc. The results of the soil correlation plot metals and radionuclide analysis results are presented in Table 4-4.

Table 4-4. Summary Results of Metals and Radionuclide Analysis

Soil Correlation Plot ID	Gamma Exposure Rate	^{226}Ra	As	Cd	Cu	Pb	Mo	U		Zn
	µR/hr*	pCi/g**	mg/kg***	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	pCi/g	mg/kg
RPSOILCORR1	12.9	1.08	71.0	0.16	16	14.0	1.1	0.610	0.4	72.0
RPSOILCORR2	16.2	3.02	23.0	0.27	8.9	10.0	1.4	2.30	1.6	65.0
RPSOILCORR3	59.8	7.5	48.0	0.15	14.0	11.0	12.0	12.0	8.1	37.0
RPSOILCORR4	32.1	7.2	40.0	0.065	8.8	9.6	13.0	5.40	3.7	35.0
RPSOILCORR5	23.2	9.9	36.0	0.60	19.0	16.0	11.0	13.0	8.8	82.0
RPSOILCORR6	146	257	1200	0.51	8.2	13.0	1000	400	271	35.0
RPSOILCORR7	493	1670	2100	0.13	32	30.0	1700	2000	1354	27.0
RPSOILCORR8	115	119	230	0.84	10	15.0	66	110	74	51.0
RPSOILCORR9	759	1860	1400	2.1	24	37.0	1500	3100	2099	31.0
RPSOILCORR10	108	108	250	2.5	24	26.0	100	220	149	64.0
RPSOILCORR11	277	772	900	3.3	24	28.0	390	730	494	230

*µR/hr = micro-Roentgen per hour
** pCi/g = picocuries per gram
*** mg/kg = milligrams per kilogram

A regression analysis was performed on the gamma exposure rate data and the various metals that were analyzed for each soil correlation plot sample. The correlation coefficient (R) and the coefficient of determination (R^2) for each simple linear regression analysis are shown in Table 4-5. The best fitting models were gamma versus uranium with an R of 0.97, gamma versus molybdenum with an R of 0.95, and gamma versus arsenic with an R of 0.92. The linear regression plots for gamma versus uranium, gamma versus arsenic, and gamma versus molybdenum are provided in Figure 4-6 through Figure 4-8, respectively. The regression equations developed for gamma versus metals were for evaluation purposes only; the XRF regression models used more data points and were used for the final predictive analysis.

Table 4-5. Summary Results of Linear Regression Coefficients Soil Correlation Metals Analysis

X-Value	Y-value	R	R^2
Gamma Exposure Rate (µR/hr*)	Uranium (mg/kg**)	0.97	0.95
Log_{10} Gamma Exposure Rate (µR/hr)	Log_{10} Arsenic (mg/kg)	0.92	0.84
Log_{10} Gamma Exposure Rate (µR/hr)	Log_{10} Cadmium (mg/kg)	0.49	0.24
Log_{10} Gamma Exposure Rate (µR/hr)	Log_{10} Copper (mg/kg)	0.53	0.28
Log_{10} Gamma Exposure Rate (µR/hr)	Log_{10} Lead (mg/kg)	0.80	0.64
Log_{10} Gamma Exposure Rate (µR/hr)	Log_{10} Molybdenum (mg/kg)	0.95	0.91
Log_{10} Gamma Exposure Rate (µR/hr)	Log_{10} Zinc (mg/kg)	0.21	0.05

*µR/hr = micro-Roentgen per hour
** mg/kg = milligrams per kilogram

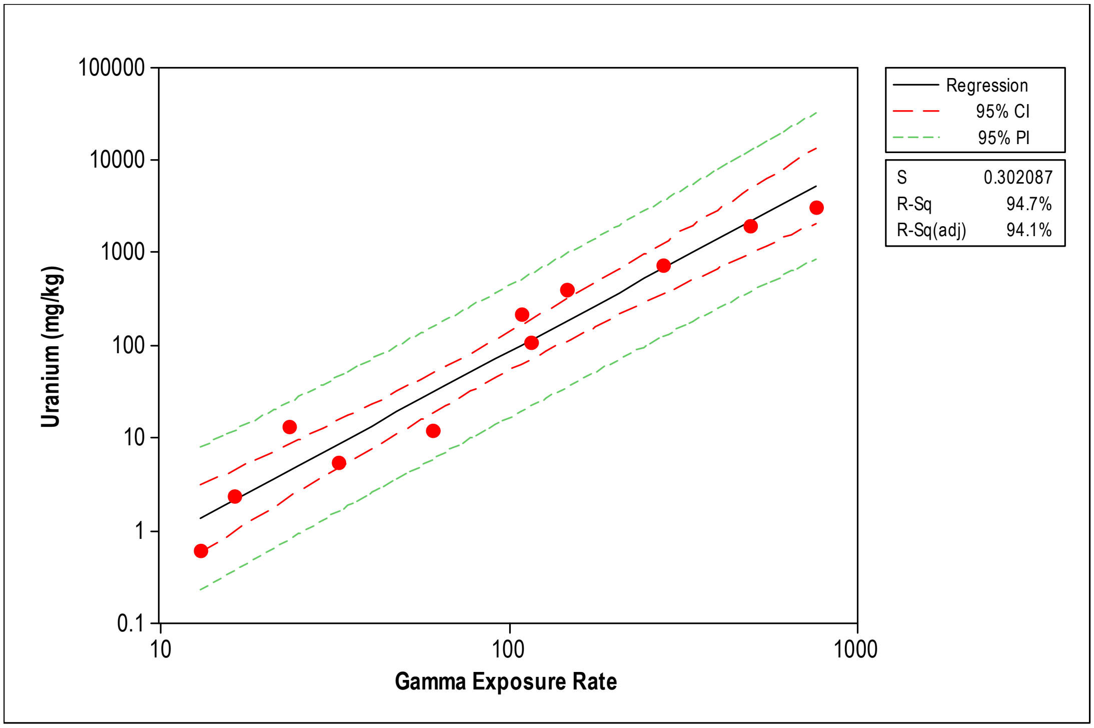


Figure 4-6. Linear Regression Model - Gamma Exposure Rate versus Uranium

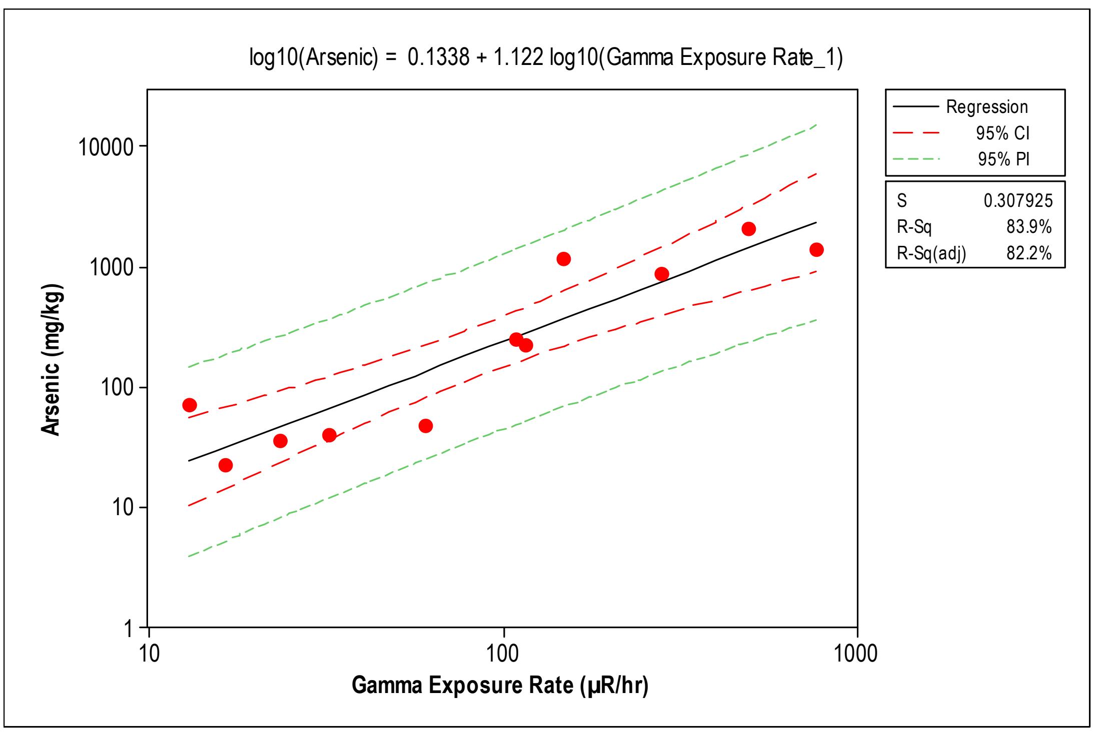


Figure 4-7. Linear Regression Model - Gamma Exposure Rate versus Arsenic (log-transformed)

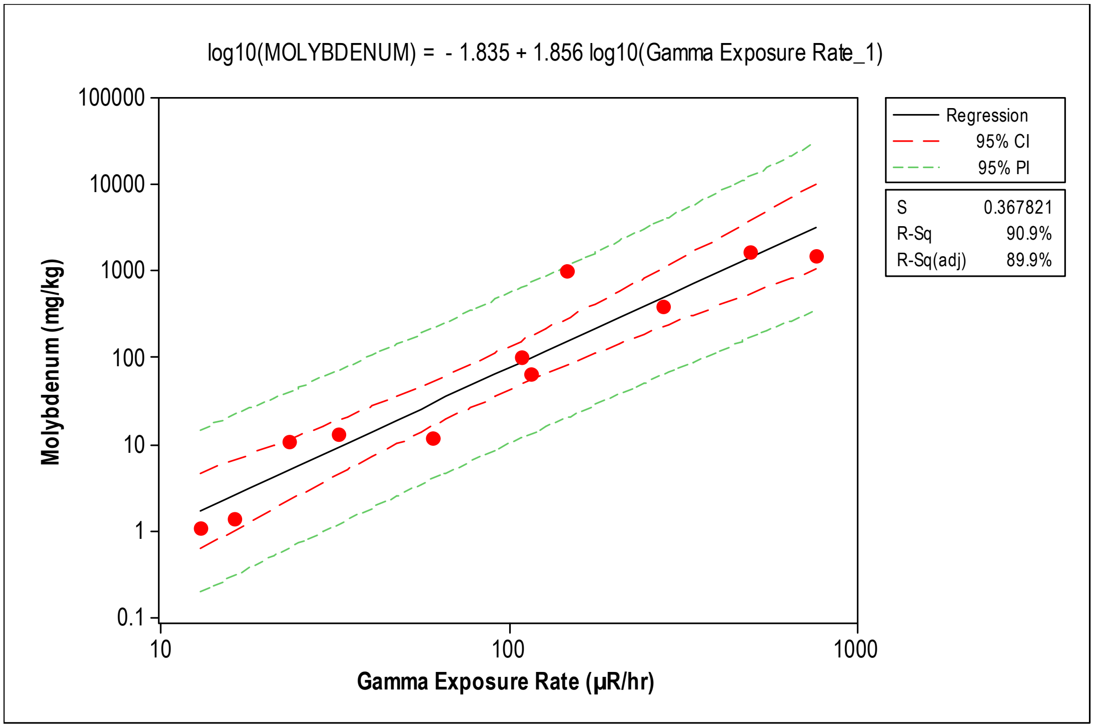


Figure 4-8. Linear Regression Model - Gamma Exposure Rate versus Molybdenum (log-transformed)

4.1.4 ^{226}Ra and Metals Correlation Results Using Scan Data

In addition to the correlation analysis between gamma exposure rates versus metal concentrations using the soil correlation plot laboratory results, a correlation analysis was performed on the estimated soil ^{226}Ra activity and the associated estimated XRF total arsenic values. This analysis was performed using the overlay tool in *ArcMap© 10* and finding the closest soil ^{226}Ra activity within a proximity of 3 feet from the *in-situ* XRF total arsenic concentration. The analysis was performed to evaluate the relationship between ^{226}Ra activity and total arsenic concentration at each bluff to determine if the correlation could be used to identify areas that exceed the risk protective levels for total arsenic.

Table 4-6 provides the R and R^2 at each bluff for both a simple linear regression and linear regression on the log-transformed data. The overall results indicate that there is a relationship between total arsenic concentration and ^{226}Ra activity at some of the bluffs. The relationship between the two contaminants is not strong enough to warrant the use of gamma radiation surveys as a verification tool to determine effectiveness of total arsenic removal.

Table 4-6. Summary of Correlation Results for ^{226}Ra versus Metals Using Scan Data

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

Figure 4-9 through Figure 4-12 provide the log-transformed regression fitted line plots for the ^{226}Ra activity and total arsenic concentration using the closest proximity scan data and *in-situ* XRF total arsenic values within 3 feet for Bluff B, CDE, H, and G, respectively.

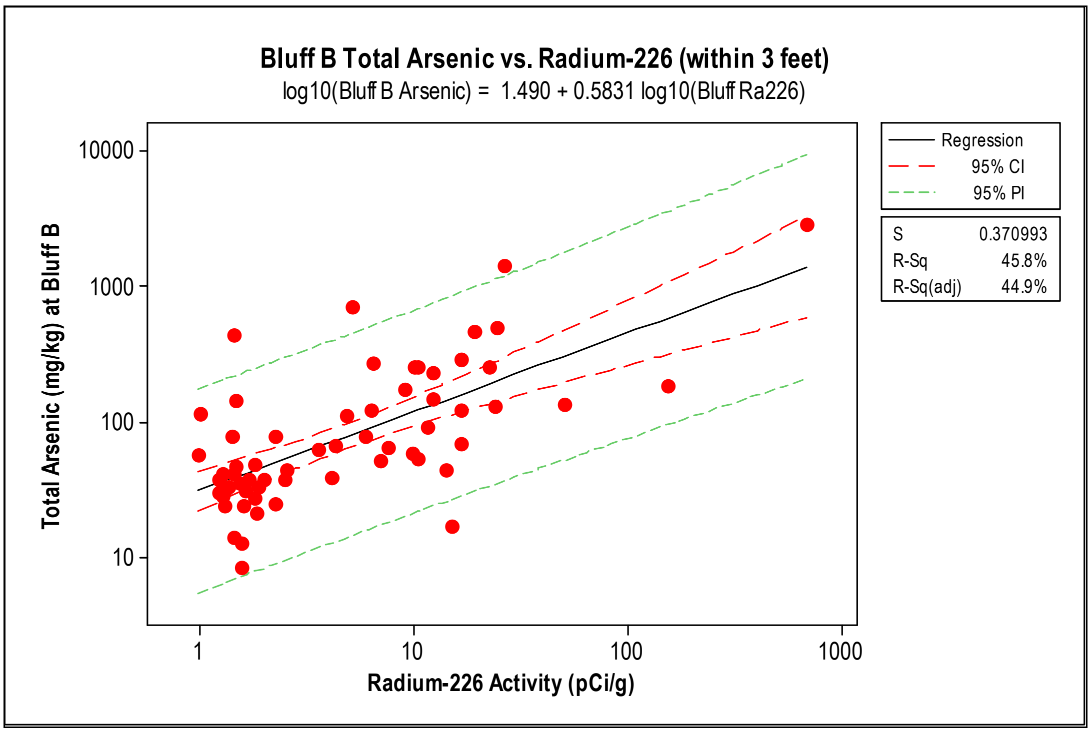


Figure 4-9. Bluff B Total Arsenic and ^{226}Ra Correlation Using Scan Data within 3 feet (log-transformed)

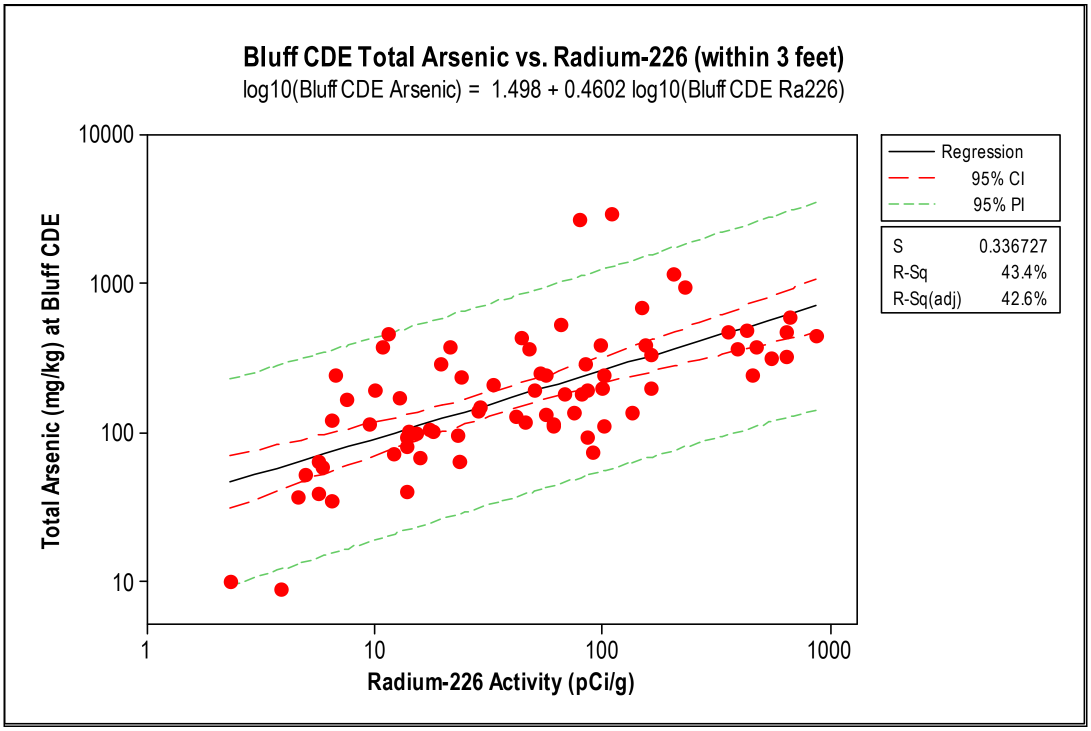


Figure 4-10. Bluff CDE Total Arsenic and ^{226}Ra Correlation Using Scan Data within 3 feet (log-transformed)

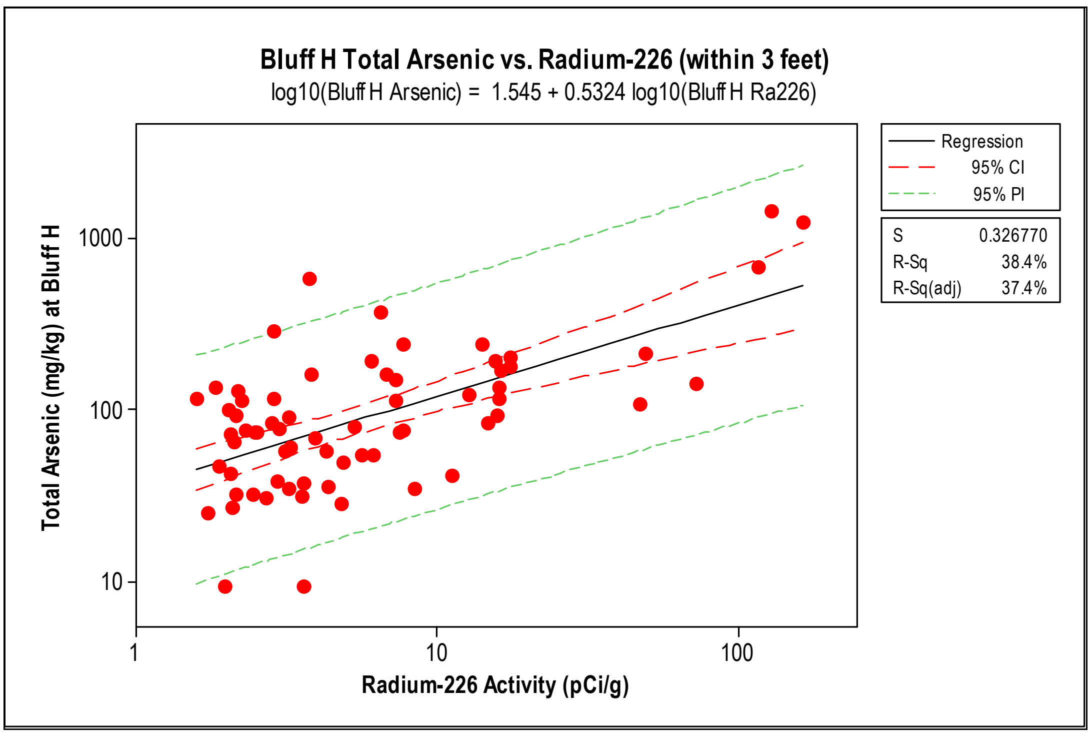


Figure 4-11. Bluff H Total Arsenic and ^{226}Ra Correlation Using Scan Data within 3 feet (log-transformed)

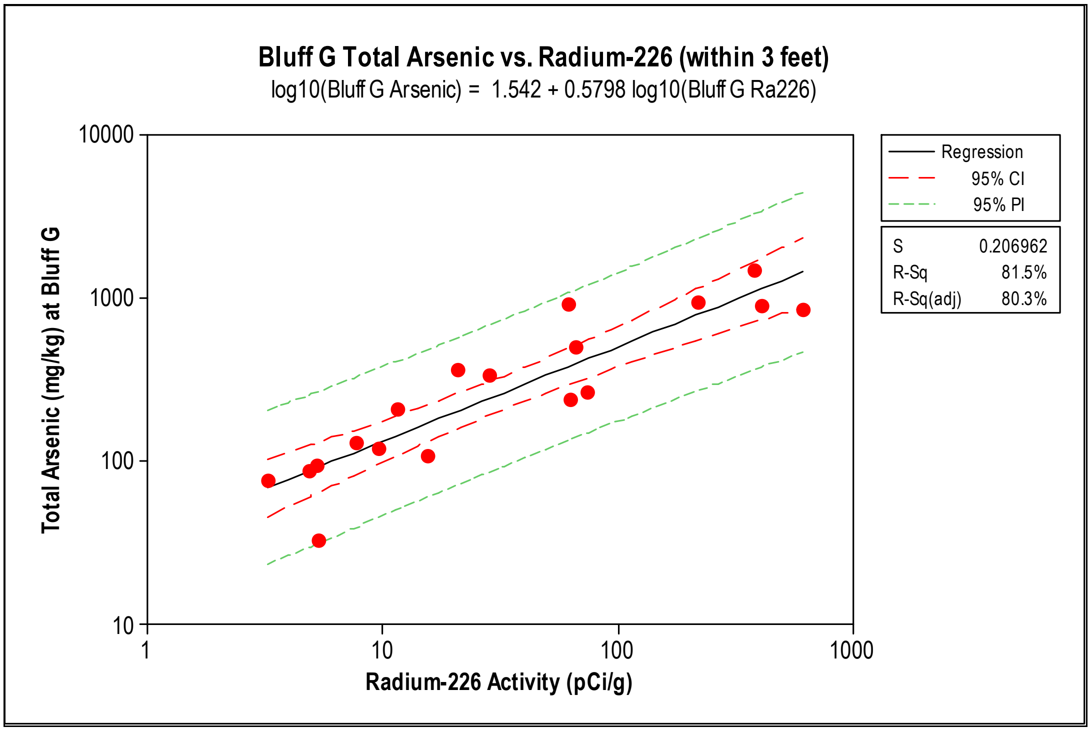


Figure 4-12. Bluff G Total Arsenic and ^{226}Ra Correlation Using Scan Data within 3 feet (log-transformed)

4.2 *In-situ* XRF Correlation Analysis

This section provides an overview of the field XRF correlation and summarizes the results of the XRF and laboratory metals correlations.

4.2.1 Overview of In-situ XRF Correlation

Tetra Tech personnel performed field *in-situ* XRF measurements to determine metal concentrations in the surface materials and confirm the presence or absence of mine contamination at the Tronox Bluffs. The XRF field survey was performed between October 23 and November 4, 2012 at the Tronox Bluffs. The XRF field survey was performed as described in Section 3.2 and consisted of *in-situ* XRF measurements and collection of surface soil confirmation samples submitted for laboratory analysis determine metals concentrations. Field *in-situ* XRF measurements were performed at the locations proposed in the SAP (Tetra Tech, 2012a); additional *in-situ* XRF measurements were collected outside of the proposed locations to increase the level of characterization detail at each of the bluffs. A summary of the proposed versus actual sample locations is presented in Section 5.2.2.

At least one of every 20 field XRF *in-situ* measurement samples was submitted for laboratory analysis. The confirmatory samples submitted were selected from the lower, middle, and upper range of concentrations measured during the waste characterization study. A total of 69 soil confirmation samples were collected at the Tronox Bluffs and submitted for laboratory analysis at ALS laboratory in Fort Collins, Colorado as described in Section 3.2.1. A total of 34 correlation samples from Bluff B, 19 correlation samples from Bluff CDE, two correlation samples from Bluff G, and 14 correlation samples from Bluff H were collected. The XRF soil correlation sample IDs and coordinates are provided in Table 4-7 through Table 4-9 for Bluffs B, CDE, G, and H, respectively. Figure 4-13 through Figure 4-16 show the *in-situ* XRF measurement locations and XRF soil correlation sample locations for Bluffs B, CDE, G, and H, respectively.

The final ALS laboratory reports of the metals analysis for the XRF soil confirmation samples are in Appendix E. Appendix F provides a detailed discussion summarizing the XRF soil correlation analysis results and provides detailed steps of how the final predictive equations were determined for the total metals concentrations.

Table 4-7. Bluff B XRF Correlation Sample Locations

Bluff Location	Sample ID	Date Sampled	Latitude (North)[1]	Longitude (West)[1]
Bluff B	AAAB2526-2	11/4/2012	45.84481	-103.47709
Bluff B	ABAC1718-1	11/1/2012	45.84708	-103.47694
Bluff B	AC23	10/31/2012	45.84546	-103.47667
Bluff B	ACAD1819-1	11/1/2012	45.84681	-103.47652
Bluff B	AE19	10/31/2012	45.84658	-103.47596
Bluff B	AF19	10/31/2012	45.84659	-103.47556
Bluff B	AF20	10/31/2012	45.84632	-103.47555
Bluff B	AF24	10/31/2012	45.84522	-103.47548
Bluff B	AI22	10/31/2012	45.84581	-103.47434
Bluff B	C19	10/30/2012	45.84625	-103.48693
Bluff B	F20	10/30/2012	45.84601	-103.48574
Bluff B	I24	10/30/2012	45.84495	-103.48450
Bluff B	K23	10/30/2012	45.84525	-103.48373
Bluff B	K25	10/30/2012	45.84470	-103.48369
Bluff B	K27	10/30/2012	45.84415	-103.48366
Bluff B	K28	10/30/2012	45.84388	-103.48364
Bluff B	M25	10/30/2012	45.84472	-103.48291
Bluff B	O17	11/1/2012	45.84694	-103.48226
Bluff B	O21	10/30/2012	45.84584	-103.48219
Bluff B	O22	10/30/2012	45.84557	-103.48218
Bluff B	P19	10/30/2012	45.84640	-103.48184
Bluff B	Q22	10/30/2012	45.84559	-103.48139
Bluff B	S19	10/30/2012	45.84644	-103.48066
Bluff B	ST45-2	11/4/2012	45.85032	-103.48063
Bluff B	T4	10/27/2012	45.85056	-103.48052
Bluff B	T5	10/27/2012	45.85029	-103.48050
Bluff B	U21	10/30/2012	45.84591	-103.47984
Bluff B	U3	10/27/2012	45.85085	-103.48015
Bluff B	V26	10/31/2012	45.84456	-103.47937
Bluff B	VW45-1	11/4/2012	45.85044	-103.47950
Bluff B	X27	11/1/2012	45.84431	-103.47856
Bluff B	Y17	11/1/2012	45.84706	-103.47834
Bluff B	Z23	10/31/2012	45.84543	-103.47785
Bluff B	Z26	10/31/2012	45.84460	-103.47780
Bluff B	ZAA2223-1	10/31/2012	45.84570	-103.47767

[1]Sample coordinates are shown in WGS 84 datum

Table 4-8. Bluff CDE XRF Correlation Sample Locations

Bluff Location	Sample ID	Date Sampled	Latitude (North)[1]	Longitude (West)[1]
Bluff C	G8A	10/26/2012	45.83546	-103.47645
Bluff C	GH89-1	10/29/2012	45.83529	-103.47631
Bluff C	HI67-2	10/29/2012	45.83590	-103.47599
Bluff C	HI78-1	10/29/2012	45.83559	-103.47596
Bluff C	HI78-2	10/29/2012	45.83569	-103.47598
Bluff C	I10	10/26/2012	45.83492	-103.47573
Bluff C	I7	10/26/2012	45.83574	-103.47579
Bluff C	K9	10/26/2012	45.83522	-103.47497
Bluff C	KL89-1	10/29/2012	45.83542	-103.47488
Bluff D	EF23-1	10/25/2012	45.83827	-103.46983
Bluff D	E6A	10/25/2012	45.83743	-103.46986
Bluff D	G4	10/25/2012	45.83793	-103.46910
Bluff D	GH45-1	10/25/2012	45.83779	-103.46883
Bluff E	AB01-2	10/29/2012	45.83537	-103.47085
Bluff E	AB12-1	10/29/2012	45.83510	-103.47073
Bluff E	AB23-1	10/29/2012	45.83484	-103.47071
Bluff E	B2	10/25/2012	45.83497	-103.47057
Bluff E	E4	10/25/2012	45.83446	-103.46936

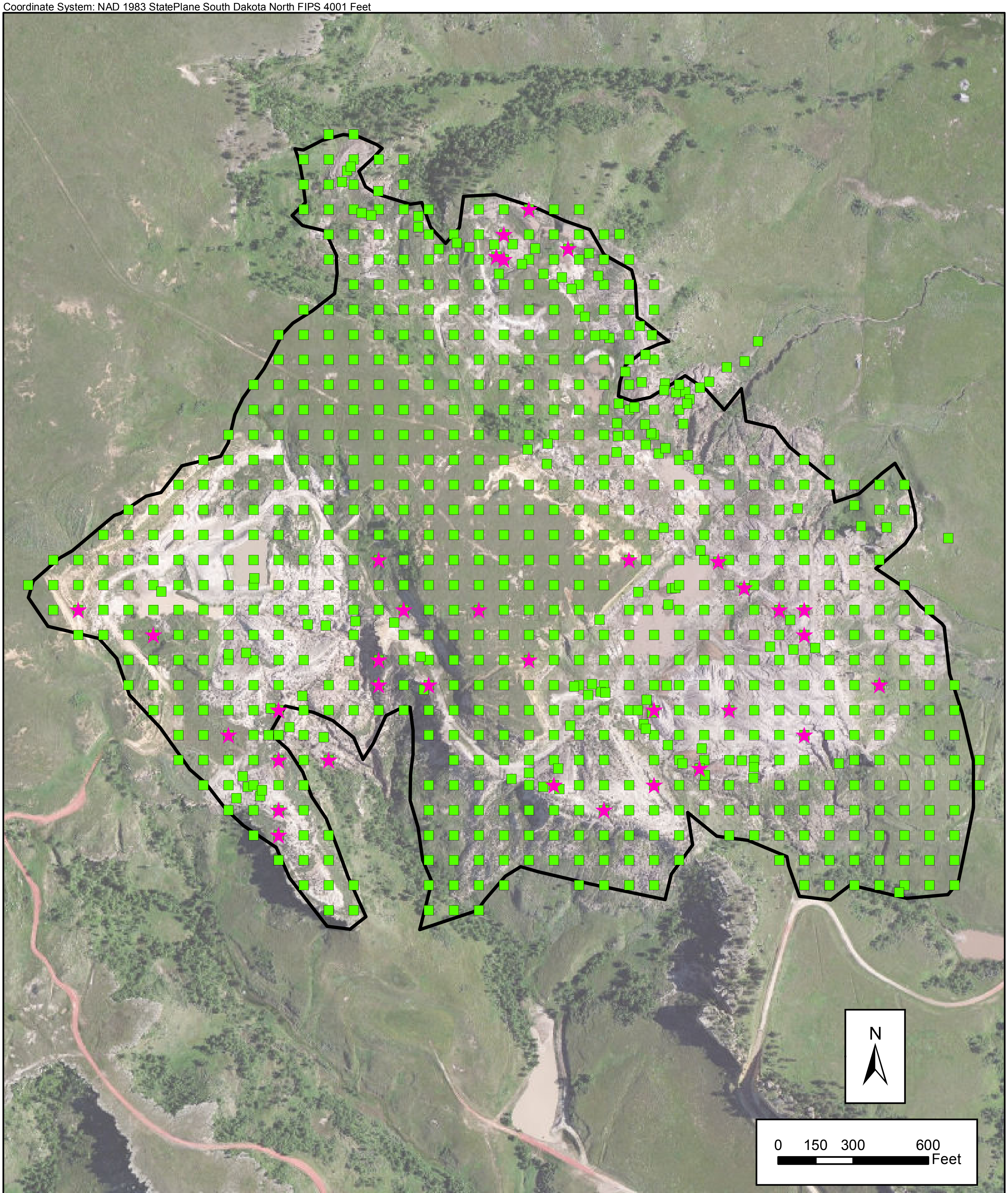
[1]Sample coordinates are shown in WGS 84 datum

Table 4-9. Bluff G and Bluff H XRF Correlation Sample Locations

Bluff Location	Sample ID	Date Sampled	Latitude (North)[1]	Longitude (West)[1]
Bluff G	DE01-1	10/22/2012	45.83325	-103.45830
Bluff G	EF01-1	10/31/2012	45.83318	-103.45778
Bluff H	D4	10/23/2012	45.83404	-103.44750
Bluff H	G2	10/23/2012	45.83462	-103.44636
Bluff H	G5	10/23/2012	45.83380	-103.44631
Bluff H	H5	10/23/2012	45.83381	-103.44592
Bluff H	I12	10/23/2012	45.83191	-103.44541
Bluff H	I7	10/23/2012	45.83328	-103.44549
Bluff H	I9	10/23/2012	45.83273	-103.44546
Bluff H	J5	10/24/2012	45.83383	-103.44513
Bluff H	K5	10/24/2012	45.83385	-103.44474
Bluff H	K9	10/24/2012	45.83275	-103.44468
Bluff H	KL78-1	10/29/2012	45.83316	-103.44454
Bluff H	LM0910-1	10/24/2012	45.83266	-103.44401
Bluff H	M11	10/24/2012	45.83223	-103.44386
Bluff H	M8	10/24/2012	45.83305	-103.44391

[1]Sample coordinates are shown in WGS 84 datum

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 4.13 Bluff B XRF Samples and Confirmation.mxd

Legend:

Bluff B Boundary

XRF Correlation Sample Location

In-Situ XRF Measurement Location

Issued by:

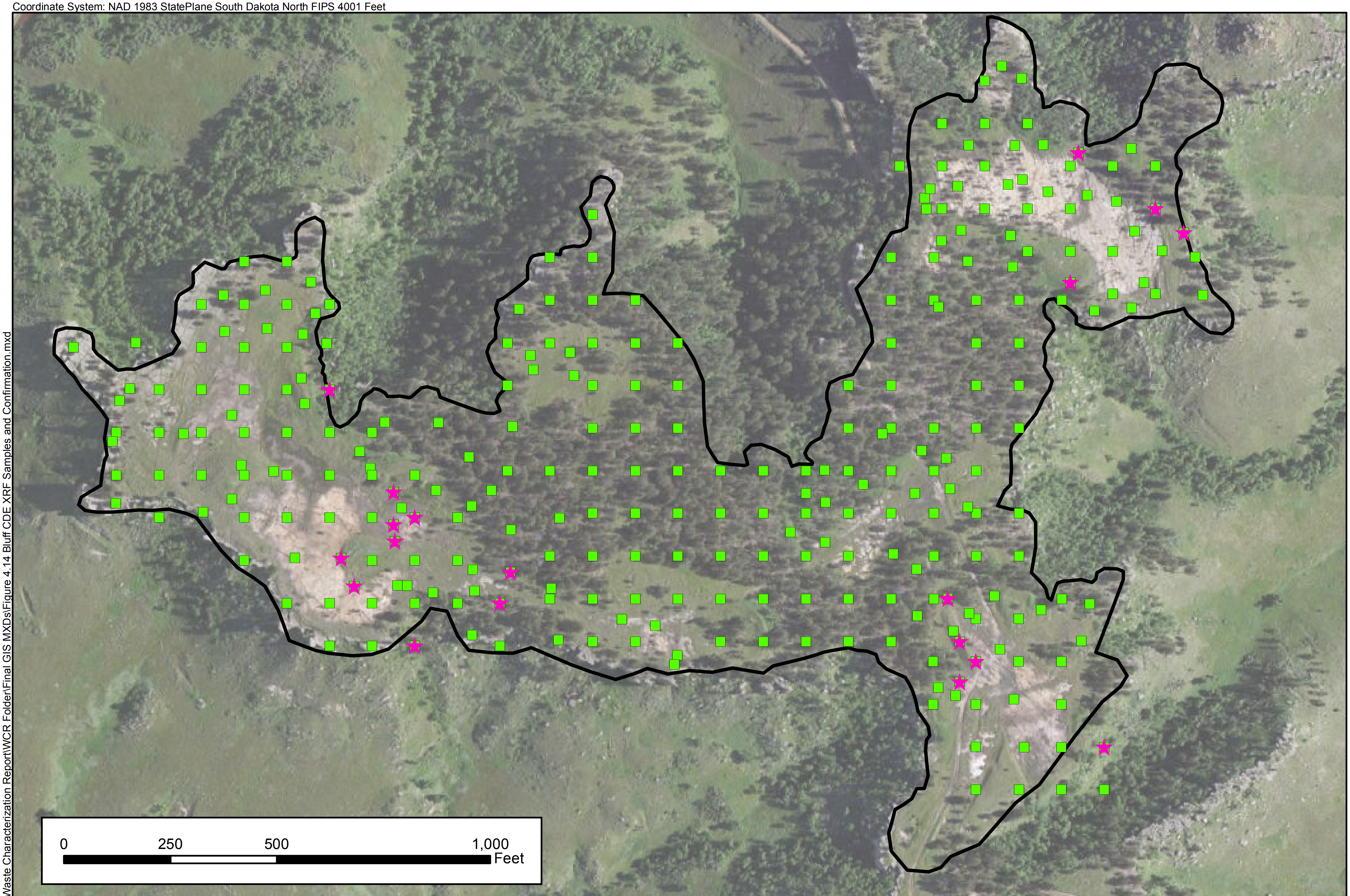
TETRA TECH
3801 Automation Way, Suite 100
Fort Collins, Colorado 80525
(970) 223-9600 (970) 223-7171 fax

Bluff B In-situ XRF Measurement and Confirmation Sample Locations

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 4-13
Location:	Harding County, South Dakota	June 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff CDE Boundary

XRF Correlation Sample Location

In-Situ XRF Measurement Location

N

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Fort Collins, Colorado 80525
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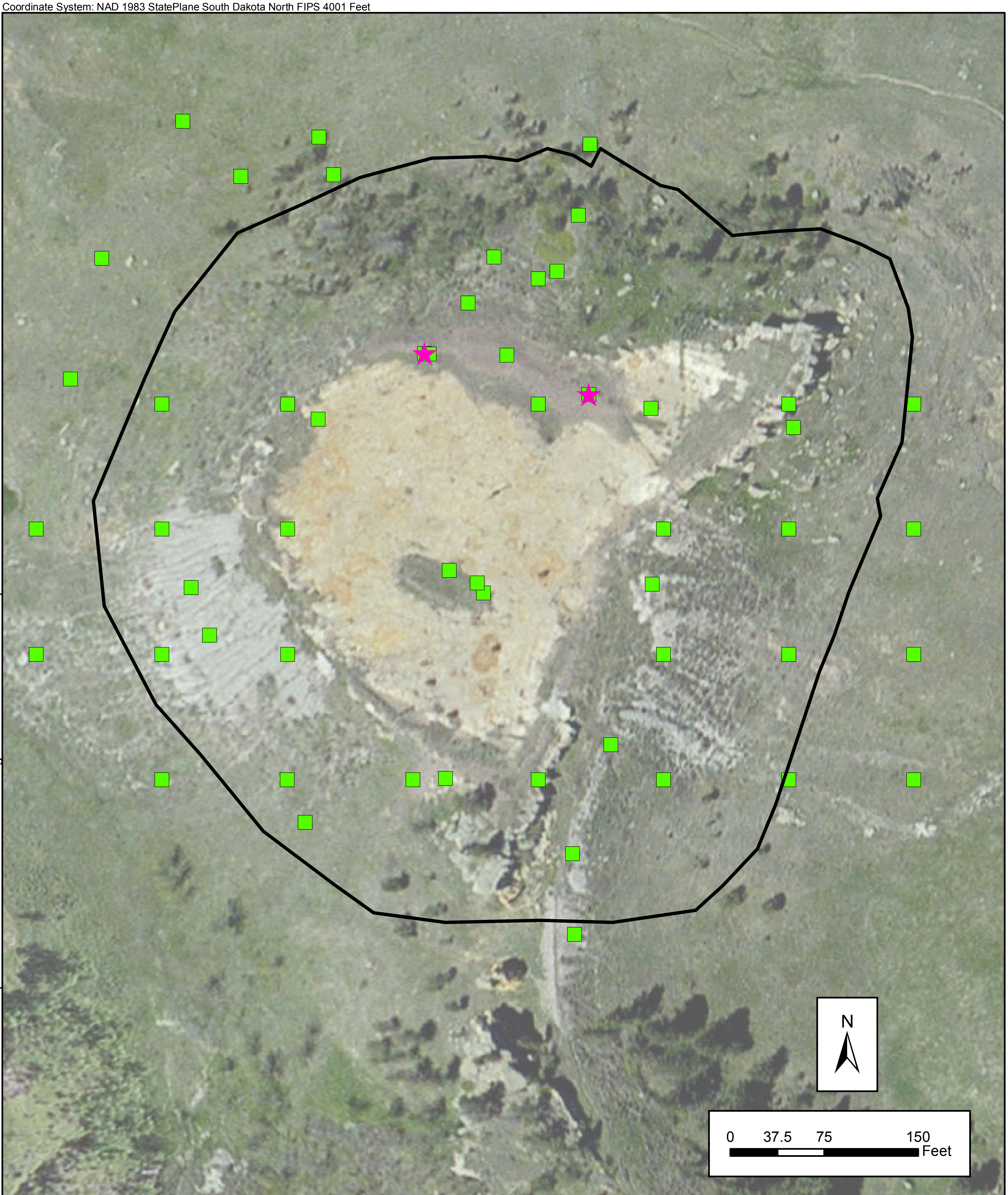
Bluff CDE In-situ XRF Measurement and Confirmation Sample Locations

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 4-14
Location:	Harding County, South Dakota	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 4.14 Bluff CDE XRF Samples and Confirmation.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff G Boundary

XRF Correlation Sample Location

In-Situ XRF Measurement Location

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Fort Collins, Colorado 80525
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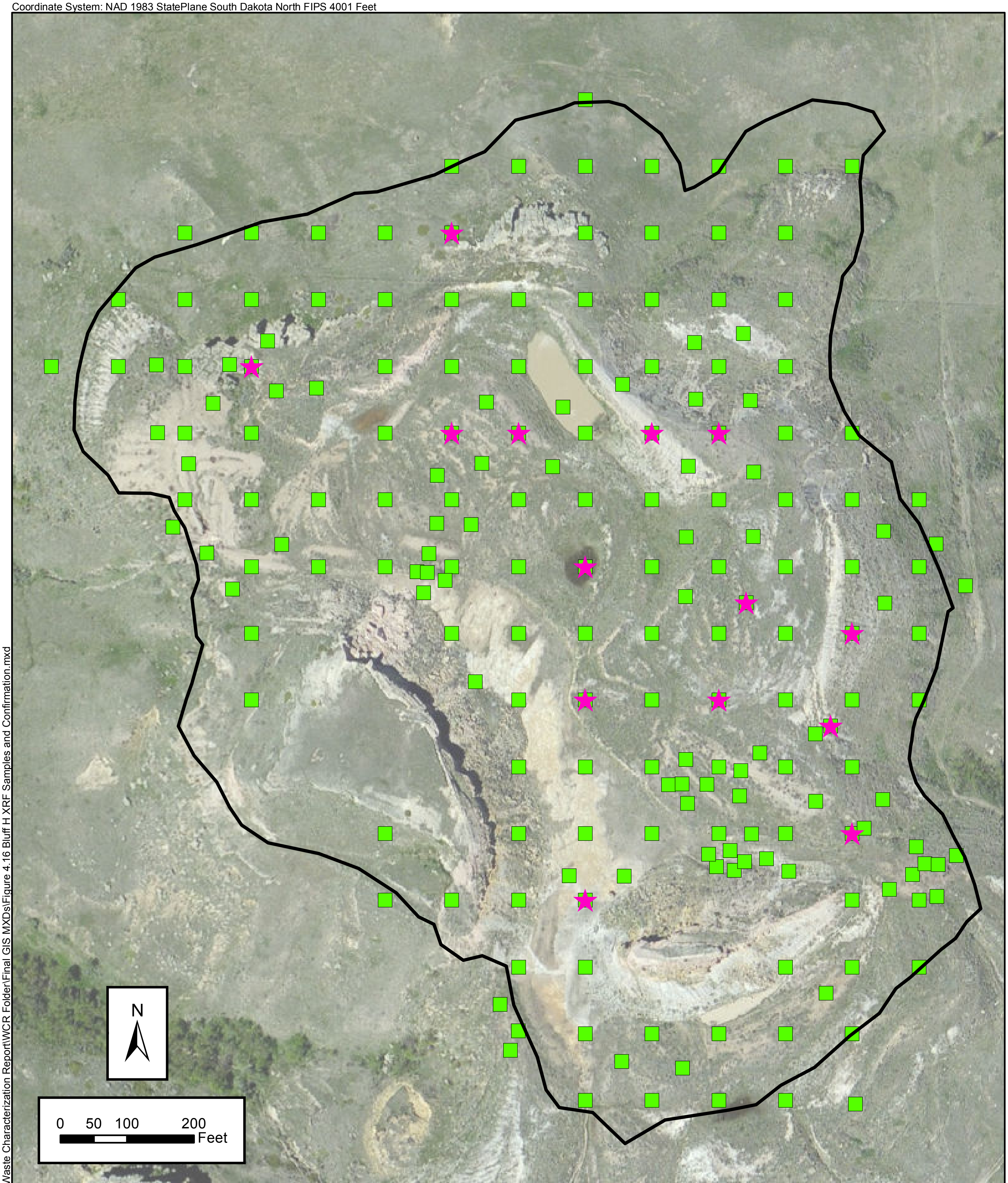
Bluff G In-situ XRF Measurement and Confirmation Sample Locations

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 4-15
Location:	Harding County, South Dakota	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 4.15 Bluff G XRF Samples and Confirmation.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 4.16 Bluff H XRF Samples and Confirmation.mxd

Legend:

2012 Revised Bluff H Boundary

XRF Correlation Sample Location

In-situ XRF Measurement Location

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Fort Collins, Colorado 80525
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Bluff H In-situ XRF Measurement and Confirmation Sample Locations

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 4-16
Location:	Harding County, South Dakota	June, 2013	

4.2.2 XRF Arsenic and Laboratory Reported Arsenic Correlation Results

A linear regression analysis using the least squares method was performed on the data sets for *in-situ* XRF-measured versus laboratory-analyzed arsenic concentrations

The purpose of the regression analysis, detailed in Appendix F, was to determine the relationship between the *in-situ* XRF measurements and the laboratory reported soil correlation samples, to develop a predictive regression model/equation that can be applied to the 1,350 *in-situ* XRF Tronox Bluffs measurements that were collected.

A variety of criteria were analyzed during the model-building process. The first criterion evaluated involved the Pearson's correlation coefficient (R). EPA Method 6200 recommends that for screening level data the correlation coefficient be greater than 0.7 and for definitive data the correlation coefficient must be greater than 0.9. The coefficient of determination (R^2) value was also analyzed to determine the model fit or the percentage of variability in the y-variable that is due to the relationship with the x-variable. Other criteria involved in building a simple linear regression model included standardized residual analysis, y-intercept evaluation, slope investigation, and outlier identification and analysis.

All of the linear regression models that were evaluated had correlation coefficients above 0.9, indicating that these models met the EPA Method 6200 criteria as a definitive prediction tool. The Scenario 3 model outlined in Appendix F was selected as the most effective predictive tool for total arsenic that should be used at the Tronox Bluffs during future reclamation. Equation 3 relates the total arsenic concentration to the field *in-situ* XRF arsenic concentration as follows:

Equation 3: $$\boldsymbol{Total\ Arsenic\ Concentration\left(\frac{mg}{kg}\right) = 10^{0.352+0.891 log_{10}\left(Arsenic_{XRF}\left(\frac{mg}{kg}\right)\right)}}$$

The final regression model and equation is shown in Figure 4-17. The normal probability plot, shown in Figure 4-18, indicates that the standardized residuals of the final regression model follow a normal distribution. Also, the residuals are within the range of -3 to +3 standard deviations. Both of these indicators demonstrate a strong, fitting model that is statistically significant ($p<0.01$) and contains no outliers.

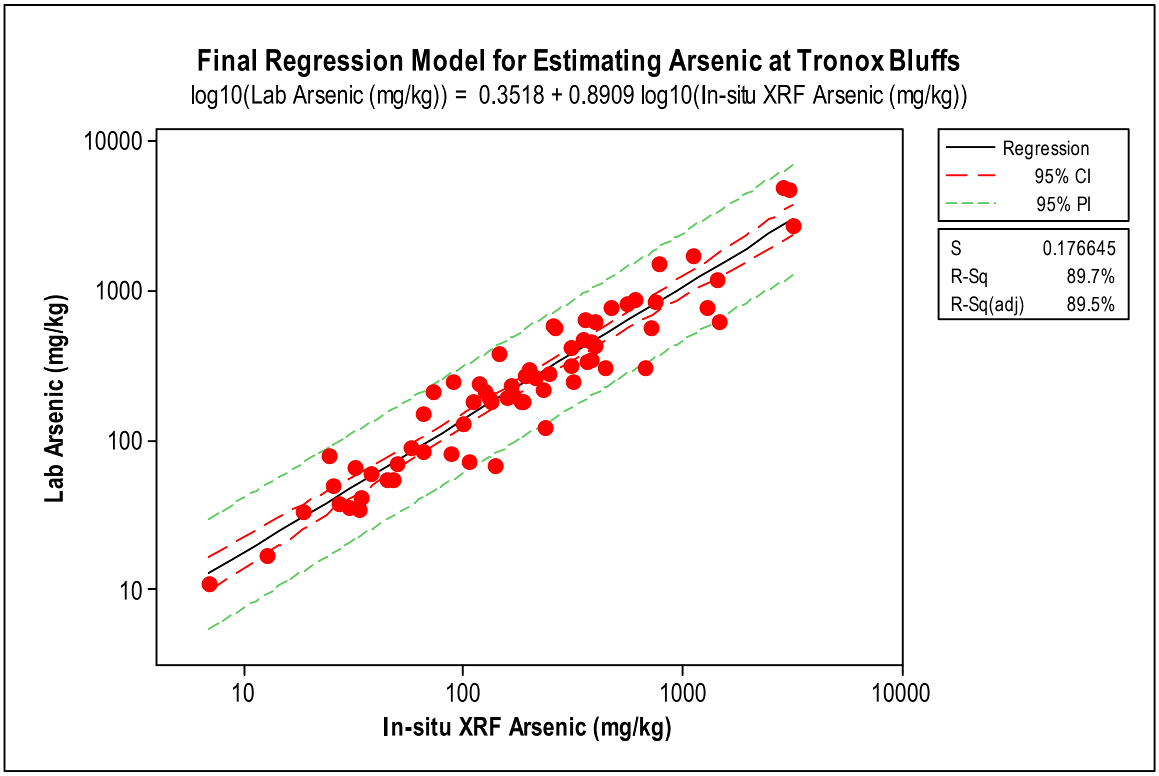


Figure 4-17. Linear Regression Model for Arsenic Concentrations at Tronox Bluffs

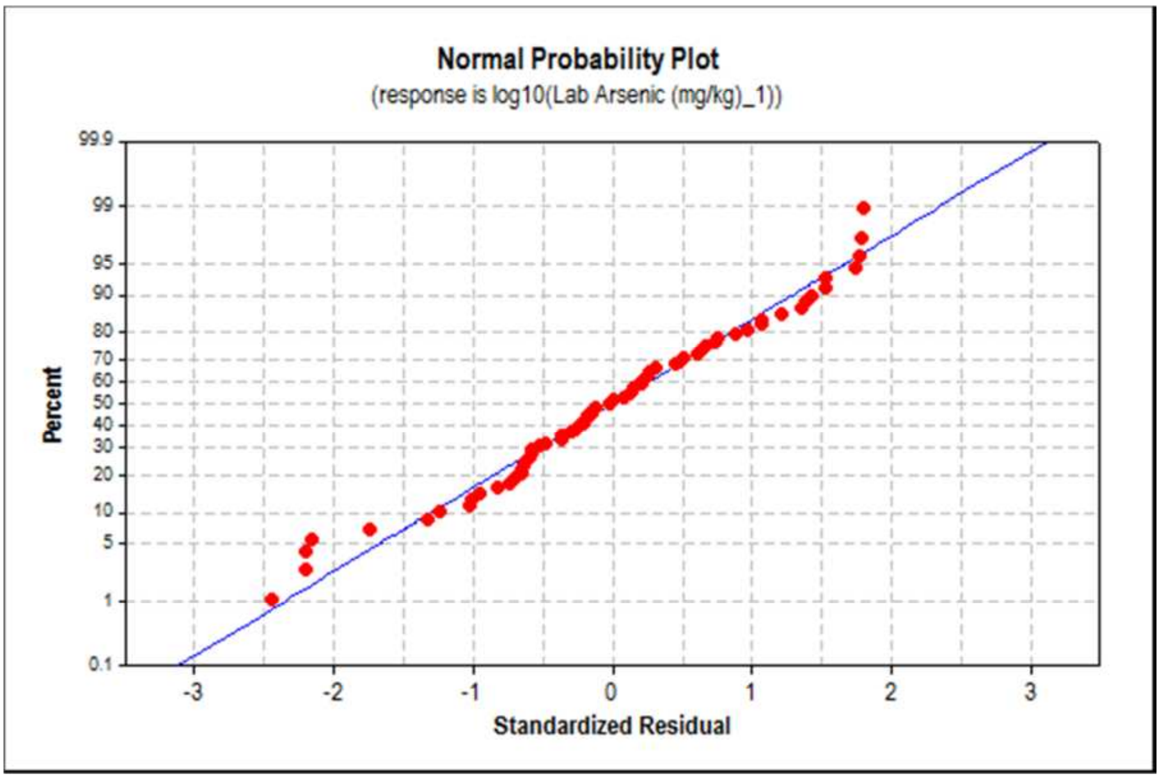


Figure 4-18. Normal Probability Plot of Standardized Residuals (Arsenic Model)

EPA Method 6200 states that arsenic concentrations cannot be effectively calculated for samples with lead to arsenic (Pb/As) ratios of 10:1 or more. If this situation is encountered, a "non-detect" or a "less than" value for As may be reported. Analysis of the Pb/As ratio from the 69 samples submitted for laboratory analysis resulted in a ratio ranging from 0.006:1.27, indicating that lead concentrations in the samples should not influence the reported arsenic results.

4.2.3 XRF Uranium and Laboratory Reported Uranium Correlation

A linear regression analysis using the least squares method was performed on the data sets of *in-situ* XRF-measured uranium concentrations versus 69 laboratory-reported uranium concentrations.

A detailed regression analysis is included in Appendix F. The purpose of the regression analysis was to develop an equation defining the relationship between the *in-situ* XRF measurements and the laboratory reported soil correlation samples, to develop a predictive regression model/equation that can be applied to each of the *in-situ* XRF measurements that were collected at the Tronox Bluffs and converted into a definitive natural uranium concentration.

The paired data sets of *in-situ* XRF uranium measurements and the laboratory reported soil correlation natural uranium samples were analyzed for linear regression using the least squares method. Figure 4-19 shows the linear regression analysis performed on the log-transformed data sets that were selected to predict natural uranium concentrations at the Site. This model was selected after removal of outlier values with high residual error; the resulting model showed standardized residuals with low error that follow a normal statistical distribution as shown in Figure 4-20. Equation 4 is used to relate natural uranium concentration in surface soil and the *in-situ* XRF measured natural uranium concentration and can be expressed as follows:

Equation 4: $$\boldsymbol{Total\ Uranium\ Concentration\left(\frac{mg}{kg}\right) = 10^{-0.2951+1.131 log_{10}\left(Uranium_{XRF}\left(\frac{mg}{kg}\right)\right)}}$$

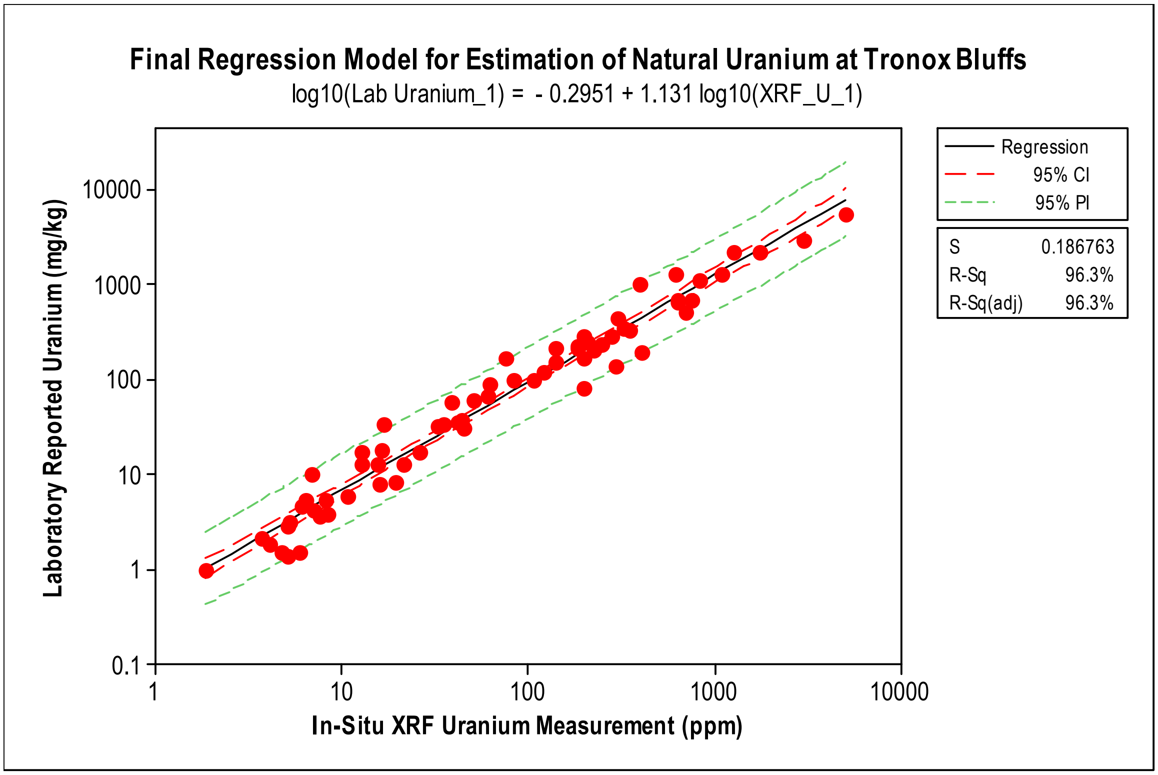


Figure 4-19. Linear Regression Model for Uranium Concentrations at Tronox Bluffs

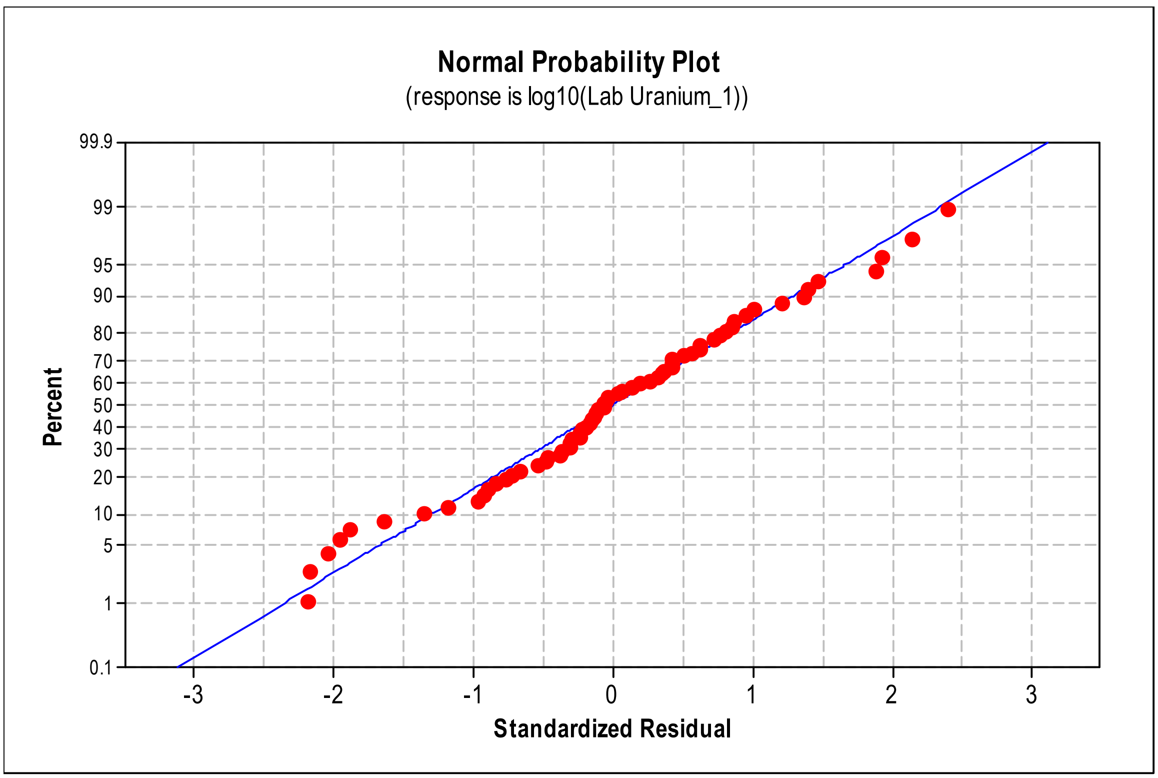


Figure 4-20. Normal Probability Plot of Standardized Residuals (Uranium Model)

4.2.4 XRF Molybdenum and Laboratory Reported Molybdenum Correlation

A linear regression analysis using the least squares method was performed on the data sets of *in-situ* XRF measurement molybdenum concentrations and resulting XRF soil correlation total molybdenum concentrations reported by the laboratory. A variety of analyses were performed on the data pairs in evaluating the different linear regression models to determine which model should be used to accurately and definitively estimate the total molybdenum at the Site based on the 1,350 *in-situ* XRF measurements collected at the Tronox Bluffs.

A detailed regression analysis is included in Appendix F. The purpose of the regression analysis was to determine the relationship between the *in-situ* XRF measurements and the laboratory reported soil correlation samples to develop a predictive regression model/equation that can be applied to each of the *in-situ* XRF measurements that were collected at the Tronox Bluffs and converted into a definitive total molybdenum concentration.

The paired data sets of *in-situ* XRF total molybdenum measurements and the laboratory reported soil correlation molybdenum samples were analyzed for linear regression using the least squares method. Figure 4-21 shows the log-transformed linear regression model that was selected to predict total molybdenum concentrations at the Site. This model was selected after removal of outlier values with high residual error; the resulting model showed standardized residuals with low error that follow a normal statistical distribution as shown in Figure 4-22.

Equation 5 is used to relate total molybdenum concentration in surface soil and the *in-situ* XRF measured total molybdenum concentration and can be expressed as follows:

Equation 5:

$$\boldsymbol{Total\ Molybdenum\ Concentration}\left(\frac{mg}{kg}\right) = \mathbf{10}^{-0.4955+1.233\log_{10}\left(Molybdenum_{XRF}\left(\frac{mg}{kg}\right)\right)}$$

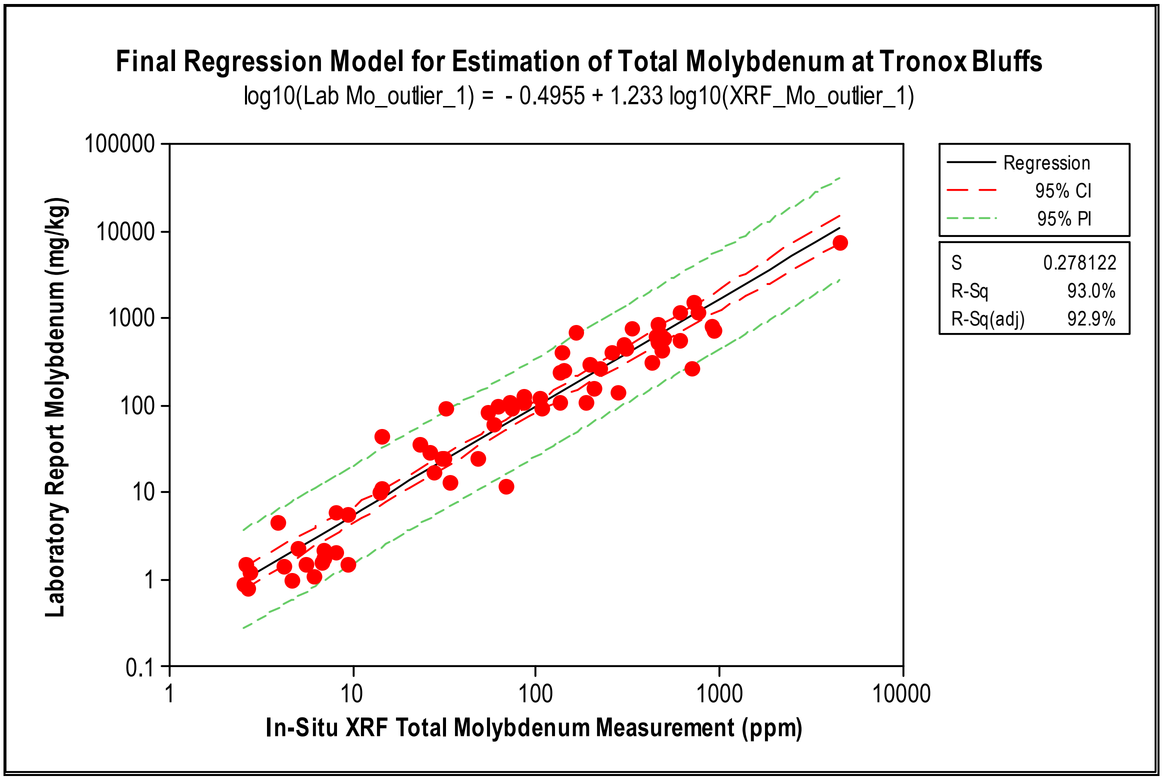


Figure 4-21. Linear Regression Model for Molybdenum Concentrations at Tronox Bluffs

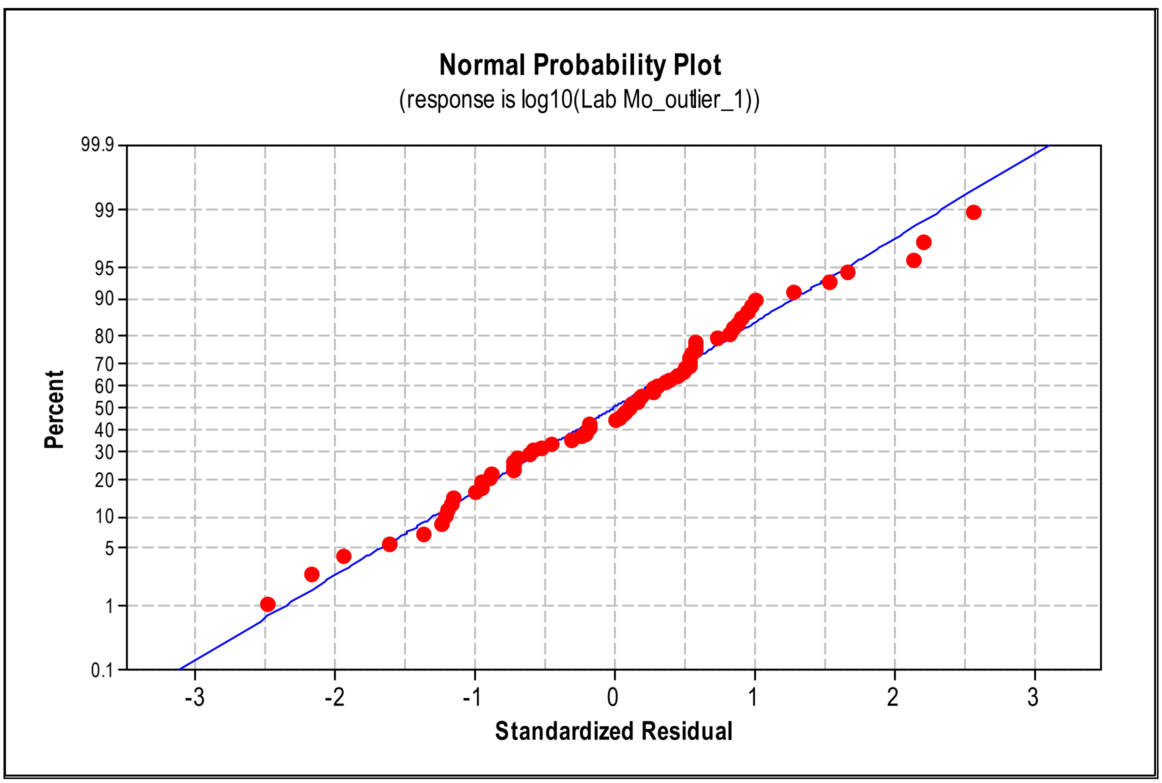


Figure 4-22. Normal Probability Plot of Standardized Residuals (Molybdenum Model)

5.0 WASTE CHARACTERIZATION TECHNIQUES AND RESULTS

This Section describes the techniques used to characterize the spatial extent of the radionuclide and heavy metal concentrations in the surface and subsurface soils at Tronox Bluffs B, CDE, G, and H. Additionally, visual and statistical results of the characterization study are presented in this section.

5.1 Overview of Spatial Interpolation Techniques

The 2007 Action Memorandum specifies that after the site reclamation, the bluffs will be divided into appropriate sized grids and a block averaging technique will be applied to the data sets. An alternative method to hand averaging the soil data is to utilize geostatistical techniques as recommended by EPA (1989). Geostatistical methods are a powerful tool for mapping spatial data and providing interpolation between existing data points that have been collected (EPA, 1987). Geostatistical methods are commonly used in geographic, geological, and environmental sciences as outlined in Journel and Huijbregts (1978), David (1977), and Verly et a. (1984). For the purposes of this study two geostatistical methods were utilized: kriging and inverse distance weighted (IDW) method. Kriging is used to interpolate the denser gamma radiation point data, and IDW is used to interpolate between the more scattered XRF point data. There are two primary types of geostatistical interpolation methods: deterministic and geostatistical. The IDW method is a deterministic method and kriging is a geostatistical method. Deterministic techniques create surfaces from measured points, and the geostatistical tools utilize the statistical properties of the measured points.

The selection of spatial interpolation methods impacts the quality of Tronox Bluff soil concentration maps. By applying advanced spatial analysis interpolation techniques to the individual data sets, values were estimated for the areas of the bluffs that were not sampled; thereby, allowing the production of a detailed map for those areas. One of the goals of collecting measurements on fixed intervals was to utilize this data to estimate the surface concentration of the bluffs. These advanced spatial analysis techniques are available using *ArcMap10©*. An important assumption is that the heavy metals and radionuclide concentrations are spatially correlated; therefore, utilizing interpolation spatial techniques is a viable option.

The grid sampling approach used for this study provided good delineations of the “hot spots” of both soil ^{226}Ra activity and metals concentrations that exceed soil cleanup values. The areas designated as contaminated have been delineated and can be used to guide the reclamation and removal action efforts at the Site.

The density of sampling is defined as the number of data points per bluff area in acres; a summary table describing the sampling density at each bluff is provided in Table 5-1. The mean sampling density of gamma radiation data and *in-situ* XRF measurements are 484 points/acre and 6 points/acre, respectively. It is cost-prohibitive to scan or sample at higher densities; therefore, spatial interpolation techniques were applied to the data sets to approximate data in unsampled locations. Spatial interpolation is the procedure of estimating value properties at unsampled locations within an area covered incompletely by actual observations. By applying spatial analysis interpolation techniques to the individual data sets, values can be estimated for portions of the bluffs that were not actually sampled; thereby, allowing the production of a detailed estimate map.

Table 5-1. Summary of Sampling Density per Bluff Area

Location	# of Scan Points	# of XRF Points	Total Area (acres)	Scan Density (points/acre)	XRF Density (points/acre)
Bluff B	67,015	804	153	438	5
Bluff CDE	22,191	293	48	458	6
Bluff G	8,778	54	7	1,236	8
Bluff H	18,341	199	32	577	6
Total(T)/Average(A)	**116,325 (T)**	**1,350 (T)**	**240 (T)**	**484 (A)**	**6 (A)**

5.1.1 Kriging Technique

Kriging is a method of interpolation that has become an important fundamental tool in the field of geostatistics and earth sciences over the past several decades. The technique of kriging was named after Daniel G. Krige (Krige and Magri, 1982), a South African mining engineer who developed the geostatistical tool in an attempt to more accurately predict ore reserves and mineral resources. There are three types of kriging: ordinary, simple, and universal. Ordinary kriging is a regression technique for estimation of values based on a best unbiased estimate of a variable at an un-sampled location. The kriging results are then displayed on a grid or mesh and provide detailed informative characterizations of radiological parameters across the entire Site. The kriged maps were applied to the ^{226}Ra and the dose rate data. Table 5-2 provides the kriging parameters and method of kriging that was applied to the values of dose rate and ^{226}Ra data at each bluff. Multiple kriging scenarios were evaluated at each bluff and the best method that visually represented the available data was then selected as the final method. The kriging method that was used was the ordinary method with the exponential semivariogram model option selected.

Table 5-2. Summary of Kriging Parameters for Dose Rate and ^{226}Ra at the Tronox Bluffs

Location	Z Value	Kriging Method/Model	Cell Size (feet)	Kriging Parameters	
Bluff B	Dose Rate	Ordinary/Exponential	15	Variable	Default (12 Pts)
	^{226}Ra	Ordinary/Exponential	25	Variable	12 points / 125 Feet
Bluff CDE	Dose Rate	Ordinary/Exponential	15	Variable	Default (12 Pts)
	^{226}Ra	Ordinary/Exponential	25	Variable	Default (12 Pts)
Bluff G	Dose Rate	Ordinary/Exponential	5	Variable	Default (12 Pts)
	^{226}Ra	Ordinary/Exponential	15	Variable	Default (12 Pts)
Bluff H	Dose Rate	Ordinary/Exponential	5	Variable	Default (12 Pts)
	^{226}Ra	Ordinary/Exponential	25	Variable	12 points / 125 Feet

5.1.2 Inverse Distance Weighted Interpolation Technique

The IDW method is one of the more commonly used techniques for interpolation of scatter points. This method is based on the assumption that the surface to be interpolated should be influenced higher by points in closer proximity and influenced less by points in further proximity. There are a variety of IDW methods that can be employed; a number of methods were investigated for this study using *ArcMap10© Spatial Analyst* tool. The surfaces that were generated using the IDW tool were based on the estimated laboratory correlated XRF metals concentrations. All metals concentrations that were below the XRF limit of detection (LOD) were set to half of the specific LOD prior to conversion using the correlation, as suggested by Nehls and Akland (1973). This method is referred to as substitution and is one of many methods for dealing with data that fall below the limit of detections, also referred to as left censored data. The IDW method was applied to the correlated total arsenic, natural uranium, and total molybdenum concentration values. Table 5-3 provides a summary of the IDW spatial analysis parameters used for each bluff.

Table 5-3. Summary of IDW Parameters for Metals Concentration at the Tronox Bluffs

Location	XRF Data Type	Interpolation Type	Output Cell Size (Feet)	Power	Search Radius	# of Points	Distance (Feet)
Total Arsenic							
Bluff B	Arsenic	IDW	25	2.5	Fixed	0	175
Bluff CDE	Arsenic	IDW	25	2	Fixed	0	125
Bluff G	Arsenic	IDW	15	2	Fixed	0	150
Bluff H	Arsenic	IDW	25	2	Fixed	0	175
Uranium Isotopes							
Bluff B	^{238}U, ^{235}U, ^{234}U,	IDW	25	3	Fixed	4	110
Bluff CDE	^{238}U, ^{235}U, ^{234}U,	IDW	25	3	Fixed	4	110
Bluff G	^{238}U, ^{235}U, ^{234}U,	IDW	15	3	Fixed	4	75
Bluff H	^{238}U, ^{235}U, ^{234}U,	IDW	25	3	Fixed	4	125
Total Molybdenum							
Bluff B	Moly	IDW	25	2	Variable	default	default
Bluff CDE	Moly	IDW	25	2	Variable	default	default
Bluff G	Moly	IDW	n/a	n/a	n/a	n/a	n/a
Bluff H	Moly	IDW	25	2	Variable	default	default

5.2 Overview of Gamma Radiation Survey XRF Field Survey Sampling Efforts

This section provides a general overview of the gamma radiation survey and the XRF field survey sampling efforts conducted as part of the 2012 Tronox Bluff waste characterization program.

5.2.1 Overview of the Gamma Radiation Survey

The gamma radiation survey was performed by Tetra Tech field personnel between October 23, and October 31, 2012. The gamma radiation survey procedures and QA/QC results are discussed in Section 3.1. The gamma exposure rates collected as part of the survey were converted to dose rate values and individual soil ^{226}Ra activity for each bluff. The results of the gamma radiation correlation analyses are summarized in Section 4.1.

Table 5-4 provides the number of survey points conducted for each bluff area. A total of 116,325 gamma survey points were collected across all the Tronox Bluffs. The scan density ranged between 438 scan points per acre and 1,236 scan points per acre, with an average density of 484 scan points per acre for the entire Site (Table 5-1). As described in Section 3.6, the instruments that were utilized for this project met the QA/QC guidelines; therefore, the 116,325 scan points are considered usable and are included in the final project database. Overall, the gamma radiation survey met the objectives and followed the procedures set forth in the SAP (Tetra Tech, 2012a). The overall objective of completeness has been achieved for this aspect of the waste characterization program. Sections 5.3 through 5.6 provide the waste characterization results for all of the Tronox Bluffs. An overall discussion of the Tronox Bluff waste characterization results is provided in Section 5.10.

Table 5-4. Gamma Exposure Rates Collected Per Study Area

Study Area	Number of Scan Points
Bluff B	67,015
Bluff CDE	22,191
Bluff G	8,778
Bluff H	18,341
Total	**116,325**

5.2.2 Overview of the XRF Survey

Tetra Tech field personnel performed the XRF field survey between October 23 and November 4, 2012. The XRF field survey procedures and the QA/QC results are discussed in Section 3.2. The measured *in-situ* XRF metals concentrations collected as part of the survey were converted into select metals concentrations using the correlation techniques described in Section 4.2.

The XRF soil correlation sample IDs and coordinates are provided in Table 4-7 through Table 4-9 for Bluff B, Bluff CDE, Bluff G, and H, respectively. Figure 4-13 through Figure 4-16 show the *in-situ* XRF measurement locations and XRF soil confirmation sample locations for Bluffs B, CDE, G, and H, respectively. A summary of the actual versus proposed number of *in-situ* XRF measurements and confirmation samples is provided in Table 5-5.

Table 5-5. Summary of Proposed and Actual XRF Samples

Proposed Bluff ID	Proposed # of XRF Samples Per Bluff	Actual Bluff ID	Actual Number of XRF Samples Collected Per Bluff	Proposed # of Soil Confirmation Samples Per Bluff	Actual Number of Soil Confirmation Samples Per Bluff
Bluff B	699	Bluff B	804	35	35
Bluff H	145	Bluff H	199	8	14
Bluff E	8	Bluff CDE	293	6	18
Bluff C	59				
Bluff D	29				
Bluff G	24	Bluff G	54	2	2
Total	**964**	**Total**	**1,350**	**51**	**69**

A total of 1,350 *in-situ* XRF data measurements were collected from the Tronox Bluffs B, CDE, G, and H. Surface soil samples were collected at *in-situ* XRF measurement locations at a frequency of 1:20; a total of 69 XRF soil confirmation samples were collected and submitted for laboratory analysis. The metals data collected for the XRF soil confirmation analysis were validated and judged to be acceptable based on the criteria set forth in the SAP, discussed in Section 3.6, and Appendix J. The overall objective of completeness has been achieved for this part of the waste characterization program. Sections 5.3 through 5.6 provide the waste characterization results for all of the Tronox Bluffs. A discussion of the Tronox Bluff waste characterization results is provided in Section 5.10.

5.3 Bluff B Waste Characterization Results

This section presents the waste characterization results for Bluff B, including an existing conditions overview, a summary, and results of the XRF field survey waste characterization and a summary and results of the gamma radiation survey waste characterization. An overall summary of the Tronox Bluff waste characterization study is presented in Section 5.10.

5.3.1 Bluff B Existing Conditions Overview

The 2007 Action Memorandum states that Bluff B encompasses approximately 153 acres of spoils piles, highwalls, and open pits. The 2012 waste characterization data indicates that this acreage estimate is valid. The 2007 Action Memorandum estimated that Bluff B has a spoils volume of 1,140,000 yd^3 and 65,600 yd^3 of acutely contaminated material consisting of primarily lignite-bearing spoil piles. Tetra Tech will revise prior volume estimates as part of ongoing reclamation design work. Erosion and sedimentation issues remain a primary concern at Bluff B, as the waste materials from the area are a major source of sediment entering Pete's Creek to the east and Schleichart Draw to the southeast. A large portion of Bluff B is either barren or sparsely vegetated, showing signs of significant erosion. Large quantities of material have been pushed over the sandstone cliffs, covering trees and shrubs and altering the overall natural conditions of this bluff significantly. A photographic log showing many of the existing site features in addition to historical photographs at Bluff B is included in Appendix N.

Historic data generally indicate that Bluff B represents the lower end of the range of contamination when compared to the other bluffs within the Riley Pass project area (both

Tronox and Non-Tronox), but that it contains a greater area of disturbance and overall more widespread contamination (USFS, 2006). A comparison of pre-mining and present conditions by way of aerial photography is shown for Bluff B in Figure 1-5. In comparison to the rest of the Site, Bluff B has the largest aerial extent of disturbance resulting from historic mining activity.

5.3.2 Bluff B Gamma Radiation Survey Waste Characterization Results

A total of 67,015 gamma exposure rate measurements were collected at Bluff B (438 points per acre). The gamma exposure rate at Bluff B ranged from 8.71 µR/hr to 722 µR/hr with a mean of 33.1 µR/hr. The standard deviation, median, 95th percentile, and 99th percentile of the gamma exposure rates collected at Bluff B were 36.6 µR/hr, 18.8 µR/hr, 97.2 µR/hr, and 183 µR/hr, respectively. Table 5-6 provides a statistical summary of the gamma exposure rate data collected at Bluff B. The raw gamma exposure rate map for Bluff B is shown in Figure 5-1.

Table 5-6. Summary Statistics of Bluff B Gamma Exposure Rates

Data Statistic	Result
# of Data Measurements Collected	67,015
Minimum (µR/hr*)	8.71
Maximum (µR/hr)	722
Mean (µR/hr)	33.1
Median (µR/hr)	18.8
Standard Deviation (µR/hr)	36.6
95th Percentile (µR/hr)	97.2
99th Percentile (µR/hr)	183

*µR/hr = micro-Roentgen per hour

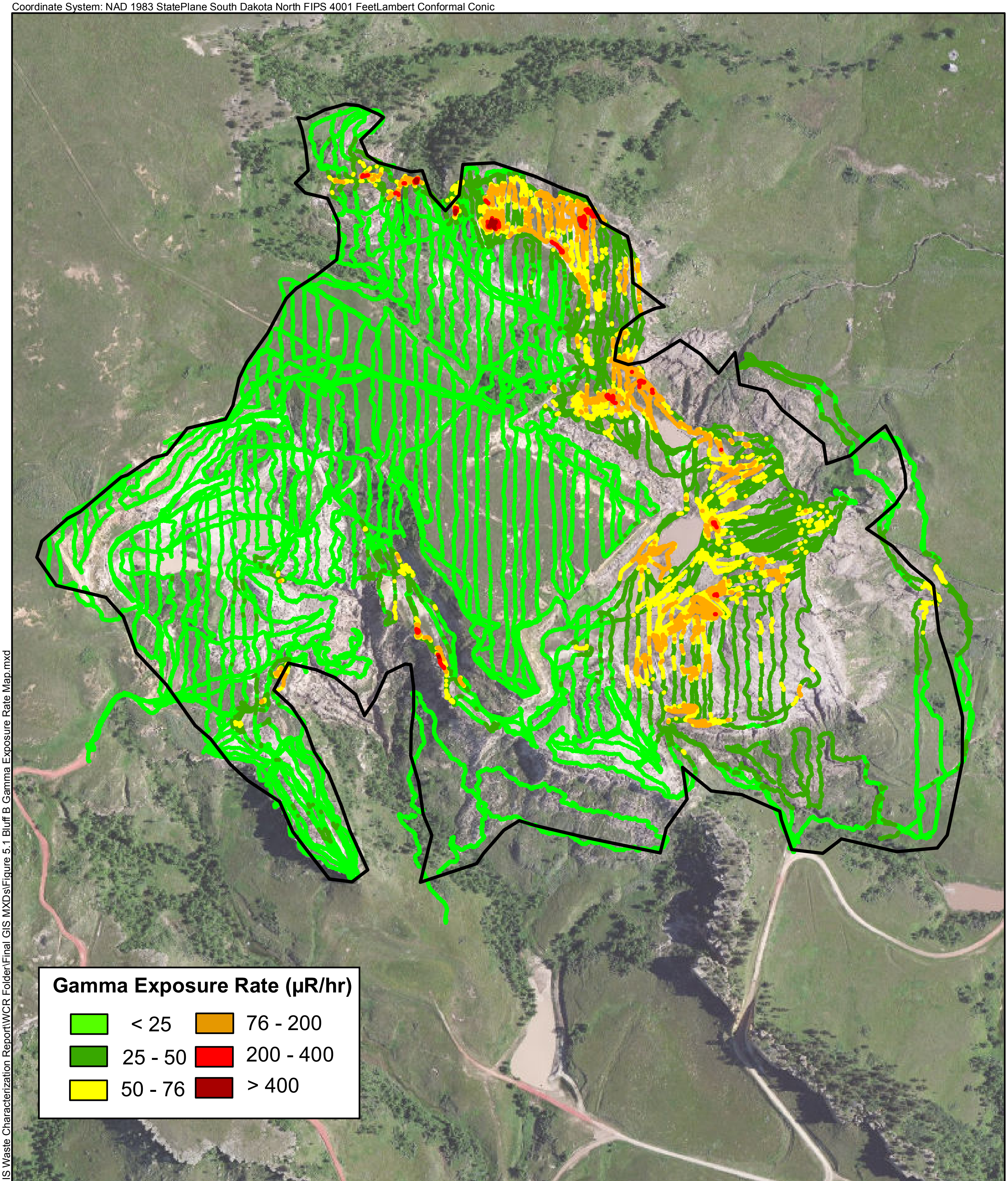
The individual gamma exposure rate measurements collected at Bluff B were converted into radiation dose rates based on the Bicron dose rate/gamma exposure rate cross calibration analysis, as discussed in Section 4.1.1. The raw and kriged dose rate maps are provided in Figure 5-2. The summary statistics for the radiation dose rates collected at Bluff B are presented in Table 5-7.

Table 5-7. Summary Statistics of Bluff B Bicron Radiation Dose Rates

Data Statistic	Result
# of Data Measurements Collected	67,015
Minimum (µR/hr*)	0.81
Maximum (µR/hr)	391
Mean (µR/hr)	14.1
Median (µR/hr)	6.32
Standard Deviation (µR/hr)	20.0
95th Percentile (µR/hr)	97.2
99th Percentile (µR/hr)	183

*µR/hr = micro-Roentgen per hour

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 FeetLambert Conformal Conic



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.1 Bluff B Gamma Exposure Rate Map.mxd

Legend:

Bluff B Boundary

N

0 125 250 500
Feet

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Bluff B Gamma Exposure Rate Map

3
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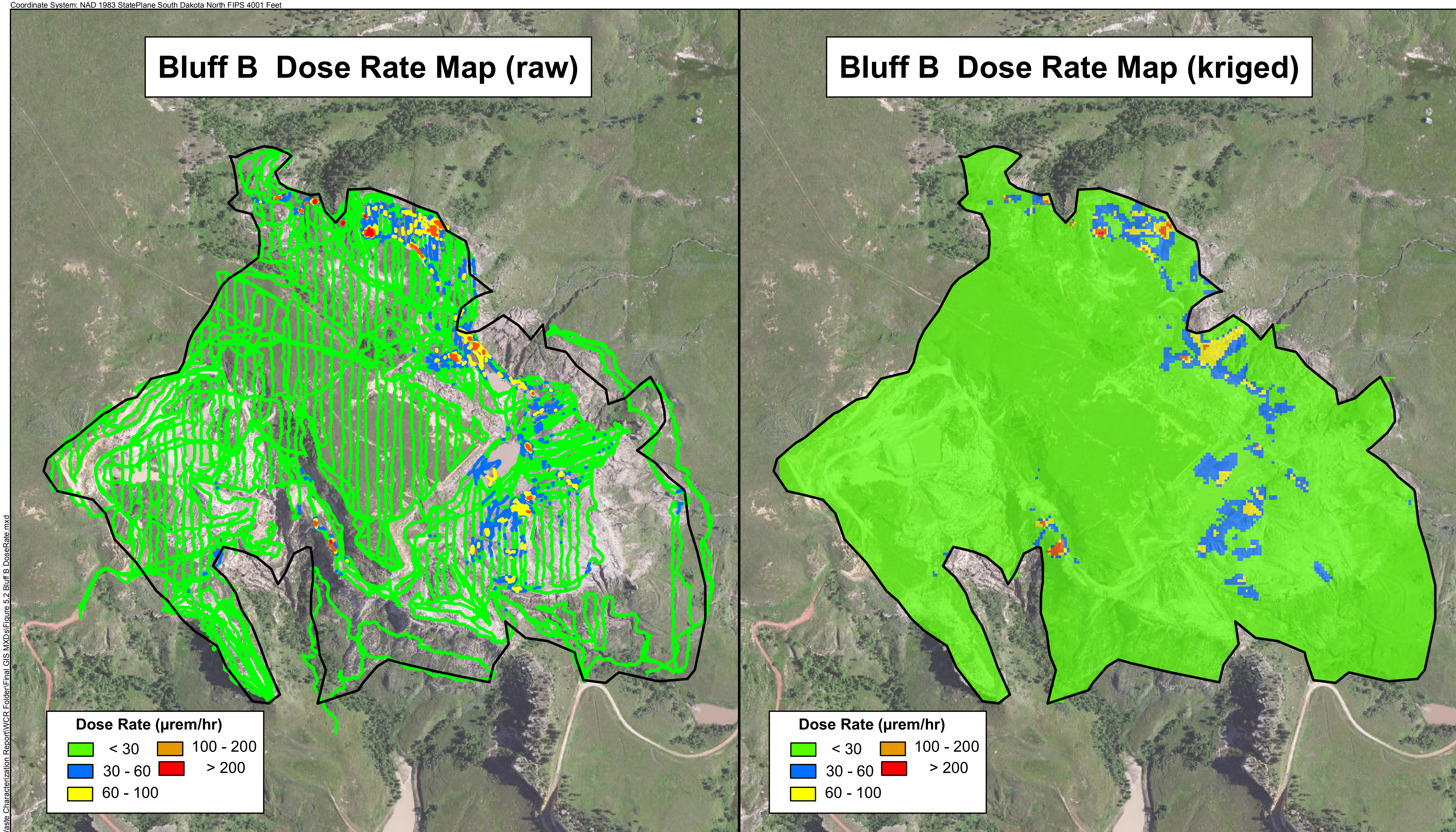
Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-1
Location:	Harding County, South Dakota	June 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Bluff B Boundary

0 250 500 1,000
Feet

N

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Bluff B Dose Rate Map
Raw and Kriged

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-2
Location: HARDING COUNTY COUNTY, SD	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.2 Bluff B DoseRate.mxd

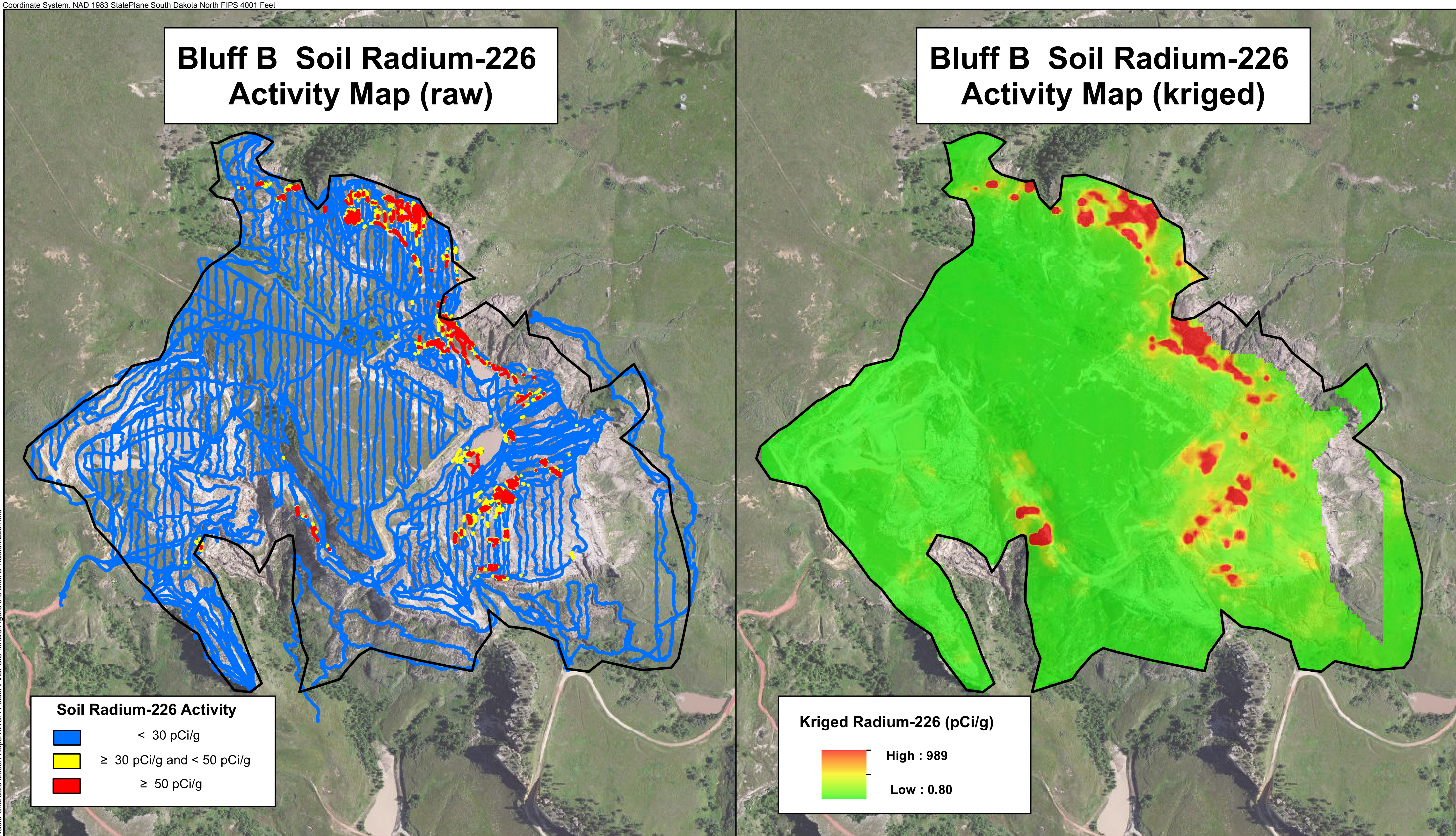
The gamma exposure rate measurements collected at Bluff B were converted into soil ^{226}Ra activity based on the ^{226}Ra /gamma correlation analysis discussed in Section 4.1.2. The soil ^{226}Ra activity at Bluff B ranged between 0.56 pCi/g and 1,846 pCi/g with an average and standard deviation of 11.8 pCi/g and 42.4 pCi/g, respectively. A total of 85 percent of the individual scan data measurements collected at Bluff B were below the soil ^{226}Ra activity cleanup value of 30 pCi/g. Two percent of the individual scan data measurements ranged between 30 pCi/g and 50 pCi/g, and 13 percent of the points were greater than or equal to 50 pCi/g. Table 5-8 presents the summary statistics for the soil ^{226}Ra activity collected at Bluff B. The raw and kriged soil ^{226}Ra activity maps are provided in Figure 5-3.

Table 5-8. Summary Statistics of Soil ^{226}Ra Activity at Bluff B

Data Statistic	Result
Number of Data Measurements Collected	67,015
Minimum (pCi/g*)	0.56
Maximum (pCi/g)	1,846
Mean (pCi/g)	11.8
Median (pCi/g)	2.29
Standard Deviation (pCi/g)	42.4
95th Percentile (pCi/g)	97.2
99th Percentile (pCi/g)	183
% of Points <30 pCi/g	85
% of Points ≥30 pCi/g and <50 pCi/g	2.0
% of Points ≥50 pCi/g	13

* pCi/g = picocuries per gram

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Bluff B Boundary

0 250 500 1,000 Feet

N

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Bluff B Soil Radium-226
Activity Map Raw and Kriged

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-3
Location: HARDING COUNTY COUNTY, SD	June 2013	

3 Revision

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.3 Bluff B Radium226.mxd

5.3.3 Bluff B Gamma Radiation Survey Waste Characterization Summary

The gamma exposure rates collected as part of the 2012 Tronox Bluff waste characterization program were used to estimate the soil ^{226}Ra activity at Bluff B. The data collected provided sufficient information to estimate the areal extent of 93 percent of the area within Bluff B. The remaining 7 percent (10.9 acres) included highwalls and steep slopes or ravines that were too dangerous for the field crew to survey. Table 5-9 provides a summary of the removal action areas based specifically on the estimated soil ^{226}Ra activity at Bluff B.

Table 5-9. Summary of Removal Action Areas by ^{226}Ra at Bluff B

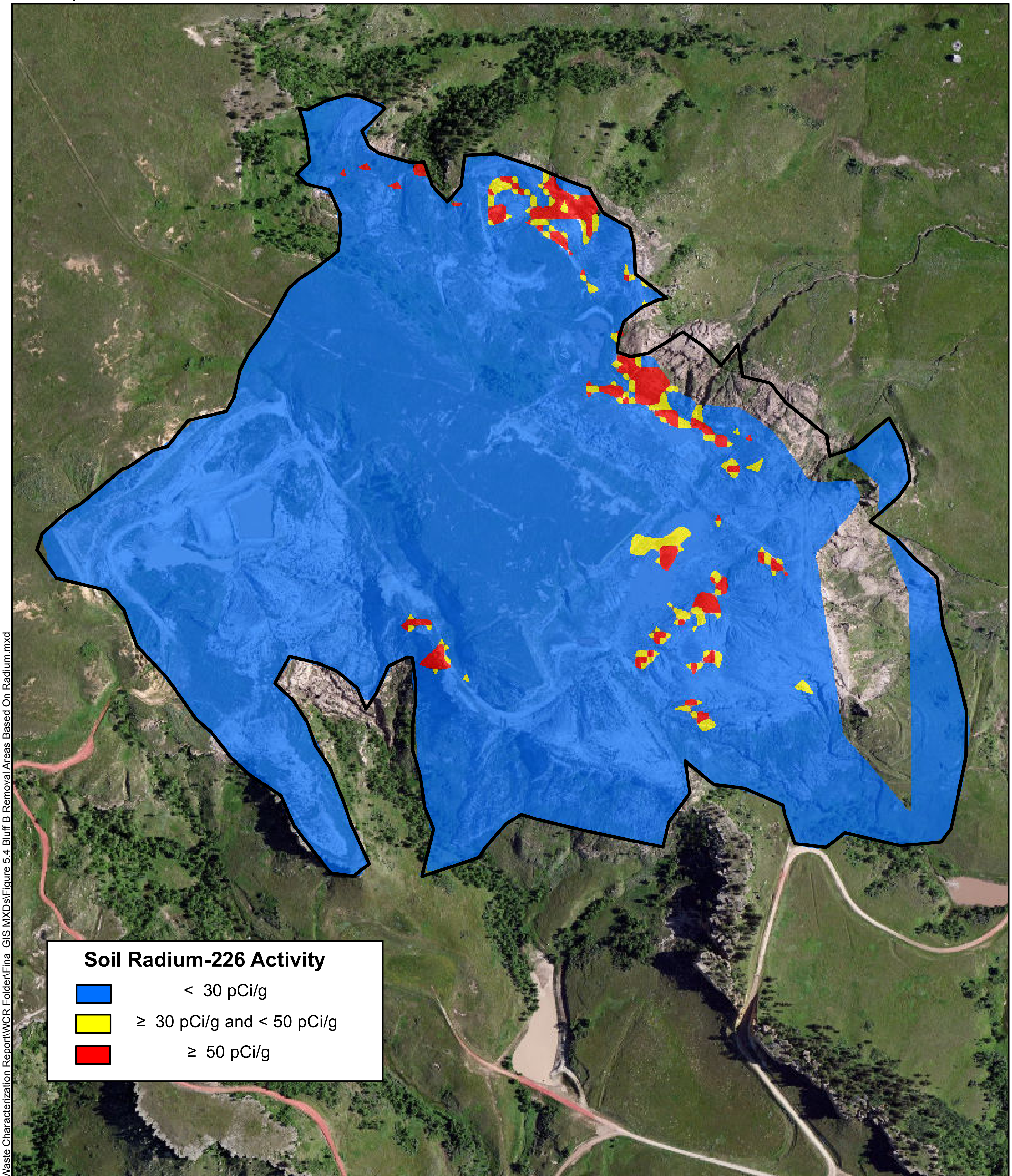
Soil ^{226}Ra Activity	Area (acres)	Percent Area of Bluff B
< 30 pCi/g*	137	90
≥ 30 and < 50 pCi/g	2.18	1.4
≥ 50 pCi/g	2.89	1.9
Unmapped**	10.9	7.1

*pCi/g = picocuries per gram
**The unmapped area at Bluff B includes highwalls and steep slopes where gamma radiation surveys were not performed due to safety considerations.

The areas of elevated soil ^{226}Ra activity at Bluff B are primarily located in the north, northeast, and east to east-central as shown in Figure 5-3. Small pockets of contamination are found in the western and central region. Unmapped areas are also displayed in Figures 5-1 through 5-4 and Figure 5-9 in the east/northeast portions of Bluff B.

Figure 5-4 shows the removal action areas that are based on the soil ^{226}Ra activity cleanup goals as discussed in Section 2.2. This map was created by kriging the individual soil ^{226}Ra activity points collected at Bluff B. The results of the gamma radiation survey show that radiological contamination at this bluff is isolated to only 3.3 percent of the total bluff area with 1.4 percent (2.18 acres) falling between soil ^{226}Ra activity values of 30 pCi/g and 50 pCi/g and 1.9 percent (2.89 acres) of the area measuring soil ^{226}Ra activity values greater than or equal to 50 pCi/g.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 FeetLambert Conformal Conic



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.4 Bluff B Removal Areas Based On Radium.mxd

Legend:

Bluff B Boundary

0 130 260 520 Feet

N

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Bluff B Removal Action Areas Based on Soil Radium-226 Activity

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-4
Location:	Harding County, South Dakota	June 2013	

5.3.4 Bluff B XRF Field Survey Waste Characterization Results

A total of 804 *in-situ* XRF measurements were collected at Bluff B, which is the highest number of XRF sample points collected compared to the other bluffs. The density of *in-situ* XRF measurements collected at Bluff B was 5.25 points per acre. The XRF sample locations, including the soil confirmation sample locations, are illustrated on Figure 4-13. A total of 34 soil confirmation samples were collected at Bluff B and submitted for laboratory analysis.

Correlation analysis and regression equations were developed between the *in-situ* field XRF measurements and laboratory confirmation samples for total arsenic, total molybdenum, and natural uranium (Section 4.2 and Appendix F). The regression equations developed were applied to the 804 *in-situ* XRF measurements collected at Bluff B in order to convert these values into individual definitive, laboratory-equivalent soil concentrations for the constituents of interest. As discussed in section 2.2.3, removal action areas for this project are based on a combination of the following constituents based on the XRF field survey: total arsenic (142 mg/kg), total molybdenum (2,775 mg/kg), ^{238}U (42.8 pCi/g), ^{235}U (2.03 pCi/g), and ^{234}U (44.6 pCi/g).

The XRF and laboratory analyses reported only the natural uranium soil concentrations at Bluff B. However, the removal action levels are based on the three naturally occurring isotopes: ^{238}U, ^{235}U, and ^{234}U as described in Section 2.2. The natural uranium soil concentrations reported in mg/kg were converted to an activity using 0.677 pCi/g per 1 mg/kg. The natural uranium soil activity was then converted into soil activities for each of the isotopes assuming that ^{238}U and ^{234}U each make up 48.9 percent of the total soil activity in natural uranium and that ^{235}U makes up 2.25 percent of the total soil activity in natural uranium. These conversions were predicated on the assumption that the uranium ore deposits analyzed at the Site are in secular equilibrium between ^{238}U and its decay products; this assumption was based on the analysis presented in Section 2.4 of Appendix D of the EE/CA (USFS, 2006). The assumptions and conversions presented herein are also applied to Bluffs CDE, G, and H.

Table 5-10 provides summary statistics for the total arsenic, total molybdenum, natural uranium, ^{238}U, ^{235}U, and ^{234}U soil concentrations measured at Bluff B. A total of 685 of 804 (85.2 percent) sample points were below the total arsenic soil cleanup value of 142 mg/kg, which is protective of human health and environmental receptors. The total arsenic concentrations in the surface soils at Bluff B ranged between 3.04 mg/kg and 2,838 mg/kg with a mean concentration of 95.0 mg/kg. The natural uranium concentration ranged between 0.835 mg/kg and 7,853 mg/kg with a mean concentration of 40.2 mg/kg. The total molybdenum concentration ranged between 0.359 mg/kg and 10,558 mg/kg with a mean concentration of 73.5 mg/kg. For both these metals, there was one point (sample ID# ST45-1) with concentrations outside of the correlation range. The levels of natural uranium and total molybdenum at the Bluff B tend to follow a spatial trend with total arsenic.

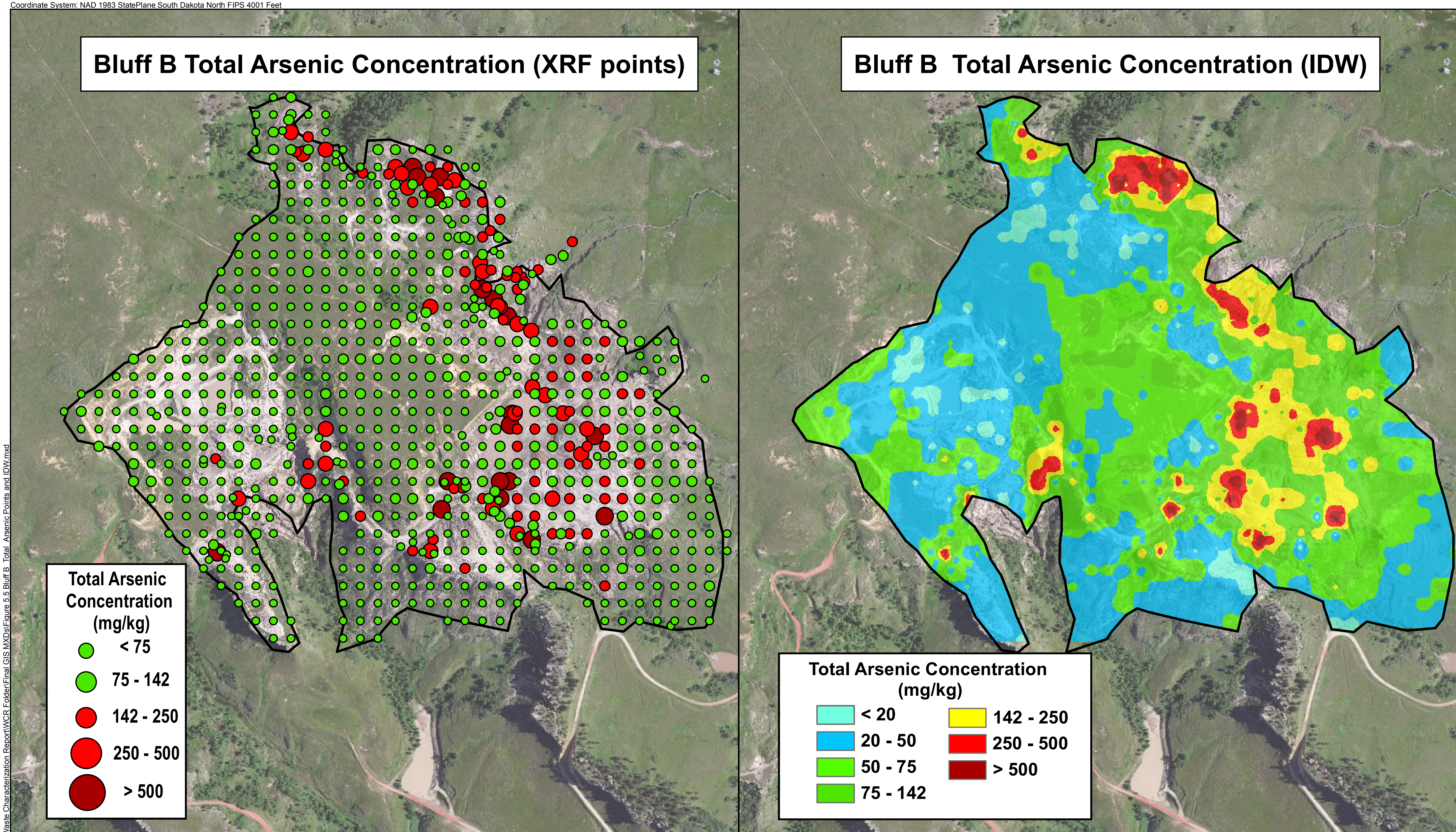
Figure 5-5 through Figure 5-7 present the *in-situ* XRF sample locations mapped by magnitude of converted soil concentrations for total arsenic, natural uranium, and total molybdenum, respectively. On the right side of these figures, the IDW maps showing the estimated ranges for each constituent by different color schemes are presented. Raster maps showing the IDW surface soil values delineated based on removal action cleanup criteria for total molybdenum, ^{238}U, ^{235}U, and ^{234}U at Bluff B are provided in Figure M-1 through Figure M-4 in Appendix M, respectively. Overall, the majority of the exceedances at point measurements of total molybdenum and uranium isotopes were at the same locations where total arsenic exceeded the cutoff value; however, most of the points collected that exceeded removal cutoff levels were for total arsenic soil concentrations at 14.8 percent of the total points.

Table 5-10. Summary Statistics of Bluff B XRF Field Survey Concentrations

Statistic	Total Arsenic (mg/kg*)	Total Molybdenum (mg/kg)	Natural Uranium (mg/kg)	^{238}U (pCi/g**)	^{235}U (pCi/g)	^{234}U (pCi/g)
Removal Action Cutoff Value	**142**	**2,775**	**n/a**	**42.8**	**2.03**	**44.6**
Count	804	803	804	804	804	804
Minimum	3.0	0.4	0.8	0.3	0.01	0.3
Maximum	2,838	10,558	7,853	2,600	120	2,600
Standard Deviation	171	498	296	98.0	4.51	98.0
Median	52.2	4.1	4.1	1.3	0.1	1.3
Mean	95	73.5	40.2	13.3	0.6	13.3
95th Percentile	269	216	130	42.9	1.98	42.9
99th Percentile	796	1,296	732	242	11.2	242
% of Points Exceeding Cutoff Value	14.8	0.50	n/a	5.10	4.85	4.98

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

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Bluff B Boundary

0 250 500 1,000 Feet

N

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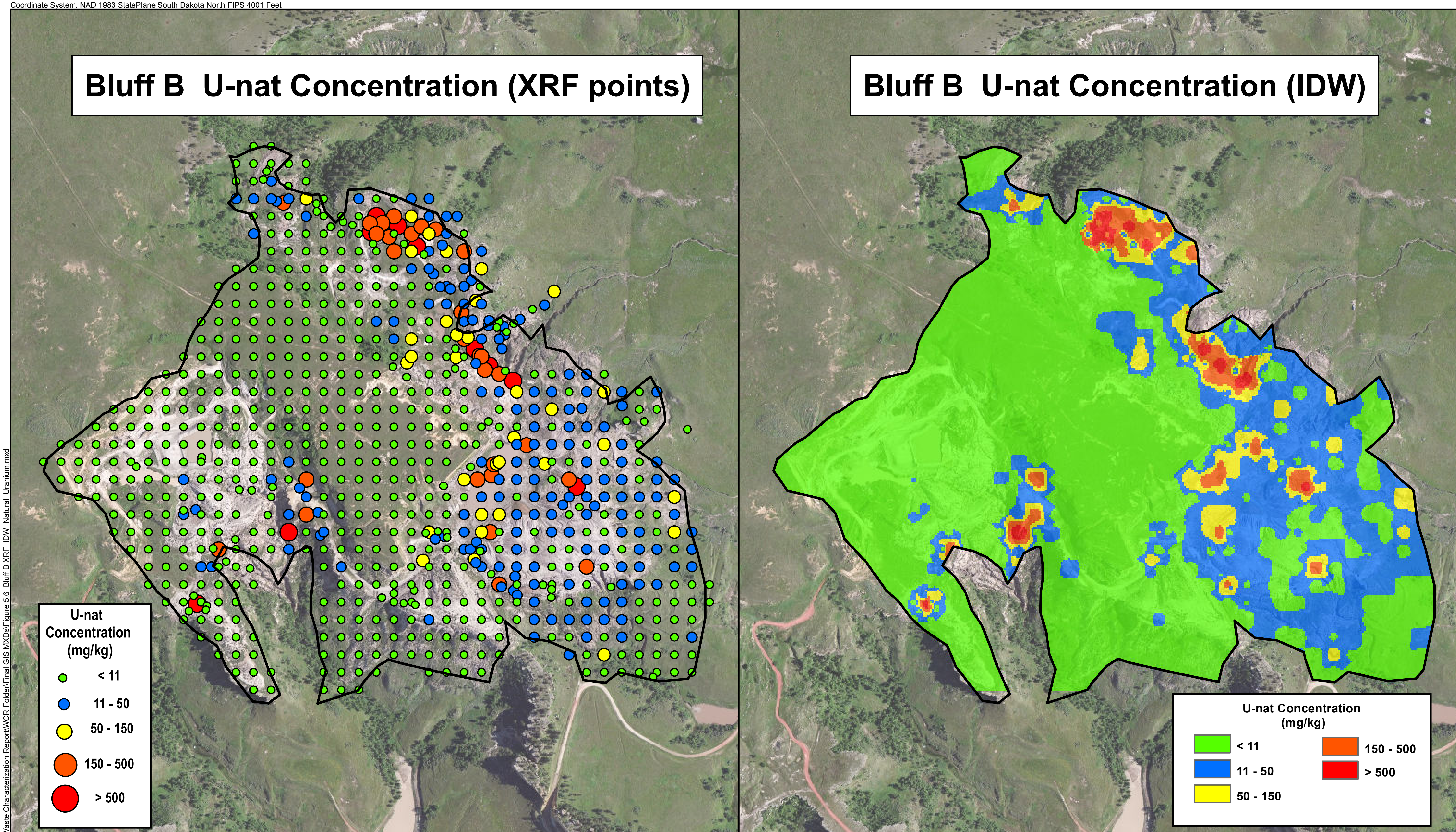
Bluff B XRF ad IDW Total Arsenic Concentration Map		3 Revision
Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-5
Location: HARDING COUNTY COUNTY, SD	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.5 Bluff B Total Arsenic Points and IDW.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Bluff B Boundary

0 250 500 1,000 Feet

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Bluff B XRF ad IDW Natural Uranium Concentration Map

3 Revision

Project: Riley Pass Tronox Bluffs

Project no.: 114-551083

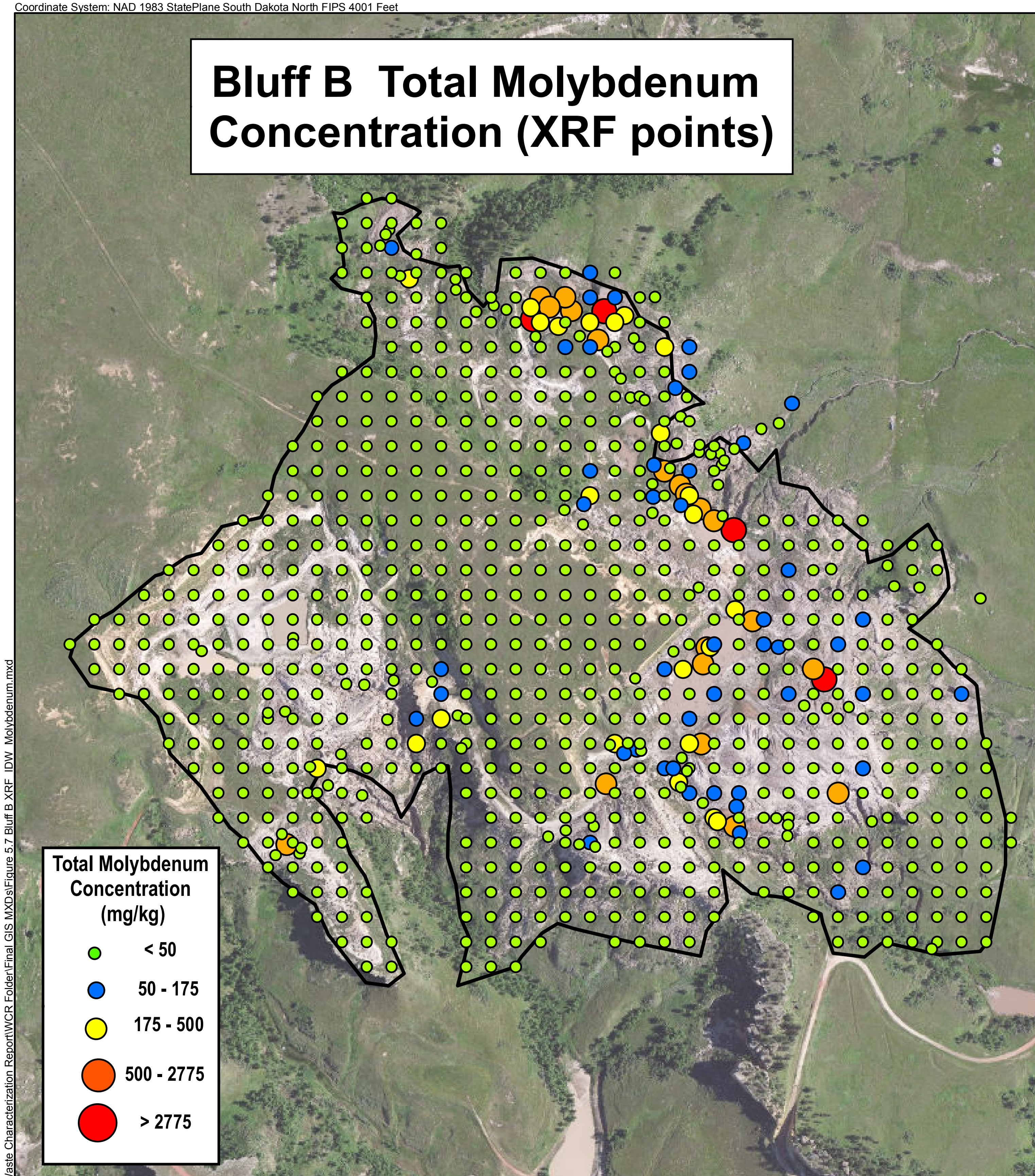
Location: HARDING COUNTY COUNTY, SD

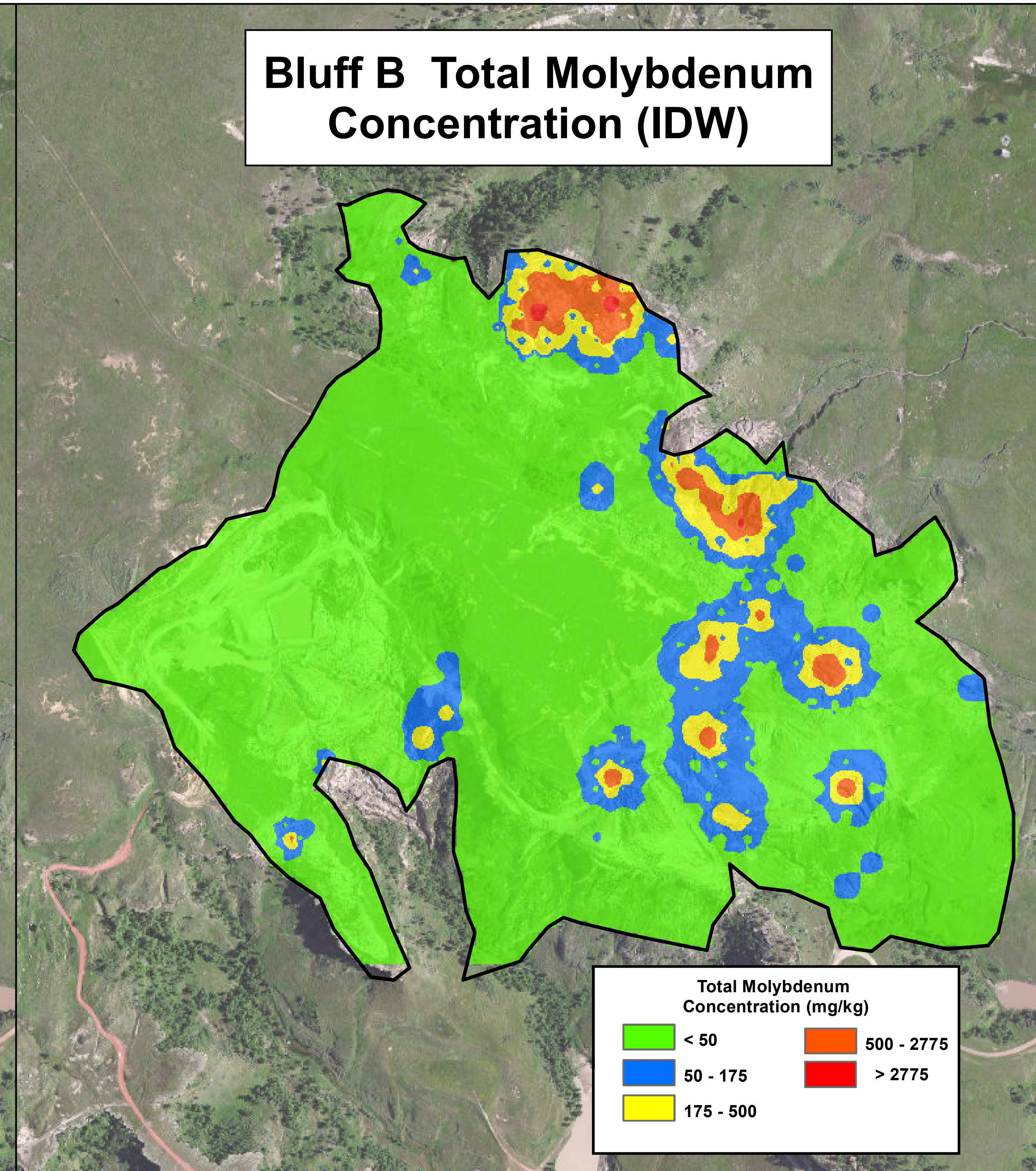
May, 2013

Figure 5-6

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.6 Bluff B XRF IDW Natural Uranium.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet





Legend:

Bluff B Boundary

0 250 500 1,000 Feet

N

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Bluff B XRF ad IDW Molybdenum Concentration Map

3
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Project: Riley Pass Tronox Bluffs

Project no.: 114-551083

Location: HARDING COUNTY COUNTY, SD

June 2013

Figure 5-7

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.7 Bluff B XRF_IDW_Molybdenum.mxd

5.3.5 Bluff B XRF Field Survey Waste Characterization Summary

The *in-situ* XRF measurements collected during the XRF field survey provided sufficient information to estimate the areal extent of total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U soil contamination within the bounds of Bluff B.

Raster data sets were developed for total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U and then combined into a final raster data set that showed the areal extent of all of the contaminated areas merged together that were estimated from the XRF field survey data. The final raster data set was converted into smoothed polygons in order to delineate and estimate the contaminated areas. A flow chart simplifying the logical steps involved for the spatial characterization of gamma radiation and XRF field survey data is provided in Appendix M.

Figure 5-8 shows the areal extent of contaminated areas that were estimated to be above removal action cleanup criteria for at least one of the following constituents: total arsenic (142 mg/kg), total molybdenum (2,775 mg/kg), ^{238}U (42.8 pCi/g), ^{235}U (2.03 pCi/g), and ^{234}U (44.6 pCi/g).

The blue areas on Figure 5-8 show the estimated area that falls below all of the removal action levels, and the red areas show the estimated areas that exceed the soil cleanup levels of at least one of the constituents of concern. Table 5-11 provides a summary of the removal action areas based on the XRF field survey data. The results of the XRF field survey show that 14 percent (21 acres) of the area within Bluff B exceeds at least one of the contaminants of concern identified from the XRF field survey waste characterization data.

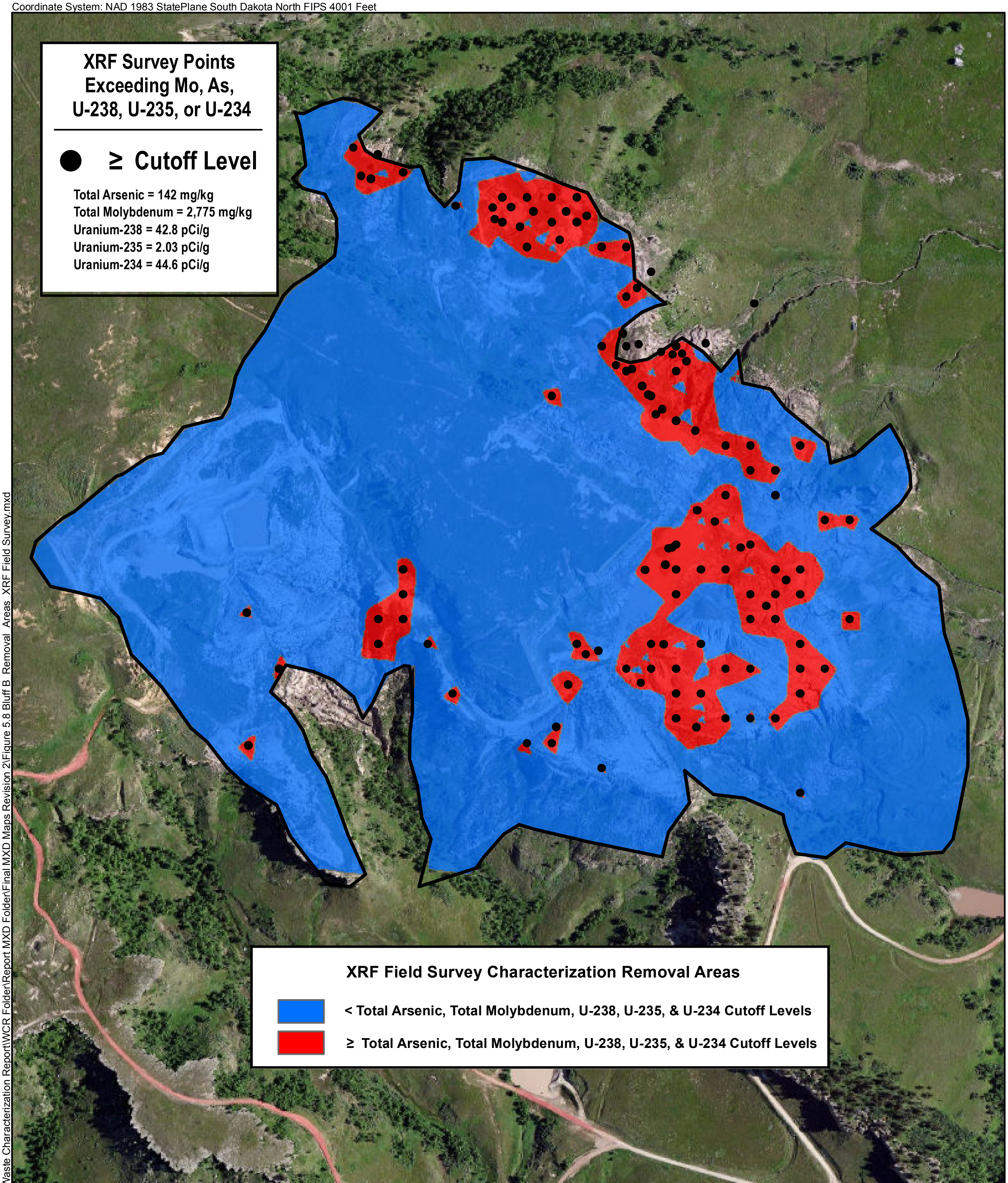
Table 5-11. Summary of Removal Action Areas by XRF Field Survey Data at Bluff B

Contaminant	Removal Action Cutoff Level	Area (acres)	Percent of Bluff B Area
Total Arsenic	<142 mg/kg*	132	86
Total Molybdenum	<2,775 mg/kg		
^{238}U	<42.8 pCi/g**		
^{235}U	<2.03 pCi/g		
^{234}U	<44.6 pCi/g		
Total Arsenic	≥142 mg/kg	21	14
Total Molybdenum	≥2,775 mg/kg		
^{238}U	≥42.8 pCi/g		
^{235}U	≥2.03 pCi/g		
^{234}U	≥44.6 pCi/g		

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

The removal action criteria are based on a combination of the soil ^{226}Ra activity and the total arsenic, total molybdenum, and uranium isotope soil concentrations; the overall waste characterization results are discussed in the following subsection.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Bluff B Boundary

0 125 250 500 Feet

N

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Bluff B Removal Action Areas
Based on XRF Field Survey Data

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-8
Location:	Harding County, South Dakota	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Report MXD Folder\Final MXD Maps Revision 2\Figure 5.8 Bluff B Removal Areas XRF Field Survey.mxd

5.3.6 Bluff B Overall Waste Characterization Summary

The procedures for estimating the ^{226}Ra and total arsenic, total molybdenum, and uranium isotopes removal area for Bluff B are discussed in the previous sections. The summaries of the removal action areas specifically based on the gamma radiation survey (^{226}Ra) and the XRF field survey (As, Mo, ^{238}U, ^{235}U, and ^{234}U) for Bluff B are provided in Table 5-9 and Table 5-11, respectively, and are visually presented in Figure 5-4 and Figure 5-8.

Using the revised mine waste categorical definitions of soil reclamation criteria described in Section 2.2, the mine waste category delineation for the surface soils at Bluff B is shown in Figure 5-9. This map was generated by using the map algebra feature in *ArcMap10©* and combining the raster sets of the gamma radiation survey and the XRF field survey data. After this step, the raster data sets were converted to polygons and then smoothed using the *paek* algorithm with a smoothing tolerance of 50 feet. The summary of removal action areas for Bluff B using the combined data from all of the removal action contaminant criteria are provided in Table 5-12.

Approximately 85.4 percent (130 acres) of the surface soil concentrations at Bluff B do not exceed the soil cleanup values for at least one of the contaminants of concern, and 21.5 acres identified as Category III, which is defined as exceeding the soil cleanup value for at least one of the contaminants and/or measuring over 50 pCi/g of ^{226}Ra. As stated in the 2007 Action Memorandum, Category III areas require remediation in order to reduce the contaminant levels to below the soil cleanup values.

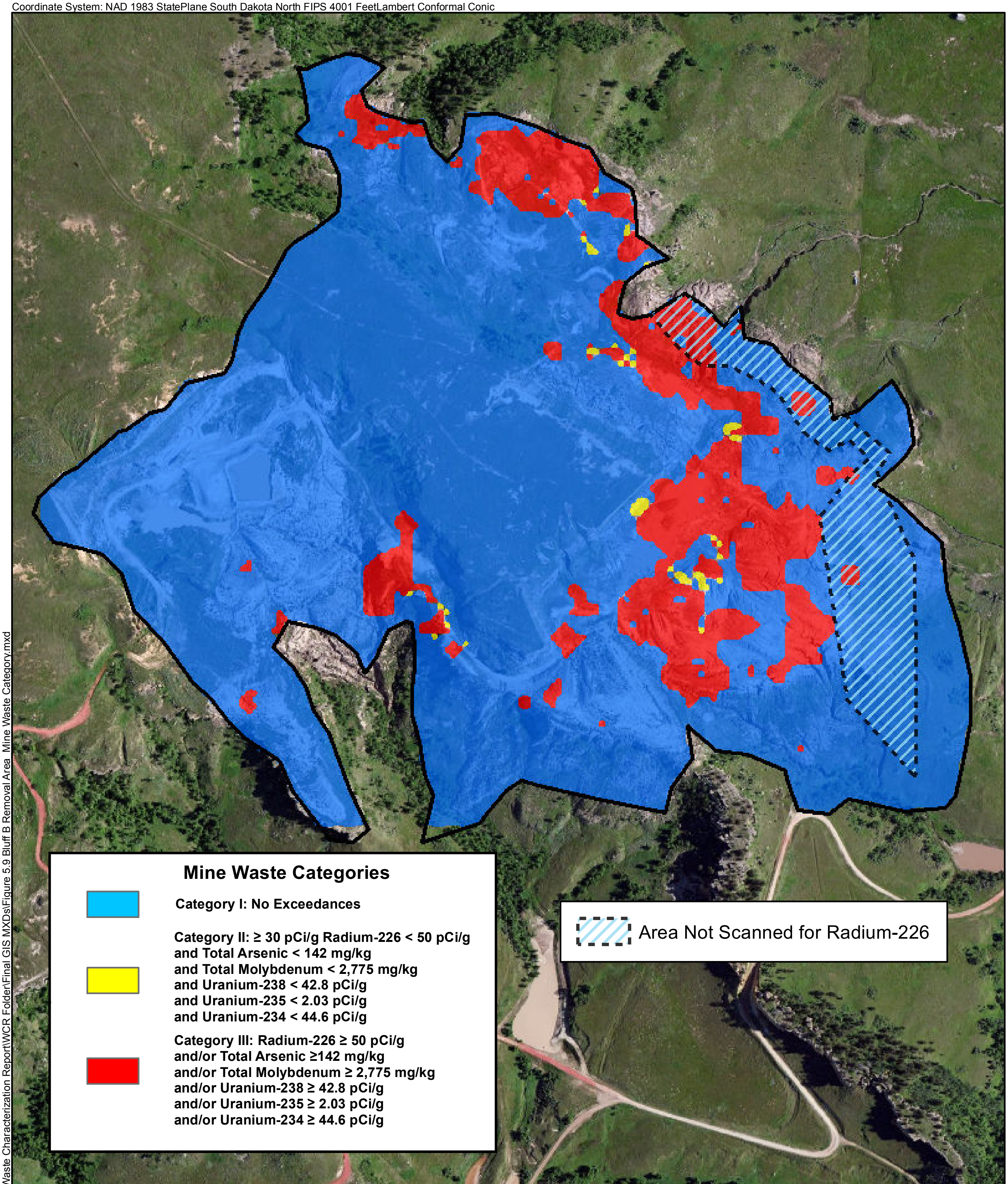
Table 5-12. Summary of Mine Waste Categories for Bluff B

Category	Soil Reclamation Criteria	Area (acres)	Percent Area of Bluff B
I	**No Exceedances**: < 30 pCi/g* ^{226}Ra and < 142 mg/kg** Total As and < 2,775 mg/kg Total Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U	130	85.4
II	**^{226}Ra Exceedance Only:** ≥ 30 pCi/g and < 50 pCi/g ^{226}Ra and < 142 mg/kg Total As and < 2,775 mg/kg Total Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U	0.684	0.45
III	**Exceedances of Any Contaminant**: ≥ 50 pCi/g ^{226}Ra and/or ≥ 142 mg/kg Total As and/or ≥ 2,775 mg/kg Total Mo and/or ≥ 42.8 pCi/g ^{238}U and/or ≥ 2.03 pCi/g ^{235}U and/or ≥ 44.6 pCi/g ^{234}U	21.5	14.1

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

Figure 5-9 shows the mine waste categories for Bluff B. As described in Section 5.3.3 (Table 5-9), there was a 10.9-acre area of Bluff B that was not surveyed for gamma radiation. This area is shown in Figure 5-9 as a hatched surface; this region has not been characterized for ^{226}Ra, but has been characterized for the other contaminants.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 FeetLambert Conformal Conic



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.9 Bluff B Removal Area Mine Waste Category.mxd

Legend:

Bluff B Boundary

0 125 250 500 Feet

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Bluff B- Removal Action Areas and Mine Waste Category Map

3
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Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-9
Location:	Harding County, South Dakota	June 2013	

5.4 Bluff CDE Waste Characterization Results

This section presents the waste characterization results for Bluff CDE, including an existing conditions overview, summary, and results of the XRF field survey waste characterization, and a summary and results of the gamma radiation survey waste characterization. An overall summary of the Tronox Bluff waste characterization study is presented in Section 5.10.

5.4.1 Bluff CDE Existing Conditions Overview

The original scope of work defined by the USFS and Tetra Tech assumed that Bluff C, D, and E were individual bluffs separated geographically and environmentally. After initial waste characterization surveys were completed within the original proposed boundaries, it was concluded that these bluffs were not, in fact, isolated, but were interconnected due to contiguous areas of elevated radiation and metals levels. As previously discussed, for the purposes of this report, all of the information collected within Bluffs C, D, and E is to be considered as one larger bluff, called Bluff CDE. The original areas delineated by the USFS of Bluff C (11.3 acres), Bluff D (5.02 acres), and Bluff E (0.935 acres) totaled 17.3 acres. The revised boundary of Buff CDE now encompasses 48.1 acres. A comparison of pre-mining and present conditions by way of aerial photography is shown for Bluff CDE in Figure 1-6. A photographic log showing many of the existing site features in addition to historical photographs at Bluff CDE is included in Appendix N.

As part of the waste characterization program and outlined in the SAP, the amount of overburden, vegetation, and extent of erosion was noted and a visual observation was performed. A reclamation scientist from KC Harvey Environmental, LLC performed an erosion and vegetation survey that is included in Appendix O. Based on this survey, there is no significant erosion at Bluffs CDE, but several areas were void of soil and vegetation that would require a soil cover and vegetation. The bluffs consists mainly of bare areas with contaminated soil at shallow depths, rock surfaces, forested areas with little to no soil over the rock, and piles of unknown materials in historic mining areas. Spoils piles and berms are scattered throughout Bluff CDE; and the overall extent of these bluffs expands past the original areas identified in the EE/CA (USFS, 2006). As stated in the 2007 Action Memorandum and EE/CA, these bluffs are overall considered stable and only minimal removal action work is assumed necessary.

5.4.2 Bluff CDE Gamma Radiation Survey Waste Characterization Results

A total of 22,191 gamma exposure rate measurements were collected at Bluff CDE, which results in a scan density of 458 points per acre. The gamma exposure rate ranged between 14.8 µR/hr and 1,054 µR/hr, with a mean exposure rate of 103 µR/hr. The standard deviation, 95^{th} percentile, and 99^{th} percentile of the gamma exposure rates collected at Bluff CDE was 101 µR/hr, 300 µR/hr, and 487 µR/hr, respectively. Table 5-13 provides a statistical summary of the gamma exposure rate data collected at Bluff CDE. The raw gamma exposure rate map for Bluff CDE is shown in Figure 5-10.

Table 5-13. Summary Statistics of Bluff CDE Gamma Exposure Rates

Data Statistic	Result
# of Data Measurements Collected	22,191
Minimum (µR/hr*)	14.8
Maximum (µR/hr)	1,054
Mean (µR/hr)	103
Median (µR/hr)	68.3
Standard Deviation (µR/hr)	101
95^{th} Percentile (µR/hr)	300
99^{th} Percentile (µR/hr)	487

*µR/hr = micro-Roentgen per hour

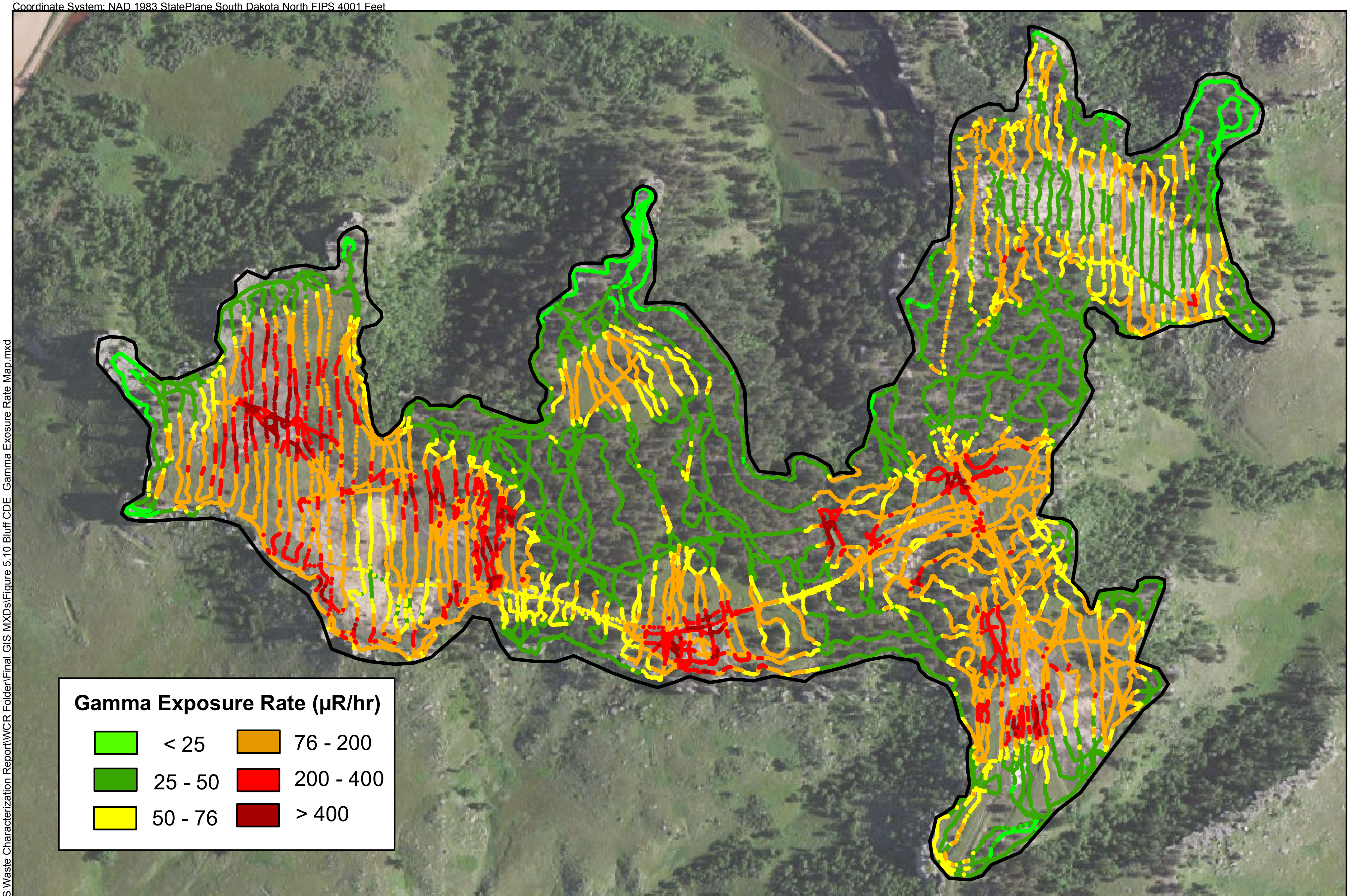
The gamma exposure rates collected at Bluff CDE were converted into radiation dose rates based on the Bicron dose rate/gamma exposure rate cross calibration analysis, discussed in Section 4.1.1. The raw and kriged dose rate maps are provided in Figure 5-11. The summary statistics for the radiation dose rates collected at Bluff CDE are presented in Table 5-14.

Table 5-14. Summary Statistics of Bluff CDE Bicron Radiation Dose Rates

Data Statistic	Result
# of Data Measurements Collected	22,191
Minimum (µR/hr*)	4.13
Maximum (µR/hr)	573
Mean (µR/hr)	52.2
Median (µR/hr)	33.4
Standard Deviation (µR/hr)	55.2
95^{th} Percentile (µR/hr)	160
99^{th} Percentile (µR/hr)	262

*µR/hr = micro-Roentgen per hour

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff CDE Boundary

0 125 250 500 Feet

N

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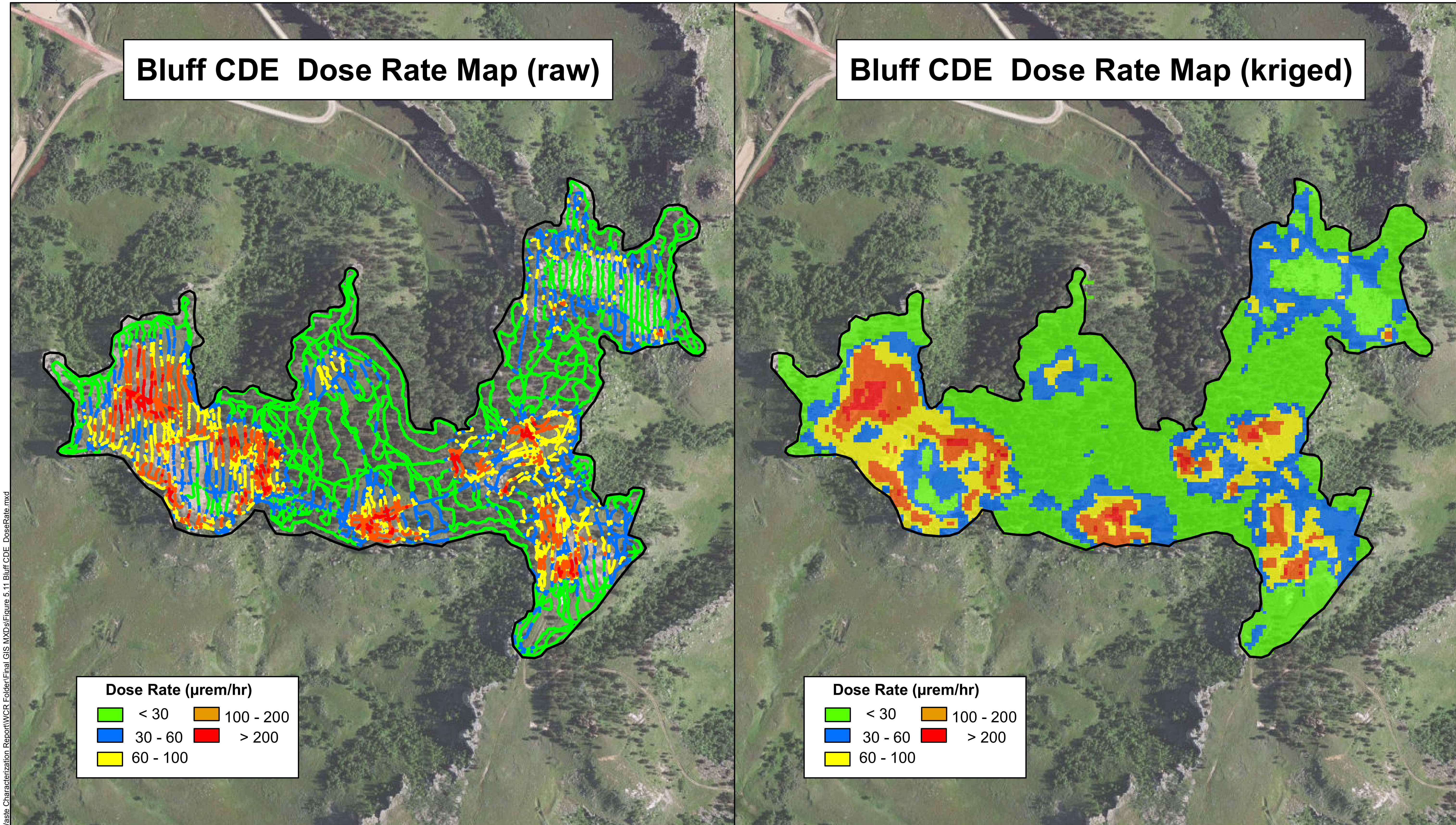
Bluff CDE
Gamma Exposure Rate Map

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083		Figure 5-10
Location: Harding County, South Dakota	June 2013		

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.10 Bluff CDE Gamma Exposure Rate Map.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff CDE Boundary

0 250 500 1,000 Feet

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Bluff CDE Dose Rate Map
Raw and Kriged

3 Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083
Location: HARDING COUNTY COUNTY, SD	June 2013

Figure 5-11

X:\551083 - Riley Pass\GIS\Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.11 Bluff CDE_DoseRate.mxd

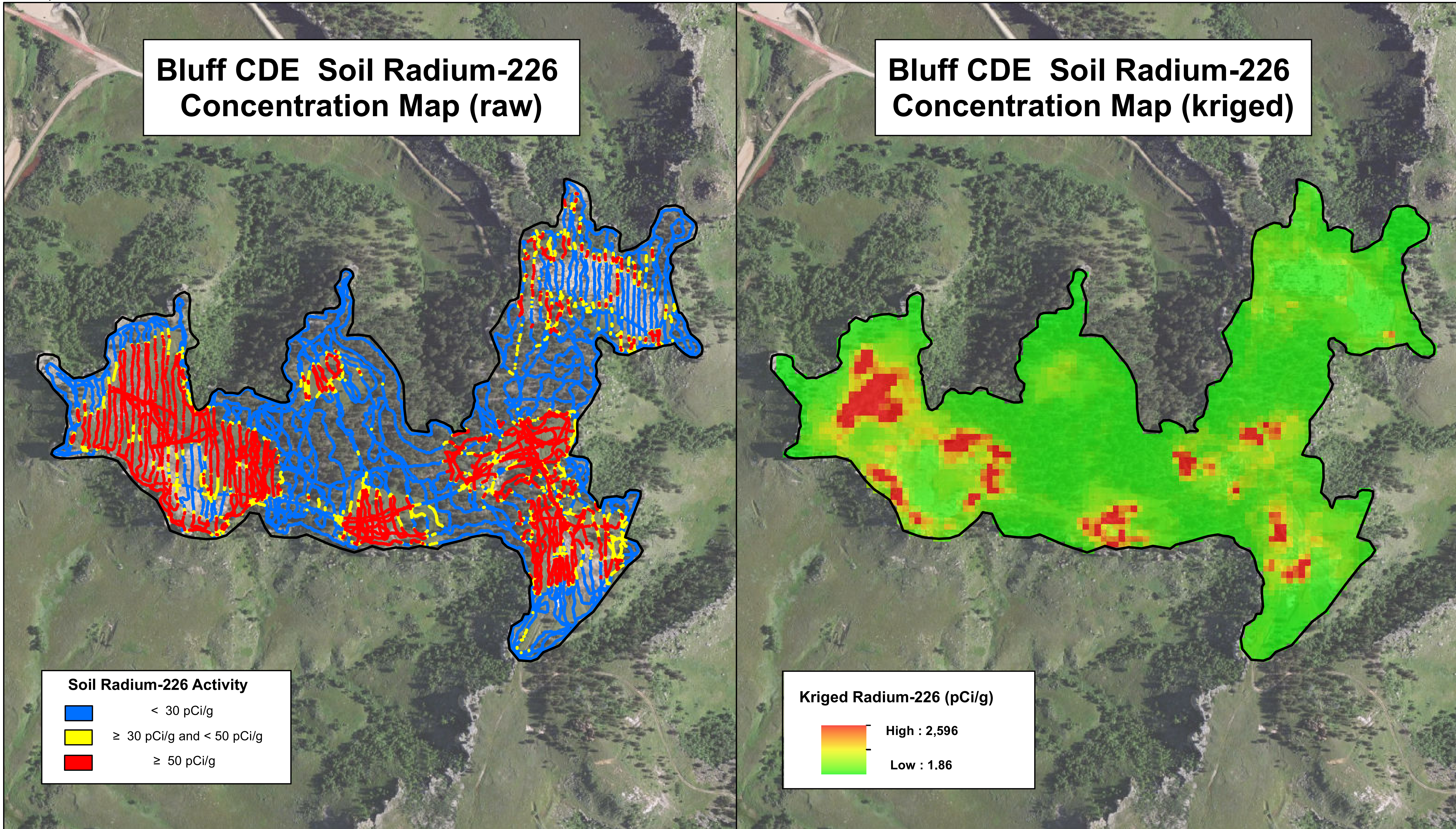
The gamma exposure rate measurements collected at Bluff CDE were converted into soil ^{226}Ra activity using the regression model presented in Section 4.1.2. The soil radium-226 activity at Bluff CDE ranged between 1.47 pCi/g and 3,699 pCi/g, with an average and standard deviation of 86.8 pCi/g and 209 pCi/g, respectively. A total of 55 percent of the scan data collected at Bluff CDE were below the ^{226}Ra soil cleanup value of 30 pCi/g. Eleven percent of the points collected ranged between 30 pCi/g to 50 pCi/g, and 35 percent of the points were greater than or equal to 50 pCi/g. Table 5-15 presents the summary statistics for the soil ^{226}Ra activity collected at Bluff CDE. The raw and kriged soil ^{226}Ra activity maps are provided in Figure 5-12.

Table 5-15. Summary Statistics of Soil ^{226}Ra Activity at Bluff CDE

Data Statistic	Result
Number of Data Measurements Collected	22,191
Minimum (pCi/g*)	1.47
Maximum (pCi/g)	3,699
Mean (pCi/g)	86.8
Median (pCi/g)	24.4
Standard Deviation (pCi/g)	209
95th Percentile (pCi/g)	368
99th Percentile (pCi/g)	895
% of Points <30 pCi/g	55
% of Points ≥30 pCi/g and <50 pCi/g	11
% of Points ≥50 pCi/g	35

*pCi/g = picocuries per gram

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff CDE Boundary

0 250 500 1,000 Feet

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Bluff CDE Soil Radium-226
Activity Map Raw and Kriged

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-12
Location: HARDING COUNTY COUNTY, SD	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.12 Bluff CDE Radium 226.mxd

5.4.3 Bluff CDE Gamma Radiation Survey Waste Characterization Summary

The gamma exposure rates collected as part of the 2012 Tronox Bluff waste characterization program were used to estimate the soil ^{226}Ra activity at Bluff CDE. The data collected provided sufficient information to estimate the areal extent of the area within the revised boundary of Bluff CDE. Table 5-16 provides a summary of the removal action areas at Bluff CDE based strictly on soil ^{226}Ra activity.

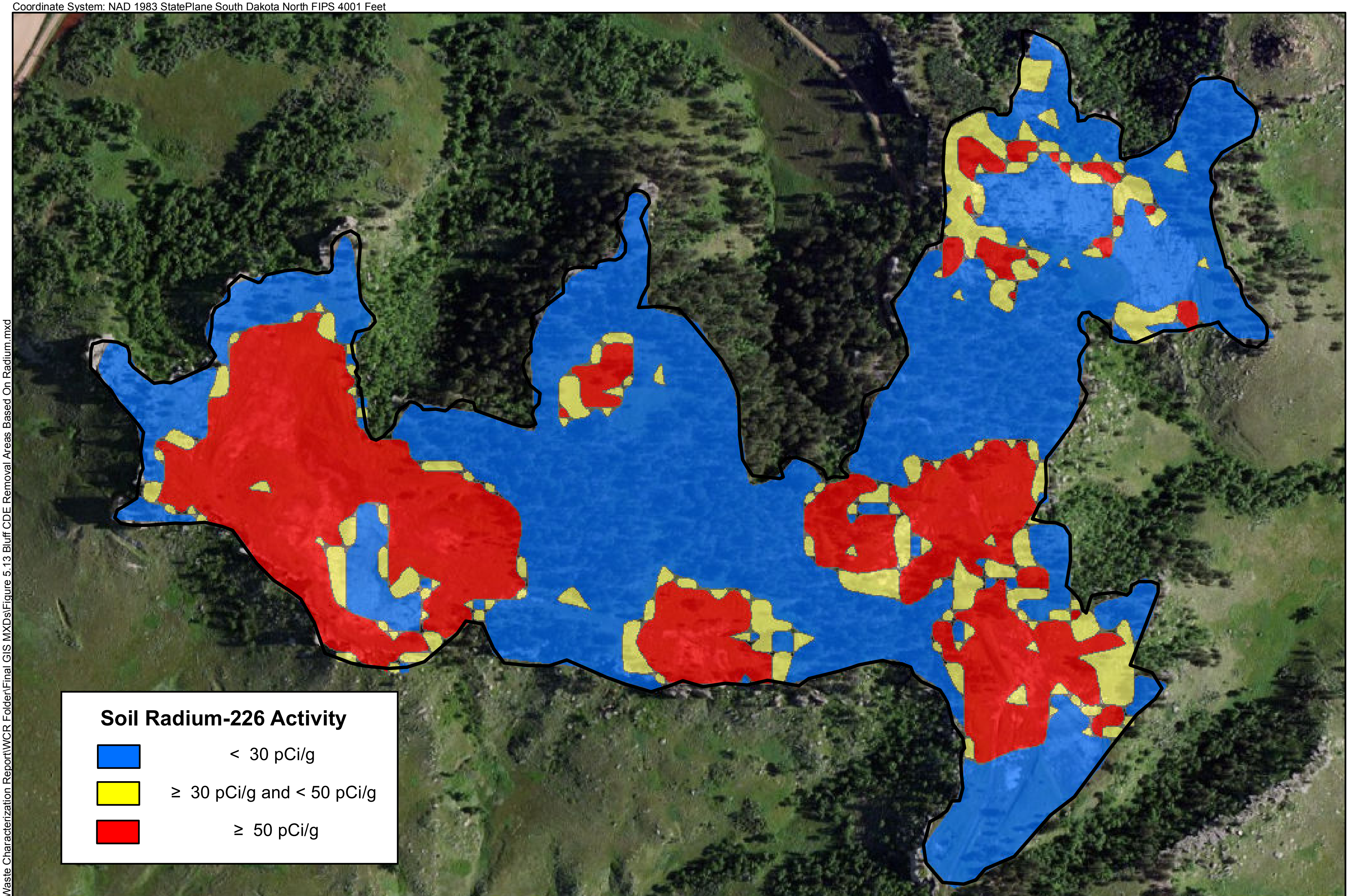
Table 5-16. Summary of Removal Action Areas by ^{226}Ra at Bluff CDE

Soil ^{226}Ra Activity	Area (acres)	Percent Area of Bluff CDE
< 30 pCi/g*	27.6	58
≥ 30 and < 50 pCi/g	5.48	12
≥ 50 pCi/g	14.5	30

*pCi/g = picocuries per gram

The areas of elevated soil ^{226}Ra activity at Bluff CDE are scattered throughout most of the bluff as shown in Figure 5-12. Figure 5-13 shows the removal action areas that are based on the criteria set forth in the 2007 Action Memorandum and discussed in Section 2.2. This map was created by kriging the individual soil ^{226}Ra activity points that were collected at Bluff CDE. The results of the gamma radiation survey show the radiological contamination at this bluff expands over 41.1 percent of the entire area; with 11.6 percent (5.5 acres) falling within soil ^{226}Ra activity values between 30 pCi/g to 50 pCi/g and 29.5 percent (14 acres) of the area that is greater than or equal to a soil ^{226}Ra activity of 50 pCi/g.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

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N

0 125 250 500 Feet

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Bluff CDE- Removal Action Areas Based on Soil Radium-226 Activity

3 Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-13
Location:	Harding County, South Dakota	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.13 Bluff CDE Removal Areas Based On Radium.mxd

5.4.4 Bluff CDE XRF Field Survey Waste Characterization Results

A total of 293 *in-situ* XRF measurements were collected at Bluff CDE, making the density of XRF measurements collected at Bluff CDE 6.1 points per acre. The XRF sample locations, including the soil confirmation sample locations, are illustrated on Figure 4-14. A total of 19 soil confirmation samples were collected at Bluff CDE and submitted for laboratory analysis.

Correlation analysis and regression equations were developed between the *in-situ* field XRF measurements and laboratory confirmation samples for total arsenic, total molybdenum, and natural uranium (Section 4.2 and Appendix F). The regression equations developed were applied to the 293 *in-situ* XRF measurements collected at Bluff CDE in order to convert these values into individual definitive, laboratory-equivalent soil concentrations for the constituents of interest. Removal action areas for this project are based on a combination of the following constituents based on the XRF field survey: total arsenic (142 mg/kg), total molybdenum (2,775 mg/kg), ^{238}U (42.8 pCi/g), ^{235}U (2.03 pCi/g), and ^{234}U (44.6 pCi/g) (Section 2.2). The methods and assumptions used in this study to convert the natural uranium concentrations to the uranium isotopes of interest are presented in Section 5.3.4.

Table 5-17 provides summary statistics for the total arsenic, total molybdenum, natural uranium, ^{238}U, ^{235}U, and ^{234}U soil concentrations measured at Bluff CDE. A total of 151 of 293 (51.5 percent) sample points were below the total arsenic soil cleanup value of 142 mg/kg, indicating that Bluff CDE has the highest percentage of points that exceed the soil cleanup value for all of the bluffs. The total arsenic concentrations in the surface soils at Bluff CDE ranged between 5.21 mg/kg and 2,953 mg/kg, with a mean concentration of 230 mg/kg. The natural uranium concentration ranged between 3.4 mg/kg and 4,305 mg/kg, with a mean concentration of 337 mg/kg. The total molybdenum concentration ranged between 2.5 mg/kg and 6,134 mg/kg, with a mean concentration of 421 mg/kg.

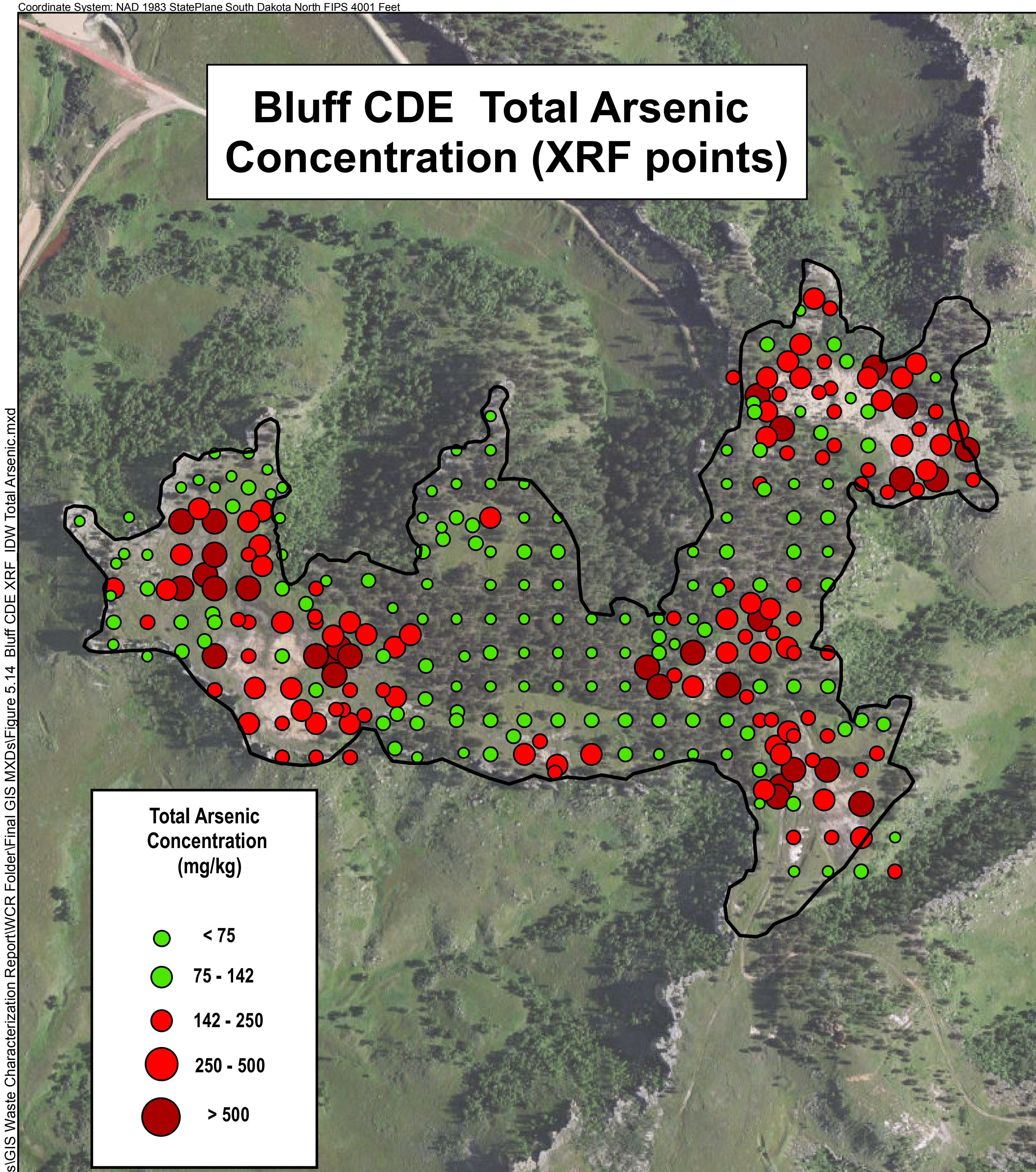
Figure 5-14 through Figure 5-16 present the *in-situ* XRF sample locations mapped by the magnitude of converted soil concentrations for total arsenic, natural uranium, and total molybdenum, respectively. On the right-hand side of these figures, the IDW maps showing the estimated ranges for each constituent by different color schemes are presented. Raster maps showing the interpolated (IDW) surface soil values delineated based on removal action cleanup criteria for total molybdenum, ^{238}U, ^{235}U, and ^{234}U at Bluff CDE are provided in Figure M-5 through Figure M-8 in Appendix M, respectively. In general, the exceedances at point measurements of total molybdenum and uranium isotopes removal action levels were co-located with samples where total arsenic also exceeded the cutoff value. A total of 48.5 percent of the total arsenic samples collected at Bluff CDE exceeded the soil cutoff value.

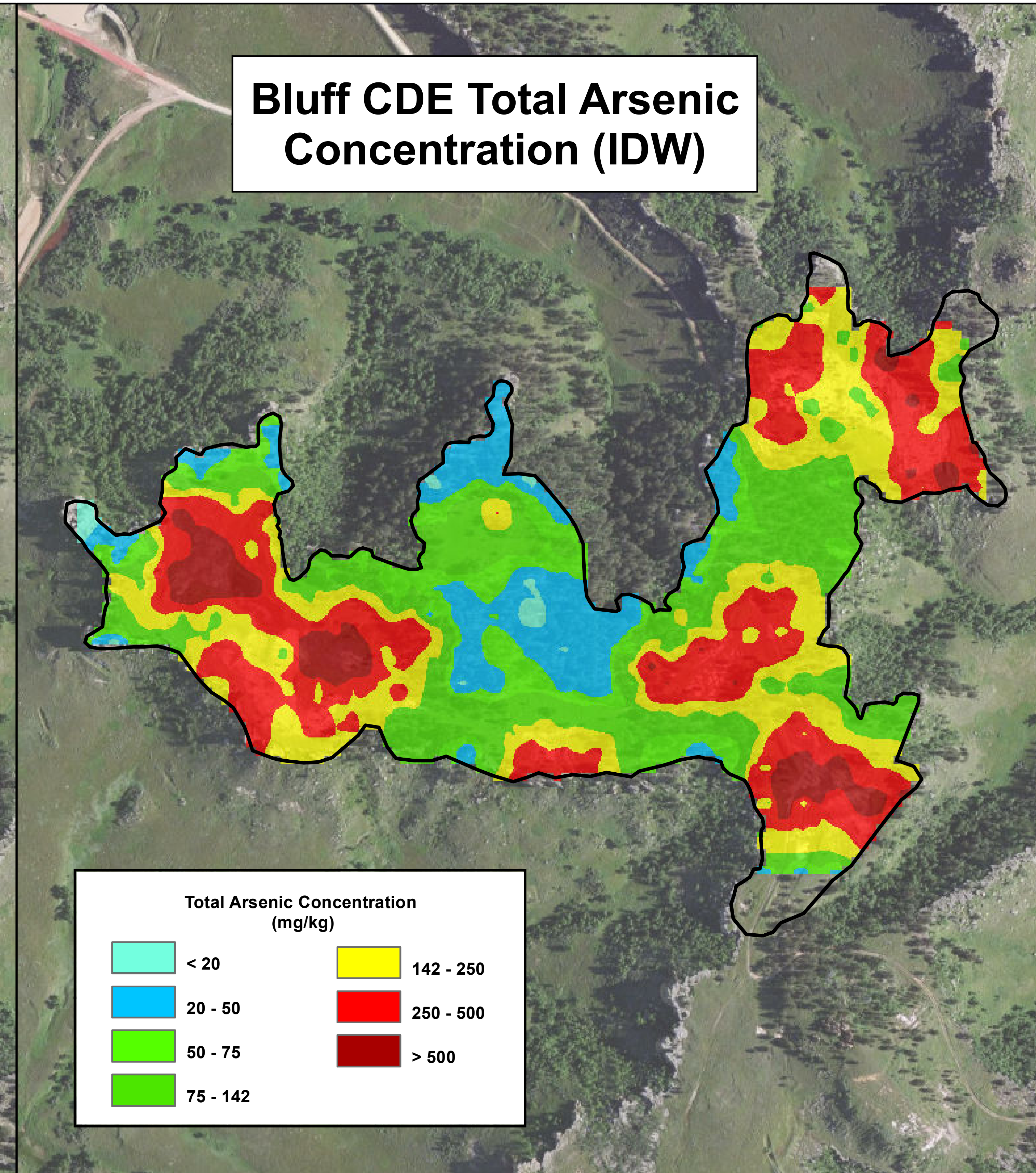
Table 5-17. Summary Statistics of Bluff CDE XRF Field Survey Concentrations

Statistic	Total Arsenic (mg/kg*)	Total Molybdenum (mg/kg)	Natural Uranium (mg/kg)	^{238}U (pCi/g**)	^{235}U (pCi/g)	^{234}U (pCi/g)
Removal Action Cutoff Value	**142**	**2,775**	**n/a**	**42.8**	**2.03**	**44.6**
Count	293	293	293	293	293	293
Minimum	5.21	2.5	3.4	1.1	0.05	1.1
Maximum	2,953	6,134	4,305	1,425	65.6	1425
Standard Deviation	306	937	673	223	10.3	223
Median	136	107	105	34.7	1.6	34.7
Mean	230	421	337	112	5.1	112
95th Percentile	645	1,633	1278	423	19.5	423
99th Percentile	1,273	5,759	4,063	1,345	61.9	1,345
% of Points Exceeding Cutoff Value	48.5	3.41	n/a	45.1	43.0	42.7

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

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet





Legend:

2012 Revised Bluff CDE Boundary

0 250 500 1,000 Feet

N

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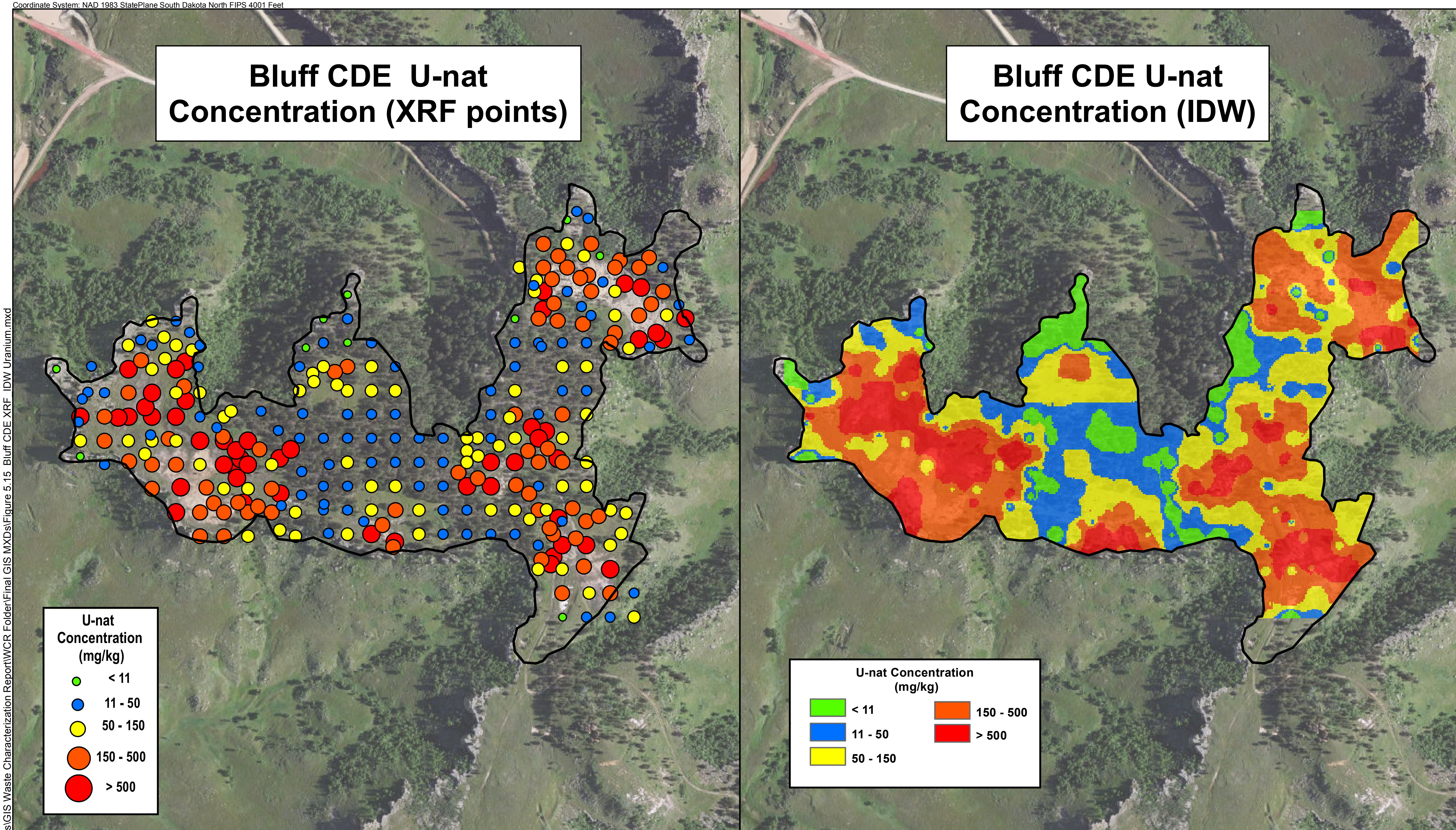
Bluff CDE XRF and IDW Total Arsenic Concentration Map

3 Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-14
Location:	HARDING COUNTY COUNTY, SD	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.14 Bluff CDE XRF IDW Total Arsenic.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

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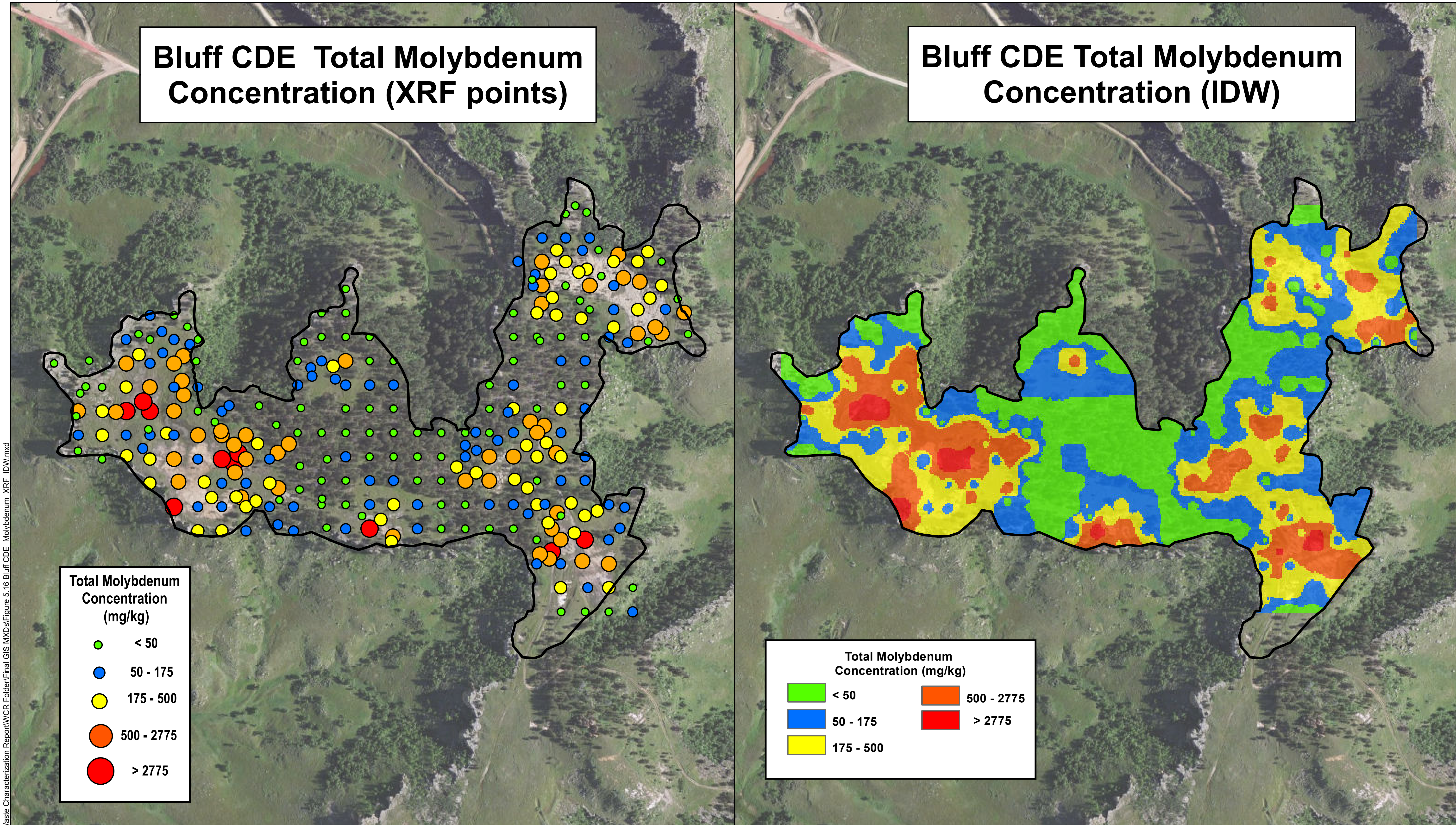
Bluff CDE XRF and IDW Natural Uranium Concentration Map

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-15
Location: HARDING COUNTY COUNTY, SD	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.15 Bluff CDE XRF IDW Uranium.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

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0 250 500 1,000 Feet

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Bluff CDE XRF and IDW Total Molybdenum Concentration Map

3 Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083
Location: HARDING COUNTY COUNTY, SD	June, 2013

Figure 5-16

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.16 Bluff CDE Molybdenum XRF IDW.mxd

5.4.5 Bluff CDE XRF Field Survey Waste Characterization Summary

The *in-situ* XRF samples collected during the field survey provided sufficient information to estimate the areal extent of total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U soil contamination within the bounds of Bluff CDE.

Raster data sets were developed for total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U, which were then combined into a final raster data set that showed the areal extent of all of the contaminated areas merged together that were estimated from the XRF field survey data. The final raster data set was converted into smoothed polygons in order to delineate and estimate the contaminated areas. A flow chart simplifying the logical steps involved for the spatial characterization of gamma radiation and XRF field survey data is provided in Appendix M.

Figure 5-17 shows the areal extent of contaminated areas that were estimated to be above removal action cleanup criteria for at least one of the following constituents: total arsenic (142 mg/kg), total molybdenum (2,775 mg/kg), ^{238}U (42.8 pCi/g), ^{235}U (2.03 pCi/g), and ^{234}U (44.6 pCi/g).

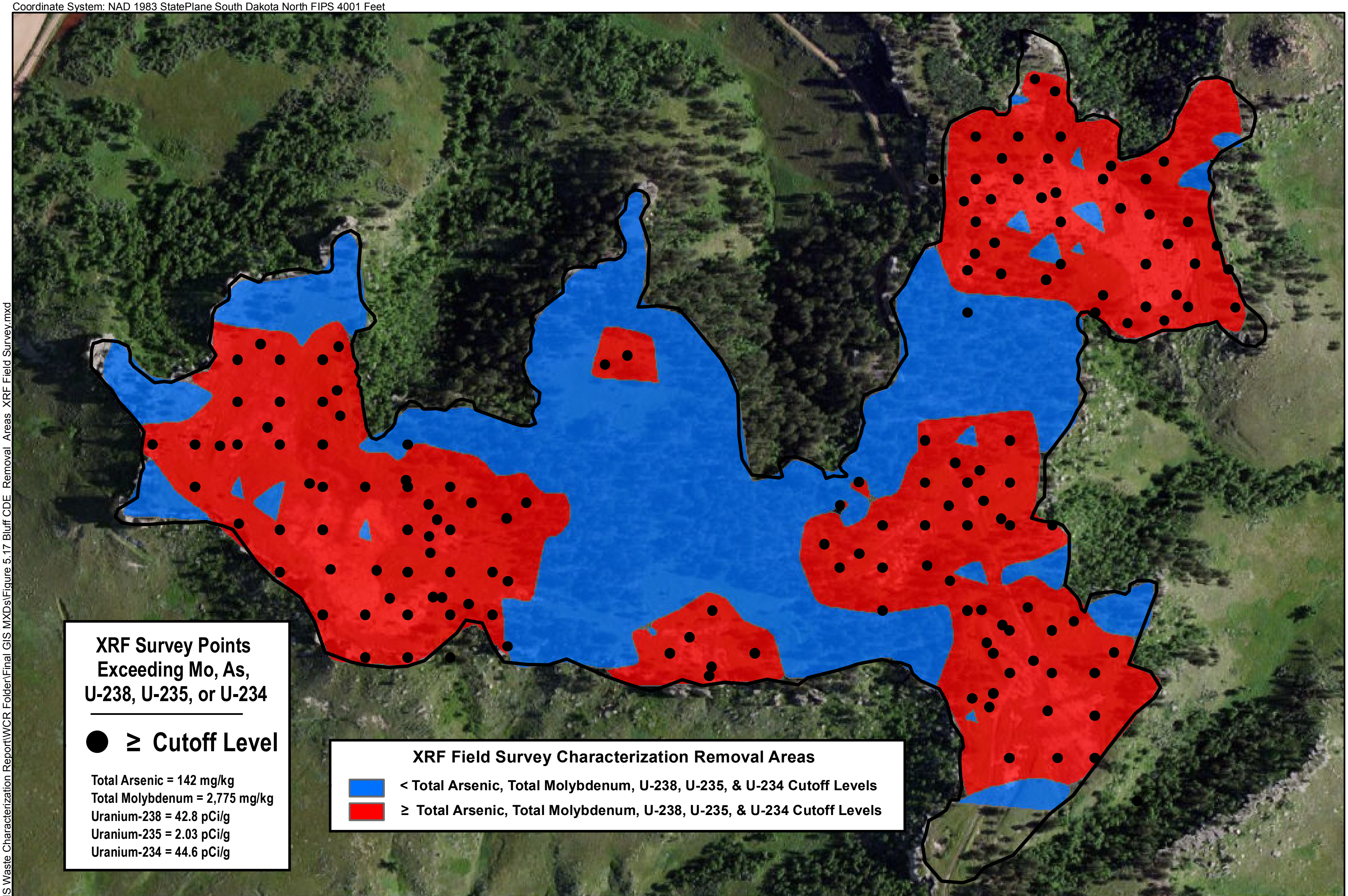
The blue areas on Figure 5-17 show the estimated area that falls below all of the removal action levels, and the red areas show the estimated areas that exceed the soil cleanup levels of at least one of the constituents of concern. Table 5-18 provides a summary of the removal action areas based on the XRF field survey data. The results of the XRF field survey show that 42 percent (20 acres) of the area within Bluff CDE exceeds at least one of the contaminants of concern identified from the XRF field survey waste characterization data.

Table 5-18. Summary of Removal Action Areas by XRF Field Survey Data at Bluff CDE

Contaminant	Removal Action Cutoff Level	Area (acres)	Percent of Bluff CDE Area
Total Arsenic	<142 mg/kg*	20	42
Total Molybdenum	<2,775 mg/kg		
^{238}U	<42.8 pCi/g**		
^{235}U	<2.03 pCi/g		
^{234}U	<44.6 pCi/g		
Total Arsenic	≥142 mg/kg	27	58
Total Molybdenum	≥2,775 mg/kg		
^{238}U	≥42.8 pCi/g		
^{235}U	≥2.03 pCi/g		
^{234}U	≥44.6 pCi/g		

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

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.17 Bluff CDE Removal Areas XRF Field Survey.mxd

Legend:

2012 Revised Bluff CDE Boundary

0 125 250 500 Feet

N

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Bluff CDE Removal Action Areas Based on XRF Field Survey Data

3 Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-17
Location:	Harding County, South Dakota	June 2013	

5.4.6 Bluff CDE 2007 Action Memorandum Criteria 2 Characterization Discussion

The 2007 Action Memorandum specifies that Criteria 2 are applicable to Tronox Bluffs C, D, and E and are listed below:

- **No Reclamation:** In areas where minimal overburden was historically present, vegetation has stabilized the soil, and no significant erosion is evident.
- **Stabilization and Vegetate:** In areas where active significant erosion is occurring due to poor vegetative cover.
- **Excavation and Consolidation:** In areas where materials associated with historic mining activities exceed Criteria 1 Category II soil radium-226 activity.

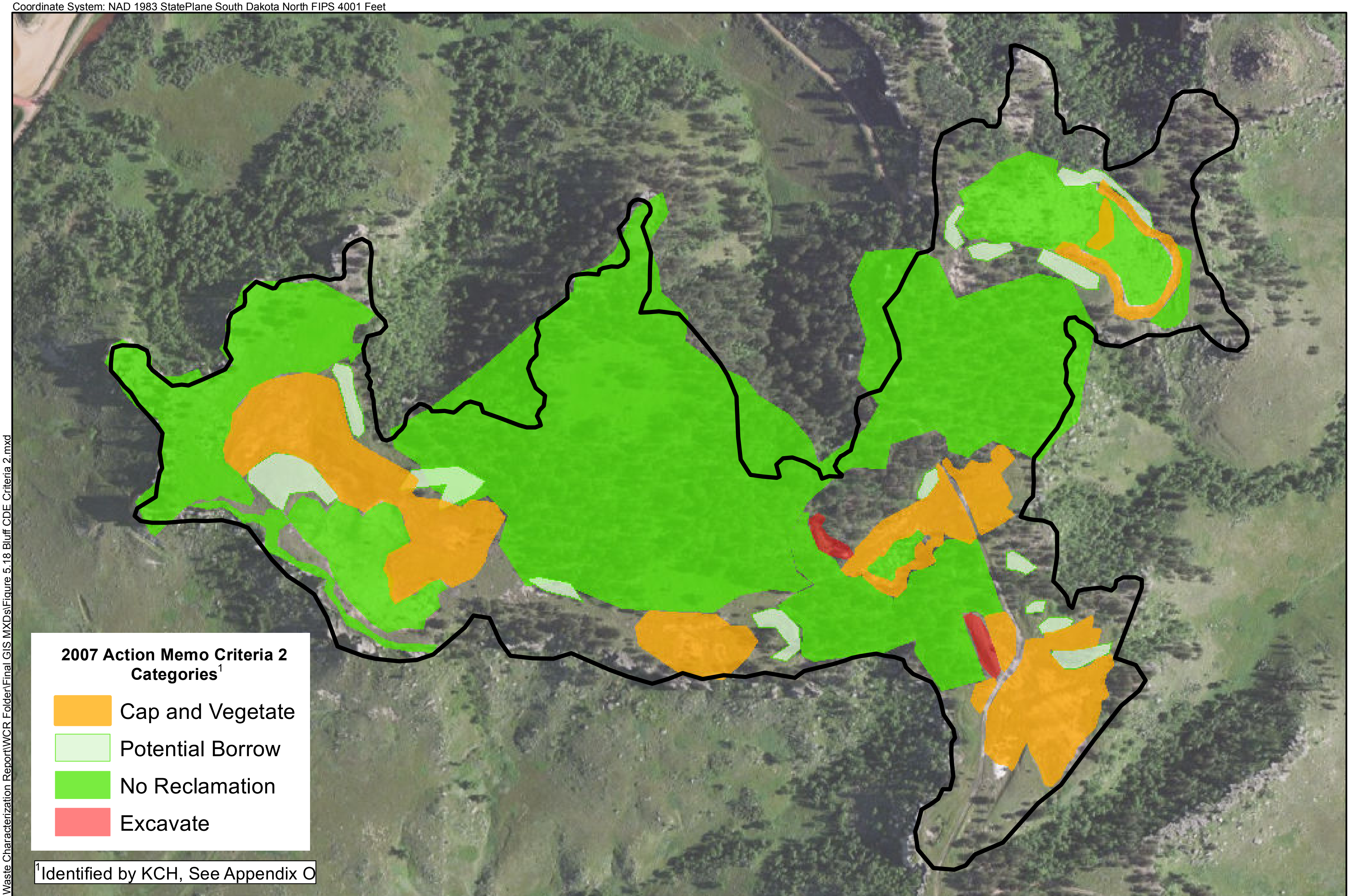
A detailed survey of the vegetation and soil conditions at Bluffs C, D, and E was performed by a KCH reclamation scientist. Full details of this survey are found in Appendix O, including site photos, GIS mapping, and comments. Areas were identified according to 2007 Action Memorandum Criteria 2 classification, discussed above. Figure 5-18 displays the classification of Bluff CDE according to Criteria 2. This figure does not include any Criteria 1 classification and is based entirely on the visual observations of the vegetation and soil conditions.

In general, there is no significant erosion observable at Bluff CDE; however, the Criteria "Stabilize and Vegetate" was further refined to "Cap and Vegetate" to include areas that will require a borrow soil cover and vegetation. The areas to be capped and vegetated include bare sandstone areas with a shallow layer of contaminated soil or areas with little to no vegetation present. Areas identified for "Excavation and Consolidation" include tailings piles and identified contaminated soils. The 2007 Action Memorandum specifies that the areas to be considered for excavation and consolidation are those locations on or immediately adjacent to Road 3130 where the soil exceeds Criteria 1 Category II ^{226}Ra concentrations.

The waste characterization data collected at Bluff CDE demonstrates that a large portion of the bluff exceeds Criteria 1 Category II and III cleanup levels. When 2007 Action Memorandum Criteria 2 category areas for "Cap and Vegetate" are overlaid on Criteria 2 mapping, all areas identified for "Cap and Vegetate" fall within areas of Criteria 2 Category III exceedances, as shown in Figure 5-19.

Due to the high levels of arsenic, uranium and ^{226}Ra present at Bluff CDE, it is recommended to apply the Criteria 1 waste characterization scheme used in this WCR in determining what removal actions should be taken Bluff CDE.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.18 Bluff CDE Criteria 2.mxd

Legend:

2012 Revised Bluff CDE Boundary

0 125 250 500 Feet

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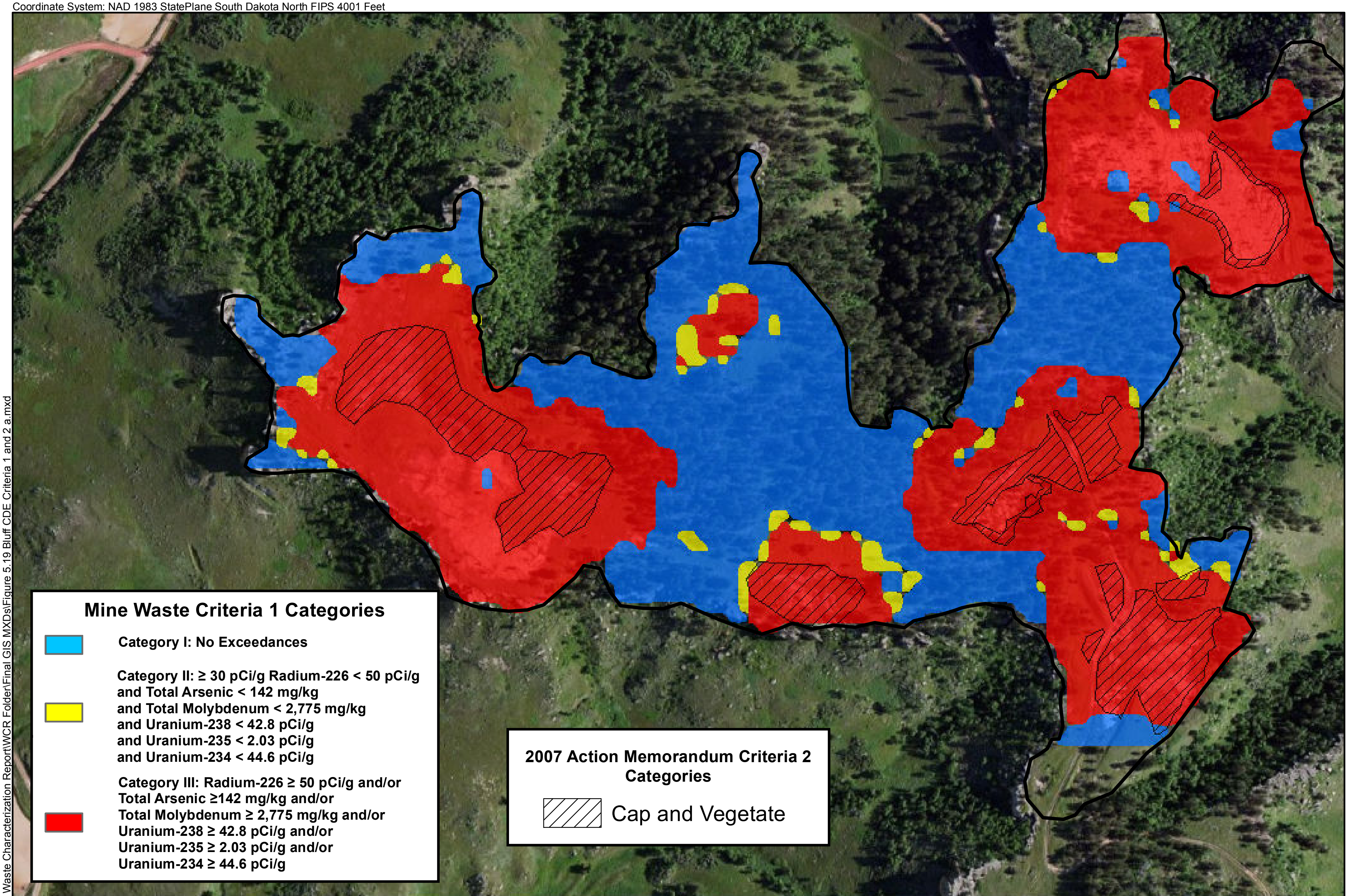
Bluff CDE- Criteria 2
Classification Map

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-18
Location:	Harding County, South Dakota	June, 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff CDE Boundary

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Bluff CDE- Criteria 1 and 2 Classification Map

3 Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-19
Location:	Harding County, South Dakota	June, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.19 Bluff CDE Criteria 1 and 2 a.mxd

5.4.7 Bluff CDE Overall Waste Characterization Summary

The procedures for estimating the ^{226}Ra and total arsenic, total molybdenum, and uranium isotopes removal area for Bluff CDE are discussed in the previous sections. The summaries of the removal action areas specifically based on the gamma radiation survey (^{226}Ra) and the XRF field survey (As, Mo, ^{238}U, ^{235}U, and ^{234}U) for Bluff CDE are provided in Table 5-16 and Table 5-18, respectively, and are visually presented in Figure 5-13 and Figure 5-17.

Using the revised mine waste categorical definitions of soil reclamation criteria described in Section 2.2, the mine waste category delineation for the surface soils at Bluff CDE is shown in Figure 5-20. This map was generated by using the map algebra feature in *ArcMap10* © and combining the raster sets of the gamma radiation survey and the XRF field survey data. After this step, the raster data sets were converted to polygons and then smoothed using the *paek* algorithm using a smoothing tolerance of 50 feet. The summary of removal action areas for Bluff CDE using the combined data from all of the removal action contaminant criteria are provided in Table 5-19.

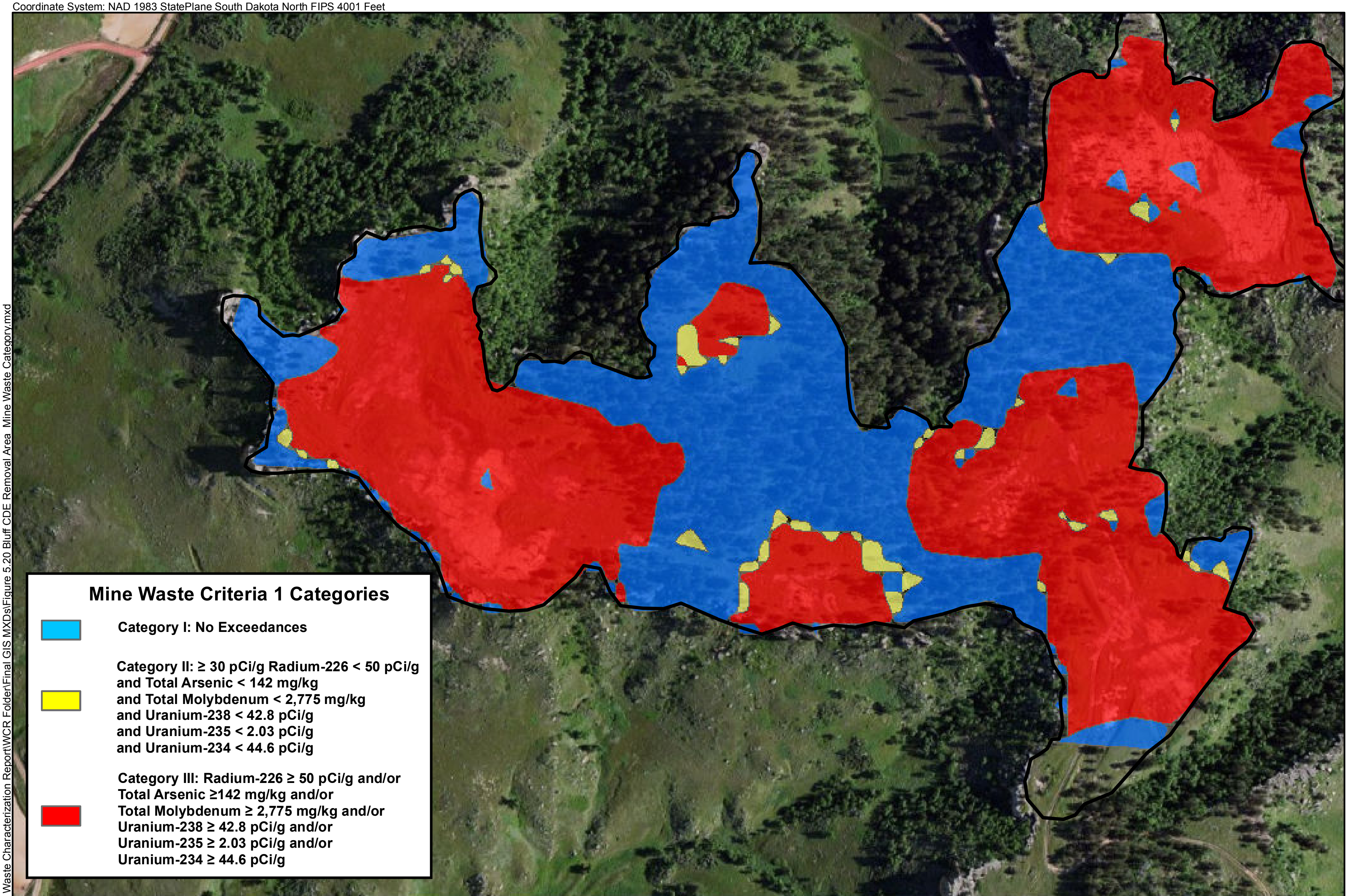
Approximately 38 percent (17.7 acres) of the surface soil concentrations at Bluff CDE do not exceed the soil cleanup values for at least one of the contaminants of concern, and over 60 percent (28 acres) of the surface area of Bluff CDE were identified as Category III, which is defined as exceeding the soil cleanup value for at least one of the contaminants and/or measuring over 50 pCi/g of ^{226}Ra. As stated in the 2007 Action Memorandum, Category III areas require remediation in order to reduce the contaminant levels to below the soil cleanup values.

Table 5-19. Summary of Mine Waste Categories for Bluff CDE

Category	Soil Reclamation Criteria	Area (acres)	Percent Area of Bluff CDE
I	**No Exceedances**: < 30 pCi/g* ^{226}Ra and < 142 mg/kg** Total As and < 2,775 mg/kg Total Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U	17.7	38
II	**^{226}Ra Exceedance Only:** ≥ 30 pCi/g and < 50 pCi/g ^{226}Ra and < 142 mg/kg Total As and < 2,775 mg/kg Total Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U	0.99	2.1
III	**Exceedances of Any Contaminant**: ≥ 50 pCi/g ^{226}Ra and/or ≥ 142 mg/kg Total As and/or ≥ 2,775 mg/kg Total Mo and/or ≥ 42.8 pCi/g ^{238}U and/or ≥ 2.03 pCi/g ^{235}U and/or ≥ 44.6 pCi/g ^{234}U	27.8	60

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

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff CDE Boundary

N

0 125 250 500 Feet

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Bluff CDE- Removal Action Areas and Mine Waste Criteria 1 Category Map

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-20
Location:	Harding County, South Dakota	June, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.20 Bluff CDE Removal Area Mine Waste Category.mxd

5.5 Bluff G Waste Characterization Results

This section presents the waste characterization results for Bluff G, including an existing conditions overview, summary and results of the XRF field survey waste characterization, and a summary and results of the gamma radiation survey waste characterization. An overall summary of the Tronox Bluff waste characterization study is presented in Section 5.10.

5.5.1 Bluff G Existing Conditions Overview

With the revised Bluff CDE boundary, Bluff G is the smallest in area of all of the bluffs evaluated during this study. The original boundary of Bluff G was 3.78 acres but was revised by Tetra Tech, and now encompasses 7.1 acres. Comparison of pre-mining and present conditions by way of aerial photography is shown for Bluff G in Figure 1-7. A photographic log showing many of the existing site features in addition to historical photos at Bluff G is included in Appendix N.

A large portion (~1.2 acres) of this bluff includes exposed sandstone bedrock that may emit elevated levels of natural radiation, the areas of sandstone is noted on the mine waste maps in the following sections and portions may be included in the mine waste boundaries. It should be noted that the portions of the sandstone that are included in the mine waste boundaries may not be removed or excavated; however, based on visual observations by field personnel there are sparse volumes of soil materials that may be contaminated within the sandstone region. At Bluff G there are several bare and eroding steep slopes, where quantities of material have been pushed off the sides of the rimrock. There is some vegetation present on some of the less steep slopes, at a cover of 40 percent to 60 percent (USFS, 2007). There are several waste piles along the north and east side of the bluff. Surface erosion is localized to two areas on the north side of Bluff G.

5.5.2 Bluff G Gamma Radiation Survey Waste Characterization Results

A total of 8,778 gamma exposure rate measurements were collected at Bluff G. The scan density at Bluff G is 1,236 points per acre, the highest scan density out of all of the bluffs. The gamma exposure rate ranged between 14.1 µR/hr and 643 µR/hr, with a mean exposure rate of 65.3 µR/hr. The standard deviation, 95th percentile, and 99th percentile of the gamma exposure rates collected at Bluff G was 74.4 µR/hr, 202 µR/hr, and 439 µR/hr, respectively. Table 5-20 provides a statistical summary of the gamma exposure rate data collected at Bluff G. The raw gamma exposure rate map for Bluff G is shown in Figure 5-21.

Table 5-20. Summary Statistics of Bluff G Gamma Exposure Rates

Data Statistic	Result
# of Data Measurements Collected	8,778
Minimum (µR/hr*)	14.1
Maximum (µR/hr)	643
Mean (µR/hr)	65.3
Median (µR/hr)	39.7
Standard Deviation (µR/hr)	74.4
95th Percentile (µR/hr)	202
99th Percentile (µR/hr)	439

*µR/hr = micro-Roentgen per hour

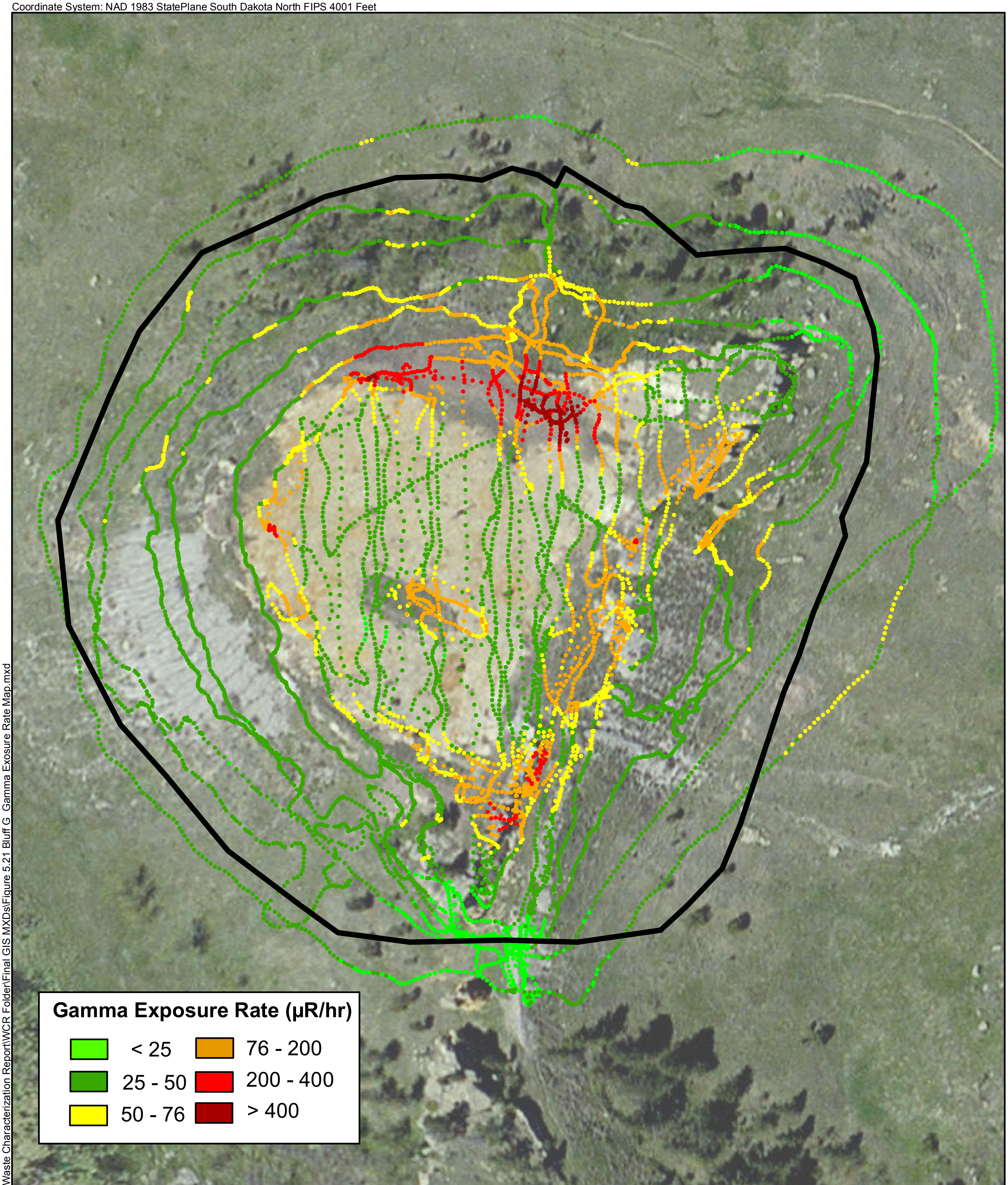
The individual gamma exposure rate measurements collected at Bluff G were converted into radiation dose rates based on the Bicron dose rate/gamma exposure rate cross calibration analysis, discussed in Section 4.1.1 The raw and kriged dose rate map are provided in Figure 5-22. The summary statistics for the radiation dose rates collected at Bluff G are presented in Table 5-21.

Table 5-21. Summary Statistics of Bluff G Bicron Radiation Dose Rates

Data Statistic	Result
# of Data Measurements Collected	8,778
Minimum (µR/hr)	3.77
Maximum (µR/hr)	348
Mean (µR/hr)	31.7
Median (µR/hr)	17.7
Standard Deviation (µR/hr)	40.7
95th Percentile (µR/hr)	107
99th Percentile (µR/hr)	236

*µR/hr = micro-Roentgen per hour

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.21 Bluff G Gamma Exposure Rate Map.mxd

Legend:

2012 Revised Bluff G Boundary

0 35 70 140 Feet

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Bluff G Gamma Exposure Rate Map

3
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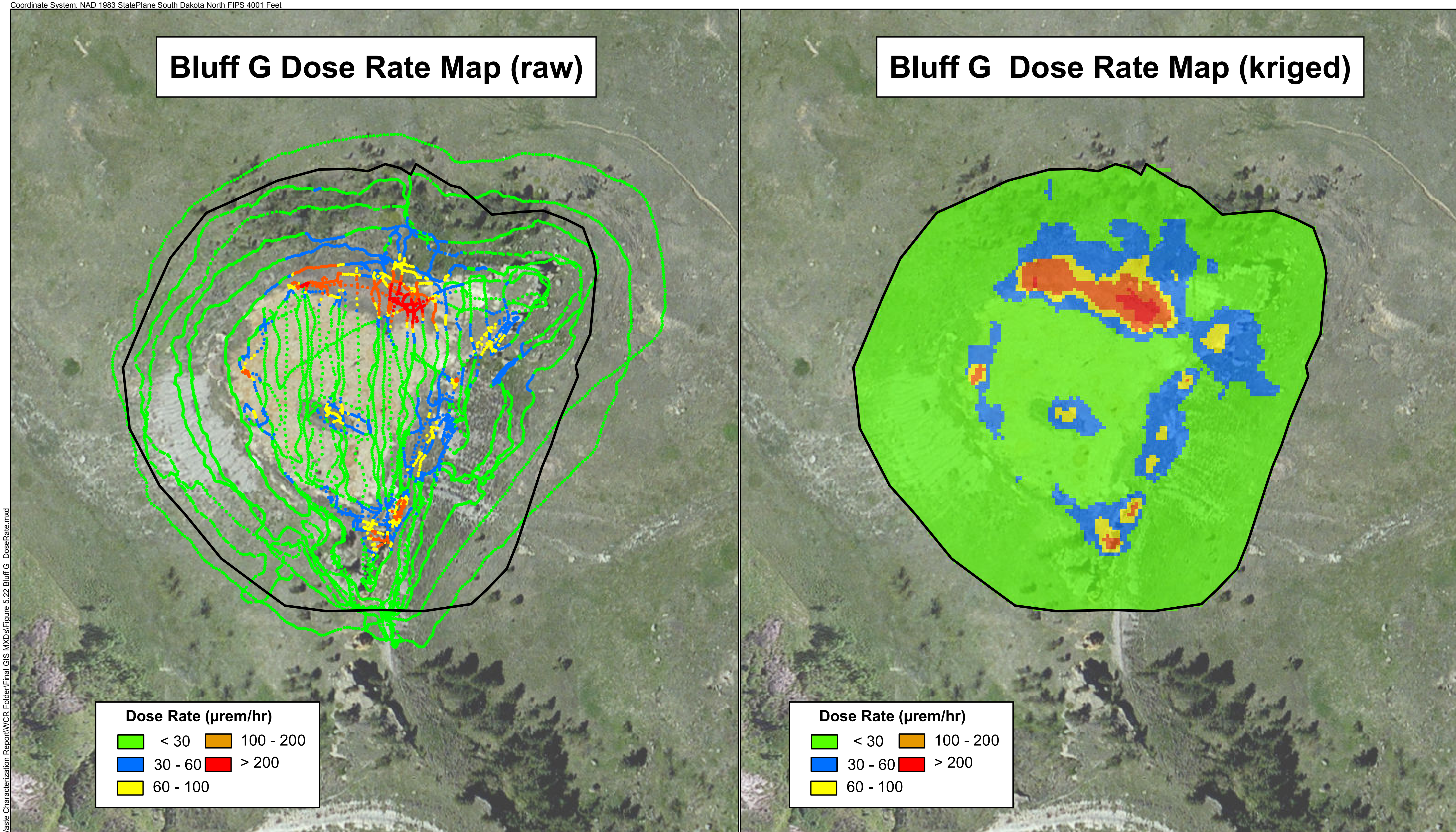
Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-21
Location:	Harding County, South Dakota	June 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff G Boundary

0 50 100 200 Feet

N

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Bluff G Dose Rate Map
Raw and Kriged

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083		Figure 5-22
Location: HARDING COUNTY COUNTY, SD	June, 2013		

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.22 Bluff G_DoseRate.mxd

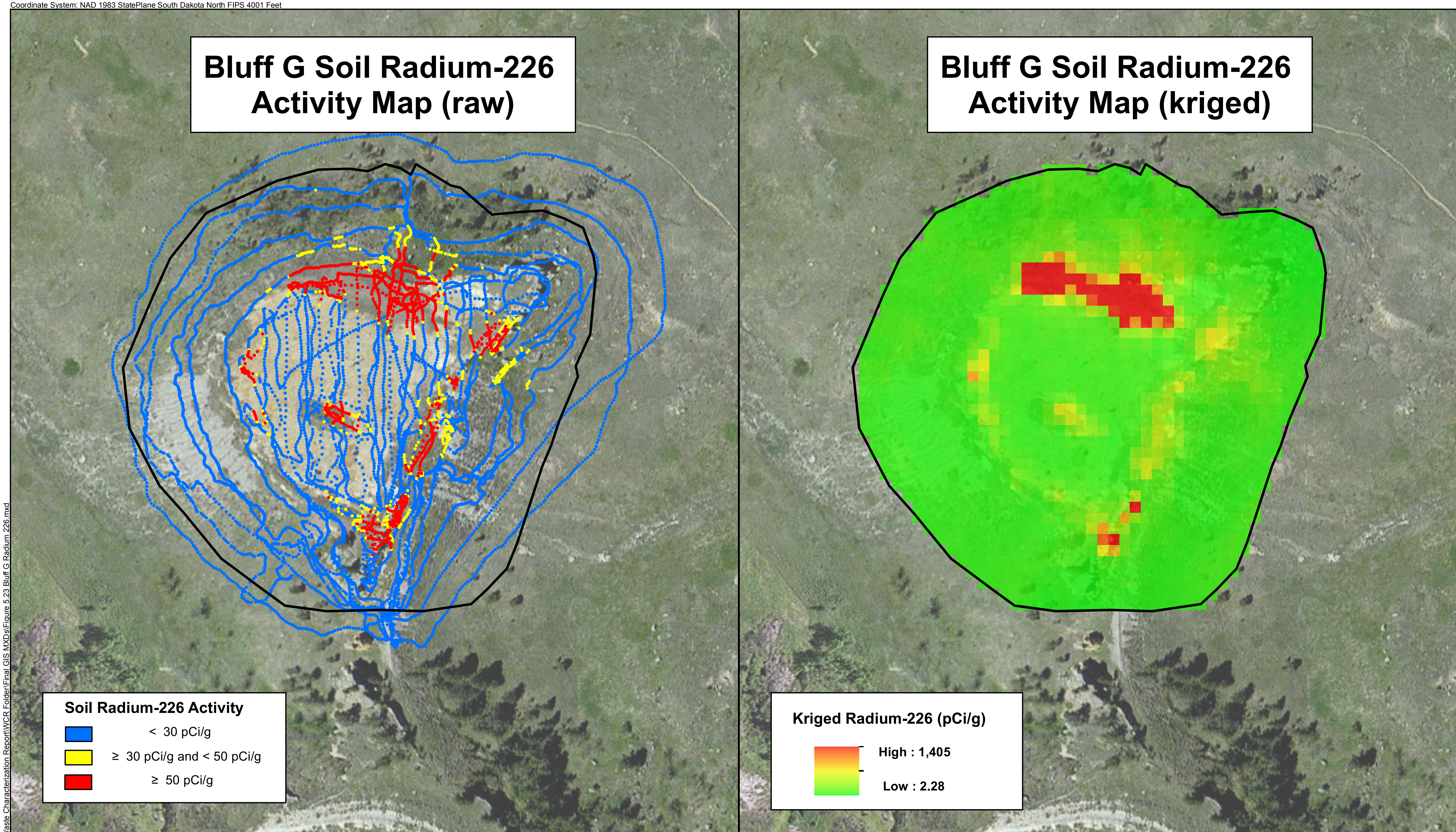
The gamma exposure rate measurements collected at Bluff G were converted into soil ^{226}Ra activity using the regression model presented in Section 4.1.2. The soil ^{226}Ra activity ranges between 1.36 pCi/g to 1,493 pCi/g, with an average and standard deviation of 42.4 pCi/g and 126 pCi/g, respectively. A total of 80 percent of the scan data collected at Bluff G were below the ^{226}Ra soil cleanup value of 30 pCi/g. Seven percent of the points collected were between 30 pCi/g to 50 pCi/g and 13 percent of the points were greater than or equal to 50 pCi/g. Table 5-22 presents the summary statistics for the soil ^{226}Ra activity measured at Bluff G. The raw and kriged soil ^{226}Ra activity map is provided in Figure 5-23. As noted earlier, there are some regions of Bluff G that include a sandstone bedrock outcrop where remediation will be difficult; some of the sandstone area is included in the removal action area as shown in Figure 5-21, while this area is included in the action area it will likely be difficult to remediate it successfully due to naturally elevated background radiation.

Table 5-22. Summary Statistics of Soil ^{226}Ra Activity at Bluff G

Data Statistic	Result
Number of Data Measurements Collected	8,778
Minimum (pCi/g*)	1.36
Maximum (pCi/g)	1,493
Mean (pCi/g)	42.4
Median (pCi/g)	9.0
Standard Deviation (pCi/g)	126
95th Percentile (pCi/g)	179
99th Percentile (pCi/g)	742
% of Points <30 pCi/g	80
% of Points ≥30 pCi/g and <50 pCi/g	7.0
% of Points ≥50 pCi/g	13

* pCi/g = picocuries per gram

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff G Boundary

0 50 100 200 Feet

N

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Bluff G Soil Radium-226
Activity Map
Raw and Kriged

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-23
Location:	HARDING COUNTY COUNTY, SD	June, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.23 Bluff G Radium 226.mxd

5.5.3 Bluff G Gamma Radiation Survey Waste Characterization Summary

The gamma exposure rates collected during the 2012 Tronox Bluff waste characterization program were used to estimate the soil ^{226}Ra activity at Bluff G. The data collected provided sufficient information to estimate the entire areal extent of Bluff G. Table 5-23 provides a summary of the removal action areas at Bluff G based strictly on soil ^{226}Ra activity.

Table 5-23. Summary of Removal Action Areas by ^{226}Ra at Bluff G

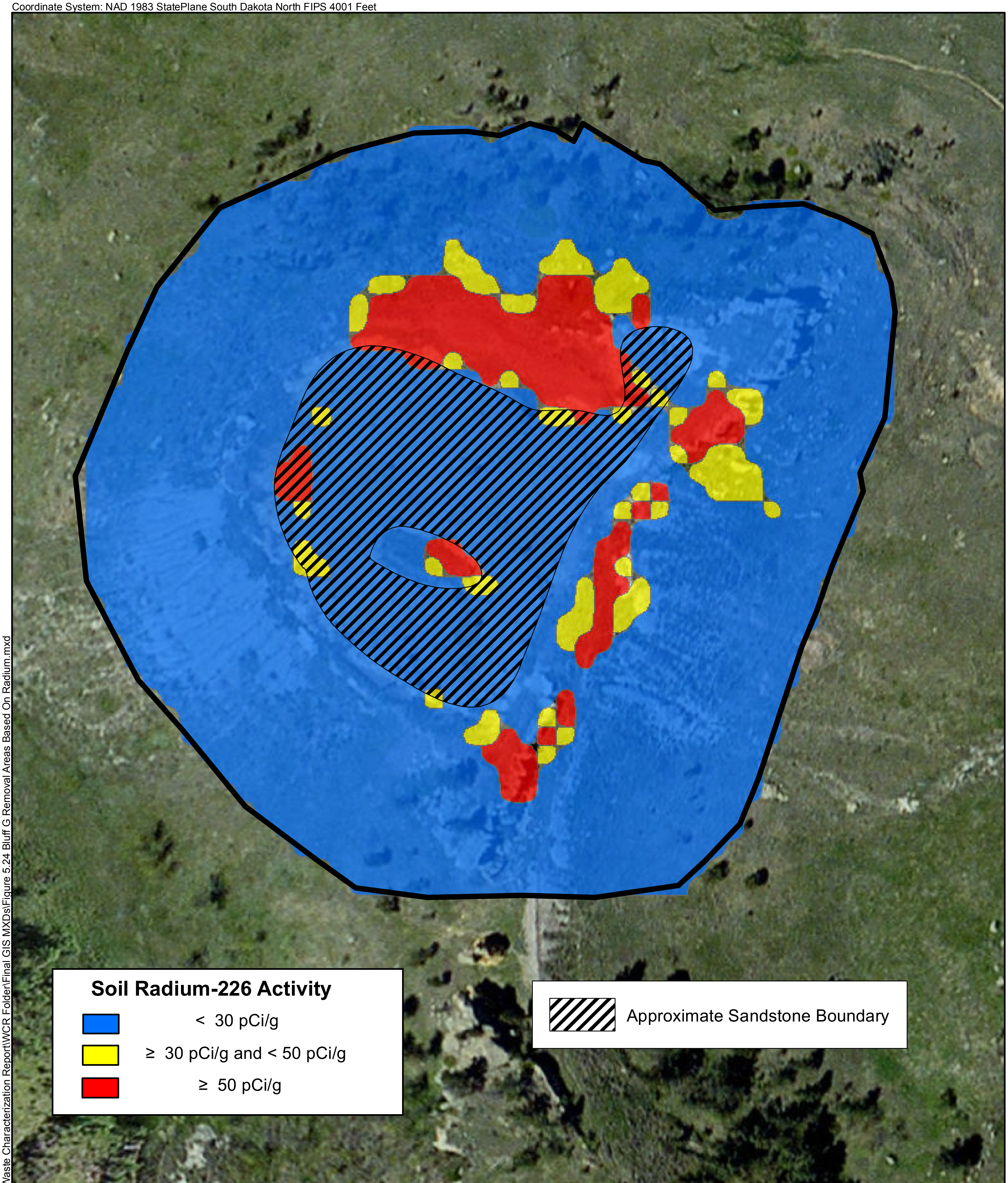
Soil ^{226}Ra Activity	Area (acres)	Percent Area of Bluff G
< 30 pCi/g*	6.16	87
≥ 30 and < 50 pCi/g	0.36	5.0
≥ 50 pCi/g	0.57	8.0

*pCi/g = picocuries per gram

The areas of elevated soil ^{226}Ra activity at Bluff G are limited to isolated mine waste piles located on the top of the bluff as shown on Figure 5-23. Overall, the spoil materials that were deposited off the sides appear to be below all removal action criteria.

Figure 5-24 shows the removal action areas that are based on the criteria set forth in the 2007 Action Memorandum and discussed in Section 2.2. This map was created by kriging the individual soil ^{226}Ra activity points that were collected at Bluff G. The results of the gamma radiation survey show the radiological contamination at this bluff is isolated to only 13 percent of the total bluff area; with 5 percent (0.36 acres) falling within soil ^{226}Ra activity values between 30 pCi/g to 50 pCi/g and 8 percent (0.57 acres) of the area that is greater than or equal to soil ^{226}Ra activity values of 50 pCi/g.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff G Boundary

0 25 50 100 Feet

N

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Bluff G Removal Action Areas Based on Soil Radium-226 Activity

3 Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-24
Location:	Harding County, South Dakota	June, 2013	

X:\551083 - Riley Pass\GIS\Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.24 Bluff G Removal Areas Based On Radium.mxd

5.5.4 Bluff G XRF Field Survey Waste Characterization Results

After boundary adjustments were refined for Bluffs C, D, and E; Bluff G became the smallest bluff by area (7.1 acres). A total of 54 *in-situ* XRF measurements were collected within the boundary and adjacent to Bluff G. The density of XRF measurements collected at Bluff G is 7.63 samples per acre, the highest density of samples per acre for all of the bluffs. The XRF sample locations, including the soil confirmation sample locations, are illustrated on Figure 4-15. A total of two soil confirmation samples were collected at Bluff G and submitted for laboratory analysis.

Correlation analysis and regression equations were developed between the *in-situ* field XRF measurements and laboratory confirmation samples for total arsenic, total molybdenum, and natural uranium (Section 4.2 and Appendix F). The regression equations developed were applied to the 54 *in-situ* XRF measurements collected at Bluff G in order to convert these values into individual definitive, laboratory-equivalent soil concentrations for the constituents of interest. Removal action areas for this project are based on a combination of the following constituents based on the XRF field survey: total arsenic (142 mg/kg), total molybdenum (2,775 mg/kg), ^{238}U (42.8 pCi/g), ^{235}U (2.03 pCi/g), and ^{234}U (44.6 pCi/g) (Section 2.2). The methods and assumptions used in this study to convert the natural uranium concentrations to the uranium isotopes of interest are presented in Section 5.3.4.

Table 5-24 provides summary statistics for the total arsenic, total molybdenum, natural uranium, ^{238}U, ^{235}U, and ^{234}U soil concentrations measured at Bluff G. A total of 30 of 54 (55.6 percent) sample points were below the total arsenic soil cleanup value of 142 mg/kg. The total arsenic concentrations in the surface soils at Bluff G ranged between 18.8 mg/kg and 1,483 mg/kg. Bluff G had the highest mean arsenic concentration (257 mg/kg) of all of the bluffs. The natural uranium concentration ranged between 4.3 mg/kg and 1,091 mg/kg, with a mean concentration of 198 mg/kg. The total molybdenum concentration ranged between 1.7 mg/kg and 1,491 mg/kg with a mean concentration of 195 mg/kg.

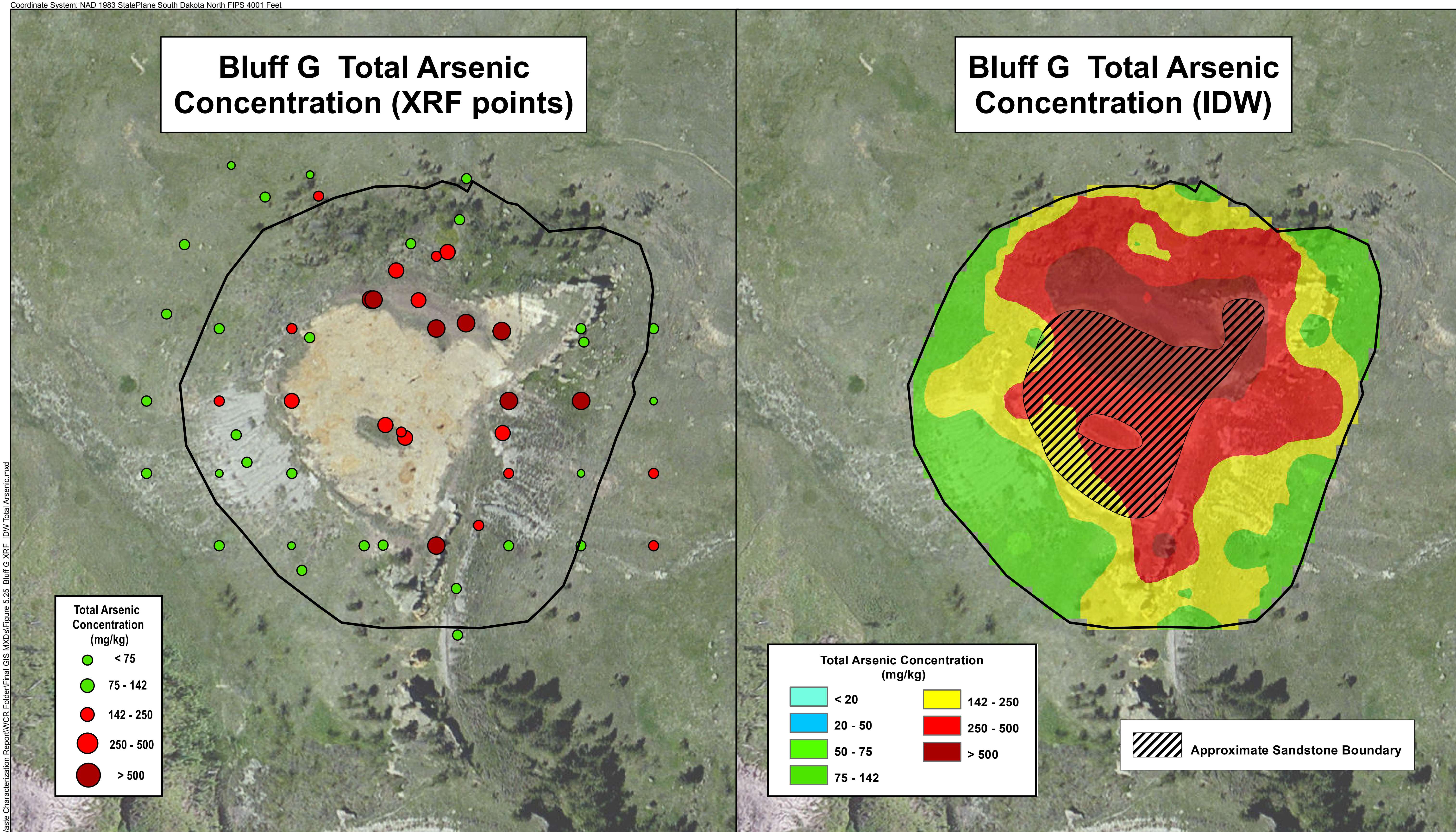
Figure 5-25 through Figure 5-27 present the *in-situ* XRF sample locations mapped by the magnitude of converted soil concentrations for total arsenic, natural uranium, and total molybdenum, respectively. On the right-hand side of these figures, the IDW maps showing the estimated ranges for each constituent by different color schemes are presented. Raster maps showing the interpolated (IDW) surface soil values delineated based on removal action cleanup criteria for total molybdenum, ^{238}U, ^{235}U, and ^{234}U at Bluff G are provided in Figure M-9 through Figure M-12 in Appendix M, respectively. In general, the exceedances at point measurements of total molybdenum and uranium isotopes removal action levels were co-located at samples where total arsenic also exceeded the cutoff value. A total of 44.4 percent of the total arsenic samples collected at Bluff G exceeded the soil cutoff value.

Table 5-24. Summary Statistics of Bluff G XRF Field Survey Concentrations

Statistic	Total Arsenic (mg/kg*)	Total Molybdenum (mg/kg)	Natural Uranium (mg/kg)	^{238}U (pCi/g**)	^{235}U (pCi/g)	^{234}U (pCi/g)
Removal Action Cutoff Value	**142**	**2,775**	**n/a**	**42.8**	**2.03**	**44.6**
Count	54	54	54	54	54	54
Minimum	18.8	1.66	4.33	1.43	0.07	1.4
Maximum	1,483	1,491	1,091	361	16.6	361
Standard Deviation	289	363	283	93.6	4.31	93.6
Median	130	32.3	64.8	21.5	0.99	21.5
Mean	256	195	198	65.5	3.01	65.5
95th Percentile	903	1,081	888	294	13.5	294
99th Percentile	1,195	1,425	1,045	346	15.9	346
% of Points Exceeding Cutoff Value	44.4	0	n/a	37.0	35.2	35.2

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

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff G Boundary

0 50 100 200 Feet

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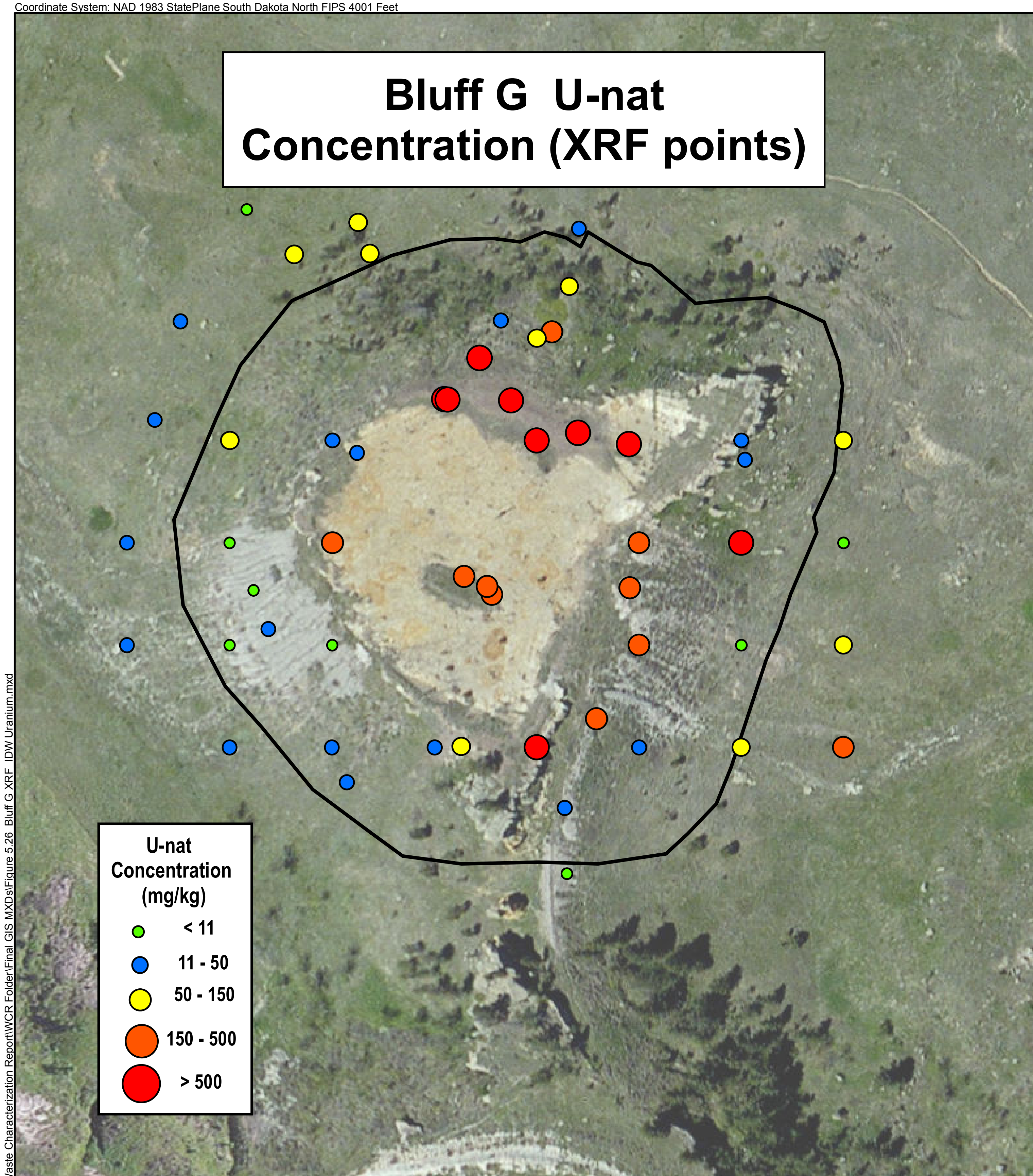
Bluff G XRF and IDW Total Arsenic Concentration Map

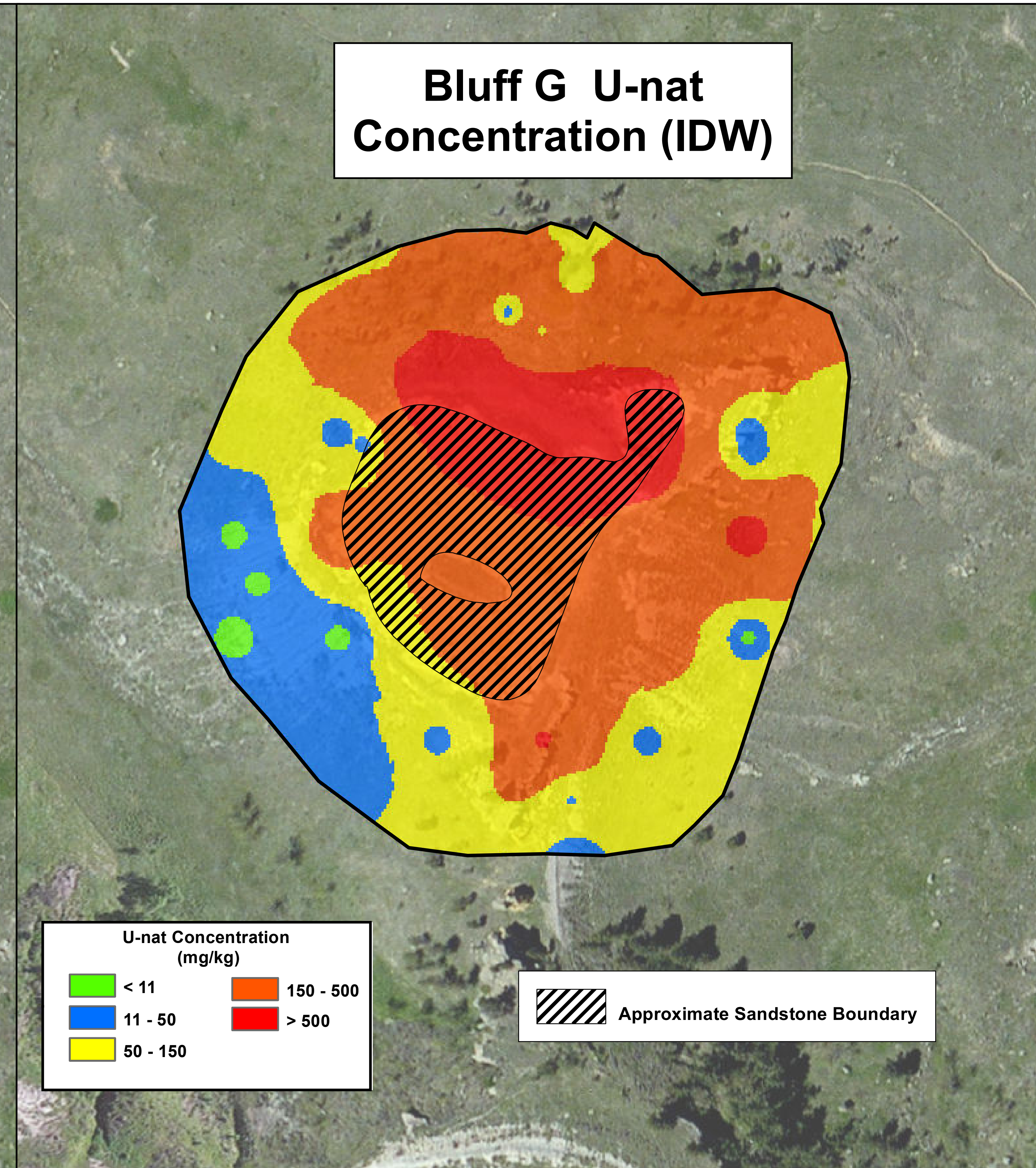
3 Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083		
Location: HARDING COUNTY COUNTY, SD	June, 2013	Figure 5-25	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.25 Bluff G XRF IDW Total Arsenic.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet





Legend:

2012 Revised Bluff G Boundary

0 50 100 200 Feet

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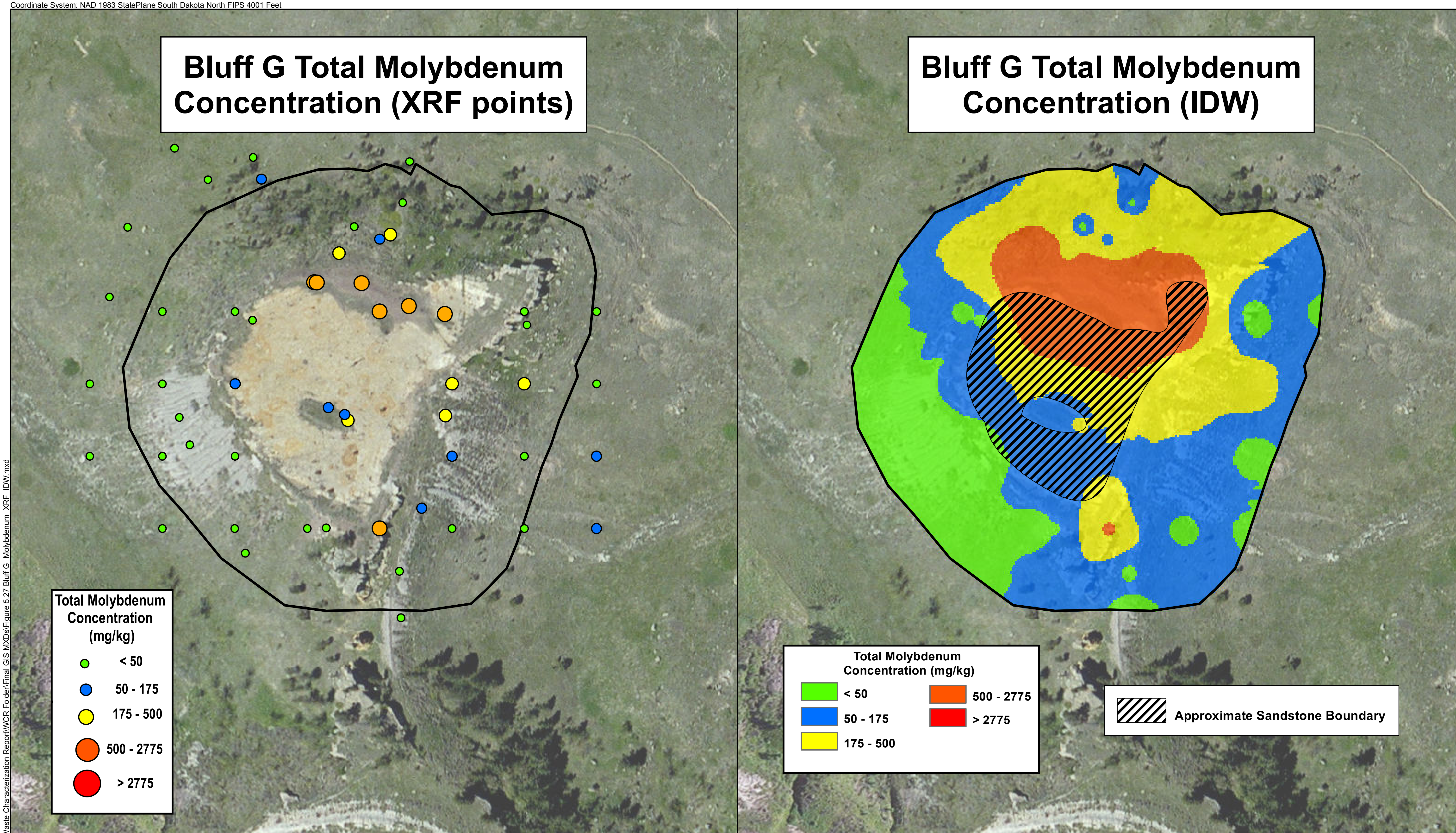
Bluff G XRF and IDW Natural Uranium Concentration Map

3 Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083		Figure 5-26
Location: HARDING COUNTY COUNTY, SD	June, 2013		

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.26 Bluff G XRF IDW Uranium.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

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Bluff G XRF and IDW Total Molybdenum Concentration Map

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-27	
Location: HARDING COUNTY COUNTY, SD	June, 2013		

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.27 Bluff G_Molybdenum_XRF_IDW.mxd

5.5.5 Bluff G XRF Field Survey Waste Characterization Summary

The *in-situ* XRF samples collected during the XRF field survey provided sufficient information to estimate the areal extent of total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U soil contamination within the bounds of Bluff G.

Raster data sets were developed for total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U and then combined into a final raster data set that showed the areal extent of all of the contaminated areas merged together that were estimated from the XRF field survey data. The final raster data set was converted into smoothed polygons in order to delineate and estimate the contaminated areas. A flow chart simplifying the logical steps involved for the spatial characterization of gamma radiation and XRF field survey data is provided in Appendix M.

Figure 5-28 shows the areal extent of contaminated areas that were estimated to be above removal action cleanup criteria for at least one of the following constituents: total arsenic (142 mg/kg), total molybdenum (2,775 mg/kg), ^{238}U (42.8 pCi/g), ^{235}U (2.03 pCi/g), and ^{234}U (44.6 pCi/g).

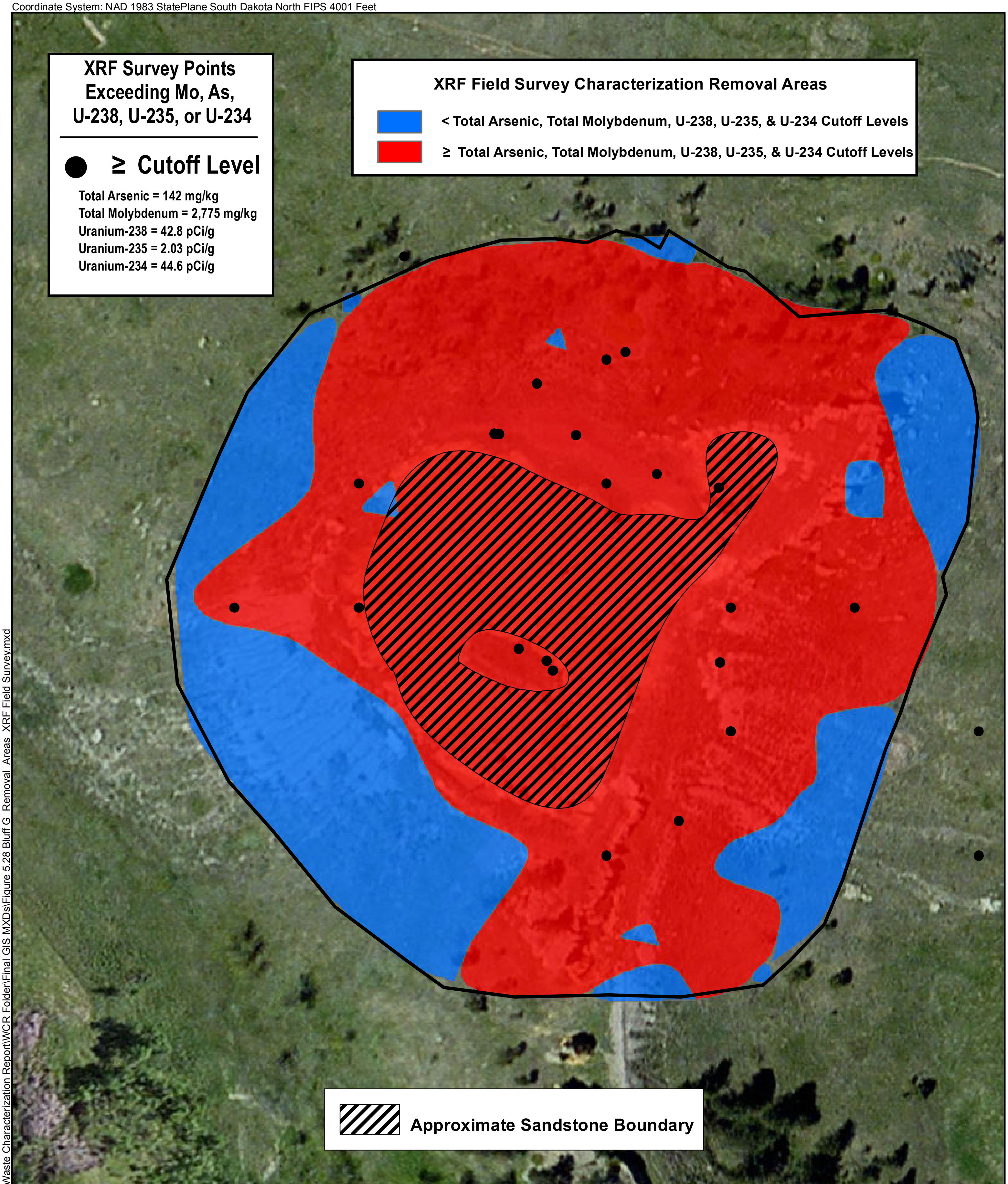
The blue areas on Figure 5-28 show the estimated area that falls below all of the removal action levels, and the red areas show the estimated areas that exceed the soil cleanup levels of at least one of the constituents of concern. Table 5-25 provides a summary of the removal action areas based on the XRF field survey data. The results of the XRF field survey show that 74 percent (5.2 acres) of the area within Bluff G exceeds at least one of the contaminants of concern identified from the XRF field survey waste characterization data.

Table 5-25. Summary of Removal Action Areas by XRF Field Survey Data at Bluff G

Contaminant	Removal Action Cutoff Level	Area (acres)	Percent of Bluff CDE Area
Total Arsenic	<142 mg/kg*	1.8	26
Total Molybdenum	<2,775 mg/kg		
^{238}U	<42.8 pCi/g**		
^{235}U	<2.03 pCi/g		
^{234}U	<44.6 pCi/g		
Total Arsenic	≥142 mg/kg	5.2	74
Total Molybdenum	≥2,775 mg/kg		
^{238}U	≥42.8 pCi/g		
^{235}U	≥2.03 pCi/g		
^{234}U	≥44.6 pCi/g		

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

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.28 Bluff G Removal Areas XRF Field Survey.mxd

Legend:

2012 Revised Bluff G Boundary

0 25 50 100 Feet

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Bluff G Removal Action Areas Based on XRF Field Survey Data

3 Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-28
Location:	Harding County, South Dakota	June, 2013	

5.5.6 Bluff G Overall Waste Characterization Summary

The procedures for estimating the radium-226 and total arsenic, total molybdenum, and uranium isotopes removal area for Bluff G are discussed in the previous sections. The summaries of the removal action areas specifically based on the gamma radiation survey (^{226}Ra) and the XRF field survey (As, Mo, ^{238}U, ^{235}U, and ^{234}U) for Bluff G are provided in Table 5-23 and Table 5-25, respectively and are visually presented in Figure 5-24 and Figure 5-28.

Using the revised mine waste categorical definitions of soil reclamation criteria described in Section 2.2, the mine waste category delineation for the surface soils at Bluff G is shown in Figure 5-29Figure 5-9. This map was generated by using the map algebra feature in *ArcMap10* © and combining the raster sets of the gamma radiation survey and the XRF field survey data. After this step, the raster data sets were converted to polygons and then smoothed using the *paek* algorithm using a smoothing tolerance of 50-feet. The summary of removal action areas for Bluff G using the combined data from all of the removal action contaminant criteria are provided in Table 5-26.

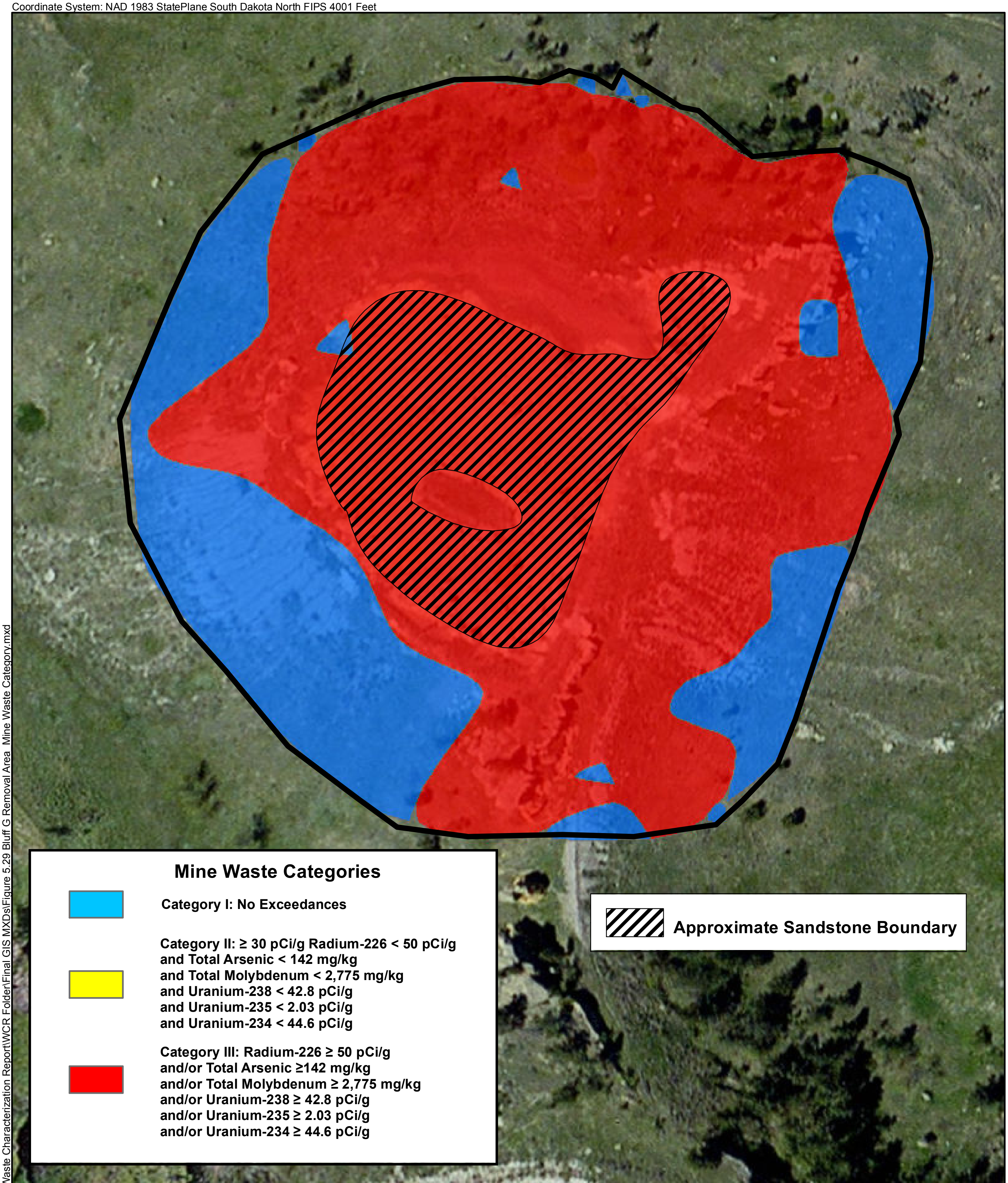
Approximately 26 percent (1.83 acres) of the surface soil concentrations at Bluff G do not exceed the soil cleanup values for at least one of the contaminants of concern, and 5.2 acres (74 percent) identified as Category III, which is defined as exceeding the soil cleanup value for at least one of the contaminants and/or measuring over 50 pCi/g of ^{226}Ra. As stated in the 2007 Action Memorandum, Category III areas require remediation in order to reduce the contaminant levels to below the soil cleanup values.

Table 5-26. Summary of Mine Waste Categories for Bluff G

Category	Soil Reclamation Criteria	Area (acres)	Percent Area of Bluff G
I	**No Exceedances**: < 30 pCi/g* ^{226}Ra and < 142 mg/kg** Total As and < 2,775 mg/kg Total Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U	1.83	26
II	**^{226}Ra Exceedance Only:** ≥ 30 pCi/g and < 50 pCi/g ^{226}Ra and < 142 mg/kg Total As and < 2,775 mg/kg Total Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U	0.0	0.0
III	**Exceedances of Any Contaminant**: ≥ 50 pCi/g ^{226}Ra and/or ≥ 142 mg/kg Total As and/or ≥ 2,775 mg/kg Total Mo and/or ≥ 42.8 pCi/g ^{238}U and/or ≥ 2.03 pCi/g ^{235}U and/or ≥ 44.6 pCi/g ^{234}U	5.17	74

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

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff G Boundary

0 25 50 100 Feet

N

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Bluff G- Removal Action Areas and Mine Waste Category Map

3 Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-29
Location:	Harding County, South Dakota	June, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.29 Bluff G Removal Area Mine Waste Category.mxd

5.6 Bluff H Waste Characterization Results

This section presents the waste characterization results for Bluff H, including an existing conditions overview, summary and results of the XRF field survey waste characterization, and a summary and results of the gamma radiation survey waste characterization. An overall summary of the Tronox Bluff waste characterization study is presented in Section 5.10.

5.6.1 Bluff H Existing Conditions Overview

Bluff H is the second largest of the Tronox Bluffs evaluated during this study. The revised Bluff H boundary encompasses approximately 31.8 acres. Comparison of pre-mining and present conditions by way of aerial photography is shown for Bluff H in Figure 1-8. A photographic log showing many of the existing site features in addition to historical photos at Bluff H is included in Appendix N.

The site consists of several spoils piles (approximately 552,850 cubic yards) that have been placed along and over the rimrock edges; these slopes are generally steep and show signs of severe erosion on the northwest and northeast spoils piles (USFS, 2006). A pit area is present with unstable highwalls on the southwest portion of the bluff. Some of the spoils piles on the north and northeast portion of Bluff H extend into private property.

5.6.2 Bluff H Gamma Radiation Survey Waste Characterization Results

A total of 18,341 gamma exposure rate measurements were collected at Bluff H (577 points per acre). The gamma exposure rate ranged between 12.7 µR/hr and 613 µR/hr, with a mean exposure rate of 35.8 µR/hr. The standard deviation, 95th percentile, and 99th percentile of the gamma exposure rates collected at Bluff H was 34.3 µR/hr, 90.1 µR/hr, and 169 µR/hr, respectively. Table 5-27 provides a statistical summary of the gamma exposure rate data collected at Bluff H. The raw gamma exposure rate map for Bluff H is shown in Figure 5-30.

Table 5-27. Summary Statistics of Bluff H Gamma Exposure Rates

Data Statistic	Result
# of Data Measurements Collected	18,341
Minimum (µR/hr*)	12.7
Maximum (µR/hr)	613
Mean (µR/hr)	35.8
Median (µR/hr)	25.1
Standard Deviation (µR/hr)	34.3
95th Percentile (µR/hr)	90.1
99th Percentile (µR/hr)	169

* µR/hr = micro-Roentgen per hour

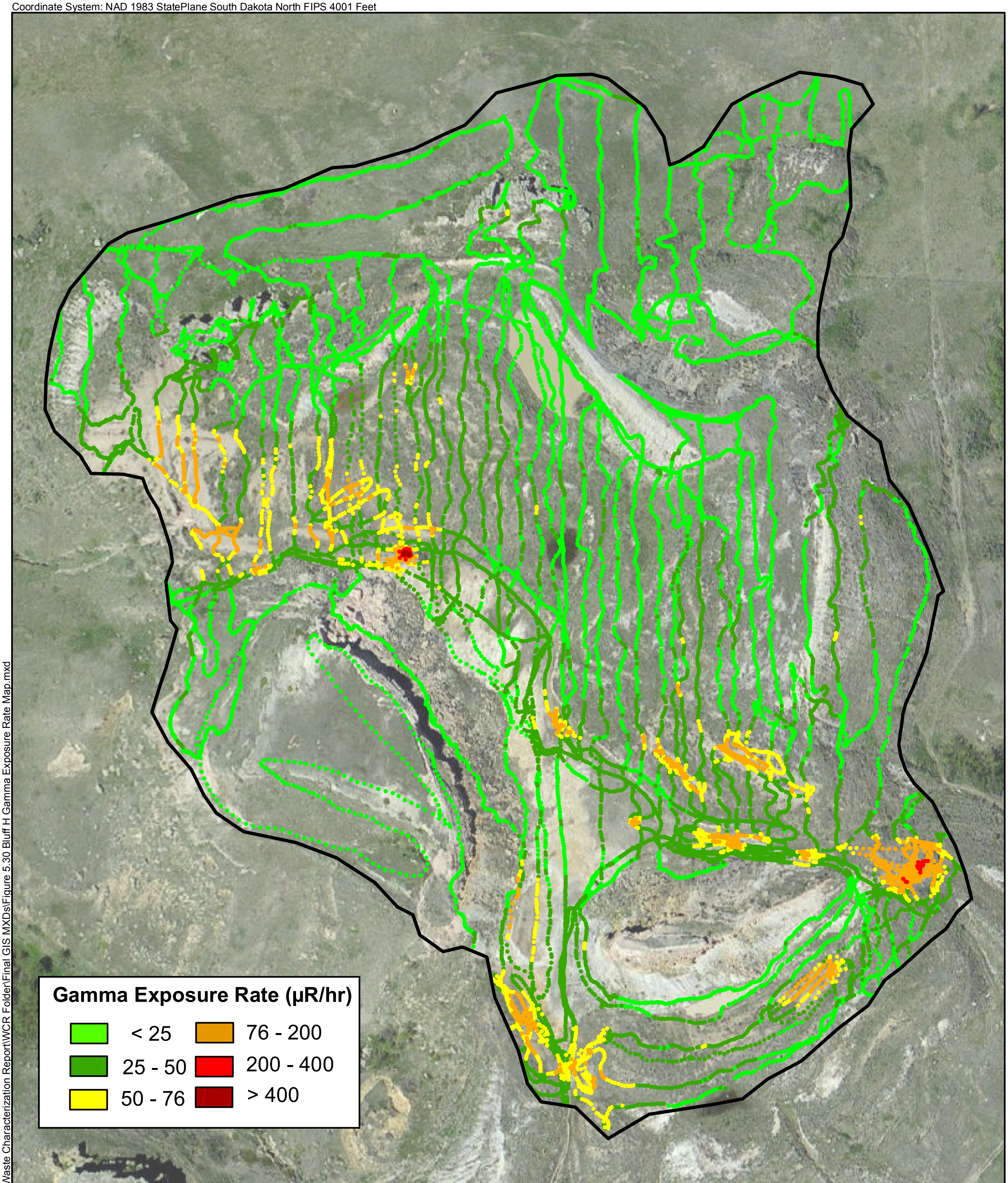
The gamma exposure rates collected at Bluff H were converted into radiation dose rates based on the Bicron dose rate/gamma exposure rate cross calibration analysis, discussed in Section 4.1.1 The raw and kriged dose rate map are provided in Figure 5-31. The summary statistics for the radiation dose rates calculated for Bluff H are presented in Table 5-28.

Table 5-28. Summary Statistics of Bluff H Bicron Radiation Dose Rates

Data Statistic	Result
# of Data Measurements Collected	18,341
Minimum (µR/hr*)	2.98
Maximum (µR/hr)	331
Mean (µR/hr)	15.6
Median (µR/hr)	9.77
Standard Deviation (µR/hr)	18.8
95th Percentile (µR/hr)	45.3
99th Percentile (µR/hr)	88.5

* µR/hr = micro-Roentgen per hour

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.30 Bluff H Gamma Exposure Rate Map.mxd

Legend:

2012 Revised Bluff H Boundary

0 50 100 200 Feet

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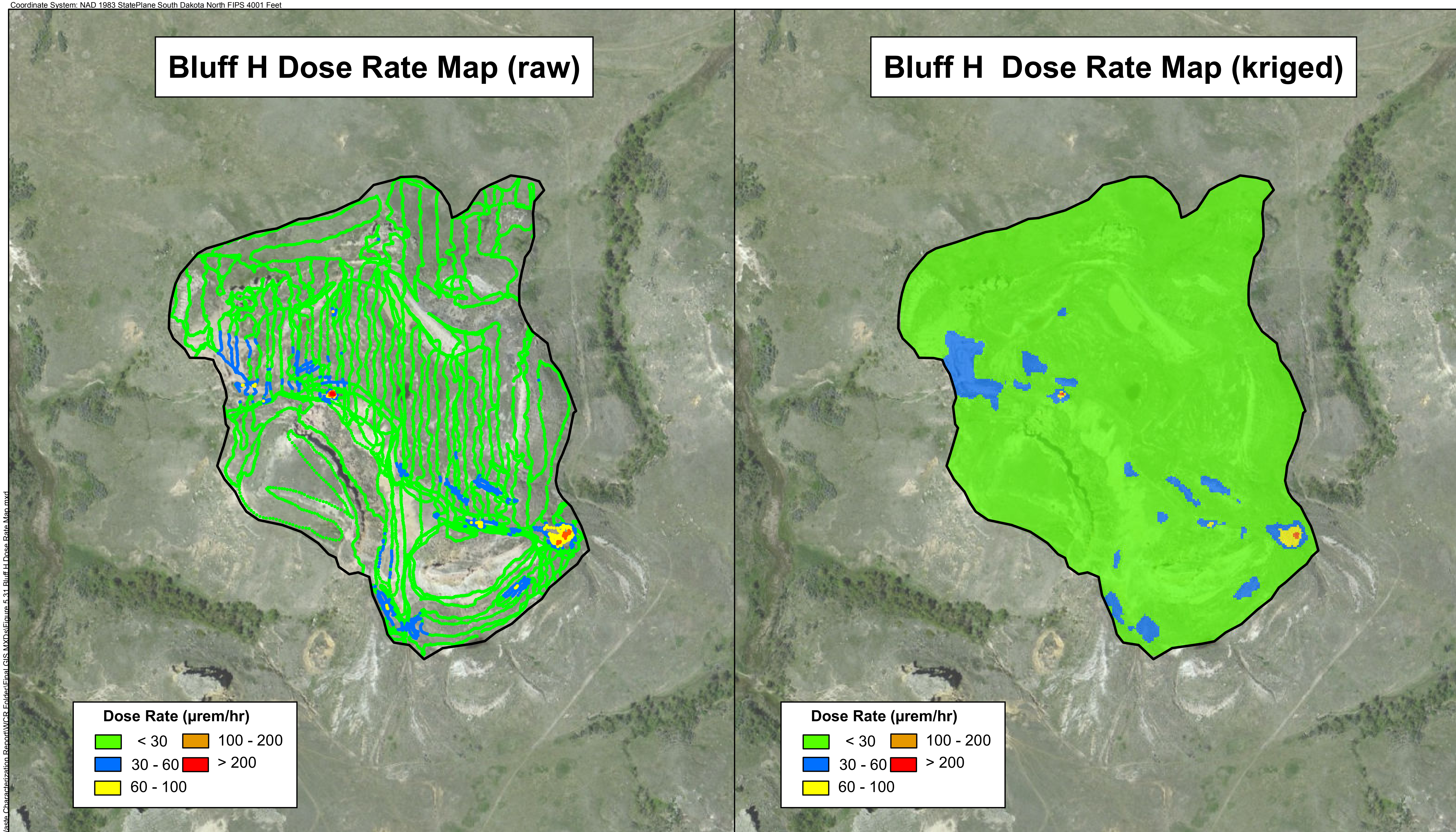
Bluff H Gamma Exposure Rate Map		3 Revision
Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-30
Location: Harding County, South Dakota	June, 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff H Boundary

0 125 250 500 Feet

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Bluff H Dose Rate Map		3 Revision
Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-31
Location: HARDING COUNTY COUNTY, SD	June, 2013	

X:\551083 - Riley Pass\GIS\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.31 Bluff H Dose Rate Map.mxd

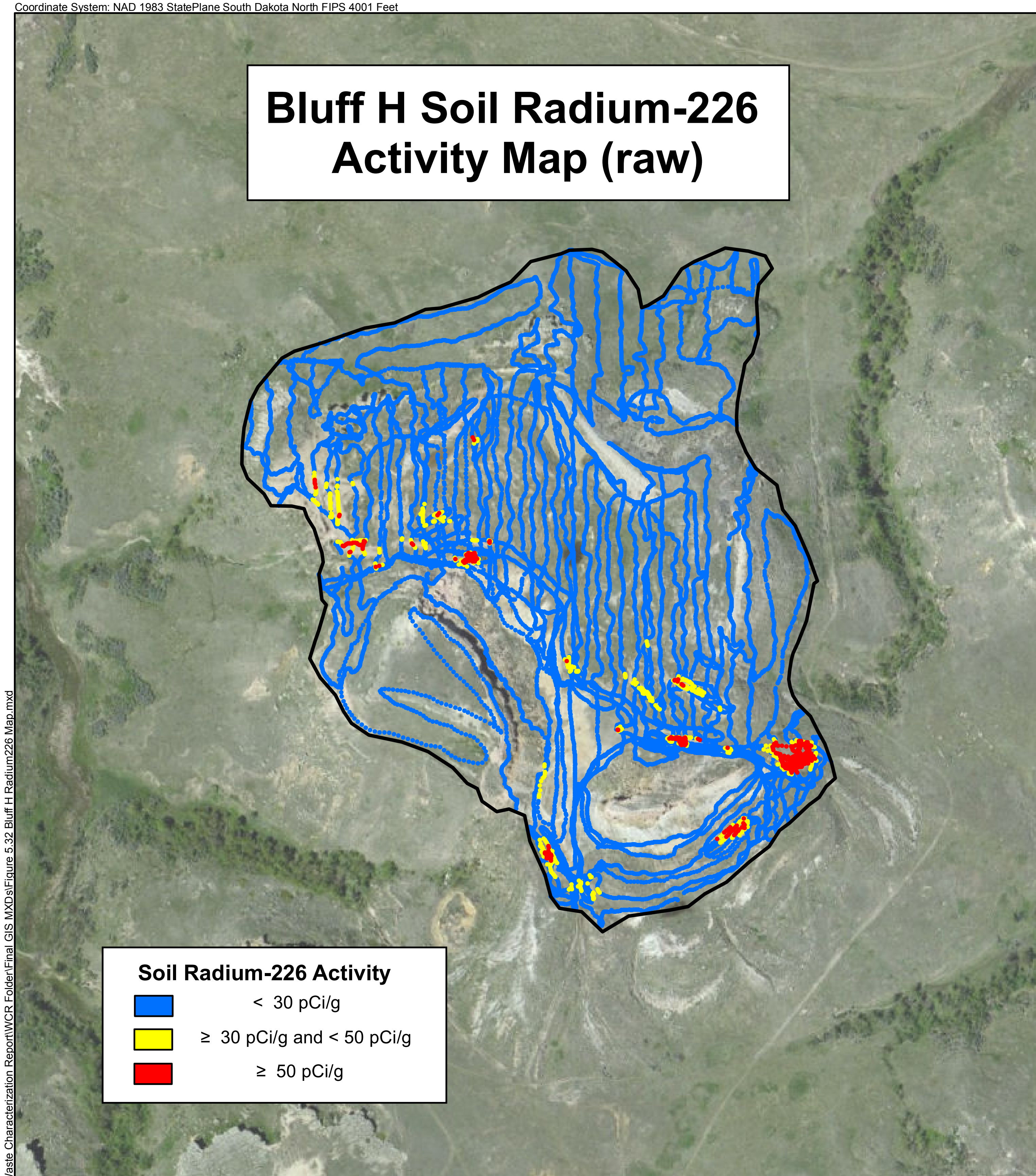
The gamma exposure rate measurements collected at Bluff H were converted into soil ^{226}Ra activity using the regression model presented in Section 4.1.2. The soil ^{226}Ra activity ranges between 1.11 pCi/g and 1,367 pCi/g, with a mean and standard deviation of 12.1 pCi/g and 44.3 pCi/g, respectively. A total of 93 percent of the individual scan data measurements collected at Bluff H were below the soil ^{226}Ra cleanup value of 30 pCi/g. A total of 3.7 percent of the individual scan data measurements collected were between 30 pCi/g and 50 pCi/g and 3.8 percent of the points were greater than or equal to 50 pCi/g. Table 5-29 presents the summary statistics for the ^{226}Ra activity measured at Bluff H. The raw and kriged soil ^{226}Ra activity map is provided in Figure 5-32.

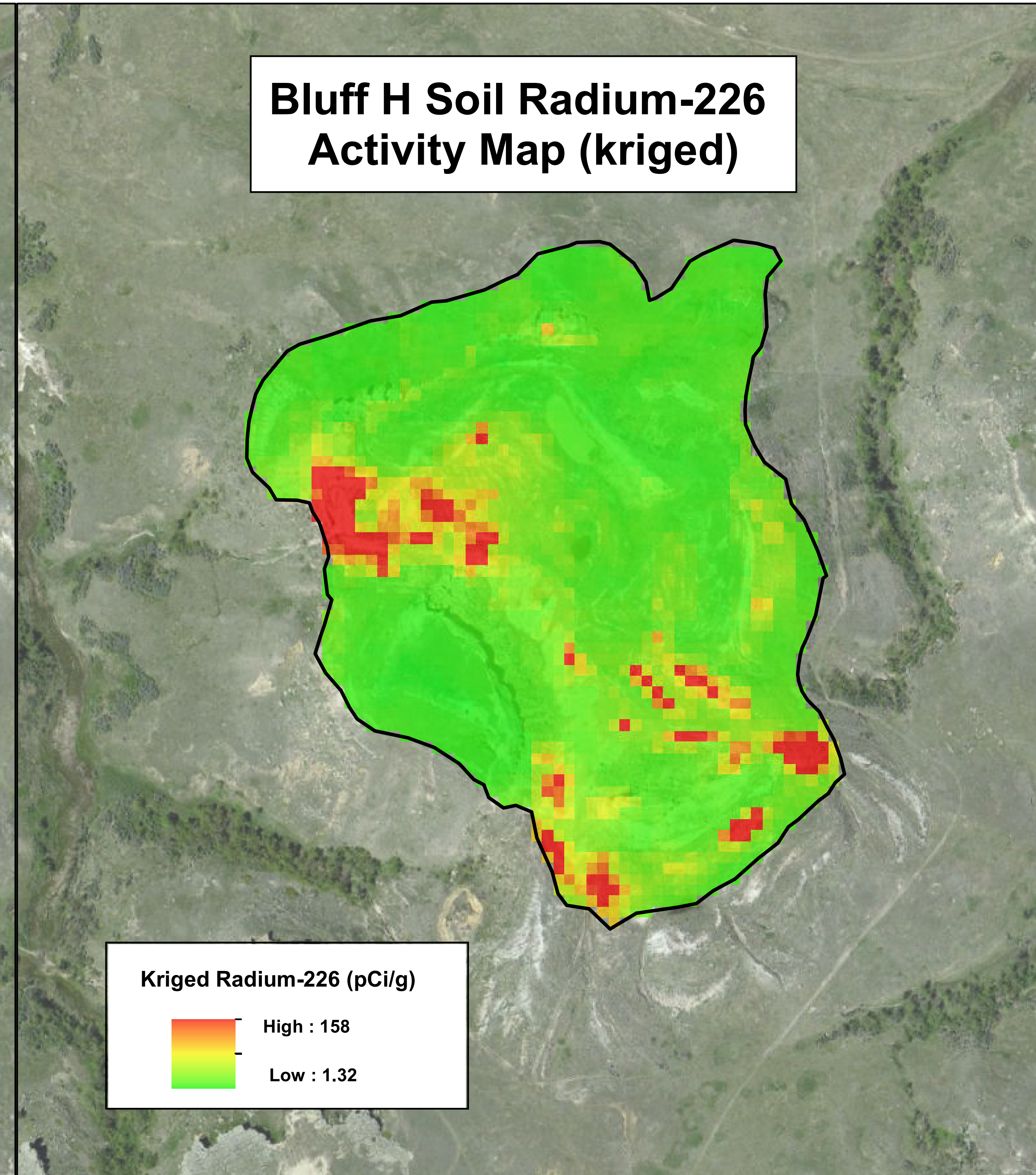
Table 5-29. Summary Statistics of Soil ^{226}Ra activity at Bluff H

Data Statistic	Result
Number of Data Measurements Collected	18,341
Minimum (pCi/g*)	1.11
Maximum (pCi/g)	1,367
Mean (pCi/g)	12.1
Median (pCi/g)	3.89
Standard Deviation (pCi/g)	44.3
95th Percentile (pCi/g)	40.6
99th Percentile (pCi/g)	129
% of Points <30 pCi/g	93
% of Points ≥30 pCi/g and <50 pCi/g	3.7
% of Points ≥50 pCi/g	3.8

* pCi/g = picocuries per gram

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet





Legend:

2012 Revised Bluff H Boundary

0 125 250 500 Feet

N

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Bluff H Soil Radium-226 Activity Map Raw and Kriged			3 Revision
Project: Riley Pass Tronox Bluffs		Project no.: 114-551083	Figure 5-32
Location: HARDING COUNTY COUNTY, SD		June, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.32 Bluff H Radium226 Map.mxd

5.6.3 Bluff H Gamma Radiation Survey Waste Characterization Summary

The gamma exposure rates collected as part of the 2012 Tronox Bluff waste characterization program were used to estimate the soil ^{226}Ra activity at Bluff H. The data collected from the gamma radiation survey provided sufficient information to estimate the areal extent of ^{226}Ra activity in the surface soils within the bounds of Bluff H. Similar to Bluff B, some areas highwalls and steep slopes in the southernmost of Bluff H were not specifically mapped due to safety concerns associated with data collection in these areas. Unmapped areas are shown in Figures 5-30, 5-31,5-32, 5-34, 5-35, and 5-36. Overall, unmapped areas comprise less than 1 percent of the total bluff acreage. Table 5-30 provides a summary of the removal action areas at Bluff H based strictly on soil ^{226}Ra activity. In terms of radiological contamination, Bluff H has the highest percentage of area that is below the soil ^{226}Ra cleanup value.

Table 5-30. Summary of Removal Action Areas by ^{226}Ra at Bluff H

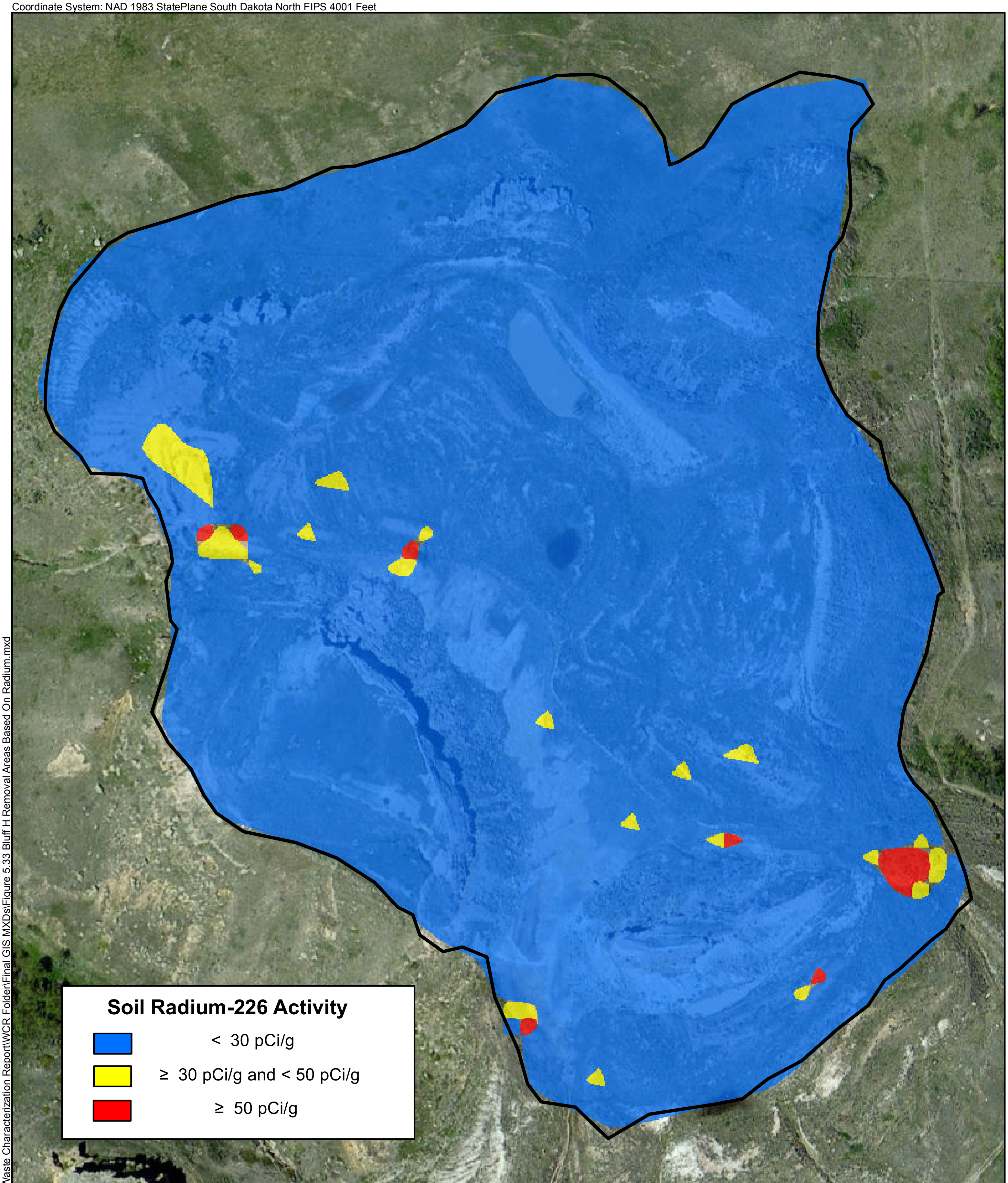
Soil ^{226}Ra Activity	Area (acres)	Percent Area of Bluff H
< 30 pCi/g*	31.2	98
≥ 30 and < 50 pCi/g	0.43	1.4
≥ 50 pCi/g	0.17	0.53

*pCi/g = picocuries per gram

The areas of elevated soil ^{226}Ra activity at Bluff H are limited to isolated mine waste piles scattered throughout the bluff, with the largest removal area being to the east side within the boundary, as shown on Figure 5-32.

Figure 5-33 shows the removal action areas that are based on the criteria set forth in the 2007 Action Memorandum and discussed in Section 2.2. This map was created by kriging the individual soil ^{226}Ra activity points that were collected at Bluff H. Bluff H has the smallest percentage of total area that requires removal action based strictly on soil ^{226}Ra activity. The results of the gamma radiation survey show the radiological contamination at this bluff is isolated to only 2 percent of the total bluff area; with 1.3 percent (0.4 acres) falling within the soil ^{226}Ra activity values between 30 pCi/g to 50 pCi/g and 1.9 percent (0.2 acres) of the area that is greater than or equal to soil ^{226}Ra activity values of 50 pCi/g.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.33 Bluff H Removal Areas Based On Radium.mxd

Legend:

Revised 2012 Bluff H Boundary

0 62.5 125 250 Feet

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Bluff H Removal Action Areas Based on Soil Radium-226 Activity

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-33
Location:	Harding County, South Dakota	June, 2013	

5.6.4 Bluff H XRF Field Survey Waste Characterization Results

A total of 199 *in-situ* XRF measurements were collected at Bluff H. The density of XRF measurements collected at Bluff H is 6.26 points per acre. The XRF sample locations, including the soil confirmation sample locations, are illustrated on Figure 4-16. A total of 14 soil confirmation samples were collected at Bluff H and submitted for laboratory analysis.

Correlation analysis and regression equations were developed between the *in-situ* field XRF measurements and laboratory confirmation samples for total arsenic, total molybdenum, and natural uranium (Section 4.2 and Appendix F). The regression equations developed were applied to the 199 *in-situ* XRF measurements collected at Bluff H in order to convert these values into individual definitive, laboratory-equivalent soil concentrations for the constituents of interest. Removal action areas for this project are based on a combination of the following constituents based on the XRF field survey: total arsenic (142 mg/kg), total molybdenum (2,775 mg/kg), ^{238}U (42.8 pCi/g), ^{235}U (2.03 pCi/g), and ^{234}U (44.6 pCi/g) (Section 2.2). The methods and assumptions used in this study to convert the natural uranium concentrations to the uranium isotopes of interest are presented in Section 5.3.4.

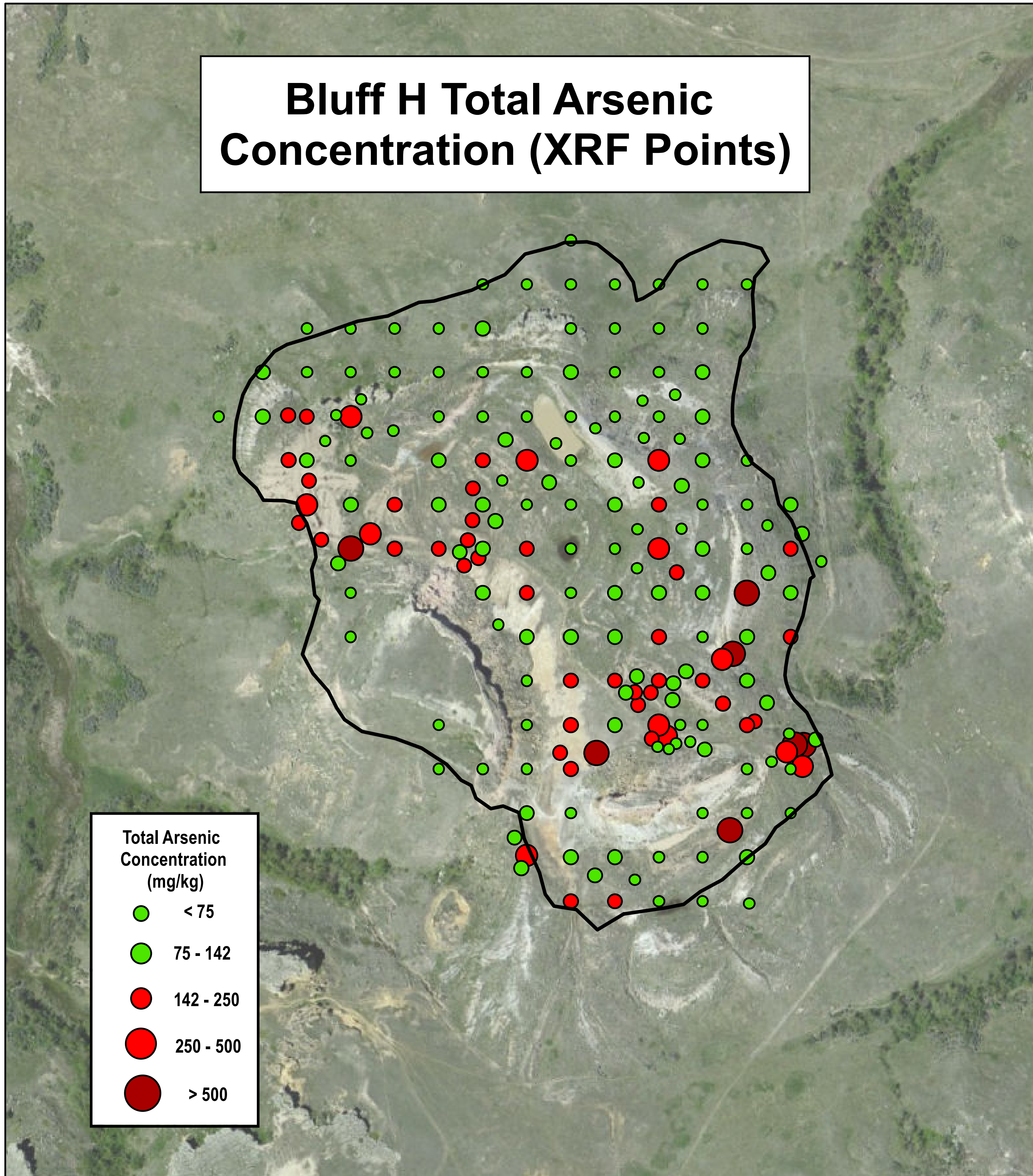
Table 5-31 provides summary statistics for the total arsenic, total molybdenum, natural uranium, ^{238}U, ^{235}U, and ^{234}U soil concentrations measured at Bluff H. A total of 141 of 199 (70.8 percent) were below the total arsenic soil cleanup value of 142 mg/kg, indicating that Bluff H has the second lowest percentage of points below the soil cleanup value behind Bluff B. The total arsenic concentrations in the surface soils at Bluff H ranged between 9.1 mg/kg and 1,431 mg/kg, with a mean concentration of 136 mg/kg. The natural uranium concentrations ranged between 3.2 mg/kg and 29,722 mg/kg, with a mean concentration of 200 mg/kg. The total molybdenum concentration ranged between 1.5 mg/kg and 11,218 mg/kg, with a mean concentration of 165 mg/kg.

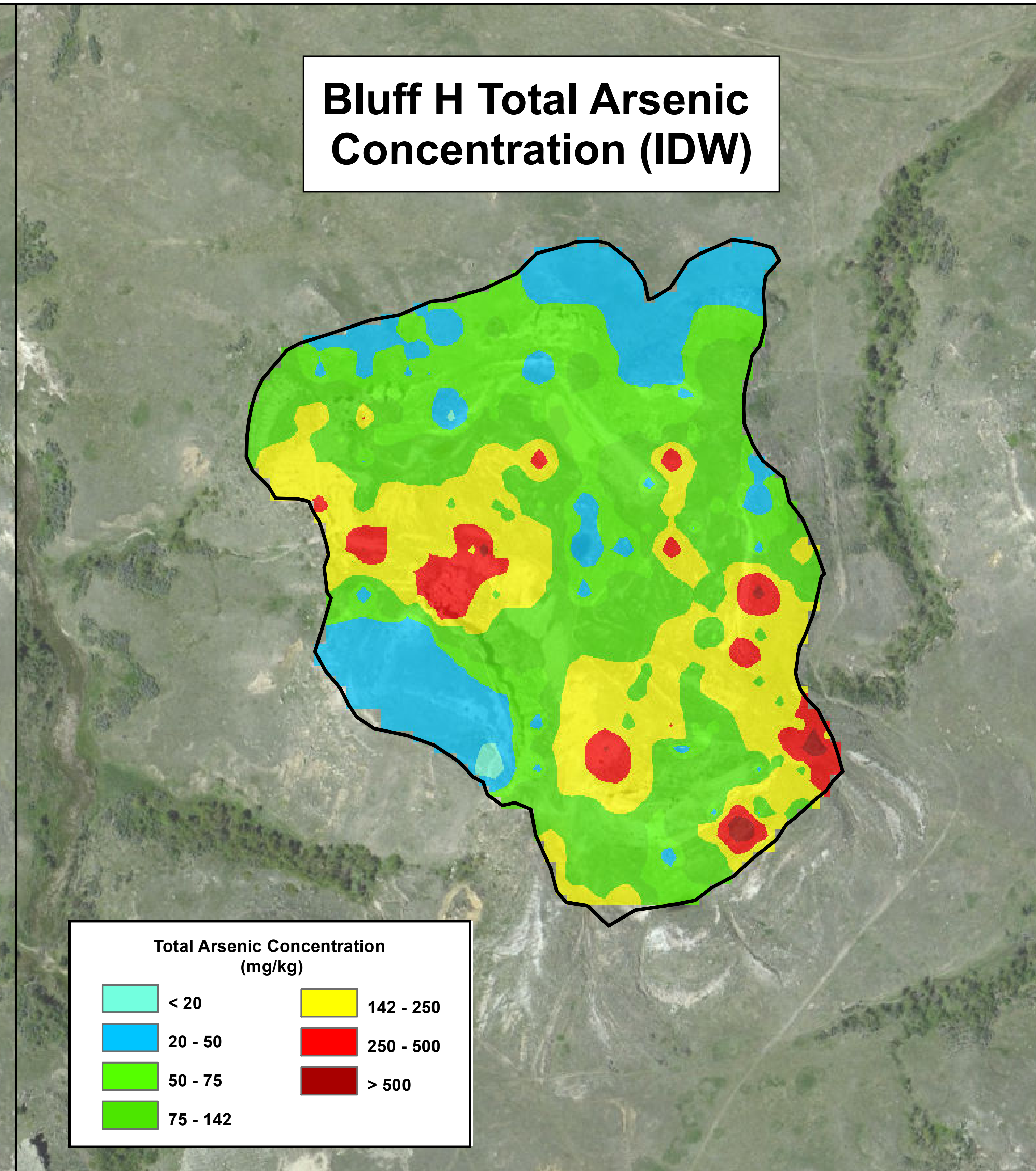
Figure 5-34 through Figure 5-36 present the *in-situ* XRF sample locations mapped by the magnitude of converted soil concentrations for total arsenic, natural uranium, and total molybdenum, respectively. On the right-hand side of these figures, the IDW maps showing the estimated ranges for each constituent by different color schemes are presented. Raster maps showing the interpolated (IDW) surface soil values delineated based on removal action cleanup criteria for total molybdenum, ^{238}U, ^{235}U, and ^{234}U at Bluff H are provided in Figure M-13 through Figure M-16 in Appendix M, respectively. In general, the exceedances at point measurements of total molybdenum and uranium isotopes removal action levels were co-located at samples where total arsenic also exceeded the cutoff value. A total of 29.1 percent of the total arsenic samples collected at Bluff H exceeded the soil cutoff value.

Table 5-31. Summary Statistics of Bluff H XRF Field Survey Concentrations

Statistic	Total Arsenic (mg/kg*)	Total Molybdenum (mg/kg)	Natural Uranium (mg/kg)	^{238}U (pCi/g**)	^{235}U (pCi/g)	^{234}U (pCi/g)
Removal Action Cutoff Value	**142**	**2,775**	**n/a**	**42.8**	**2.03**	**44.6**
Count	199	199	199	199	199	199
Minimum	9.09	1.45	3.23	1.07	0.05	1.07
Maximum	1,431	11,218	29,722	9,840	452.7	9,840
Standard Deviation	177	834	2,113	699	32.19	699
Median	89	15.6	13.6	4.5	0.21	4.5
Mean	136	165	200	66.2	3.04	66.2
95th Percentile	399	482	194	64	3.0	64
99th Percentile	993	1,563	565	187	8.6	187
% of Points Exceeding Cutoff Value	29.1	0.50	n/a	8.5	8.0	8.0

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





Legend:

2012 Revised Bluff H Boundary

0 125 250 500 Feet

N

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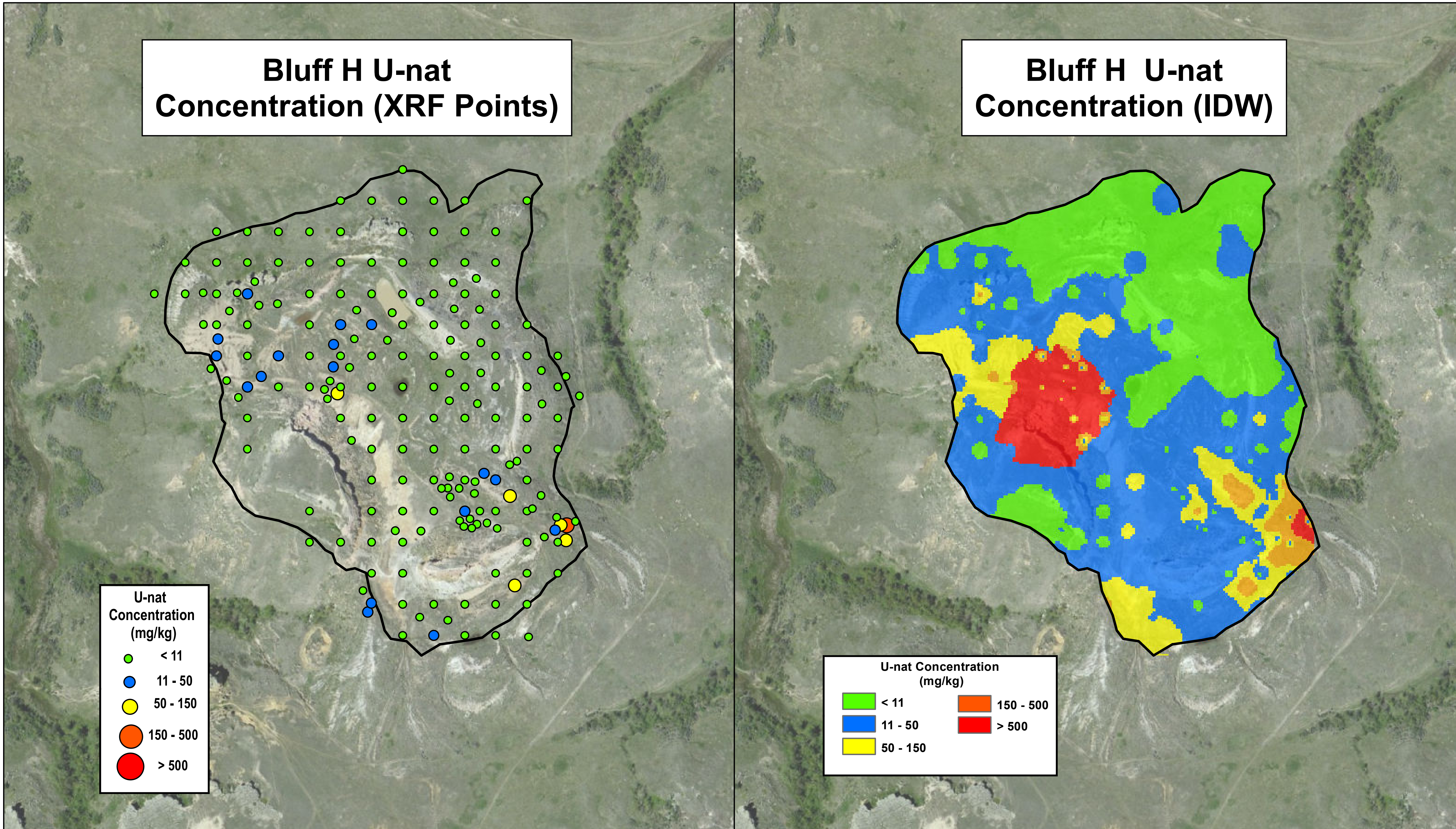
Bluff H XRF and IDW Total Arsenic Concentration Map

3 Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-34
Location: HARDING COUNTY COUNTY, SD	June, 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.34 Bluff H XRF_IDW Total Arsenic.mxd



Legend:

2012 Revised Bluff H Boundary

0 125 250 500 Feet

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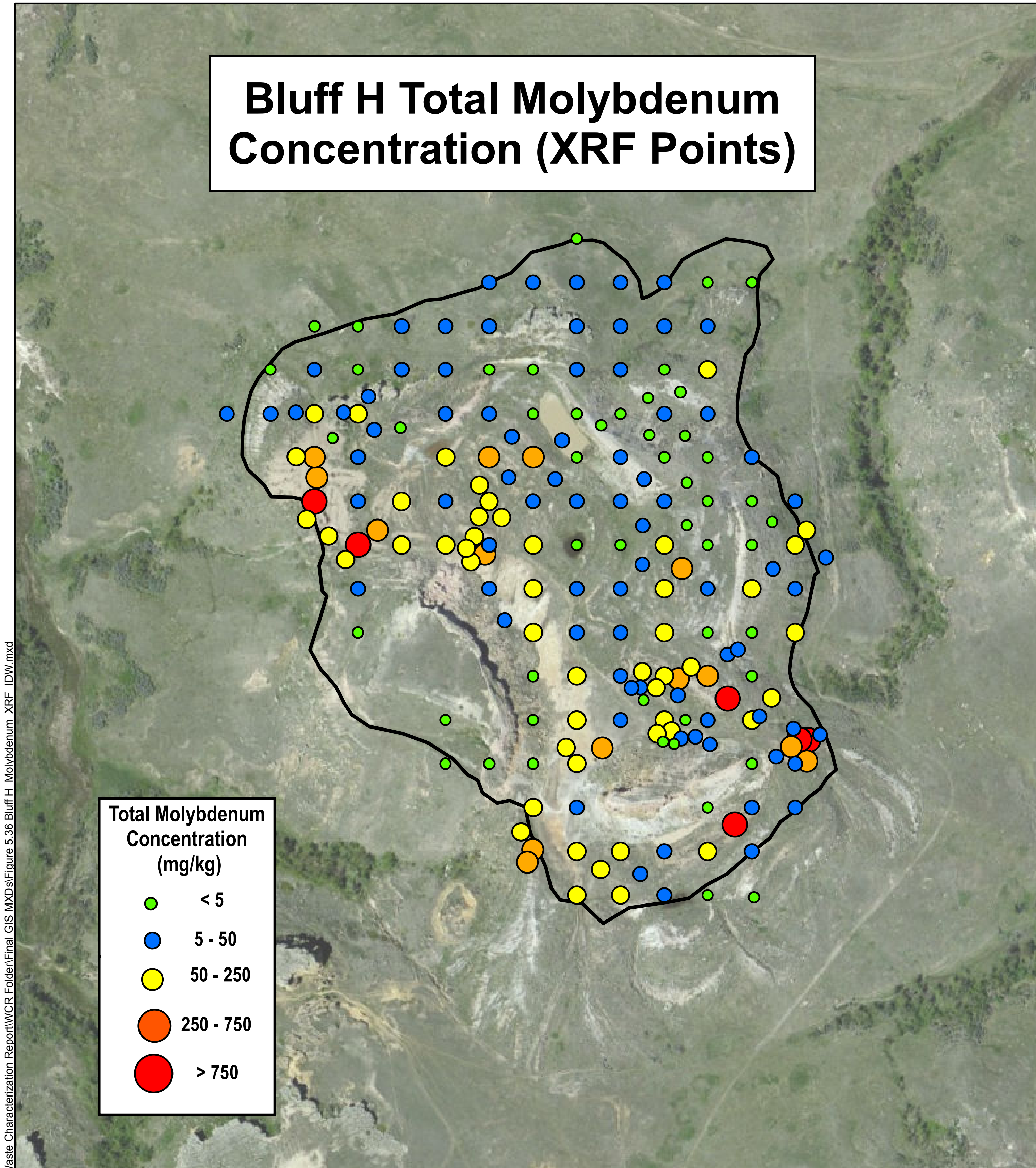
Bluff H XRF and IDW Natural Uranium Concentration Map

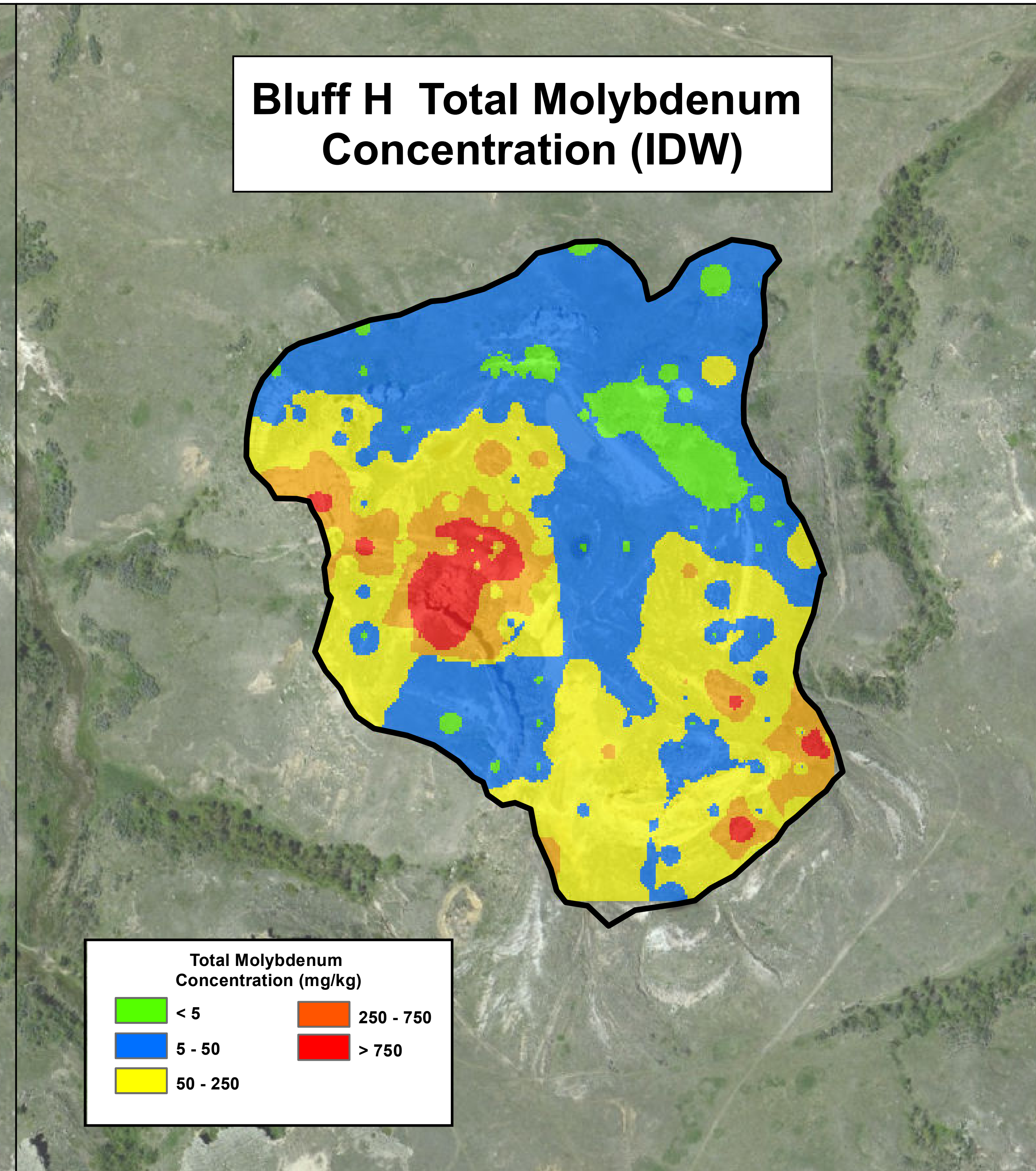
3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-35
Location: HARDING COUNTY COUNTY, SD	June, 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.35 Bluff H XRF_IDW Uranium.mxd





Legend:

2012 Revised Bluff H Boundary

0 125 250 500 Feet

N

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Bluff H XRF and IDW Total Molybdenum Concentration Map

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Revision 3
Location: HARDING COUNTY COUNTY, SD	June, 2013	Figure 5-36

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.36 Bluff H_Molybdenum_XRF_IDW.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet

5.6.5 Bluff H XRF Field Survey Waste Characterization Summary

The *in-situ* XRF samples collected during the XRF field survey provided sufficient information to estimate the areal extent of total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U soil contamination within the bounds of Bluff H.

Raster data sets were developed for total arsenic, total molybdenum, ^{238}U, ^{235}U, and ^{234}U and then combined into a final raster data set that showed the areal extent of all of the contaminated areas merged together that were estimated from the XRF field survey data. The final raster data set was converted into smoothed polygons in order to delineate and estimate the contaminated areas. A flow chart simplifying the logical steps involved for the spatial characterization of gamma radiation and XRF field survey data is provided in Appendix M.

Figure 5-37 shows the areal extent of contaminated areas that were estimated to be above removal action cleanup criteria for at least one of the following constituents: total arsenic (142 mg/kg), total molybdenum (2,775 mg/kg), ^{238}U (42.8 pCi/g), ^{235}U (2.03 pCi/g), and ^{234}U (44.6 pCi/g).

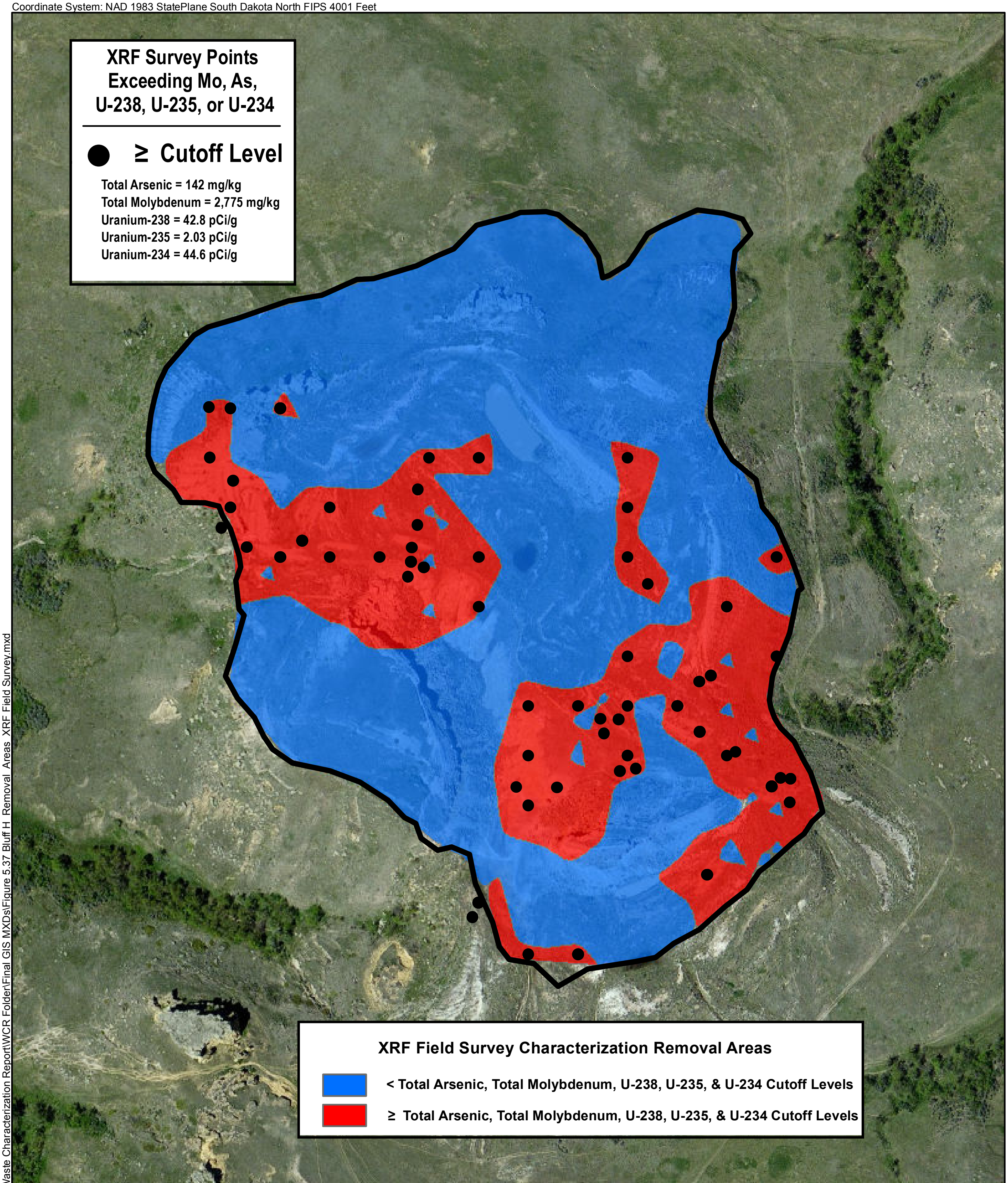
The blue areas on Figure 5-37 show the estimated area that falls below all of the removal action levels, and the red areas show the estimated areas that exceed the soil cleanup levels of at least one of the constituents of concern. Table 5-32 provides a summary of the removal action areas based on the XRF field survey data. The results of the XRF field survey show that 31 percent (9.7 acres) of the area within Bluff H exceeds at least one of the contaminants of concern identified from the XRF field survey waste characterization data.

Table 5-32. Summary of Removal Action Areas by XRF Field Survey Data at Bluff H

Contaminant	Removal Action Cutoff Level	Area (acres)	Percent of Bluff CDE Area
Total Arsenic	<142 mg/kg*	22.0	69
Total Molybdenum	<2,775 mg/kg		
^{238}U	<42.8 pCi/g**		
^{235}U	<2.03 pCi/g		
^{234}U	<44.6 pCi/g		
Total Arsenic	≥142 mg/kg	9.7	31
Total Molybdenum	≥2,775 mg/kg		
^{238}U	≥42.8 pCi/g		
^{235}U	≥2.03 pCi/g		
^{234}U	≥44.6 pCi/g		

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

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

2012 Revised Bluff H Boundary

0 75 150 300 Feet

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Bluff H Removal Action Areas Based on XRF FIeld Survey Data

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-37
Location:	Harding County, South Dakota	June, 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.37 Bluff H Removal Areas XRF Field Survey.mxd

5.6.6 Bluff H Overall Waste Characterization Summary

The procedures for estimating the ^{226}Ra and total arsenic, total molybdenum, and uranium isotopes removal area for Bluff H are discussed in the previous sections. The summaries of the removal action areas specifically based on the gamma radiation survey (^{226}Ra) and the XRF field survey (As, Mo, ^{238}U, ^{235}U, and ^{234}U) for Bluff H are provided in Table 5-30 and Table 5-32, respectively, and are visually presented in Figure 5-33 and Figure 5-37.

Using the revised mine waste categorical definitions of soil reclamation criteria described in Section 2.2, the mine waste category delineation for the surface soils at Bluff H is shown in Figure 5-38. This map was generated by using the map algebra feature in *ArcMap10* © and combining the raster sets of the gamma radiation survey and the XRF field survey data. After this step, the raster data sets were converted to polygons and then smoothed using the *paek* algorithm using a smoothing tolerance of 50-feet. The summary of removal action areas for Bluff H using the combined data from all of the removal action contaminant criteria are provided in Table 5-33.

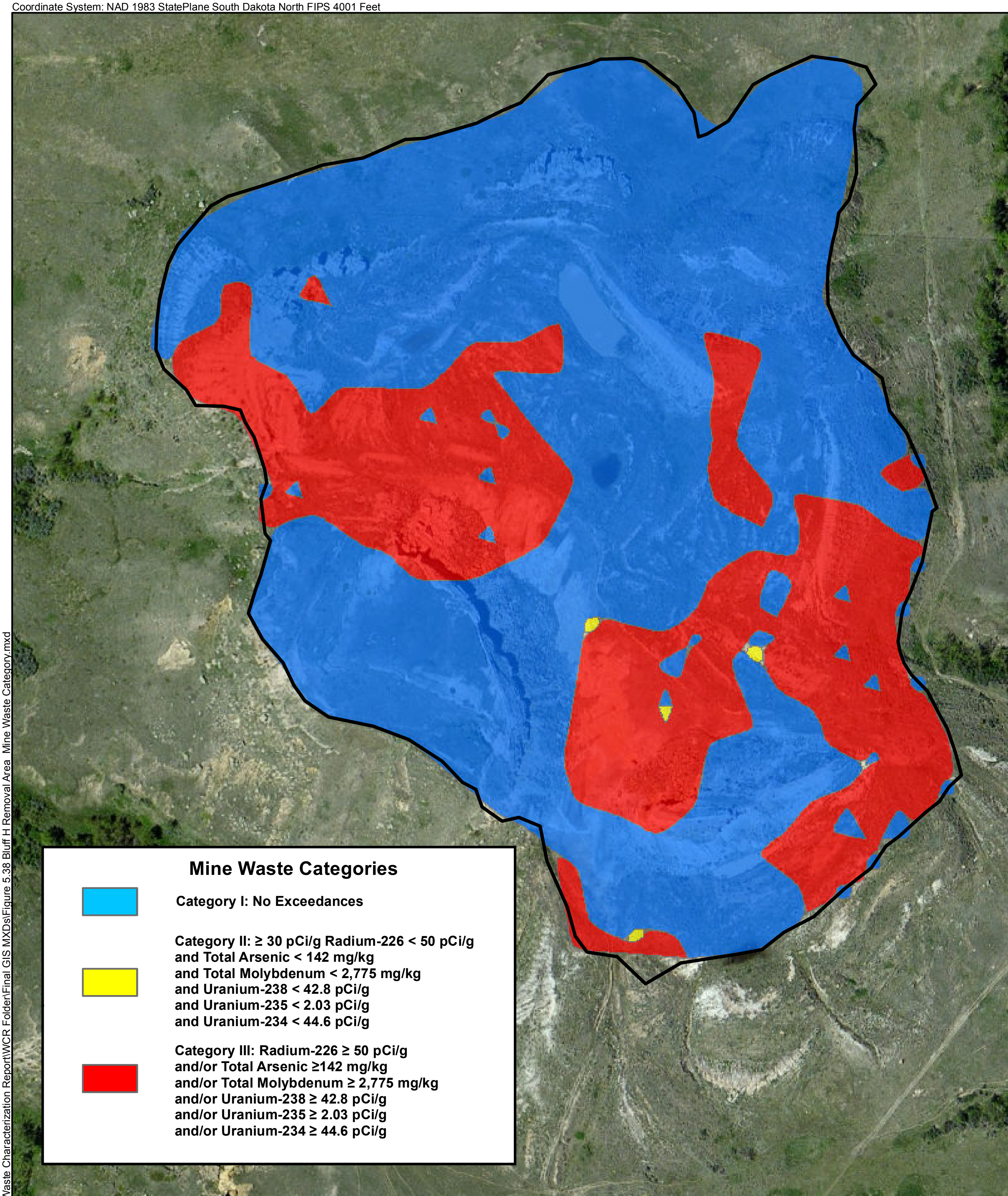
Approximately 69.3 percent (21.9 acres) of the surface soil concentrations at Bluff H do not exceed the soil cleanup values for at least of the contaminants of concern, and over 30.5 percent (9.67 acres) of the surface area of Bluff H were identified as Category III, which is defined as exceeding the soil cleanup value for at least one of the contaminants and/or measuring over 50 pCi/g of ^{226}Ra. As stated in the 2007 Action Memorandum, Category III areas require remediation in order to reduce the contaminant levels to below the soil cleanup values.

Table 5-33. Summary of Mine Waste Categories for Bluff H

Category	Soil Reclamation Criteria	Area (acres)	Percent Area of Bluff H
I	**No Exceedances**: < 30 pCi/g* ^{226}Ra and < 142 mg/kg** Total As and < 2,775 mg/kg Total Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U	21.9	69.3
II	**^{226}Ra Exceedance Only:** ≥ 30 pCi/g and < 50 pCi/g ^{226}Ra and < 142 mg/kg Total As and < 2,775 mg/kg Total Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and < 44.6 pCi/g ^{234}U	0.051	0.2
III	**Exceedances of Any Contaminant**: ≥ 50 pCi/g ^{226}Ra and/or ≥ 142 mg/kg Total As and/or ≥ 2,775 mg/kg Total Mo and/or ≥ 42.8 pCi/g ^{238}U and/or ≥ 2.03 pCi/g ^{235}U and/or ≥ 44.6 pCi/g ^{234}U	9.67	30.5

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

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.38 Bluff H Removal Area Mine Waste Category.mxd

Legend:

2012 Revised Bluff H Boundary

0 70 140 280 Feet

N

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Bluff H- Removal Action Areas and Mine Waste Category Map

3
Revision

Project: Riley Pass Tronox Bluffs

Project no.: 114-551083

Location: Harding County, South Dakota

June, 2013

Figure 5-38

5.7 Test Pit Sampling Results

Test pit sampling was performed according to the methods specified in Section 3.4 and in accordance with the SAP (Tetra Tech, 2012a). The purpose of the test pit sampling by backhoe was intended to estimate the vertical extent of mine-affected materials at the Site. However, after the waste characterization sampling was conducted it was noted that much of the contamination likely exceeds the depth capabilities of the backhoe test pit sampling methods proposed in the SAP. The SAP specified that the sample locations were to be based on professional judgment, areas that are known to require removal action, elevated radionuclide and metals concentrations and accessibility by heavy equipment. It was concluded during the initial sampling trip in 2012 that there were access limitations at Bluff B, Bluff G, and Bluff H. However, the criteria for test pit sampling were met at Bluff CDE, so all of the sample locations were selected within the boundary of Bluff CDE.

A total of nine test pits were excavated to a minimum depth of 5-feet below ground surface (bgs) and a maximum depth of 6-feet bgs. The test pit soil samples were submitted for laboratory analysis using the methods presented in Table 3-4. Eight of the nine test pits had a grab sample from 0-feet to 1-feet bgs and a composite sample from 1-feet to 5-feet (or 6-feet bgs), grab samples were taken from one test pit location in one-foot intervals from 0-feet to 6-feet bgs. The laboratory results of the test pit sampling are presented in Table 5-34. The mine cleanup criteria are shown in this table and any test pit samples that exceeded these criteria are bold highlighted in red. The locations of the test pits are provided in Figure 5-39.

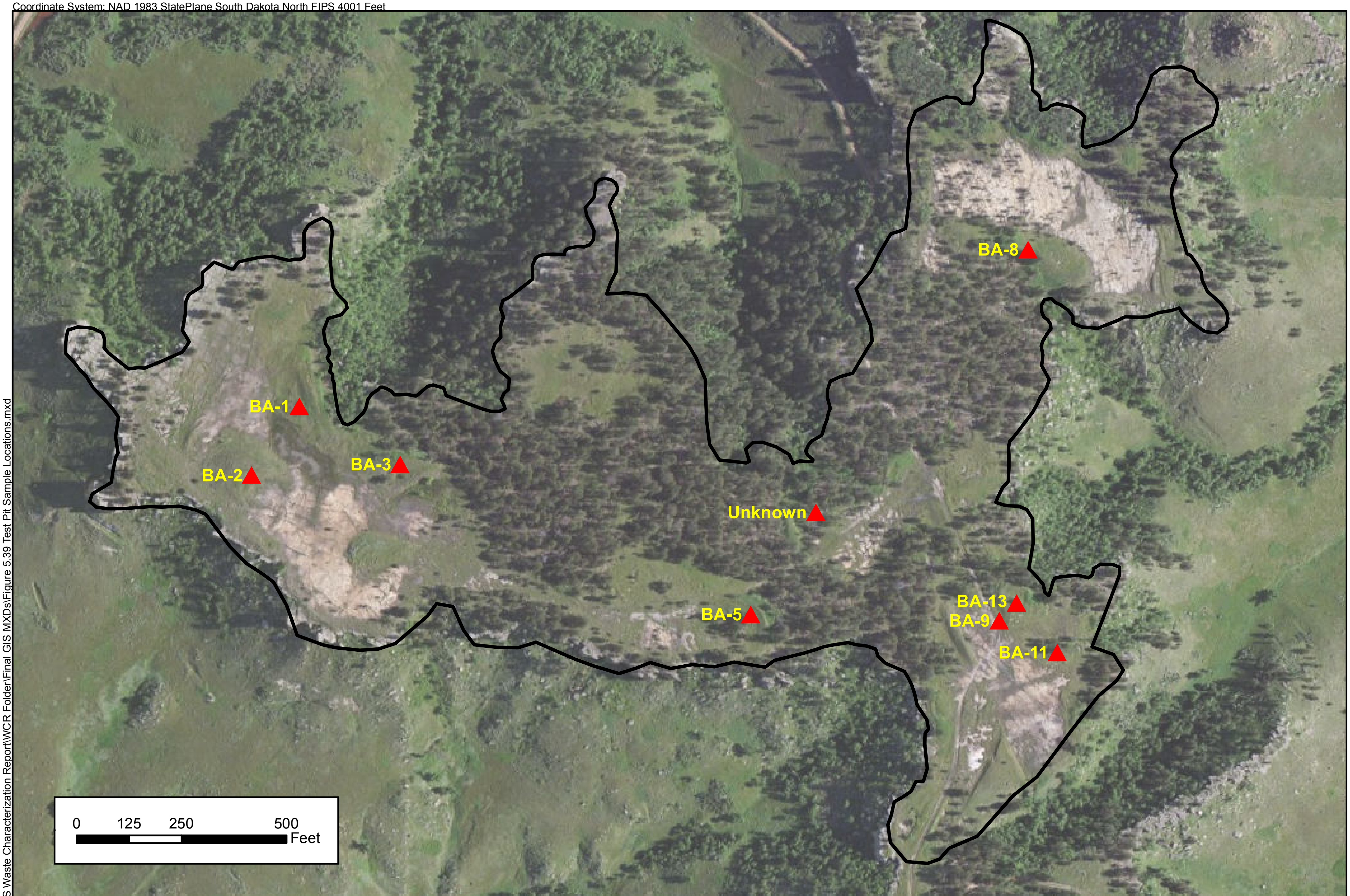
The elevated gamma exposure rates and XRF metals concentrations collected at Bluff CDE matched closely with the corresponding ^{226}Ra activity and metals concentrations measured in the test pit surface samples. The test pit surface samples that exceeded removal action levels (0-feet to 1-feet bgs) were consistent with the contamination levels measured in subsurface samples (1-feet to 5/6-feet bgs) for 7 of the 9 test pit locations. In general, the test pit sampling indicates that the surface and subsurface contaminant levels were uniform and there was no apparent increasing or decreasing trends in contaminant concentration with depth. In each of the test pits analyzed, the deepest test pit sample collected had contaminant levels that exceeded the removal action cutoff levels. The test pit sampling at Bluff CDE does not reflect the conditions observed at the other bluffs; therefore, the average waste pile height of 6-feet bgs should only be applied to estimate the volumes of mine waste materials at Bluff CDE. The test pit field notes are included in Appendix B. The final test pit sample laboratory reports are provided in Appendix P. The laboratory data validation assessment summary for the test pit sampling laboratory analyses is provided in Appendix J.

Table 5-34. Test Pit Sample Results

Test Pit ID	Depth (bgs*)	Sample ID	Sample Type	^{226}Ra (pCi/g**)	Total Arsenic (mg/kg**)	Total Molybdenum (mg/kg)	Natural Uranium (mg/kg)	^{238}U (pCi/g)	^{235}U (pCi/g)	^{234}U (pCi/g)
Cutoff Values:				**50**	**142**	**2,775**	**-**	**42.8**	**2.03**	**44.6**
BA-1	0' to 1'	BA-1 0-1'	Grab	**527**	**530**	220	790	**262**	**12.0**	**262**
	1' to 5'	BA-1 1'-5'	Composite	**393**	**520**	300	590	**195**	**8.99**	**195**
BA-2	0' to 1'	BA-2 0-1'	Grab	**61.5**	**200**	84.0	81.0	26.8	1.23	26.8
	1' to 6'	BA-2 1'-6'	Composite	**53.9**	**240**	110	220	**72.8**	**3.35**	**72.8**
BA-3	0' to 1'	BA-3 0'-1'	Grab	**504**	**430**	240	430	**142**	**6.55**	**142**
	1' to 5'	BA-3 1'-5'	Composite	**149**	**280**	140	340	**113**	**5.18**	**113**
BA-5	0' to 1'	BA-5 0-1'	Grab	**67.1**	**160**	42.0	59.0	19.5	0.899	19.5
	1' to 6'	BA-5 1'-6'	Composite	**89.0**	120	33.0	76.0	25.2	1.16	25.2
BA-8	0' to 1'	BA-8 0-1'	Grab	**80.5**	**270**	92.0	70.0	23.2	1.07	23.2
	1' to 6'	BA-8 1'-6'	Composite	**194**	**410**	210	280	**92.7**	**4.27**	**92.7**
BA-9	0' to 1'	BA-9 0-1'	Grab	34.8	**150**	28.0	43.0	14.2	0.65	14.2
	1' to 6'	BA-9 1'-6'	Composite	**76.3**	**180**	65.0	83.0	27.5	1.26	27.5
BA-11	0' to 1'	BA-11 0-1'	Grab	**80.8**	**170**	73.0	64.0	21.2	0.97	21.2
	1' to 6'	BA-11 Comp	Composite	**294**	**400**	190	440	**146**	**6.70**	**146**
BA-13	0' to 1'	BA-13 0-1'	Grab	18.1	78.0	23.0	34.0	11.3	0.518	11.3
	1' to 2'	BA-13 1'-2'	Grab	26.2	**170**	51.0	20.0	6.62	0.305	6.62
	2' to 3'	BA-13 2'-3'	Grab	26.6	80	22.0	22.0	7.28	0.335	7.28
	3' to 4'	BA-13 3'-4'	Grab	32.1	80	23.0	20.0	6.62	0.305	6.62
	4' to 5'	BA-13 4'-5'	Grab	23.9	43.0	13.0	21.0	6.95	0.320	6.95
	5' to 6'	BA-13 5'-6'	Grab	**81.3**	**170**	70.0	93.0	30.8	1.42	30.8
Unknown	0' to 1'	Unk-1 0-1'	Grab	**196**	**210**	48.0	85.0	28.1	1.29	28.1
	1' to 6'	Unk-1 1'6'	Composite	**150**	**220**	68.0	190	**62.9**	**2.89**	**62.9**

*bgs = below ground surface
**pCi/g = picocuries per gram
***mg/kg = milligrams per kilogram

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.39 Test Pit Sample Locations.mxd

Legend:

2012 Revised Bluff CDE Boundary

Test Pit Locations

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Test Pit Sample Locations

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 5-39
Location:	Harding County, South Dakota	June 2013	

5.8 Sediment Sampling Results

The sediment samples were analyzed for a suite of total metals (arsenic, cadmium, copper, lead, molybdenum, uranium, and zinc) and agronomic soil salinity parameters (pH, EC, SAR) in order to evaluate the sediments with respect to current reclamation criteria and removal action goals (Table 5-35). Additional preliminary topsoil suitability criteria for the Riley Pass Mining Area are provided in Table 5-35 and are largely based on texture, coarse fragment content, soil salinity indicators, and site-specific metal concentration limits. The sediment sample location maps are shown on Figure 5-40 through Figure 5-42.

The total metal results for all sediment samples collected in 2012 are provided in Table 5-36, and indicate similar ranges in metals concentrations across all sampling locations, with arsenic concentrations tending to decrease heading downstream. Comparatively lower metals concentrations were observed within Brown's Reservoir. All sediment metal concentrations meet the suitability requirement for use as topsoil (Table 5-35), including arsenic which is below the risk-based arsenic cleanup criteria level of 142 mg/kg (Table 5-36). In addition, a previous evaluation of ^{226}Ra in Sediment Ponds 1 through 5, Schleichart Reservoir, and the Ducks Unlimited Pond (Portage, 2006) showed that ^{226}Ra activity ranged between 2.1 and 6.7 pCi/g, which are below the risk-based ^{226}Ra cleanup criteria of 30 pCi/g. Therefore, sediment metal and radiological characteristics from these eight locations meet the Category I criteria (Table 5-35), which would require only revegetation and stabilization if sediments are relocated to the bluffs or elsewhere during reclamation.

The samples were collected following a simple random sampling scheme as outlined in Gilbert (1987). The variance and standard error of the mean are computed based on the type of sampling scheme performed and are provided in Table 5-37. The low standard error for each constituent indicates that the sampling accurately portrays sediment characteristics of the surface sediments (first 6-inches) in each pond. Additional sampling is unlikely to result in a significant refinement of the average metals concentrations of the pond sediments. However, because sediment samples were taken only from the first 6-inches of sediment, additional sampling is recommended to verify the sediment characteristics at depth.

The agronomic soil testing results for all sediment samples are provided in Table 5-37. Although particle size analysis was not conducted on the samples, large proportions of coarse fragments were not observed during sampling, and therefore sediment textural characteristics may be suitable for use as topsoil material. The sediment pH values (7.32 to 8.71) are within the range required for topsoil suitability (Table 5-35), and the EC values indicate that salinity levels are also suitable, with the exception of two samples from the Ducks Unlimited Pond that contained elevated EC values (>6 dS/m). The soluble calcium, magnesium, and sodium concentrations were used to calculate the sodium adsorption ratio (SAR) and the related exchangeable sodium percentage (ESP), which provide an indication of the potential sodium hazard to crops and soils. The majority of the values exceed topsoil guidelines for SAR (Table 5-35) and ESP (Hanson et. al., 2006), and therefore may contribute to poor infiltration and surface runoff if the sediments were to be used as cover material during reclamation unless amended. The elevated SAR poses the greatest risk associated with use of sediment as a cover material, and can only be corrected by blending of sediments with lower SAR material and/or by reclaiming the sediments with gypsum application followed by active leaching with good quality water, which may be impractical to implement. The final sediment sample laboratory reports are provided in Appendix H. The laboratory data validation assessment summary for the sediment sampling laboratory analyses is provided in Appendix J.

Table 5-35. Preliminary Topsoil Suitability Criteria – Riley Pass Mining Area

Property	Suitable	Unsuitable
Depth (cover depth)	12-18 inches	<12 inches
USDA Texture (thickest layer 0-40 in.)	SL	> 45% Clay content and LS, S
Rock Fragments (% by volume)	<45 (all fragments less than six inches diameter)	>45
Depth to High Water Table (feet)	---	Perennial wetness
Soil Reaction (pH)	6.5 to 8.5	< 6.5 to > 8.5
Electrical Conductivity (EC)	≤ 6 dS/m*	> 6 dS/m
Sodium Adsorption Ratio (SAR)	≤ 12	> 12
Exchangeable Sodium Percentage (ESP)**	≤ 15	> 15
Arsenic	≤ 142 ppm***	>142 ppm
Cadmium	≤ 4 ppm	> 4 ppm
Copper	≤ 100 ppm	> 100 ppm
Lead	≤ 100 ppm	> 100 ppm
Zinc	≤ 250 ppm	> 250 ppm

*dS/m = deciSiemens per meter
**ESP limit calculated using stated SAR limit and the conversion provided by Hanson et al. (2006).
***ppm = parts per million

Table 5-36. Total Metal Results (mg/kg*) for Riley Pass 2012 Sediment Samples

Location	Field ID	Arsenic	Cadmium	Copper	Lead	Molybdenum	Uranium	Zinc
Schleichart Draw	SED-DRAW-1	26	0.26	19	16	2.0	5.5	69
	SED-DRAW-2	28	0.50	31	28	6.9	11	100
	SED-DRAW-3	38	0.51	27	24	4.7	8.8	91
Brown's Reservoir	SED-BROWN-1	12	0.14	6.8	6.9	1.0	1.3	30
	SED-BROWN-2	7.9	0.069	3.2	4.2	0.74	0.83	25
	SED-BROWN-3	6.4	0.23	14	11	0.65	2.1	70
Ducks Unlimited	SED-DUCK-1	48	0.29	14	13	1.3	2.7	65
	SED-DUCK-2	54	0.57	38	31	6.2	16	160
	SED-DUCK-3	43	0.41	25	24	4.3	8.7	130
Sediment Pond 1	SED-SP1-1	99	0.29	9.8	10	13	6.1	83
	SED-SP1-2	43	0.20	9.2	10	8.9	3.2	58
	SED-SP1-3	54	0.27	13	12	6.7	8.5	110
Sediment Pond 2	SED-SP2-1	77	0.36	18	15	15	13	100
	SED-SP2-2	25	0.53	23	18	18	11	130
	SED-SP2-3	69	0.20	14	11	25	14	78
Sediment Pond 3	SED-SP3-1	26	0.30	13	13	2.0	5.2	81
	SED-SP3-2	25	0.18	7.9	8.7	4.0	3.1	63
	SED-SP3-3	31	0.58	8	8	2.4	4.0	56
Sediment Pond 4	SED-SP4-1	61	0.57	28	27	3.6	6.1	160
	SED-SP4-2	58	0.55	27	26	4.8	11	99
	SED-SP4-3	37	0.28	19	19	1.8	3.5	98
Sediment Pond 5	SED-SP5-1	60	0.48	31	26	2.9	5.5	110
	SED-SP5-2	48	0.33	23	22	3.9	6.3	100

* mg/kg = milligrams per kilogram

Table 5-37. Sediment Sampling Standard Error

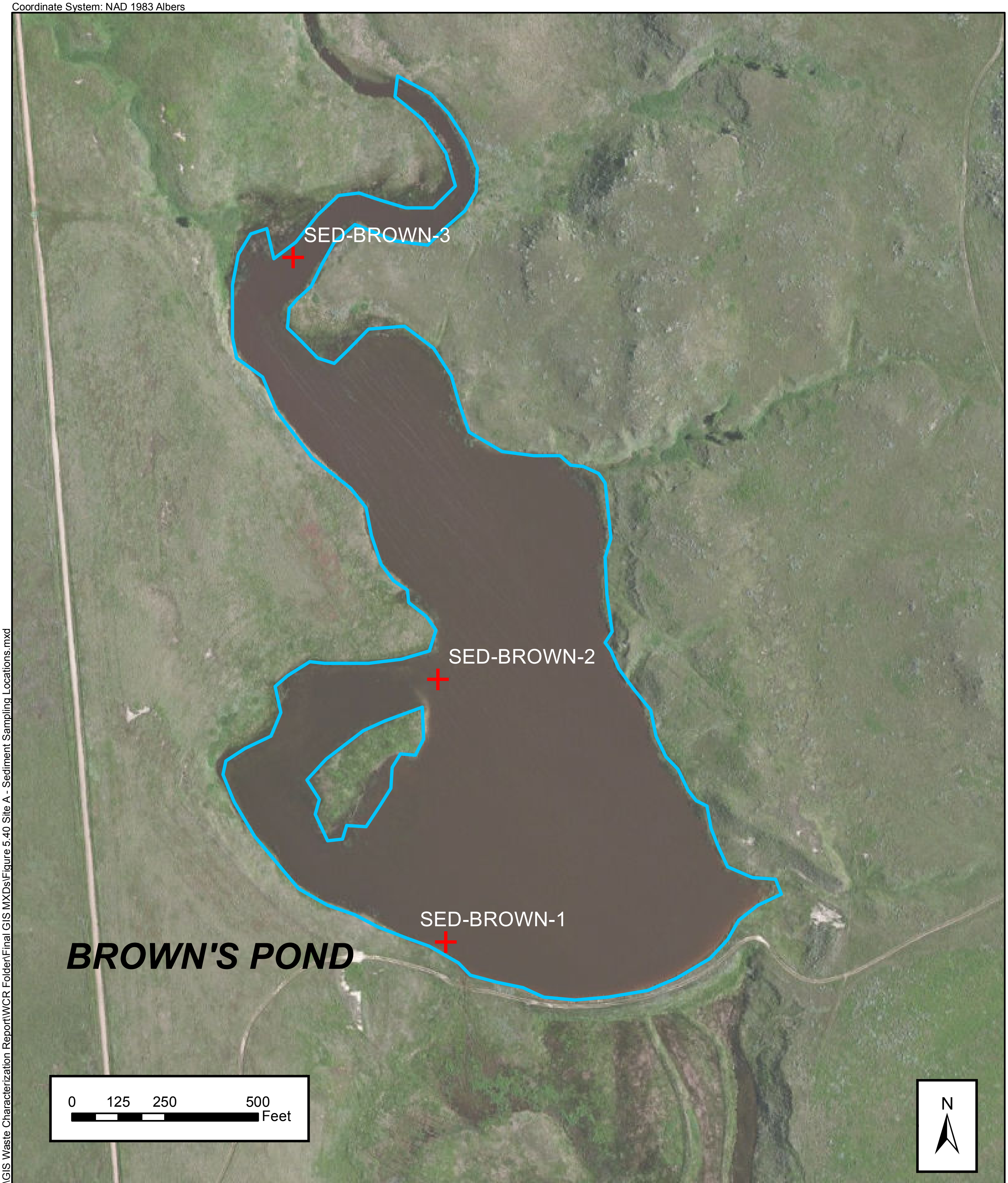
Location	Arsenic		Cadmium		Copper		Lead		Molybdenum		Uranium		Zinc	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Schleichart Draw	30.7	3.7	0.4	0.08	25.7	3.53	22.7	3.53	4.5	1.42	8.4	9.21	86.7	9.21
Brown's Reservoir	8.8	1.7	0.1	0.05	8.0	3.17	7.4	1.98	0.8	0.10	1.4	0.37	41.7	14.24
Ducks Unlimited	48.3	3.2	0.4	0.08	25.7	6.94	22.7	5.24	3.9	1.43	9.1	3.85	118.3	28.04
Sediment Pond 1	65.3	17.1	0.3	0.03	10.7	1.18	10.7	0.67	9.5	1.85	5.9	1.53	83.7	15.01
Sediment Pond 2	57.0	16.2	0.4	0.10	18.3	2.60	14.7	2.03	19.3	2.96	12.7	0.88	102.7	15.07
Sediment Pond 3	27.3	1.9	0.4	0.12	9.6	1.68	9.9	1.56	2.8	0.61	4.1	0.61	66.7	7.45
Sediment Pond 4	52.0	7.5	0.5	0.09	24.7	2.85	24.0	2.52	3.4	0.87	6.9	2.20	119.0	20.50
Sediment Pond 5	54.0	6.0	0.4	0.07	27.0	4.00	24.0	2.00	3.4	0.50	5.9	0.40	105.0	5.00

Table 5-38. Agronomic Testing Results (Saturation Paste Extract) for Riley Pass Sediment Samples (0- to 8-inch Depth)[1]

Location	Field ID	pH	EC (dS/m*)	Nitrate-N (mg/L**)	Phosphorus (mg/L)	Potassium (mg/L)	Calcium (me/L***)	Magnesium (me/L)	Sodium (me/L)	SAR	ESP	Gypsum (T/acre+)
Schleichart Draw	SED DRAW-1	8.71	2.49	0.02	0.13	43.9	1.47	5.37	32.6	17.6	25	9.75
	SED DRAW-2	8.08	4.52	2.33	0.58	53.4	1.89	9.84	55.1	22.8	33	9.68
	SED DRAW-3	8.09	4.95	4.53	1.11	43.8	2.32	10.6	63.8	25.1	36	15.8
Brown's Reservoir	SED BROWN-1	8.09	1.85	0.15	0.01	35.8	1.11	11.1	43.8	17.8	25	10.6
	SED BROWN-2	7.73	1.80	2.44	0.03	32.9	2.93	8.03	38.6	16.5	23	8.8
	SED BROWN-3	7.32	2.67	0.02	0.02	41.4	6.72	10.5	42.8	14.6	20	11.6
Ducks Unlimited	SED DUCK-1	8.26	7.02	0.02	0.02	51.9	2.95	28.1	152	38.8	56	6.12
	SED DUCK-2	8.14	4.77	1.81	0.44	33.9	3.69	9.55	69.7	27.1	39	10.2
	SED DUCK-3	7.98	8.19	0.04	0.04	86.2	2.90	24.8	137	37.0	54	9.98
Sediment Pond 1	SED SP1-1	7.41	1.76	5.46	0.02	27.5	7.31	4.67	20.7	8.5	11	1.21
	SED SP1-2	8.02	1.35	11.4	0.01	13.7	2.33	1.41	16.3	11.9	17	1.47
	SED SP1-3	7.57	1.87	0.01	0.07	24.6	5.61	4.97	30.4	13.2	18	2.09
Sediment Pond 2	SED SP2-1	7.42	3.57	0.02	0.22	46. 7	16.32	12.8	62.0	16.3	23	2.37
	SED SP2-2	7.81	2.29	13.8	0.13	22.4	7.37	6.41	54.1	20.6	29	2.29
	SED SP2-3	7.64	2.89	0.55	0.11	26.2	5.77	4.65	39.1	17.1	24	3.40
Sediment Pond 3	SED SP3-1	7.38	1.08	0.02	0.14	5.22	0.86	0.39	10.9	13.8	19	1.92
	SED SP3-2	7.82	1.22	1.23	0.06	8.42	1.17	0.97	18.8	18.2	26	1.84
	SED SP3-3	8.47	0.54	25.4	0.47	3.74	0.32	0.01	9.8	24.2	35	1.65
Sediment Pond 4	SED SP4-1	7.93	3.95	1.58	1.71	17.9	1.09	1.83	61.2	50.7	74	9.16
	SED SP4-2	7.80	3.58	0.22	0.08	20.2	2.22	3.04	40.8	25.2	36	9.13
	SED SP4-3	7.71	3.43	0.57	0.11	18.1	3.91	3.87	43.9	22.3	32	7.61
Sediment Pond 5	SED SP5-1	8.04	4.92	1.21	0.29	29.9	3.03	4.62	65.1	33.3	48	30.3
	SED SP5-2	7.59	5.75	0.03	0.19	44.8	7.34	11.9	74.1	23.9	34	21.3

[1] Bold values exceed the topsoil suitability criteria provided in Table 5-35.
*dS/m = deciSiemens per meter
**mg/L = milligrams per liter
***me/L = milliequivalent per liter
+T/acre = tons per acre

Coordinate System: NAD 1983 Albers



Legend:

Sediment Pond Boundary

Sediment Sampling Locations

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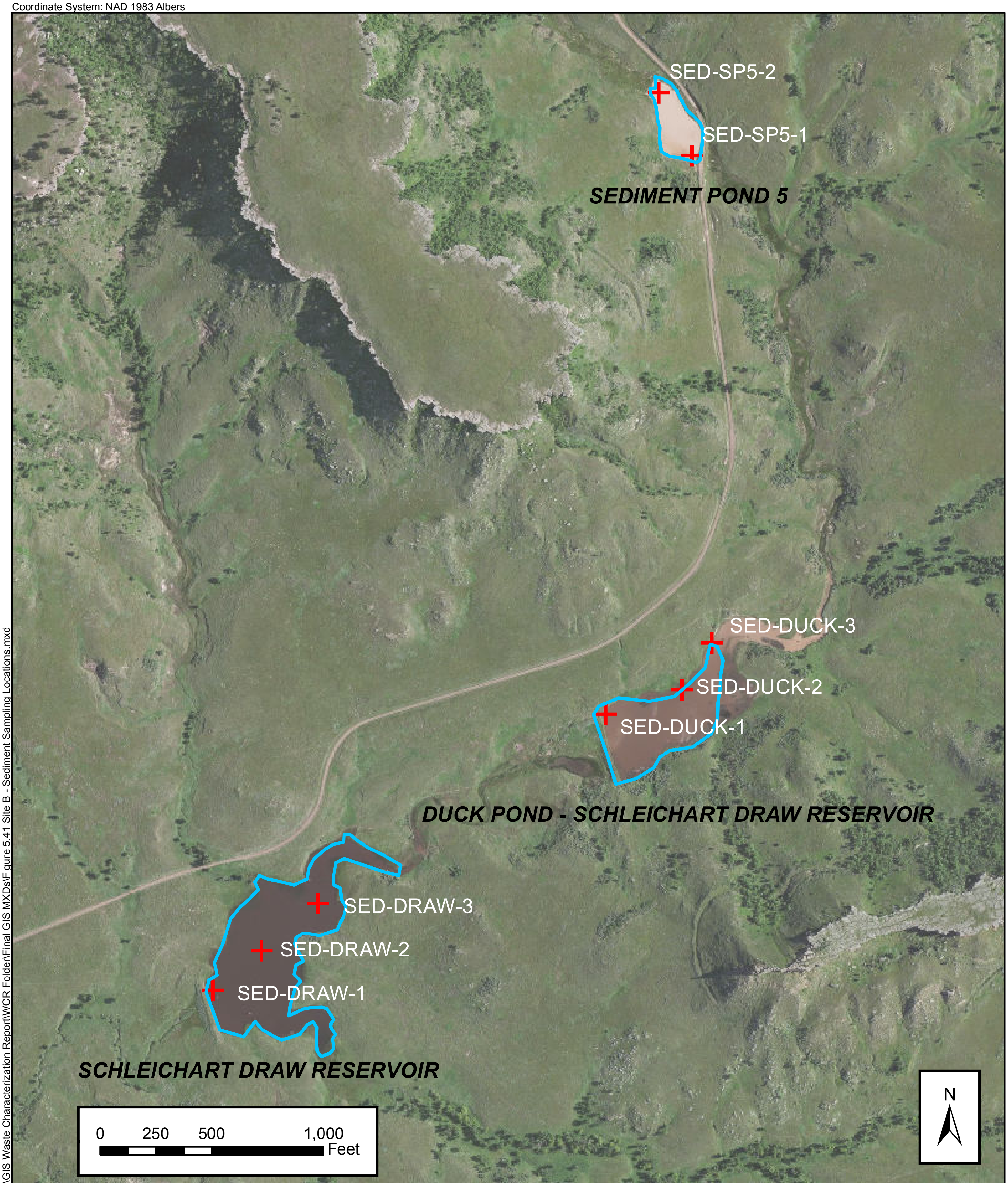
Fort Collins, Colorado 80525
(970) 223-9600 (970) 223-7171 fax

Sediment Sampling Locations-
Location A Map

Project:	RILEY PASS - URANIUM MINE	Project no.: 114-511083	Figure 5-40
Location:	HARDING COUNTY, SOUTH DAKOTA	June 2013	

Path: X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.40 Site A - Sediment Sampling Locations.mxd

Coordinate System: NAD 1983 Albers



Path: X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.41 Site B - Sediment Sampling Locations.mxd

Legend:

Sediment Pond Boundary

Sediment Sampling Locations

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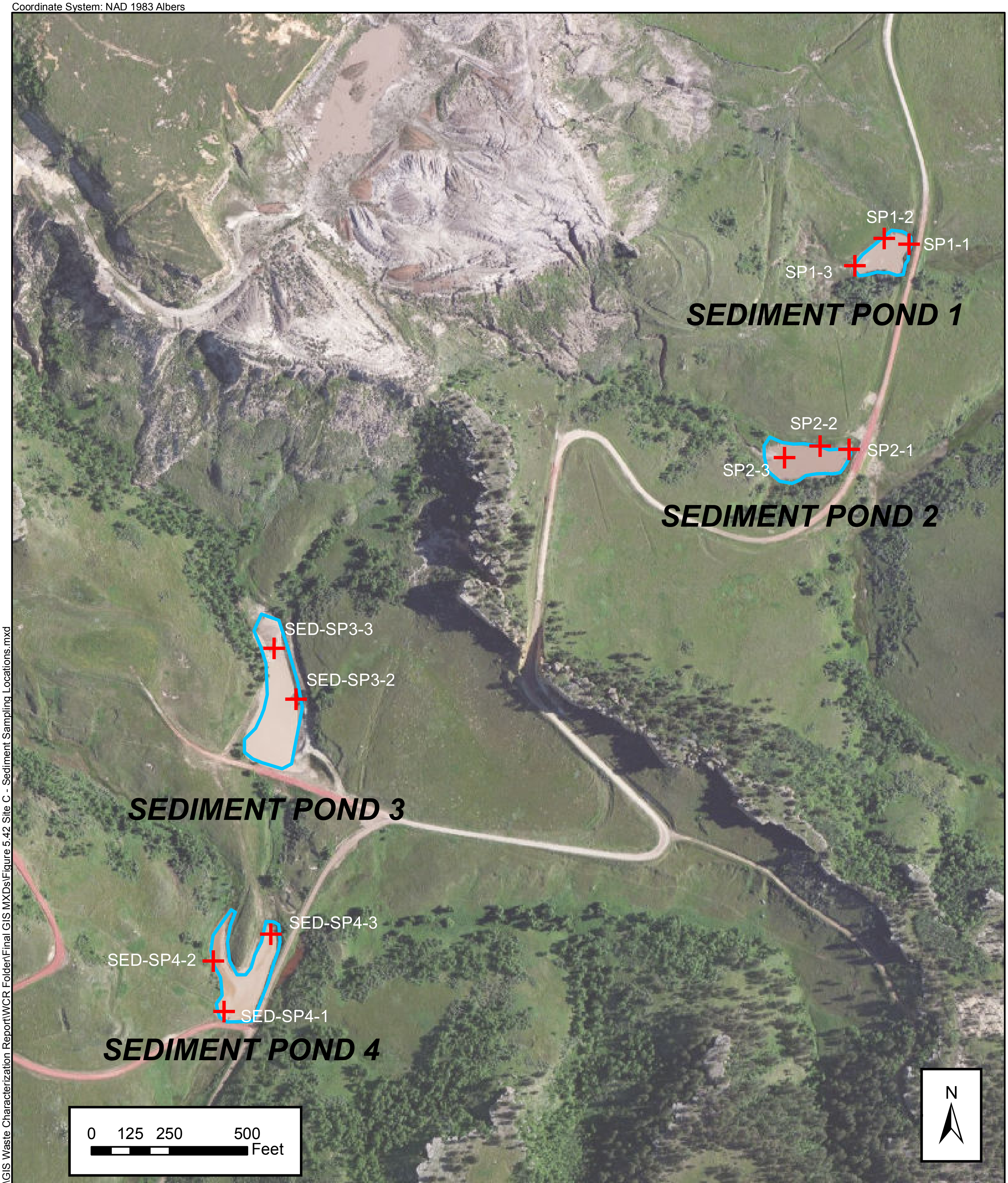
Sediment Sampling Locations-
Location B Map

Project:	RILEY PASS - URANIUM MINE	Project no.: 114-511083		Figure 5-41
Location:	HARDING COUNTY, SOUTH DAKOTA	June 2013		

Coordinate System: NAD 1983 Albers



Path: X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.42 Site C - Sediment Sampling Locations.mxd

Legend:

Sediment Pond Boundary

Sediment Sampling Locations

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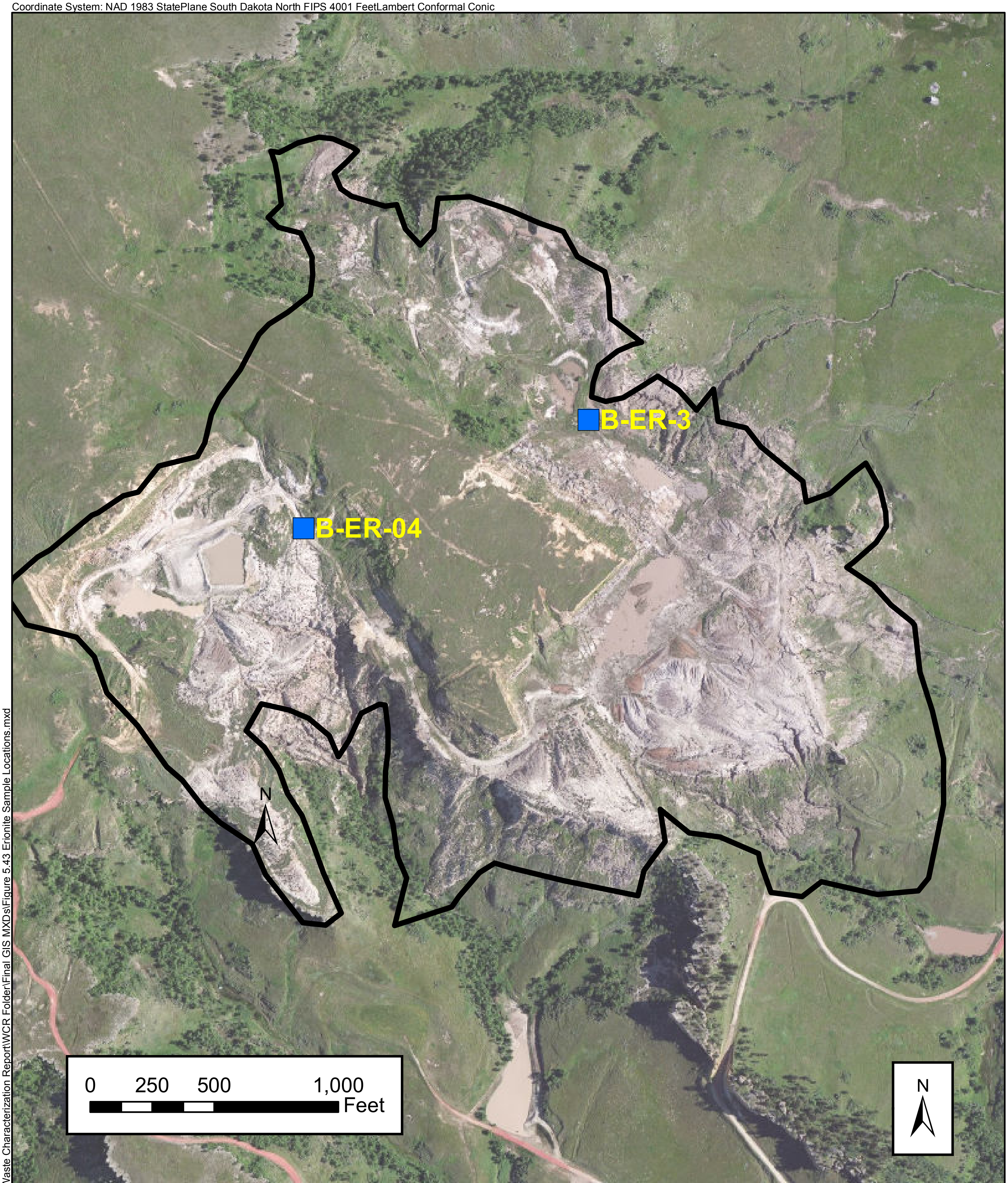
Sediment Sampling Locations-
Location C Map

Project:	RILEY PASS - URANIUM MINE	Project no.: 114-511083	Figure 5-42
Location:	HARDING COUNTY, SOUTH DAKOTA	June 2013	

5.9 Erionite Sampling Results

Per request of the USFS and in accordance with the SAP, limited sampling of road surfacing materials was performed by field personnel on November 4, 2012 and submitted for laboratory erionite analysis. PLM bulk analysis indicates percent sample composition by volume ranges from trace to five percent erionite. The locations of erionite samples B-ER-03 and B-ER-04 are shown on Figure 5-43. The final erionite results, photographs, and laboratory reports are provided in Appendix I. The laboratory data validation assessment summary for the erionite sampling laboratory analyses is provided in Appendix J.

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 FeetLambert Conformal Conic



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 5.43 Erionite Sample Locations.mxd

Legend:

Bluff B Boundary

Erionite Sample Locations

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Erionite Sampling Locations

3
Revision

Project: Riley Pass Tronox Bluffs

Project no.: 114-551083

Location: Harding County, South Dakota

June 2013

Figure 5-43

5.10 Summary of Tronox Bluffs Waste Characterization Results

A detailed, comprehensive, high-density gamma radiation survey and XRF field survey were conducted at each of the Tronox Bluffs B, CDE, G, and H as part of the waste characterization program. Each of these surveys utilized state-of-the art double sampling techniques to gather large amounts of environmental monitoring data using a less expensive method (gamma radiation survey, XRF field survey), which was then used estimate the more accurate and expensive parameters (^{226}Ra, As, etc.) and effectively characterize each bluff to a definitive level of accuracy. The gamma radiation survey defined the range and spatial extent of soil ^{226}Ra activity at each of the bluffs and the XRF field survey defined the range and spatial extent of total arsenic soil concentration, total molybdenum soil concentration, natural uranium soil concentration, soil ^{238}U activity, soil ^{235}U activity, and the soil ^{235}U activity at each bluff. The results of both surveys for each bluff are presented in Section 5.3 to Section 5.6. This section describes the overall waste characterization results for both surveys and provides a preliminary volume estimate of mine waste materials that need to be excavated and placed in a repository.

5.10.1 Summary of Gamma Radiation Survey Waste Characterization Results for the Tronox Bluffs

The gamma radiation survey performed by Tetra Tech was successful in characterizing the overall soil ^{226}Ra activity at each of the bluffs. The individual gamma radiation survey results for Bluff B, CDE, G, and H are presented in Section 5.3 through Section 5.6, respectively. Geostatistical analysis methods (kriging) were applied to each bluff to delineate the removal action areas. Statistical evaluations were performed on the individual bluffs in addition to statistical evaluations used to compare the bluff areas.

An individual distribution analysis was performed on each of the bluffs to evaluate if the soil ^{226}Ra activity followed a specific parametric distribution; in addition to individual bluff analysis, the entire data set was evaluated and goodness of fit methods were applied to all of the bluffs. The results of the individual distribution analysis indicated that the target population of soil ^{226}Ra activities evaluated at the Tronox Bluffs does not closely resemble any of the parametric distributions that were evaluated. This is similar to the soil ^{226}Ra data collected at the mine disturbed Non-Tronox Bluff areas. Performing this analysis has proven to be a useful tool in evaluating the success of reclamation efforts. In general, the background, non-disturbed area gamma exposure rates and soil ^{226}Ra activities follow a normal distribution, and this can be compared to the reclaimed bluff area to graphically and statistically show the efficiency of the reclamation efforts (Tetra Tech, 2012c; Tetra Tech, 2013). The soil ^{226}Ra activity from the bluffs is shown in Figure 5-44 and compared to a lognormal probability plot. The data does not follow a lognormal distribution; however, after reclamation has been completed, the data will more closely resemble the background distribution.

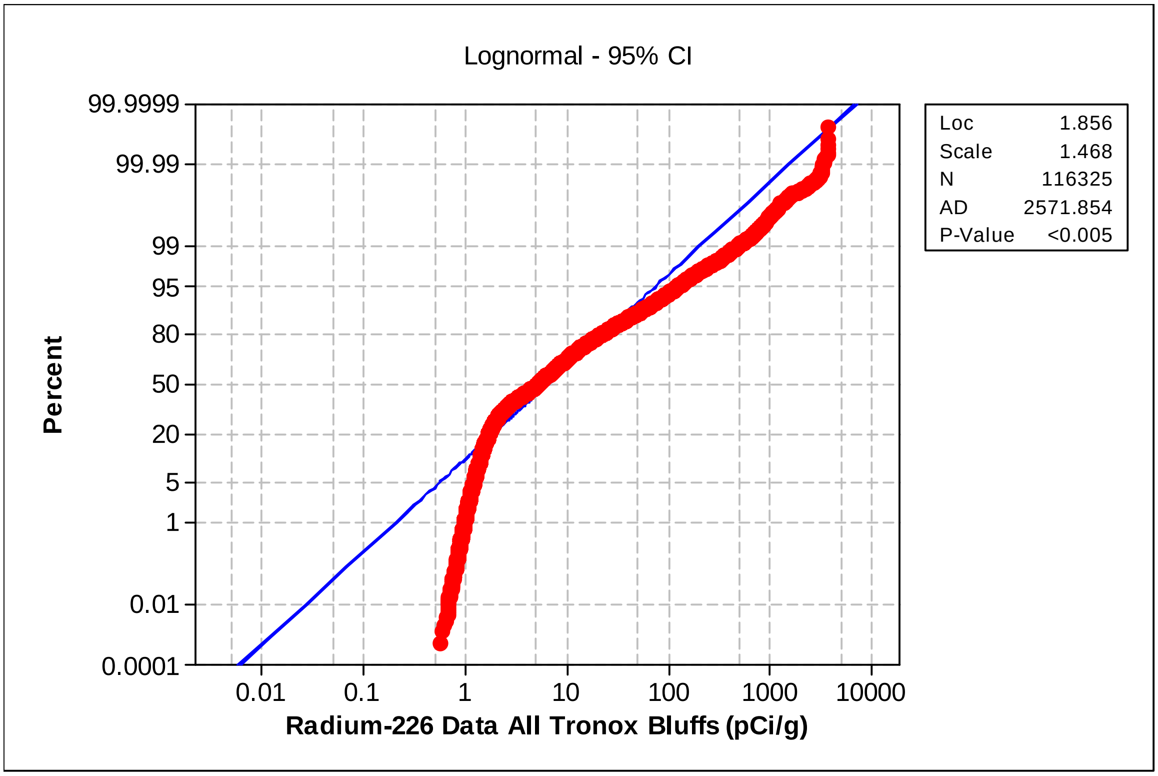


Figure 5-44. Lognormal Probability Plot of Soil ^{226}Ra Activity for Tronox Bluffs

An interval plot, showing the mean soil ^{226}Ra activity with an interval bar on the 95th confidence interval of the mean, is shown for each bluff area in Figure 5-45. A reference line is included on that figure placed at the ^{226}Ra soil cleanup value of 30 pCi/g and 50 pCi/g. The mean soil ^{226}Ra activity for both Bluff B and Bluff H fall below the cutoff value of 30 pCi/g. The mean soil ^{226}Ra activity for Bluff G is between 30 pCi/g to 50 pCi/g and the mean soil ^{226}Ra activity at Bluff CDE exceeds the 50 pCi/g cutoff value.

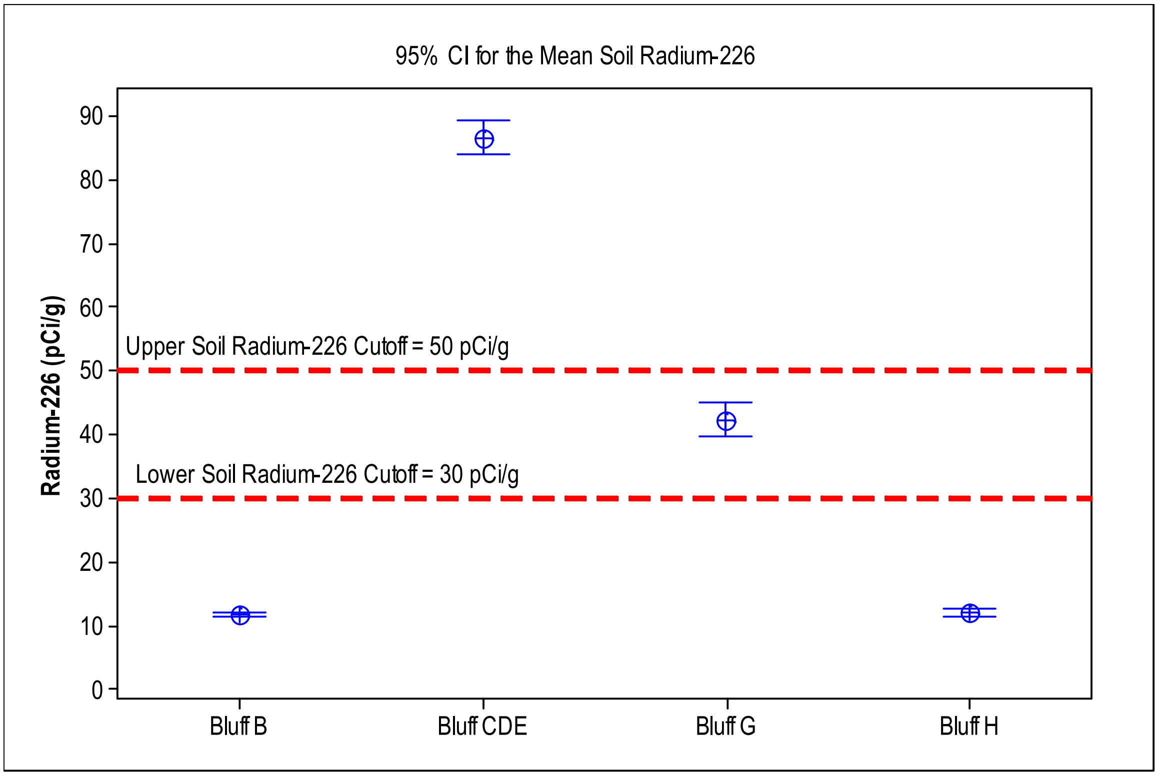


Figure 5-45. Interval Plot of Mean Soil ^{226}Ra Activity at Tronox Bluffs

The highest mean ^{226}Ra activity (86.8 pCi/g) is observed at Bluff CDE followed by Bluff G (42.4 pCi/g); both of which are over the site specific soil cleanup values for ^{226}Ra. The mean ^{226}Ra activity at Bluff H (12.1 pCi/g) is similar to the mean activity at Bluff B (11.8 pCi/g). Summary statistics of the soil ^{226}Ra data points collected at all of the bluff areas is provided in Table 5-39.

Table 5-39. Summary Statistics of Soil ^{226}Ra Activity at All Tronox Bluffs

Data Statistic	Result
Number of Data Measurements Collected	116,325
Minimum (pCi/g*)	0.56
Maximum (pCi/g)	3,699
Mean (pCi/g)	28.5
Standard Deviation (pCi/g)	108
95th Percentile (pCi/g)	116
99th Percentile (pCi/g)	446
% of Points <30 pCi/g	84.5
% of Points >30 pCi/g and <50 pCi/g	4.6
% of Points >50 pCi/g	10.9

*pCi/g = picocuries per gram

The estimated soil ^{226}Ra activity at all of the bluff areas ranged between 0.56 pCi/g and 3,699 pCi/g with a mean activity of 28.5 pCi/g. A total of 84.5 percent of the 116,325 data points collected were below the ^{226}Ra soil cleanup value of 30 pCi/g.

The removal areas associated with the soil ^{226}Ra activity are presented in Table 5-40. A total of 88.6 percent of the surface soils areas were below the ^{226}Ra soil cleanup value. Bluff CDE has the greatest total surface area of ^{226}Ra contamination greater than 30 pCi/g, followed by Bluff G. The ^{226}Ra contaminated soils greater than 30 pCi/g at Bluff G and Bluff B are limited in comparison to Bluff CDE and Bluff G.

Table 5-40. Summary of Tronox Bluff Soil Areas Contaminated by ^{226}Ra

Location	Removal Area Acres by ^{226}Ra			Percent* of Bluff that is Removal Area by ^{226}Ra		
	< 30 pCi/g**	≥ 30 and < 50 pCi/g	≥ 50 pCi/g	< 30 pCi/g	≥ 30 and < 50 pCi/g	≥ 50 pCi/g
Bluff B	137	2.18	2.89	90	1.4	1.9
Bluff CDE	27.6	5.48	14.5	58	12	30
Bluff G	6.16	0.36	0.57	87	5.0	8.0
Bluff H	31.2	0.43	0.17	98	1.4	0.53
All Bluffs	**202**	**8**	**18**	**88.6**	**3.5**	**7.9**

*Percent based on total area scanned; some of Bluff B was not scanned due to safety reasons (10.91 acres/7.1%)
**pCi/g = picocuries per gram

5.10.2 Summary of XRF Field Survey Waste Characterization Results for the Tronox Bluffs

In addition to the high density gamma radiation survey, a pre-designed grid was systematically sampled as part of the XRF field survey. The minimum grid size was 100 foot by 100 foot as specified in the SAP (Appendix A). The *in-situ* XRF measurements were collected at the designated grid locations as shown in Figure 4-13 through Figure 4-16 for Bluffs B, CDE, G, and H, respectively. These measurements were then converted into laboratory reported metals concentrations using the methods discussed in Section 4.2. From a metal concentration standpoint, the areal extent of total arsenic concentration, total molybdenum, and uranium isotope activities were the primary focus of this study. High correlation coefficients were calculated as part of the regression analysis for total arsenic (R=0.95), natural uranium (R=0.98), and total molybdenum (R=0.96) as presented in Section 4.2. Spatial interpolation techniques (IDW) were used to estimate the unsampled areas using the known sample locations; the results of this analysis were used in order to estimate the removal areas designated by total arsenic concentrations, total molybdenum, soil ^{238}U activity, soil ^{235}U activity, and soil ^{234}U activity.

Similar to the analysis performed on the soil ^{226}Ra activity data, an individual distribution analysis was performed on the converted XRF field survey data sets for total arsenic, natural uranium, and total molybdenum. The results of individual distribution analysis are presented on plots comparing the data sets for total arsenic, natural uranium, and total molybdenum to a lognormal probability scale on Figure 5-46 through Figure 5-48, respectively. The total arsenic concentrations appear to follow a lognormal distribution for all of the bluffs based on the linearity of the data shown in Figure 5-46. The target populations sampled for natural uranium and total molybdenum follow lognormal distributions for Bluff CDE and Bluff G. However, at Bluff B and Bluff H, the data do not follow a lognormal distribution at the lower levels as shown in Figure 5-47 and Figure 5-48. This corresponds to the overall lower concentrations of both natural uranium and total molybdenum at these bluffs. This analysis can be used to compare the target populations of the reclaimed areas to the pre-reclamation conditions.

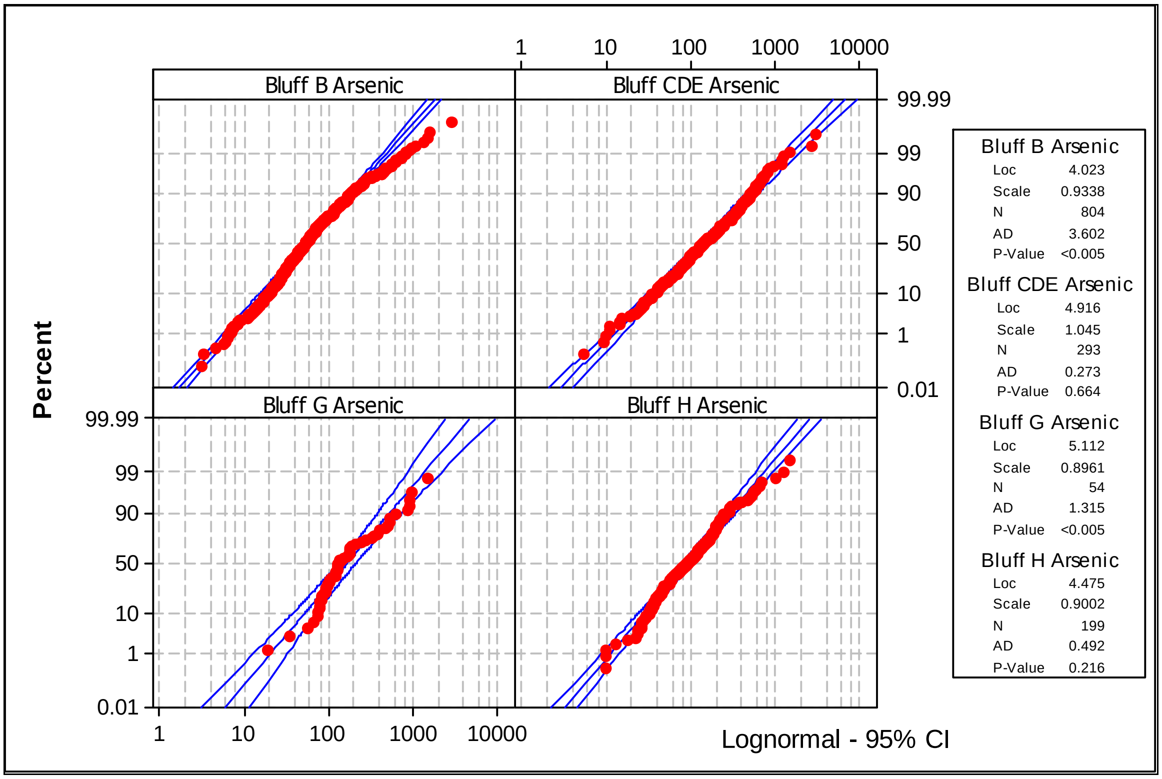


Figure 5-46. Lognormal Probability Plots of Total Arsenic (mg/kg) at Tronox Bluffs

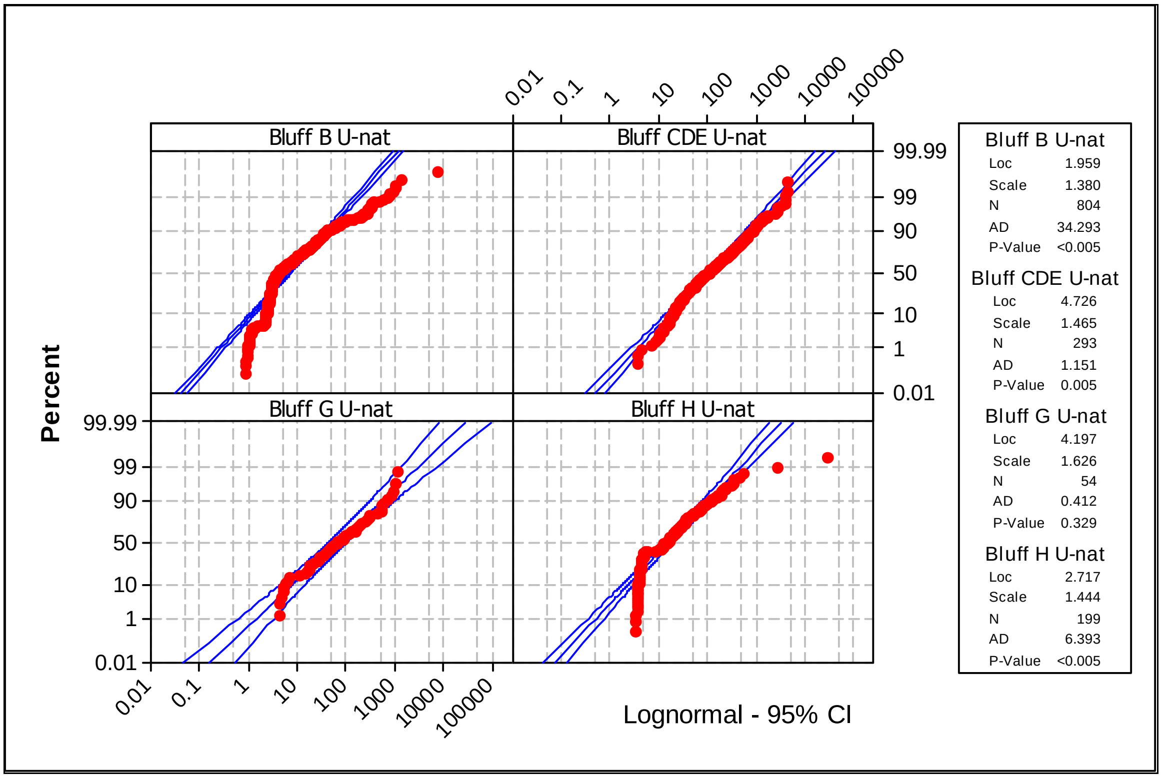


Figure 5-47. Lognormal Probability Plots of Natural Uranium (mg/kg) at Tronox Bluffs

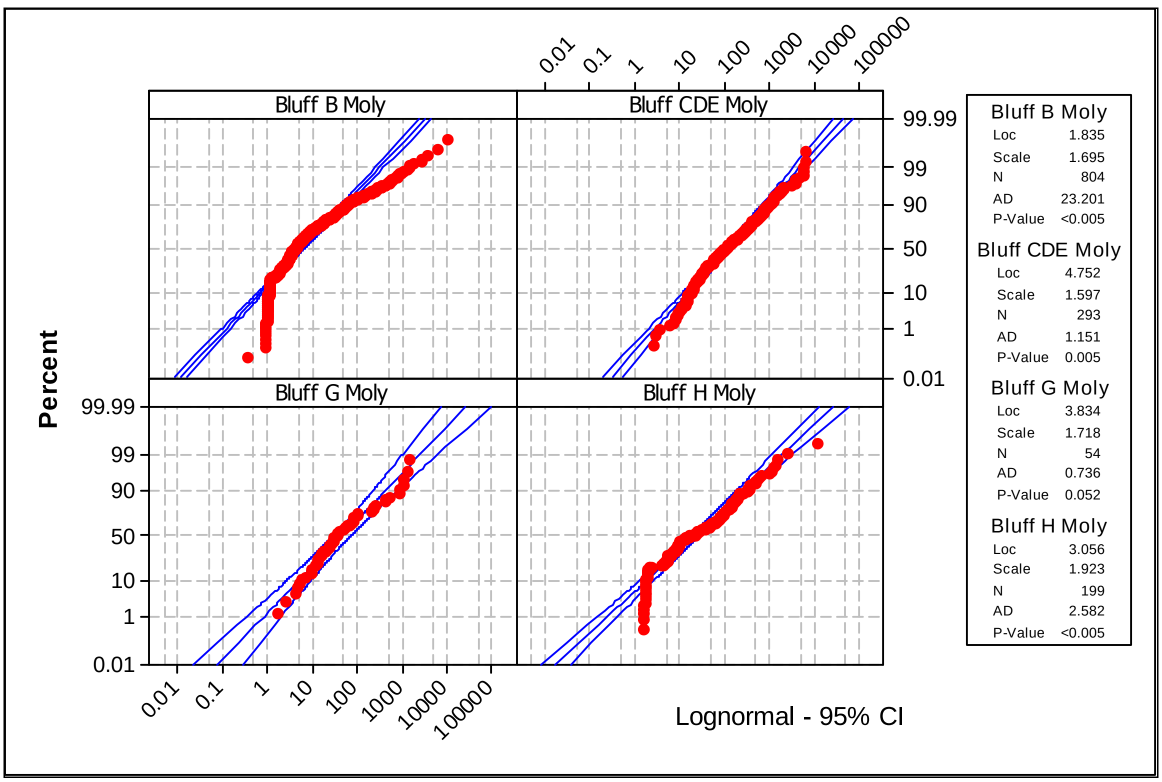


Figure 5-48. Lognormal Probability Plots of Total Molybdenum (mg/kg) at Tronox Bluffs

An interval plot, which shows the mean total arsenic concentration with an interval bar on the 95th confidence interval of the mean, is shown for the bluff areas in Figure 5-49. A reference line is also shown at the total arsenic soil cleanup value of 142 mg/kg. Both Bluff CDE and Bluff G reported mean total arsenic soil concentrations above the soil cleanup values. The mean total arsenic concentration calculated at Bluff H is higher than Bluff B.

An individual value plot showing every converted *in-situ* XRF measurement for total arsenic collected at each bluff is provided in Figure 5-50. This graph provides the reader a better understanding for the number of points that exceed the cutoff value for total arsenic.

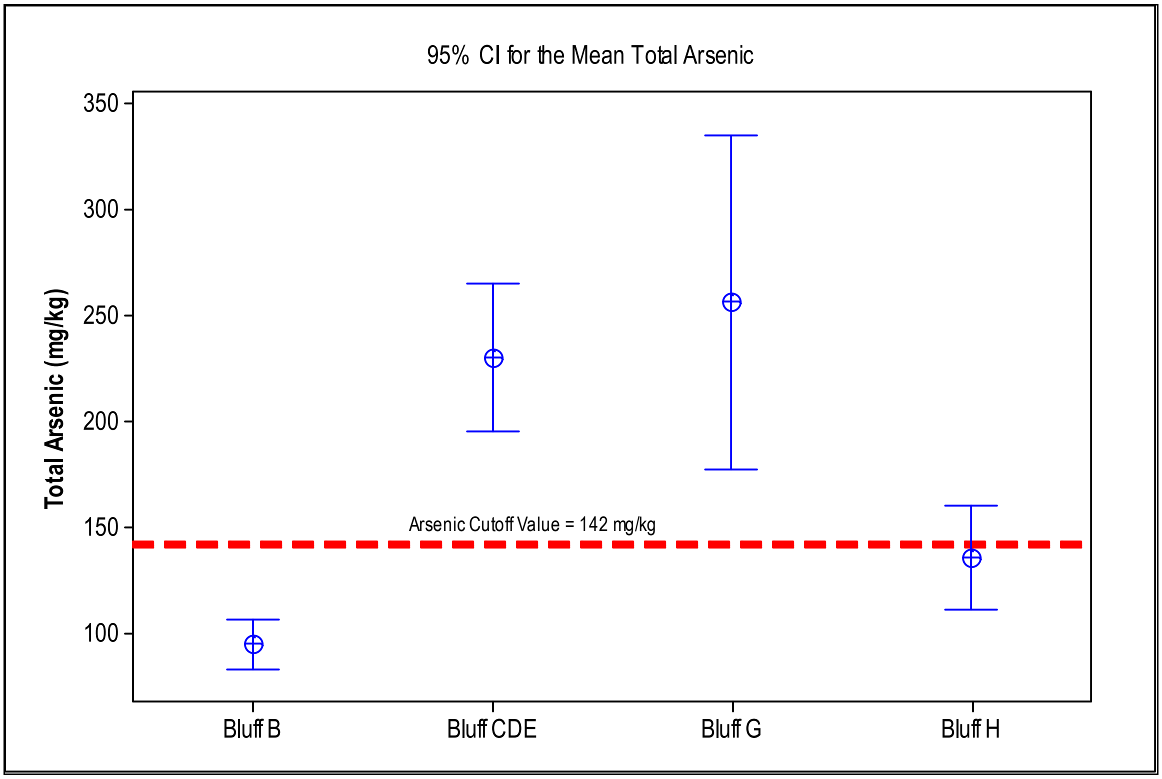


Figure 5-49. Interval Plot of Mean Total Arsenic Concentrations at Tronox Bluffs

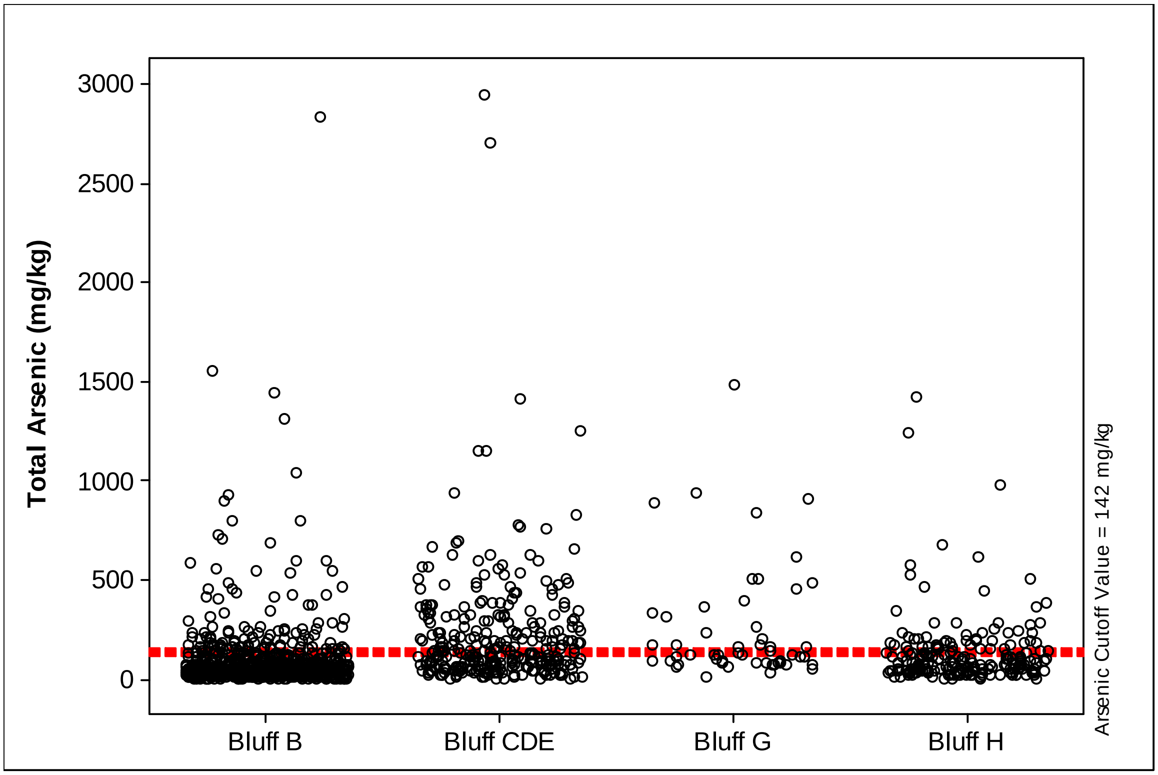


Figure 5-50. Individual Value Plot for Total Arsenic Soil Concentrations at Tronox Bluffs

An interval plot for the mean $^{238}U/^{234}U$, and ^{235}U soil activities with an interval bar on the 95th confidence interval of the mean is shown for the bluff areas in Figure 5-51 and Figure 5-52, respectively. Reference lines are shown at the cutoff values for each isotope as presented in Section 2.2. The mean uranium isotopes exceeded the cutoff values for each bluff except at Bluff B. Similarly, individual value plots showing the cutoff levels at each bluff for $^{238}U/^{234}U$ and ^{235}U soil activities are provided in Figure 5-53 and Figure 5-54, respectively.

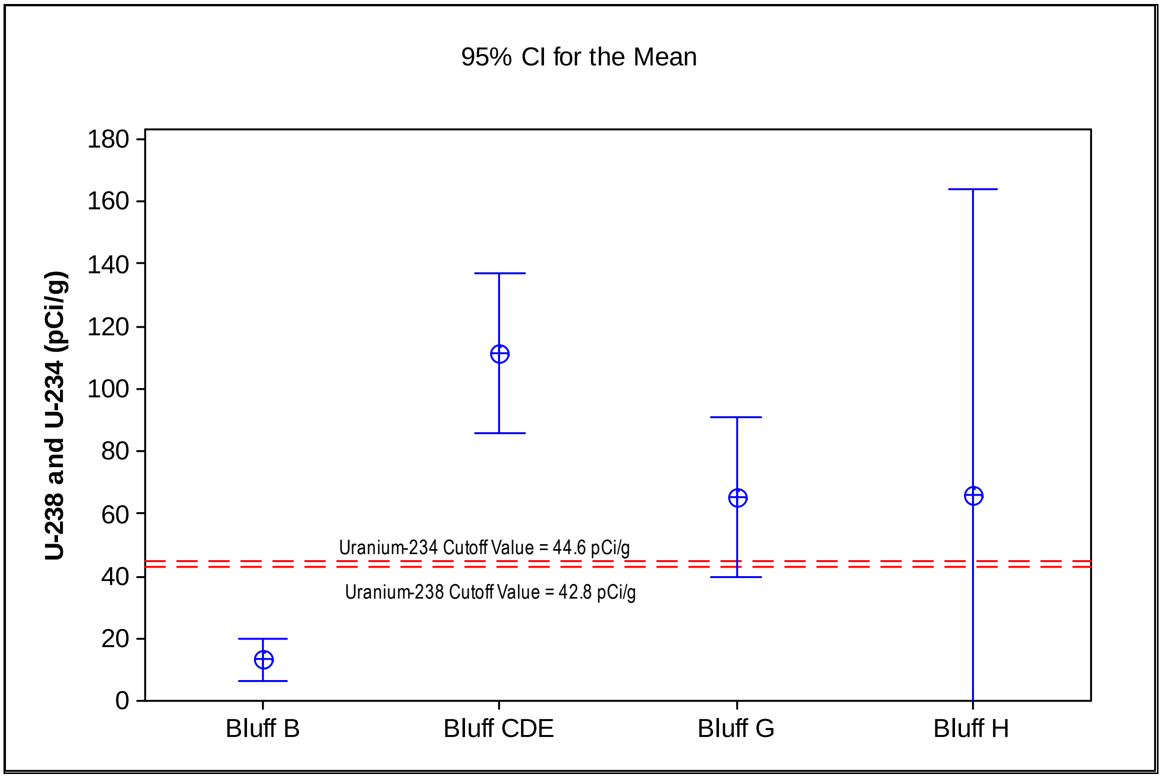


Figure 5-51. Interval Plot of Mean $^{238}U/^{234}U$ Activity at Tronox Bluffs

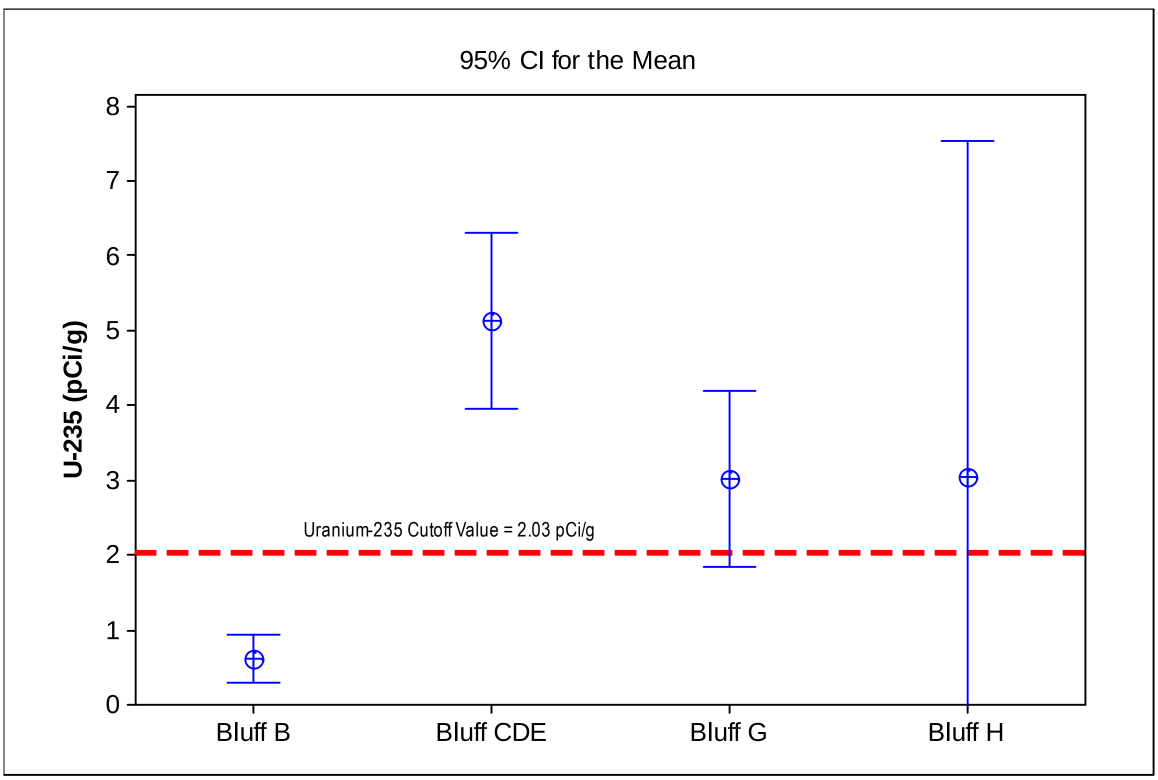


Figure 5-52. Interval Plot of Mean ^{235}U Activity at Tronox Bluffs

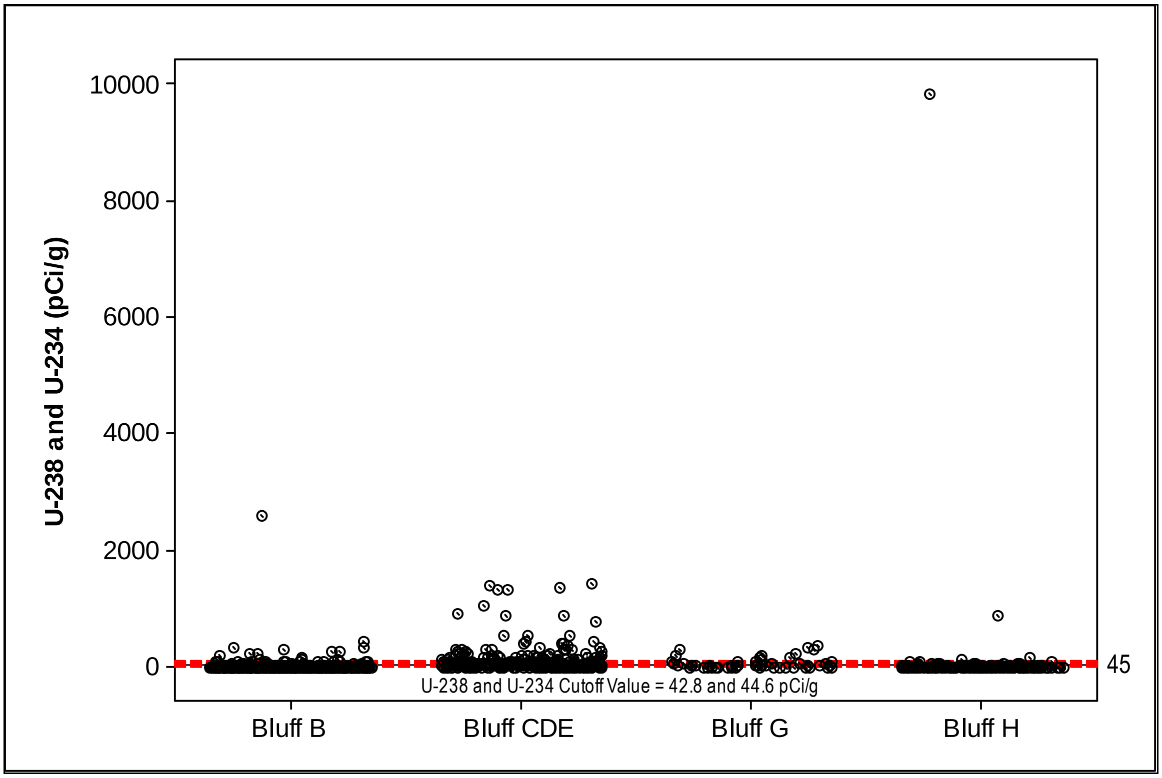


Figure 5-53. Individual Value Plot for $^{238}U/^{234}U$ Activity at Tronox Bluffs

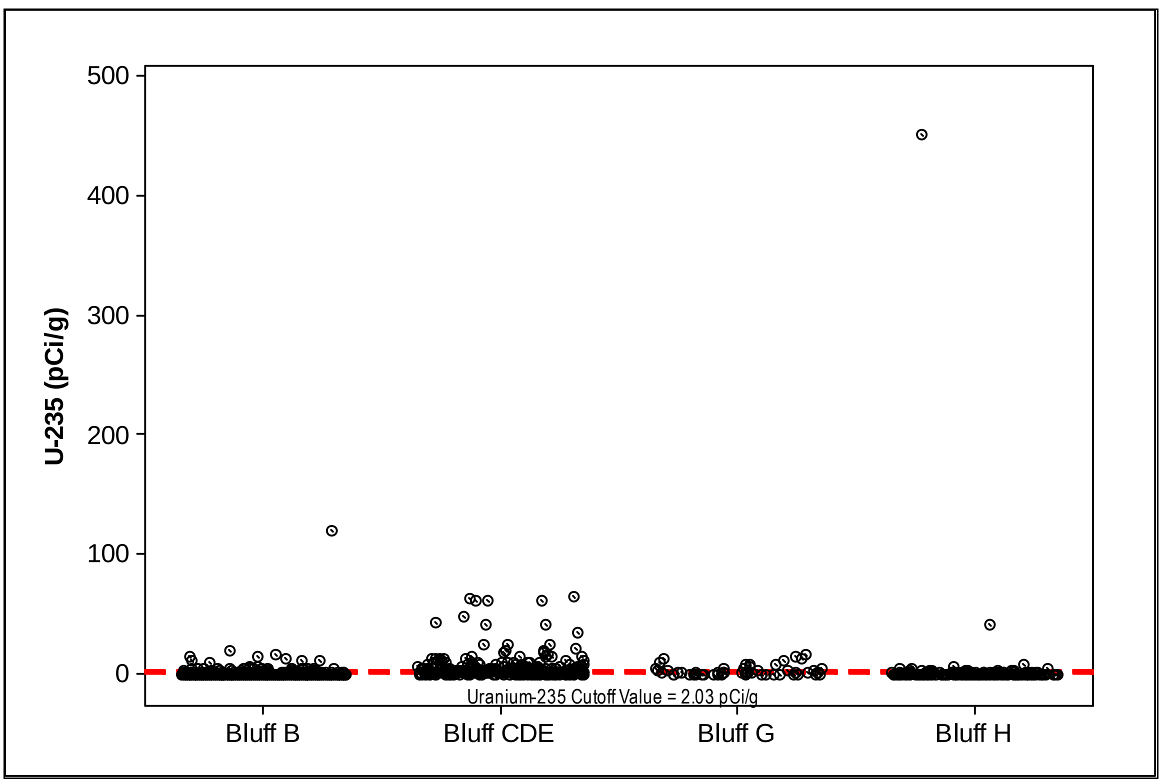


Figure 5-54. Individual Value Plot for ^{235}U Activity at Tronox Bluffs

An interval plot for the mean total molybdenum concentrations with an interval bar on the 95th confidence interval of the mean is shown for the bluff areas in Figure 5-55. A reference line is shown at the cutoff values for total molybdenum (2,775 mg/kg) as presented in Section 2.2. The mean total molybdenum and 95 percent confidence interval of the mean were both below the cutoff value for all bluffs. Similarly, an individual value plot showing the cutoff level for total molybdenum is provided in Figure 5-56.

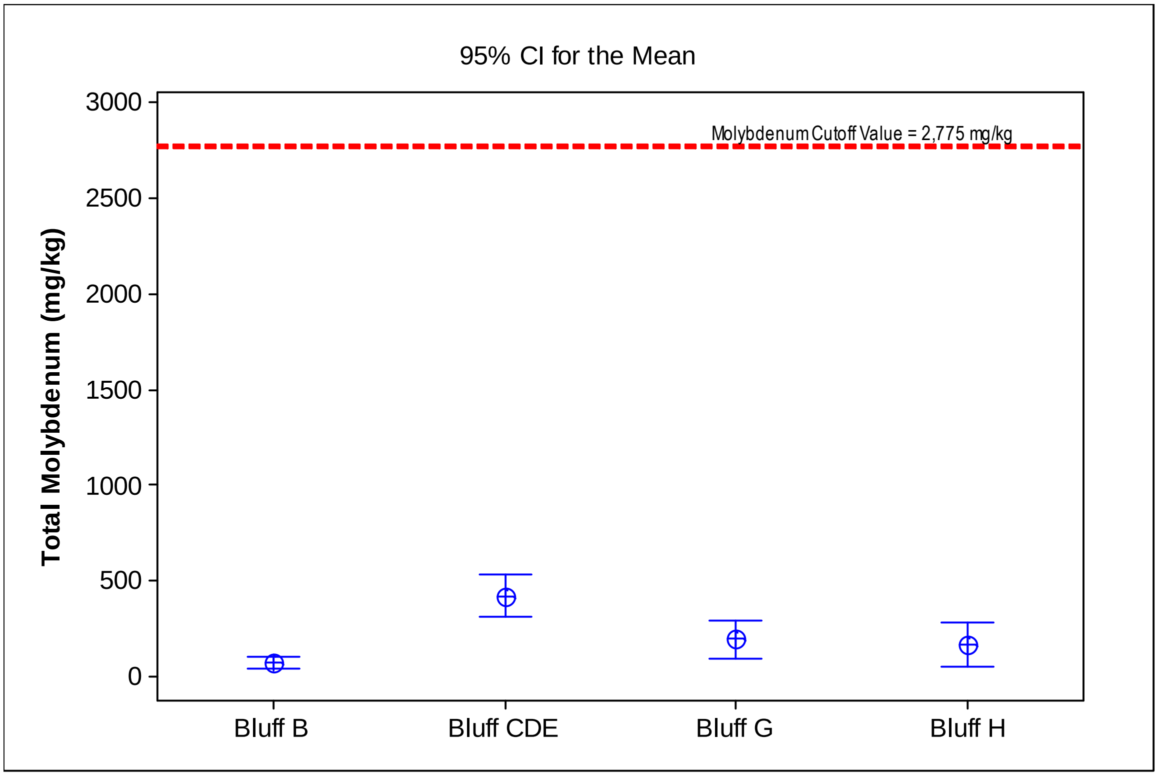


Figure 5-55. Interval Plot of Mean Total Molybdenum at Tronox Bluffs

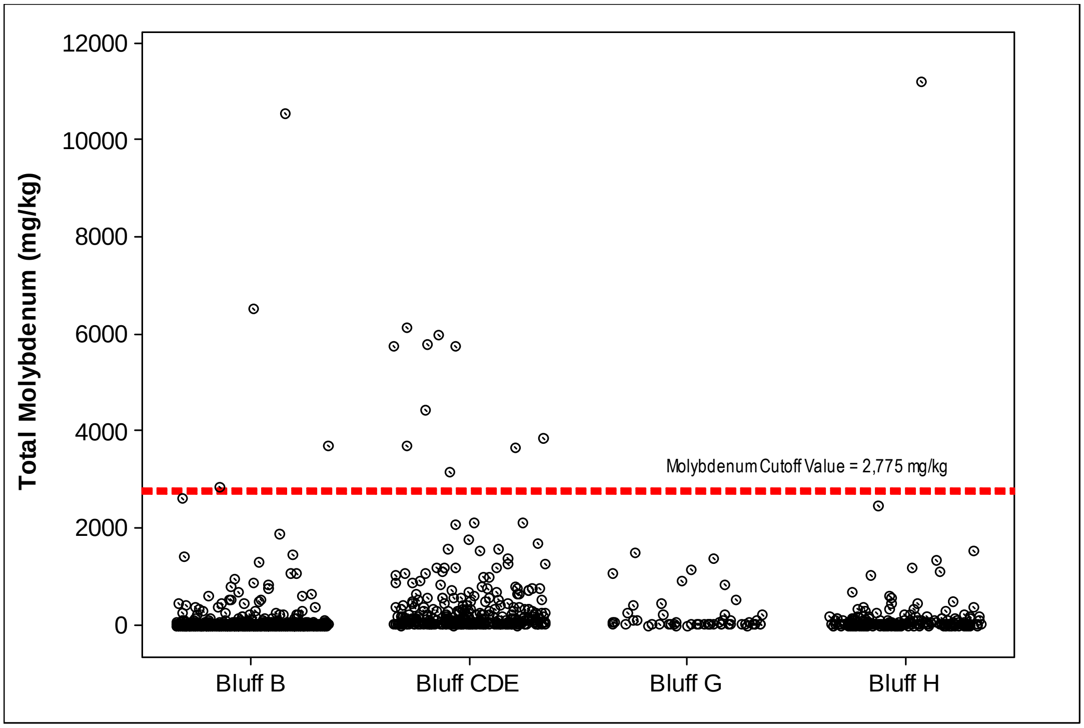


Figure 5-56. Individual Value Plot for Total Molybdenum at Tronox Bluffs

Summary statistics of the total arsenic concentration, total molybdenum concentration, natural uranium concentration, soil ^{238}U activity, soil ^{235}U activity, and soil ^{234}U activity, compared to each contaminants respective soil cutoff value is provided in Table 5-41. A total of 1,350 *in-situ* XRF measurements were collected at all of the bluffs.

Table 5-41. Summary Statistics of Tronox Bluffs XRF Field Survey Concentrations

Statistic	Total Arsenic (mg/kg*)	Total Molybdenum (mg/kg)	Natural Uranium (mg/kg)	^{238}U (pCi/g**)	^{235}U (pCi/g)	^{234}U (pCi/g)
Removal Action Cutoff Value	**142**	**2,775**	**n/a**	**42.8**	**2.03**	**44.6**
Count	1,350	1,350	1,350	1,350	1,350	1,350
Minimum	3.04	0.4	0.8	0.3	0.01	0.3
Maximum	2,953	11,218	29,722	9,840	453	9,840
Standard Deviation	221	681	908	300	13.8	300
Median	70	10.1	11	3.7	0.2	3.7
Mean	137	167.3	135	44.5	2.0	44.5
95th Percentile	488	750	532	176	8.10	176
99th Percentile	1,016	3,002	1,615	535	24.6	535
% of Points Exceeding Cutoff Value	25.4%	1.11%	n/a	15.6%	14.9%	14.8%

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

Table 5-42 provides a summary of the removal action areas based on the XRF field survey data for all of the Tronox Bluffs. The XRF field survey results provided sufficient areal coverage to estimate total arsenic concentration, total molybdenum concentration, ^{238}U activity, ^{235}U activity and ^{234}U activity levels in the surface soils for all of the bluff areas.

Table 5-42. Summary of Removal Action Areas by XRF Field Survey Data at Tronox Bluffs

Location	Total Bluff Area (Acres)	< 142 mg/kg* As & <2,775 mg/kg Mo & < 42.8 pCi/g** ^{238}U & <2.03 pCi/g ^{235}U & <44.6 pCi/g ^{234}U		≥ 142 mg/kg As &/or ≥2,775 mg/kg Mo &/or ≥ 42.8 pCi/g ^{238}U &/or ≥2.03 pCi/g ^{235}U &/or ≥44.6 pCi/g ^{234}U	
	Acres	Acres	Percent	Acres	Percent
Bluff B	153	132	86	21	14
Bluff CDE	48	20	42	27	58
Bluff G	7.1	1.8	26	5.2	74
Bluff H	32	22	69	9.7	31
All Tronox Bluffs	**240**	**176**	**74**	**63**	**26**

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

5.10.3 Summary of Overall Mine Waste Characterization Areas for the Tronox Bluffs

The mine waste categories and removal areas for each of the bluffs were based on the risk protective criteria for soil ^{226}Ra activity, total arsenic concentrations, total molybdenum concentration, soil ^{238}U activity, soil ^{235}U activity, and soil ^{234}U activity (Table 5-43).

Table 5-43. Summary of Tronox Bluff Soil Areas Contaminated by Mine Waste Category

Location	Total Bluff Area Analyzed (Acres)	Category I: No Exceedances: < 30 pCi/g* ^{226}Ra and < 142 mg/kg** As and < 2,775 mg/kg Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and <44.6 pCi/g ^{234}U		Category II: ≥ 30 pCi/g and <50 pCi/g ^{226}Ra and < 142 mg/kg As and < 2,775 mg/kg Mo and < 42.8 pCi/g ^{238}U and < 2.03 pCi/g ^{235}U and <44.6 pCi/g ^{234}U		Category III: ≥ 50 pCi/g ^{226}Ra and/or ≥ 142 mg/kg As and/or ≥ 2,775 mg/kg Mo and/or ≥ 42.8 pCi/g ^{238}U and/or ≥ 2.03 pCi/g ^{235}U and/or 44.6 pCi/g ^{234}U	
	Acres	Acres	Percent	Acres	Percent	Acres	Percent
Bluff B	153	130	85.4	0.684	0.45	21.5	14
Bluff CDE	46.5	17.7	38	0.99	2.1	27.8	60
Bluff G	6.99	1.83	26	0.00	0.0	5.17	74
Bluff H	31.6	21.9	69.3	0.051	0.2	9.67	31
All Tronox Bluffs	**238**	**172**	**72**	**1.7**	**0.70**	**64.4**	**27**

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

5.10.4 Volume Estimation of 2007 Action Memorandum Criteria 2 Mine Waste at Bluff CDE

A KCH reclamation scientist performed a detailed survey of the vegetation and soil conditions at Bluffs C, D, and E. Full details of this survey are found in Appendix O, including site photographs, GIS mapping, and comments. Areas were identified according to 2007 Action Memorandum Criteria 2 classification, discussed below. Figure 5-18 displays the classification of Bluff CDE according to Criteria 2. This figure does not include any Criteria 1 classification and is based entirely on the visual observations of the vegetation and soil conditions. Table 5-44, below, provides the areal extents and volumes where applicable, for each category according to the Criteria 2 definitions. The volume estimation for the Criteria 2 material that was designated to be excavated and consolidated was calculated by assuming the depth of contamination was 6-feet bgs and applied to the area that was surveyed, as discussed in Section 5.7. Of the area designated for excavation and consolidation a total volume of 2,323 yd^3 was estimated.

The 2007 Action Memorandum specifies that Criteria 2 are applicable to Tronox Bluffs C, D, and E and are listed below:

- **No Reclamation:** In areas where minimal overburden was historically present, vegetation has stabilized the soil and no significant erosion is evident.
- **Stabilization and Vegetate:** In areas where active significant erosion is occurring due to poor vegetative cover.
- **Excavation and Consolidation:** In areas immediately adjacent to Road 3130 where materials associated with historic mining activities exceed Criteria 1 Category II soil ^{226}Ra activity.

Table 5-44. Summary of Criteria 2 Volume Estimation for Bluff CDE

Category	Area (ft^2*)	Area (acres)	Estimated Waste Volume (yd^3**)
No Reclamation	1,216,957	27.9	n/a
Stabilization and Vegetate	283,904	6.52	n/a
Excavation and Consolidation	10,474	0.24	2,323

*ft^2 = square feet
**yd^3 = cubic yard

5.10.5 Volume Estimation of Mine Waste Using Bedrock Elevation, Historical Aerial Imagery, LIDAR, and Test Pit Data

An estimate of the volume of soils to be excavated at Bluff CDE based on Criteria 2 is presented in Section 5.10.4. A volume estimate approach was performed based on Criteria 1 in order to estimate volumes for Category I, Category II, and Category III mine waste materials throughout the Site.

This approach utilized a combination of 1954 imagery and LIDAR data points provided to Tetra Tech by the USFS. A combination of methods was used to calculate the volumes of spoils at Bluff B, Bluff G, and Bluff H. The results of the test pit sampling (Section 5.7) were used to estimate the volume of mine waste materials at Bluff CDE.

The following general methods were used to estimate volumes of spoils:

1. For bluff areas where the comparison between the 1954 surface and the existing ground LIDAR surface resulted in fill, volumes were estimated for spoils that were considered “clean,” mine waste Category II spoils, and mine waste Category III spoils.

2. For bluff-top areas with relatively uniform topography, volumes were calculated based on the mine waste category areas and typically a removal depth of 1-foot.

3. For the main bench areas where there was evidence of waste materials present over uniform bedrock surface, the bedrock surface elevation was estimated and created to calculate the volume of materials in the piles laid over the bedrock.

4. At Bluff CDE, the test pit sampling data (Section 5.7) were used, assuming a depth of contamination of 6-feet bgs and was applied to all of the mine waste Category II and Category III areas.

Table 5-45 provides the mine waste volume estimates for each of the Tronox Bluffs using the methods described above. Bluff B has the highest volume of Category III materials, with an estimated 280,090 yd^3.

Table 5-45. Mine Waste Volume Estimation

Location	Mine Waste Category I Materials (yd^3)	Mine Waste Category II Materials (yd^3)	Mine Waste Category III Materials (yd^3)	Total Materials (yd^3)
Bluff B	1,623,530	4,892	280,090	1,908,512
Bluff H	438118	1,013	260,381	699,513
Bluff G	28,220	0	44,175	72,395
Bluff CDE	0	9,583	269,104	269,104
Total	**2,089,868**	**15,488**	**853,750**	**2,949,524**

*yd^3 = cubic yards

6.0 LEACHABILITY OF CONTAMINANTS

As described in Section 3.2.1, the XRF soil confirmation samples from Bluffs B, CDE, G, and H which were previously analyzed for total metals were also evaluated for soluble metals content (arsenic, cadmium, chromium, copper, iron, lead, manganese, molybdenum, selenium, thallium, uranium, vanadium, and zinc) using the SPLP (EPA, 1994). The SPLP provides a direct indication of the relative mobility of constituents based on their concentrations in the SPLP leachate (mg/L). However, the procedure is not intended to simulate field conditions and therefore direct comparisons between SPLP leachate concentrations and water quality standards are not necessarily appropriate. Rather, the SPLP results are useful in identifying materials with the greatest potential for leaching of soluble constituents by natural precipitation.

In order to evaluate the relative solubility of various constituents in the soils, the SPLP leachate results (mg/L) for arsenic, copper, lead, molybdenum, selenium, uranium, and zinc were converted to a solids basis (mg/kg) and then compared to the total metals concentrations (mg/kg) for each sample. No comparisons between total and soluble are presented for those constituents which were either mostly below detection in the SPLP leachates (cadmium), or which were not previously analyzed for total concentrations (chromium, iron, manganese, thallium, and vanadium). Additionally, regression analyses were performed on the total metal concentration in the soil and the field leachate concentration of the soil sample, however there was not a strong correlation coefficient ($R<0.5$) for all of the constituents.

Total arsenic was detected in SPLP results from all of the 69 soil confirmation samples and ranged between 0.010 mg/L and 5.4 mg/L at all of the bluffs. The percent solubility of total arsenic ranged from 0.04 percent to 33 percent. Bluff B had the highest mean percent solubility of total arsenic (7.6 percent). The percent solubility of the total arsenic of individual soil samples at Bluff B and Bluffs G, H, and CDE are shown on Figure 6.1 and Figure 6.2, respectively. Comparison of these figures indicated that the percent solubility is higher at Bluff B then any of the other bluffs. Table 6-1 provides summary statistics of the leachable total arsenic results for all of the bluffs.

The percent solubility of the natural uranium, total copper, total lead, total molybdenum, total selenium and total zinc of individual soil samples at Bluff B are provided in Figure 6-3, Figure 6-5, Figure 6-7, Figure 6-9, Figure 6-11 and Figure 6-13, respectively. The percent solubility of the natural uranium, total copper, total lead, total molybdenum, total selenium and total zinc of individual soil samples at Bluff CDE, G and H are provided in Figure 6-4, Figure 6-6, Figure 6-8, Figure 6-10, Figure 6-12 and Figure 6-14, respectively. The leachate summary statistics for natural uranium, total copper, total lead, total molybdenum, total selenium, and total zinc (min, max, and mean leachate concentration plus soluble percentages) are provided in Table 6-2 through Table 6-7, respectively.

The majority of soluble cadmium measurements (84 percent) were below detection (<0.0003 mg/L) and are provided with the detailed SPLP results in Appendix P. The SPLP results show that the proportion of soluble arsenic, uranium, copper, molybdenum, selenium, and zinc is consistently higher in the Bluff B soils compared to the remaining locations; Bluff G soils on the other hand, tend to have the lowest proportion of soluble constituents compared to their total concentrations. The calculated soluble percentage of total constituents were consistently less than 10 percent at Bluff locations CDE, G, and H, with the exception of molybdenum, selenium, and zinc, which were relatively more soluble compared to the remaining constituents at all of the bluff locations. In summary, the SPLP results indicate that Bluff B soils have the greatest potential for natural leaching of metals, with molybdenum, selenium, and zinc having the greatest potential mobility of the SPLP constituents analyzed.

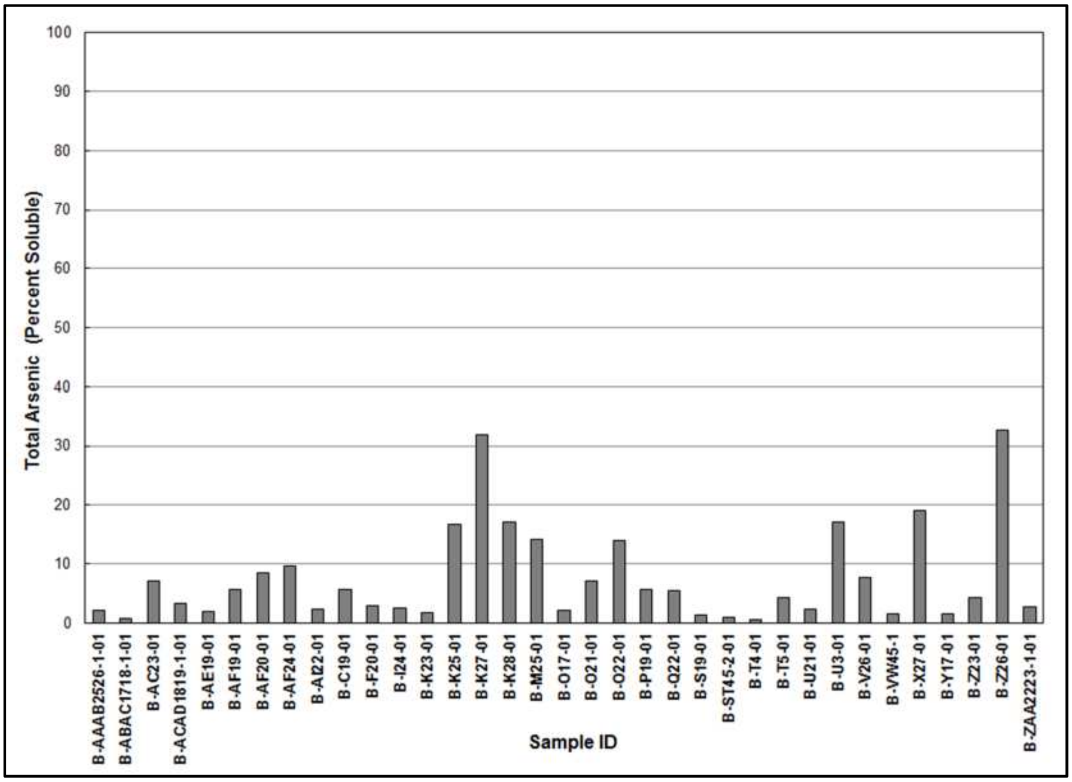


Figure 6-1. Percent Solubility of Total Arsenic at Bluff B

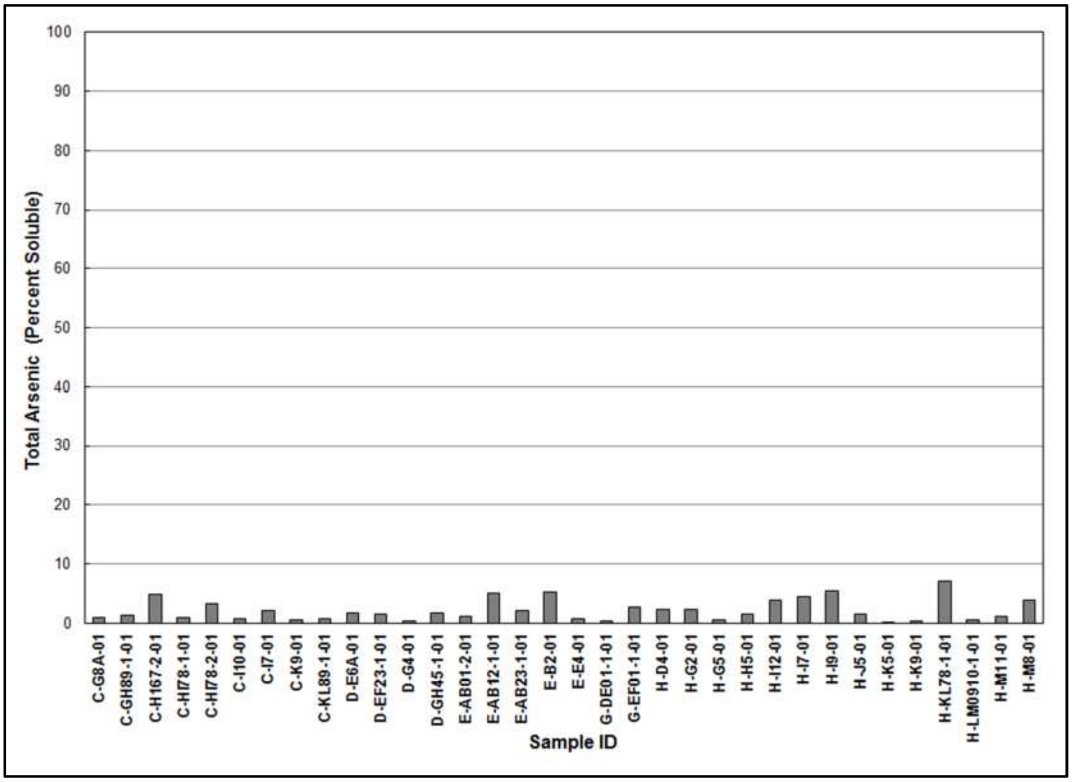


Figure 6-2. Percent Solubility of Total Arsenic at Bluff CDE, G, and H

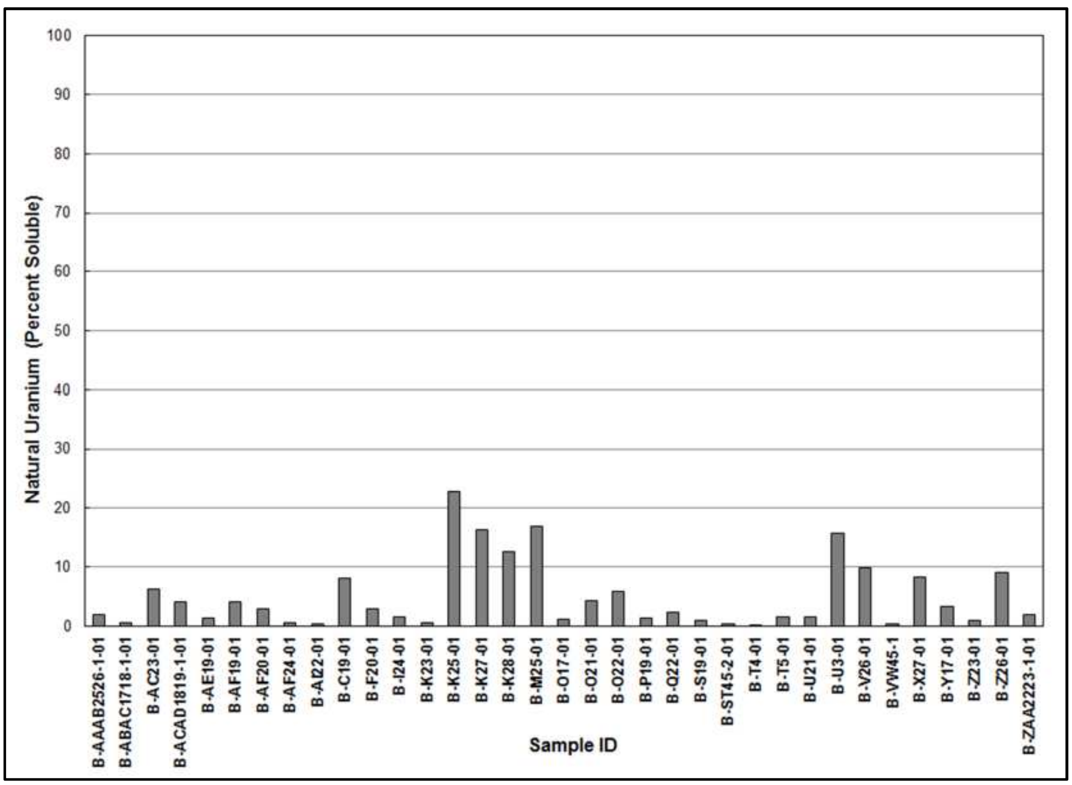


Figure 6-3. Percent Solubility of Natural Uranium at Bluff B

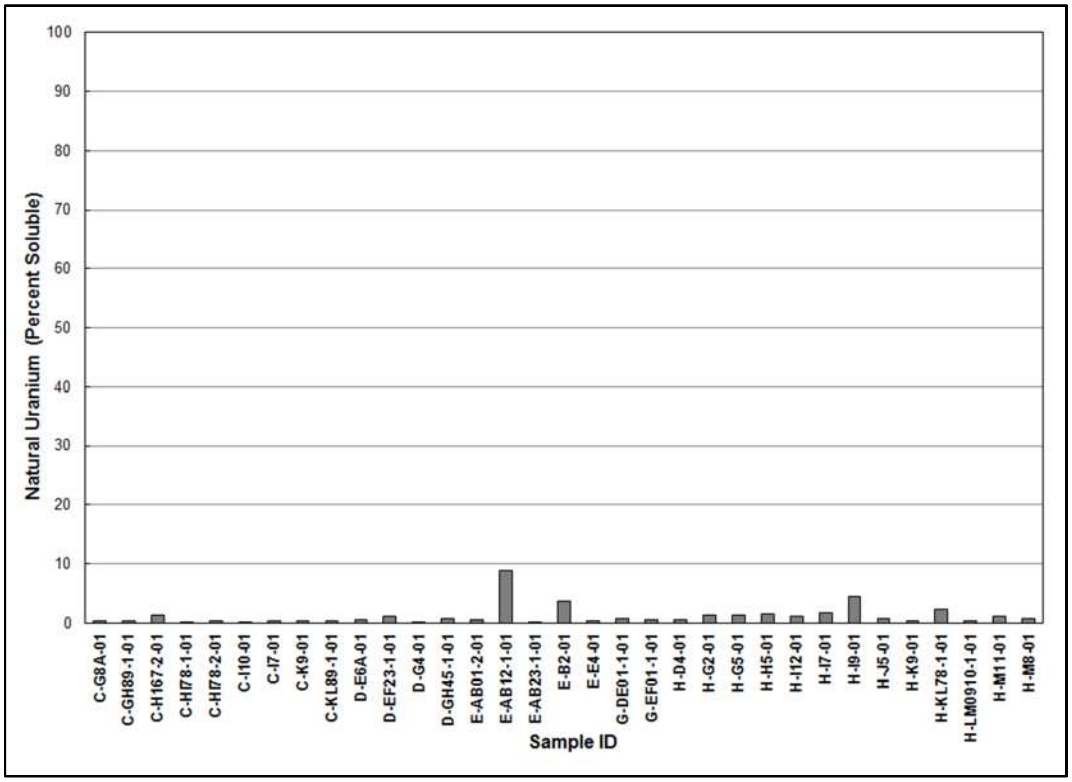


Figure 6-4. Percent Solubility of Natural Uranium at Bluff CDE, G, and H

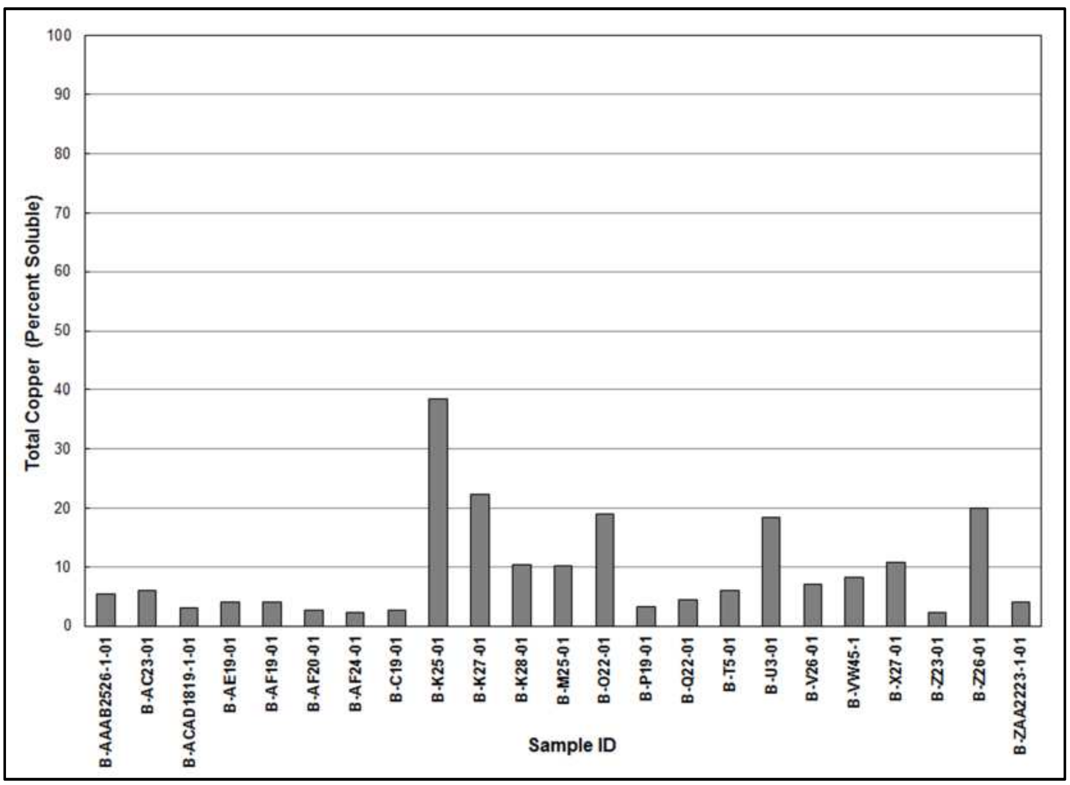


Figure 6-5. Percent Solubility of Total Copper at Bluff B

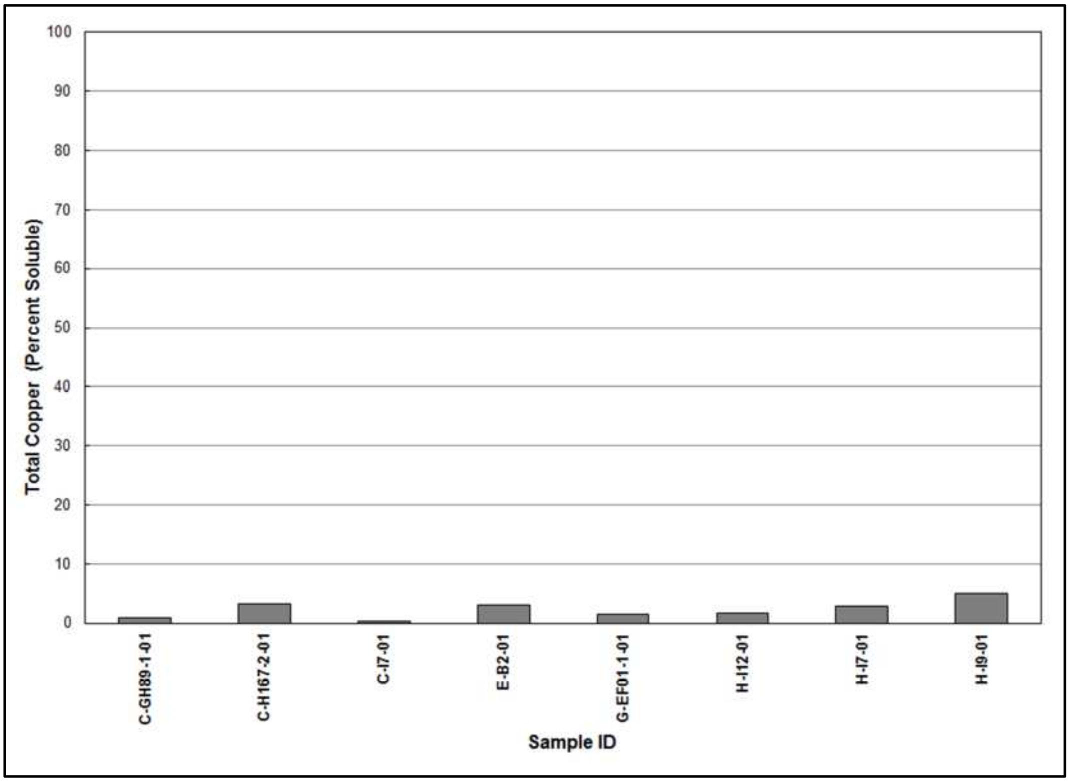


Figure 6-6. Percent Solubility of Total Copper at Bluff CDE, G, and H

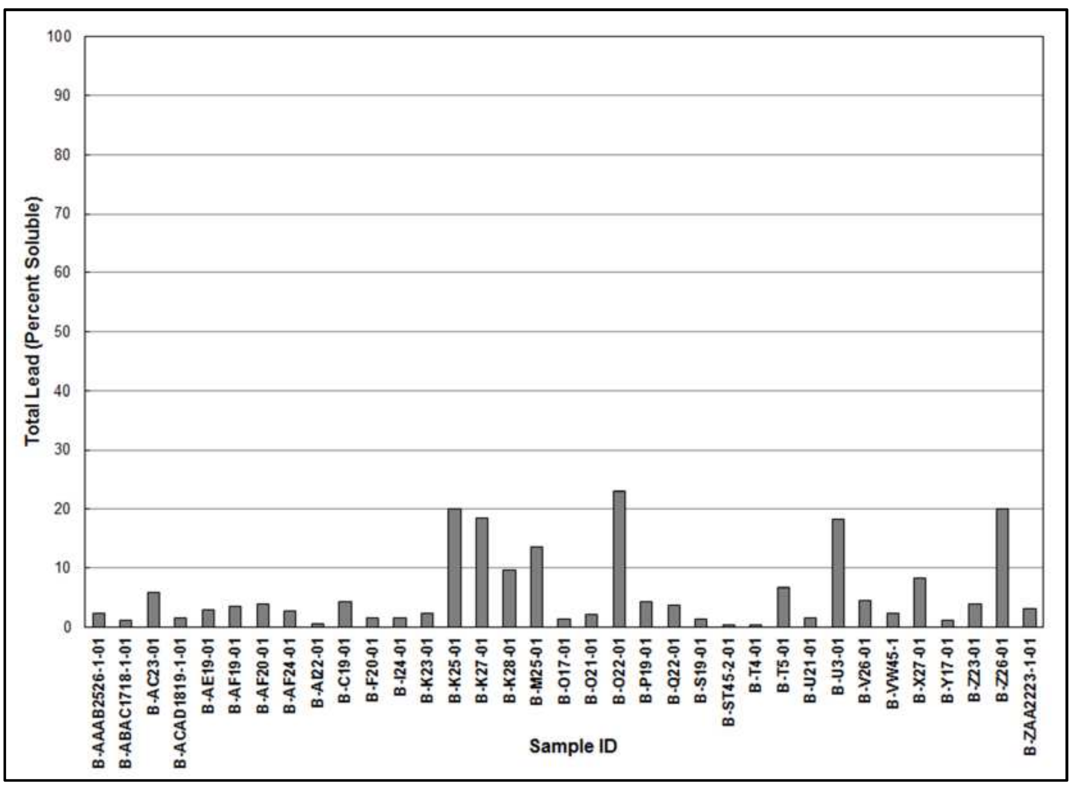


Figure 6-7. Percent Solubility of Total Lead at Bluff B

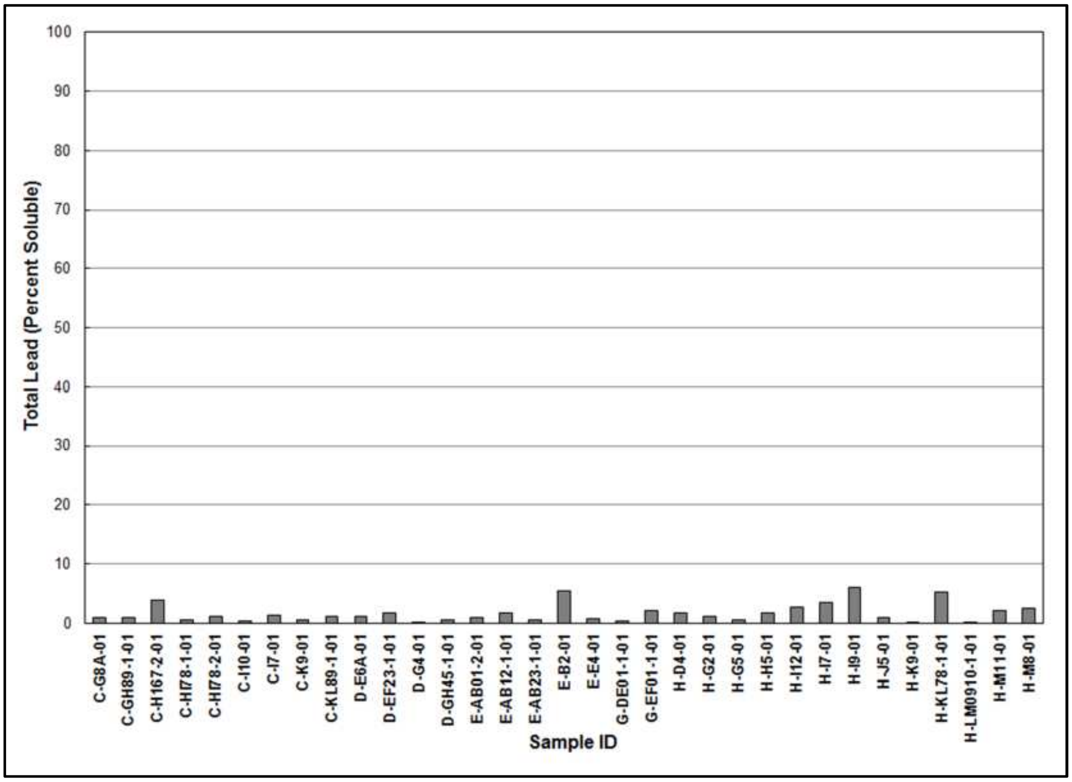


Figure 6-8. Percent Solubility of Total Lead at Bluff CDE, G, and H

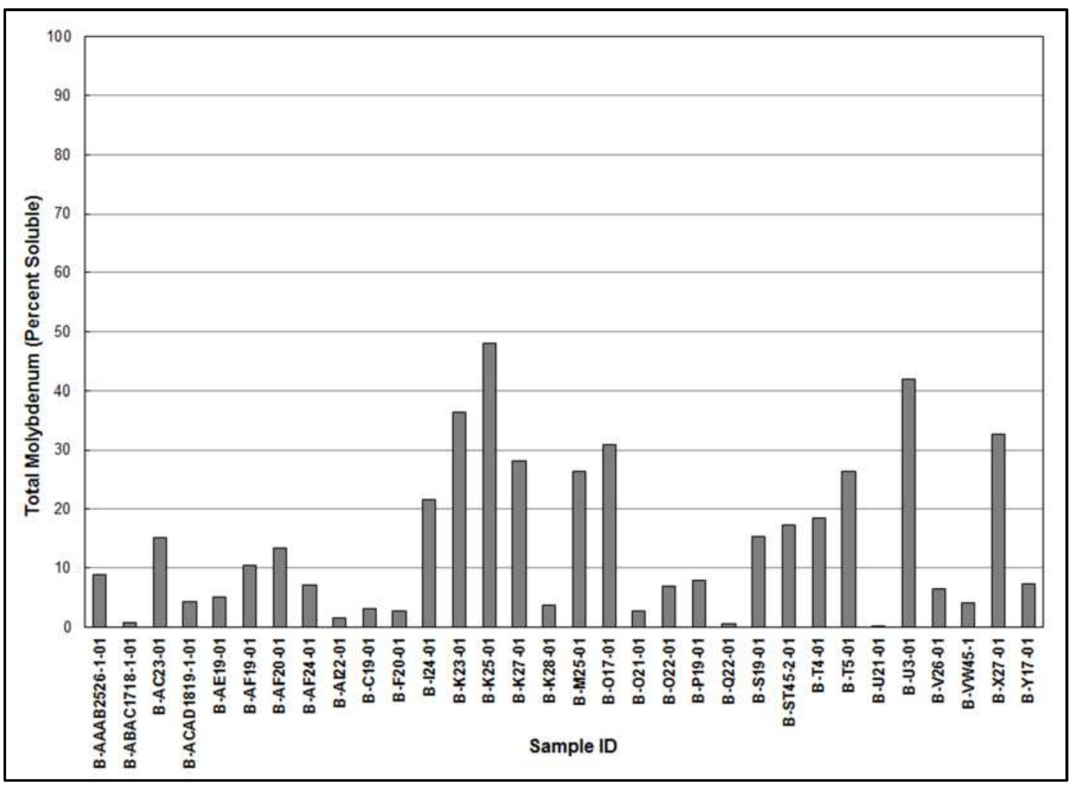


Figure 6-9. Percent Solubility of Total Molybdenum at Bluff B

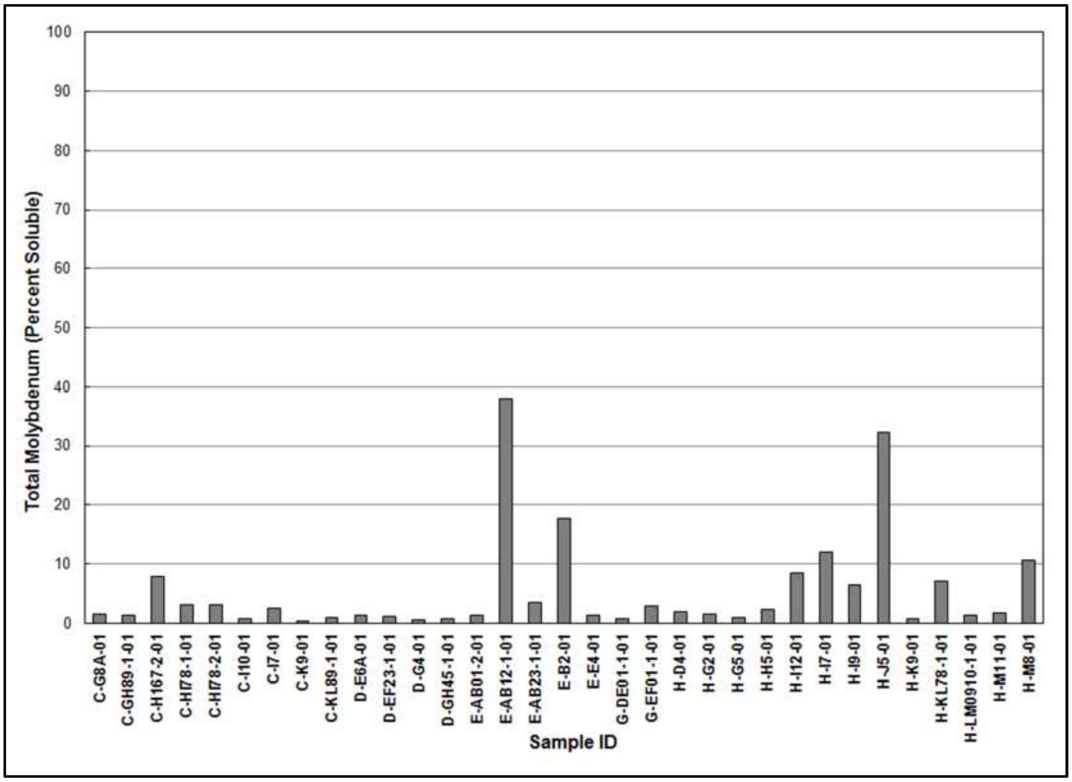


Figure 6-10. Percent Solubility of Total Molybdenum at Bluff CDE, G, and H

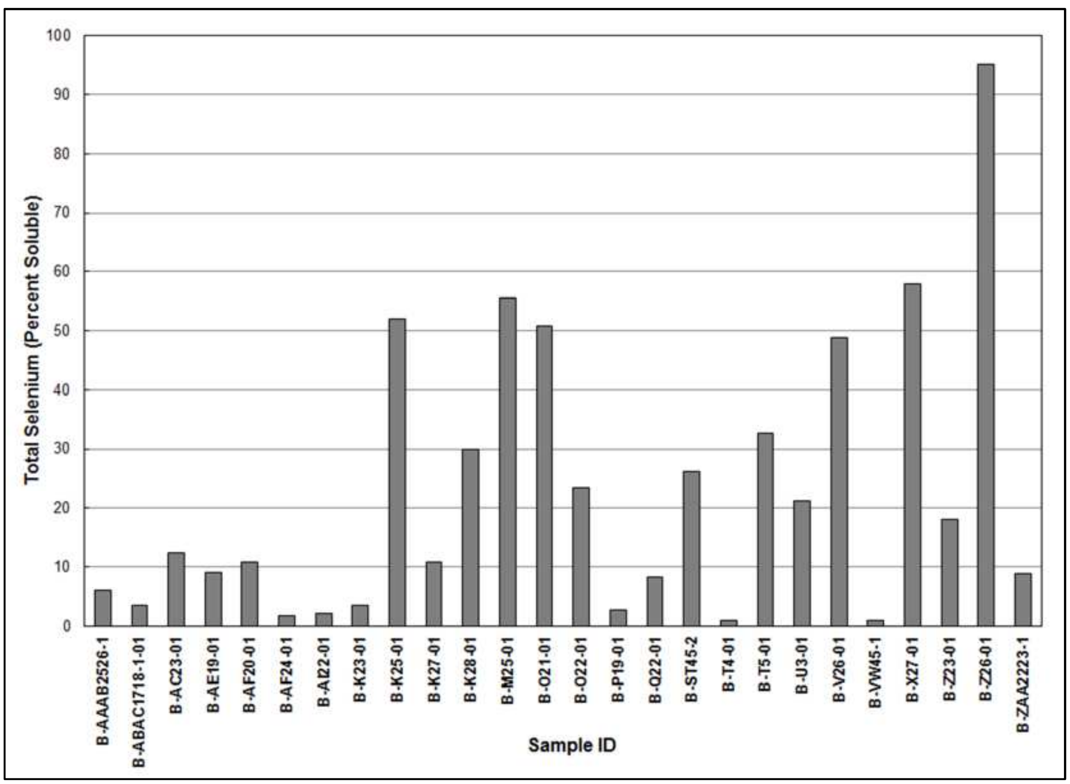


Figure 6-11. Percent Solubility of Total Selenium at Bluff B

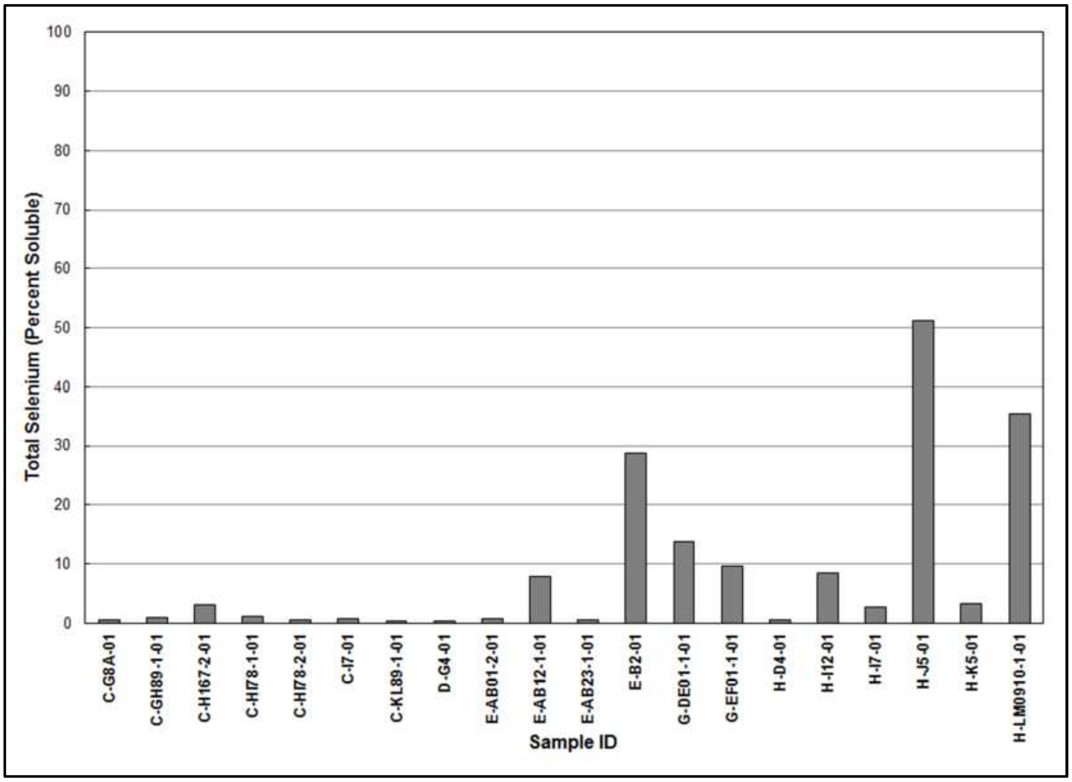


Figure 6-12. Percent Solubility of Total Selenium at Bluff CDE, G, and H

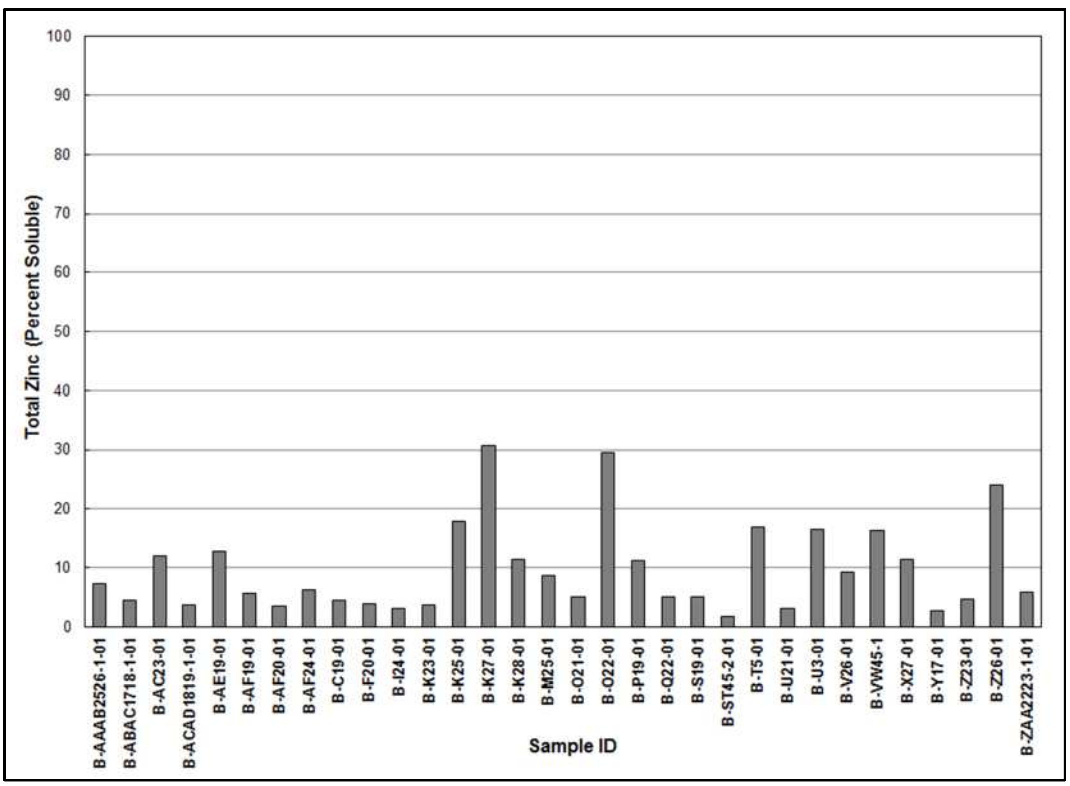


Figure 6-13. Percent Solubility of Total Zinc at Bluff B

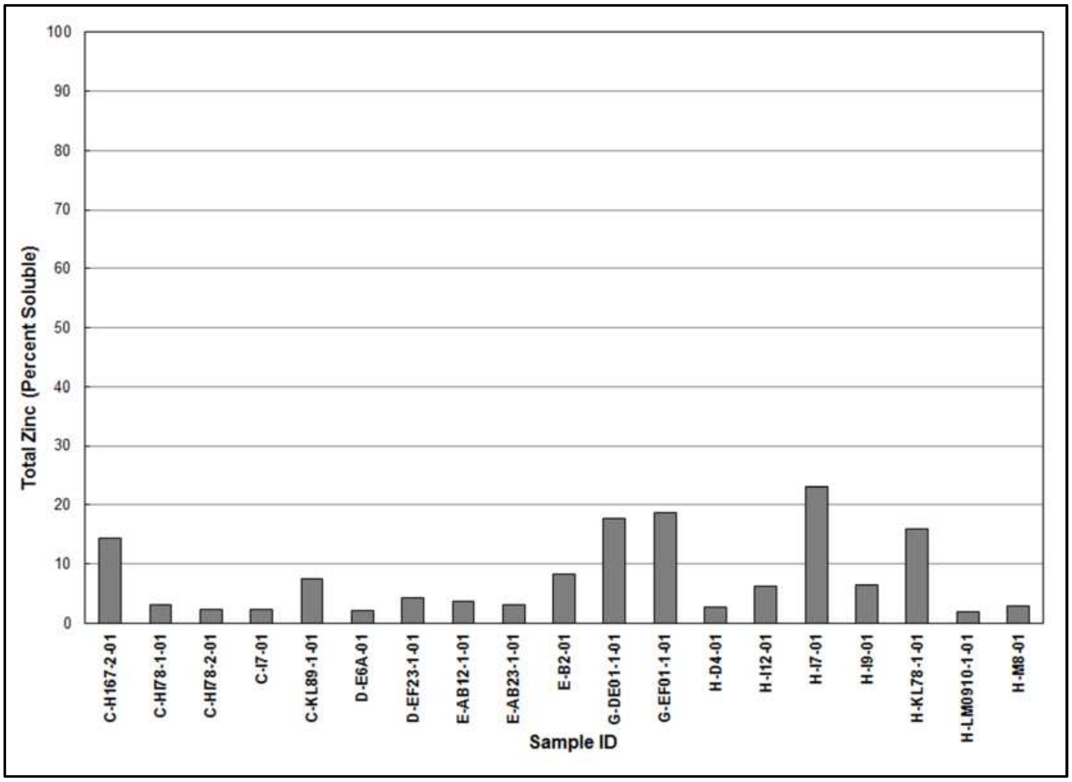


Figure 6-14. Percent Solubility of Total Zinc at Bluff CDE, G, and H

Table 6-1. Summary of Total Arsenic SPLP Results at Tronox Bluffs

Total Arsenic	Bluff B	Bluff CDE	Bluff G	Bluff H	All Bluffs
Total Samples	35	18	2	14	69
Detectable	35	18	2	14	69
% Detectable	100	100	100	100	100
Min Leachate Concentration (mg/L*)	0.036	0.034	0.099	0.010	0.010
Max Leachate Concentration (mg/L)	3.0	5.4	2.0	1.6	5.4
Average Leachate Concentration (mg/L)	0.61	1.09	1.05	0.28	0.68
Minimum Percent Soluble	0.68	0.38	0.32	0.04	0.04
Maximum Percent Soluble	33	5.4	2.7	7.1	33
Average Percent Soluble	7.6	2.0	1.5	2.6	4.9

*mg/L = milligrams per liter

Table 6-2. Summary of Natural Uranium SPLP Results at Tronox Bluffs

Natural Uranium	Bluff B	Bluff CDE	Bluff G	Bluff H	All Bluffs
Total Samples	35	18	2	14	69
Detectable	35	18	2	13	68
% Detectable	100	100	100	93	99
Min Leachate Concentration (mg/L*)	0.001	0.010	0.29	<0.001	<0.001
Max Leachate Concentration (mg/L)	1.9	4.4	0.38	0.10	4.4
Average Leachate Concentration (mg/L)	0.14	0.58	0.34	0.03	0.24
Minimum Percent Soluble	0.094	0.087	0.58	0.39	0.087
Maximum Percent Soluble	23	8.9	0.84	4.5	23
Average Percent Soluble	5.0	1.1	0.71	1.4	3.2

*mg/L = milligrams per liter

Table 6-3. Summary of Total Copper SPLP Results at Tronox Bluffs

Total Copper	Bluff B	Bluff CDE	Bluff G	Bluff H	All Bluffs
Total Samples	35	18	2	14	69
Detectable	23	4	1	3	31
% Detectable	66	22	50	21	0.45
Min Leachate Concentration (mg/L*)	<0.10	<0.10	<0.10	<0.10	<0.10
Max Leachate Concentration (mg/L)	0.52	0.031	0.025	0.053	0.52
Average Leachate Concentration (mg/L)	0.079	0.026	0.025	0.030	0.066
Minimum Percent Soluble	2.2	0.42	1.5	1.8	0.42
Maximum Percent Soluble	39	3.3	1.5	5.0	39
Average Percent Soluble	9.4	1.9	1.5	3.3	7.6

*mg/L = milligrams per liter

Table 6-4. Summary of Total Lead SPLP Results at Tronox Bluffs

Total Lead	Bluff B	Bluff CDE	Bluff G	Bluff H	All Bluffs
Total Samples	35	18	2	14	69
Detectable	32	18	2	13	65
% Detectable	91	100	100	93	94
Min Leachate Concentration (mg/L*)	0.004	0.002	0.005	<0.005	<0.005
Max Leachate Concentration (mg/L)	0.23	0.065	0.032	0.065	0.23
Average Leachate Concentration (mg/L)	0.044	0.019	0.019	0.018	0.031
Minimum Percent Soluble	0.0039	0.11	0.39	0.25	0.11
Maximum Percent Soluble	0.23	5.4	2.2	6.2	23
Average Percent Soluble	5.8	1.3	1.3	2.3	3.8

*mg/L = milligrams per liter

Table 6-5. Summary of Total Molybdenum SPLP Results at Tronox Bluffs

Total Molybdenum	Bluff B	Bluff CDE	Bluff G	Bluff H	All Bluffs
Total Samples	35	18	2	14	69
Detectable	32	18	2	13	65
% Detectable	91	100	100	93	94
Min Leachate Concentration (mg/L*)	<0.01	0.021	0.28	<0.01	<0.01
Max Leachate Concentration (mg/L)	29	7.8	1.8	3.6	29
Average Leachate Concentration (mg/L)	1.7	1.0	1.04	0.49	1.25
Minimum Percent Soluble	0.26	0.45	0.78	0.75	0.26
Maximum Percent Soluble	48	38	3.0	32	48
Average Percent Soluble	14	4.9	1.9	6.7	9.8

*mg/L = milligrams per liter

Table 6-6. Summary of Total Selenium SPLP Results at Tronox Bluffs

Total Selenium	Bluff B	Bluff CDE	Bluff G	Bluff H	All Bluffs
Total Samples	35	18	2	14	69
Detectable	26	12	2	6	46
% Detectable	74	67	100	43	67
Min Leachate Concentration (mg/L*)	<0.01	<0.01	0.050	<0.01	<0.01
Max Leachate Concentration (mg/L)	0.29	0.23	0.058	0.11	0.29
Average Leachate Concentration (mg/L)	0.054	0.036	0.054	0.053	0.049
Minimum Percent Soluble	0.89	0.37	9.7	0.59	0.37
Maximum Percent Soluble	95	29	14	51	95
Average Percent Soluble	23	3.8	12	17	17

*mg/L = milligrams per liter

Table 6-7. Summary of Total Zinc SPLP Results at Tronox Bluffs

Total Zinc	Bluff B	Bluff CDE	Bluff G	Bluff H	All Bluffs
Total Samples	35	18	2	14	69
Detectable	32	10	2	7	60
% Detectable	91	56	100	50	87
Min Leachate Concentration (mg/L*)	<0.20	<0.20	0.290	<0.20	<0.20
Max Leachate Concentration (mg/L)	0.81	0.20	0.30	0.53	0.81
Average Leachate Concentration (mg/L)	0.26	0.11	0.30	0.22	0.22
Minimum Percent Soluble	1.7	2.2	18	2.0	1.7
Maximum Percent Soluble	31	14	19	23	31
Average Percent Soluble	9.7	5.1	18	8.5	8.9

*mg/L = milligrams per liter

7.0 COMPARISON TO PREVIOUS INVESTIGATIONS

7.1 Comparison of Soil Sampling Results from the 2004 and 2012 Investigations

This section presents the soil sampling results from Tetra Tech's 2012 Tronox Bluff waste characterization program and compares the summary statistics of these data to the results of the composite soil sampling presented in the EE/CA study performed by Pioneer Technical Services (USFS, 2006). Both composite samples of the spoils areas at each bluff and discrete samples of the lignite soils at each bluff were collected and analyzed in 2004. Results for the metals and radionuclide analysis of the bluff source area sampling performed for the EE/CA alongside summary statistics of the 2012 sampling for Bluff B, CDE, G, and H are provided in Table 7-1 through Table 7-4, respectively.

Table 7-1. Bluff B Comparison of 2004 and 2012 Investigations*

Analyte	2004 Investigation		2012 Data			
	RP-SS-B1 (Composite)	RP-SS-B2 (Lignite)	Mean	Median	Min	Max
As (mg/Kg**)	43.7	2,190	95	52.2	3	2,838
Mo (mg/Kg)	17.2	17.2	73.5	4.1	0.8	10,558
U (mg/Kg)	23.6	12,800	40.2	4.1	0.8	7,853
^{226}Ra (pCi/g***)	9.8	915	11.8	2.29	0.56	1,846
^{235}U (pCi/g)	2.1	203	0.6	0.1	0.01	120

*Values from Appendix C, EE/CA (USFS, 2006)
**pCi/g = picocuries per gram
***mg/kg = milligrams per kilogram

Table 7-2. Bluff CDE Comparison of 2004 and 2012 Investigations*

Analyte	2004 Investigation			2012 Data			
	RP-SS-C (Composite)	RP-SS-D (Composite)	RP-SS-E (Composite)	Mean	Median	Min	Max
As (mg/Kg**)	807	521	28.6	230	136	5.21	2,953
Mo (mg/Kg)	477	25	1.3	421	107	2.5	6,134
U (mg/Kg)	2,930	517	16.2	337	105	3.4	4,305
^{226}Ra (pCi/g***)	314	80.3	42.6	86.8	24.4	1.47	3,699
^{235}U (pCi/g)	28.8	11.3	5.8	5.1	1.6	0.05	65.6

*Values from Appendix C, EE/CA (USFS, 2006)
**pCi/g = picocuries per gram
***mg/kg = milligrams per kilogram

Table 7-3. Bluff G Comparison of 2004 and 2012 Investigations*

Analyte	2004 Investigation		2012 Data			
	RP-SS-G1 (Composite)	RP-SS-G2 (Lignite)	Mean	Median	Min	Max
As (mg/Kg**)	399	2,880	256	130	18.8	1,483
Mo (mg/Kg)	352	2,970	195	32.3	1.66	1,491
U (mg/Kg)	293	2,410	198	64.8	4.33	1,091
^{226}Ra (pCi/g***)	53.2	903	42.4	9	1.36	1,493
^{235}U (pCi/g)	9.6	48	3.01	0.99	0.07	16.6

*Values from Appendix C, EE/CA (USFS, 2006)
**pCi/g = picocuries per gram
***mg/kg = milligrams per kilogram

Table 7-4. Bluff H Comparison of 2004 and 2012 Investigations*

Analyte	2004 Investigation			2012 Data			
	RP-SS-H1 (Composite)	RP-SS-H2 (Composite)	RP-SS-H3 (Lignite)	Mean	Median	Min	Max
As (mg/Kg**)	538	34.6	2,140	136	89	9.09	1,431
Mo (mg/Kg)	1,660	3.5	5,730	165	15.6	1.45	11,218
U (mg/Kg)	466	16.2 U	2,810	200	13.6	3.23	29,722
^{226}Ra (pCi/g***)	49.9	3.6	250	12.1	1.11	1.11	1,367
^{235}U (pCi/g)	12.5	0.5 U	71.3	3.04	0.21	0.05	452.7

*Values from Appendix C, EE/CA (USFS, 2006); U indicates a censored value
**pCi/g = picocuries per gram
***mg/kg = milligrams per kilogram

The composite sample results reported in the EE/CA fell within the range of metals and radionuclide concentrations reported by Tetra Tech in the 2012 waste characterization program. In general, the composite samples were higher than the mean concentrations reported by Tetra Tech study; however, the 2004 composite samples aimed at isolating the contaminated soils while the 2012 sampling included grids across the entirety of each bluff. However, there were limited situations where some of the 2004 lignite samples were outside of the upper limits of the Tetra Tech study. Tetra Tech did not specifically include sampling of *in-situ* lignite outcrops during the 2012 study.

7.2 Comparison to ENSR Study

This section presents a comparison of Tetra Tech's 2012 Tronox Bluff Waste Characterization results to the 2008 study performed by ENSR and AECOM (ENSR, 2008). Both the 2012 and 2008 characterization studies involved comprehensive radiological site surveys. Figure 7-1 through Figure 7-6 present side by side comparisons of these scans. The studies developed separate correlations to convert exposure rate readings to estimated soil ^{226}Ra activity; therefore, differences in estimates of remediation areas are expected and apparent.

The 2012 addition of an XRF survey for heavy metals allowed for the determination of contamination that was not identified by the 2008 radiological surveys. Previous studies performed limited field work to estimate metals concentrations, relying on the assumption that a correlation between gamma exposure and arsenic soil concentration could be established. The XRF survey performed during the Tetra Tech project showed that many areas previously considered to be "clean" by the previous study were found to have elevated levels of arsenic. Table 7-5 provides a comparison of the removal areas across the Tronox Bluffs.

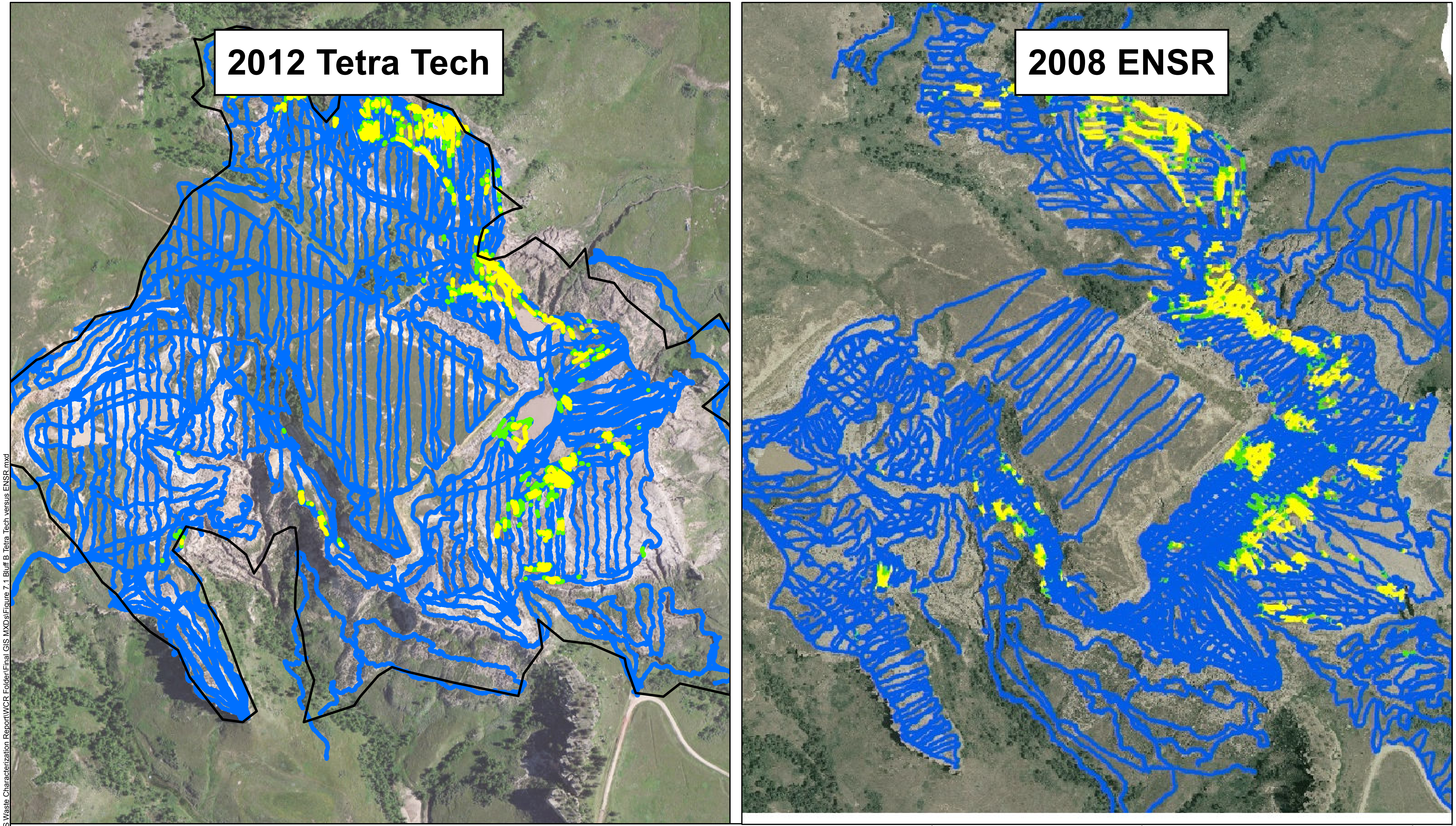
Table 7-5. Comparison of Category III Removal Area Estimates at Tronox Bluffs

Location	2008 ENSR Category III Removal Estimates (yd^2*)	2012 Tetra Tech Areas ≥ 50 pCi/g ^{226}Ra (yd^2)	Category III: ≥ 50 pCi/g** ^{226}Ra and/or ≥ 142 mg/kg*** As and/or ≥ 2,775 mg/kg Mo and/or ≥ 42.8 pCi/g ^{238}U and/or ≥ 2.03 pCi/g ^{235}U and/or 44.6 pCi/g ^{234}U (yd^2)
Bluff B	55,484	13,981	104,060
Bluff CDE	72,225	70,150	135,520
Bluff G	8,205	2,768	25,168
Bluff H	11,179	819	46,948

*yd^2 = square yards
**pCi/g = picocuries per gram
***mg/kg = milligrams per kilogram

Removal estimates developed by ENSR (2008) were based only on ^{226}Ra soil cleanup values. The 2012 study included a larger set of metals analysis and identified a larger area likely to require removal action. Differing spatial analysis techniques and differing ^{226}Ra gamma exposure rate correlations account for much of the increase. The 2008 areal estimates are based on applying a 15-foot radius around any data point exceeding the ^{226}Ra soil cleanup value (ENSR, 2008). Tetra Tech's analysis used spatial interpolation to estimate the extent of contaminated material. The radiological correlation used by Tetra Tech uses a larger data set, resulting in different gamma exposure rate correlating to the same ^{226}Ra soil cleanup value.

The 2008 ENSR study also included analysis of total arsenic soil concentrations at Bluff B. The results of the total arsenic analysis were based on bulk soil sample measurements. An IDW analysis was performed and the results were presented in the 2008 report. A comparison between the IDW total arsenic analysis performed by Tetra Tech and ENSR side by side is shown in Figure 7-7. This comparison shows that the total area identified in the 2012 study as above total arsenic concentrations cutoff values at Bluff B is greater than that identified in the 2008 study. Only a single point over 120 mg/kg of total arsenic was measured in the 2008 study, compared to the 2012 XRF field data which identified multiple areas exceeding the total arsenic cutoff.



Legend:

Soil Radium-226 Activity

- < 30 pCi/g
- ≥ 30 pCi/g and < 50 pCi/g
- > 50 pCi/g

0 250 500 1,000 Feet

N

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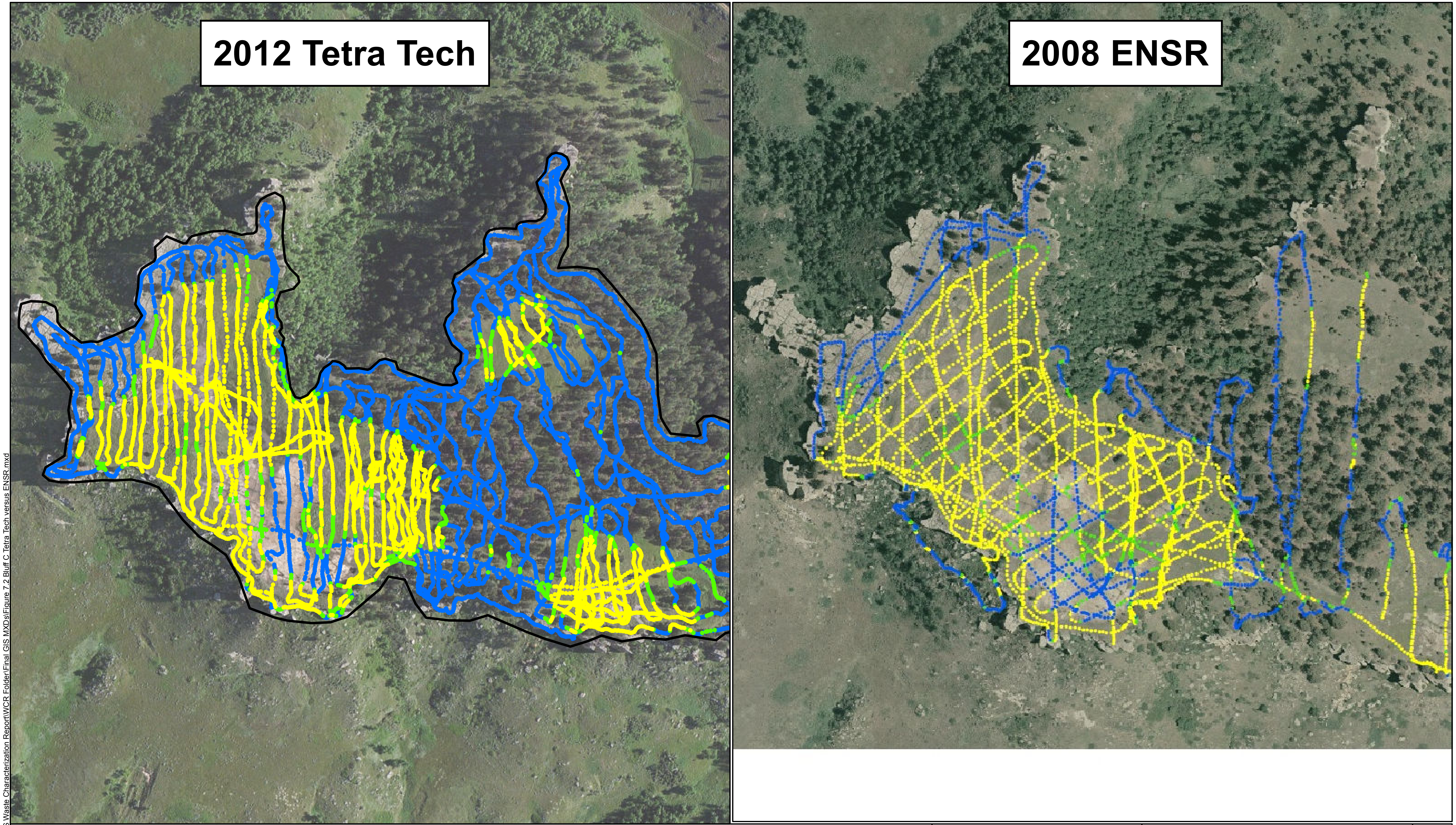
Bluff B Radium-226 Survey Map
Tetra Tech and ENSR Studies

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 7-1
Location:	HARDING COUNTY COUNTY, SD	June 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 7.1 Bluff B Tetra Tech versus ENSR.mxd



X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 7.2 Bluff C Tetra Tech versus ENSR.mxd

Legend:

Soil Radium-226 Activity

- Blue: < 30 pCi/g
- Green: ≥ 30 pCi/g and < 50 pCi/g
- Yellow: > 50 pCi/g

0 125 250 500 Feet

N

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Bluff C Radium-226 Survey Map
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3
Revision

Project: Riley Pass Tronox Bluffs

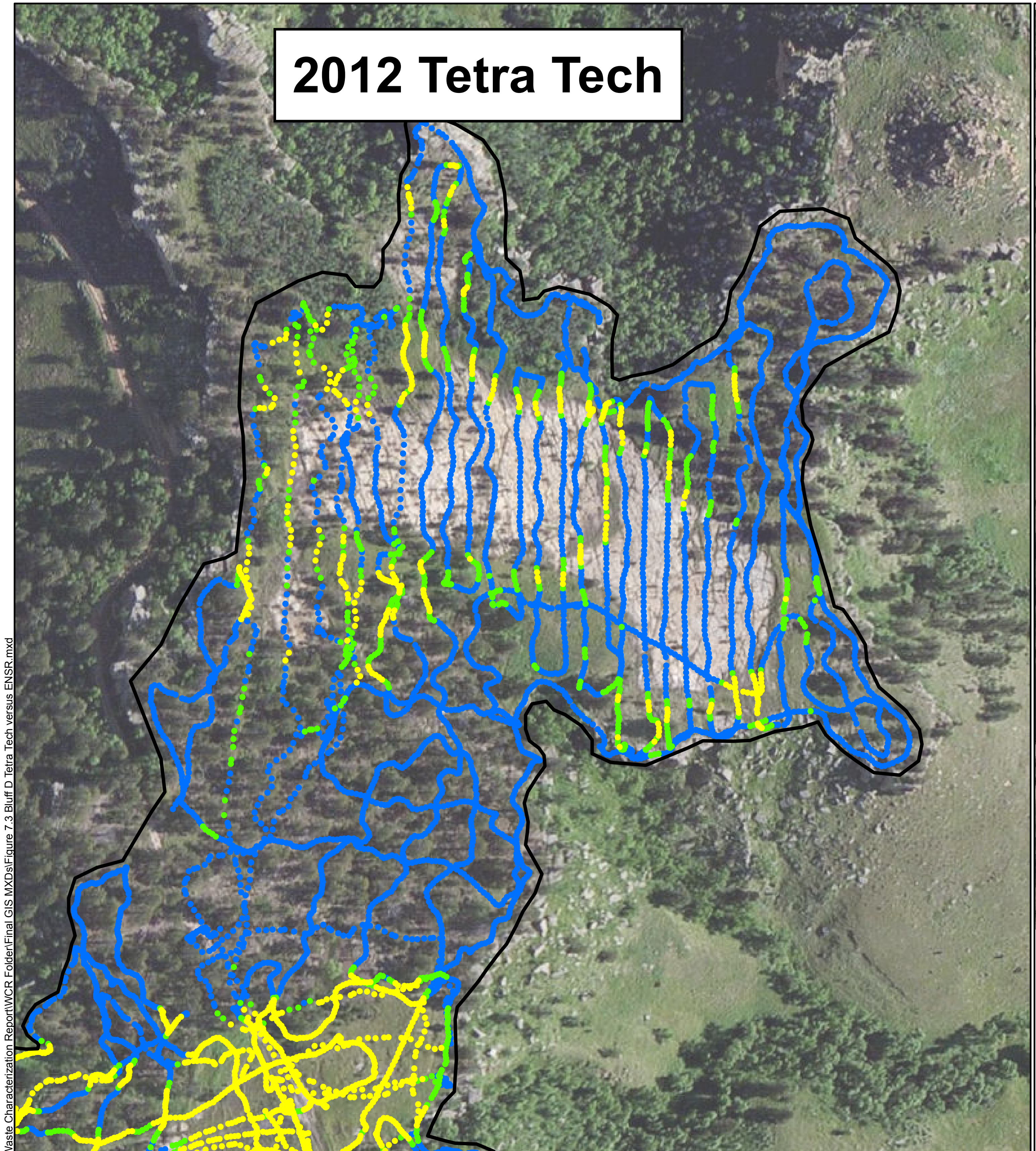
Project no.: 114-551083

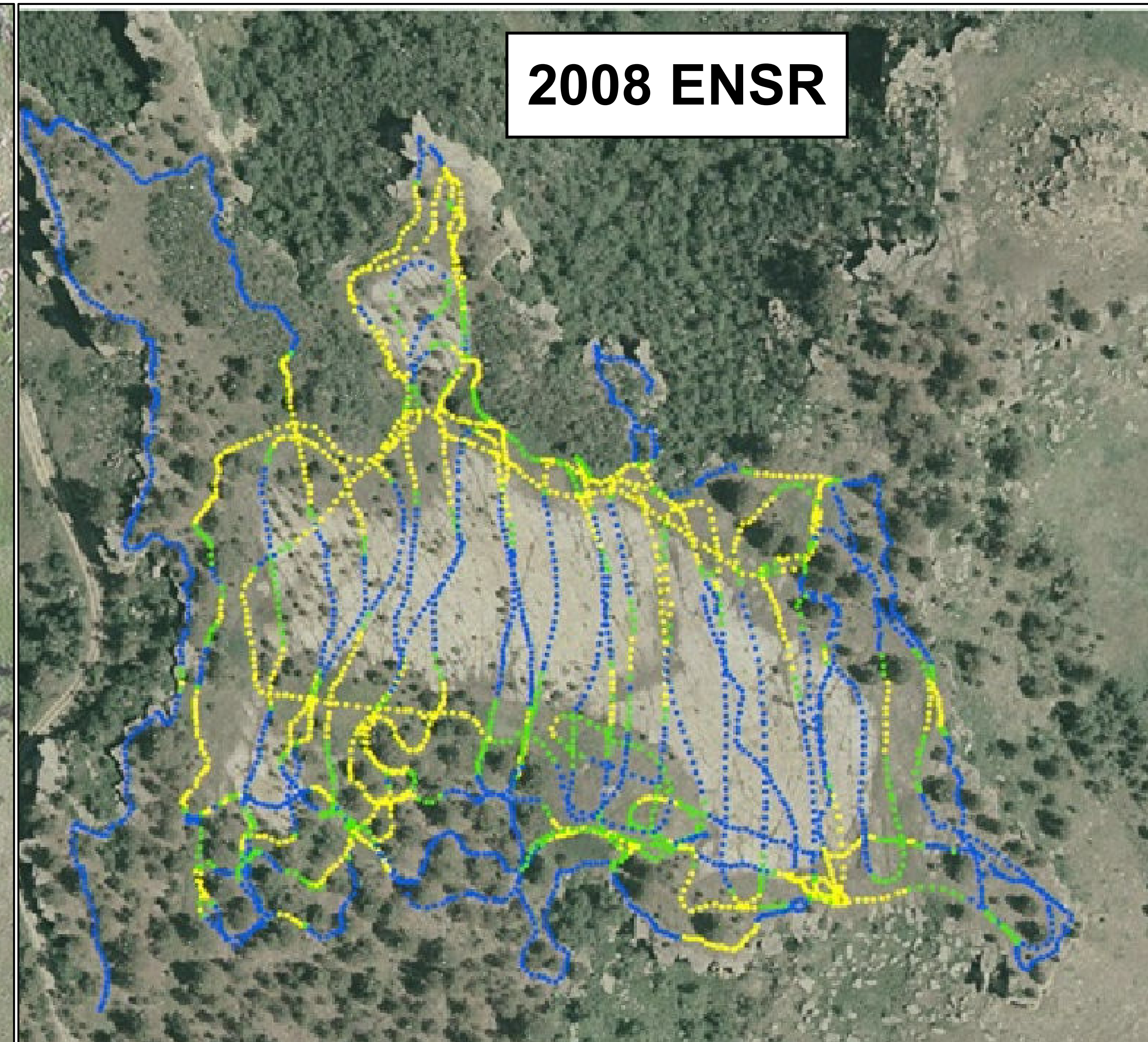
Location: HARDING COUNTY COUNTY, SD

June 2013

Figure 7-2

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet





Legend:

Soil Radium-226 Activity

- < 30 pCi/g
- ≥ 30 pCi/g and < 50 pCi/g
- > 50 pCi/g

0 125 250 500 Feet

N

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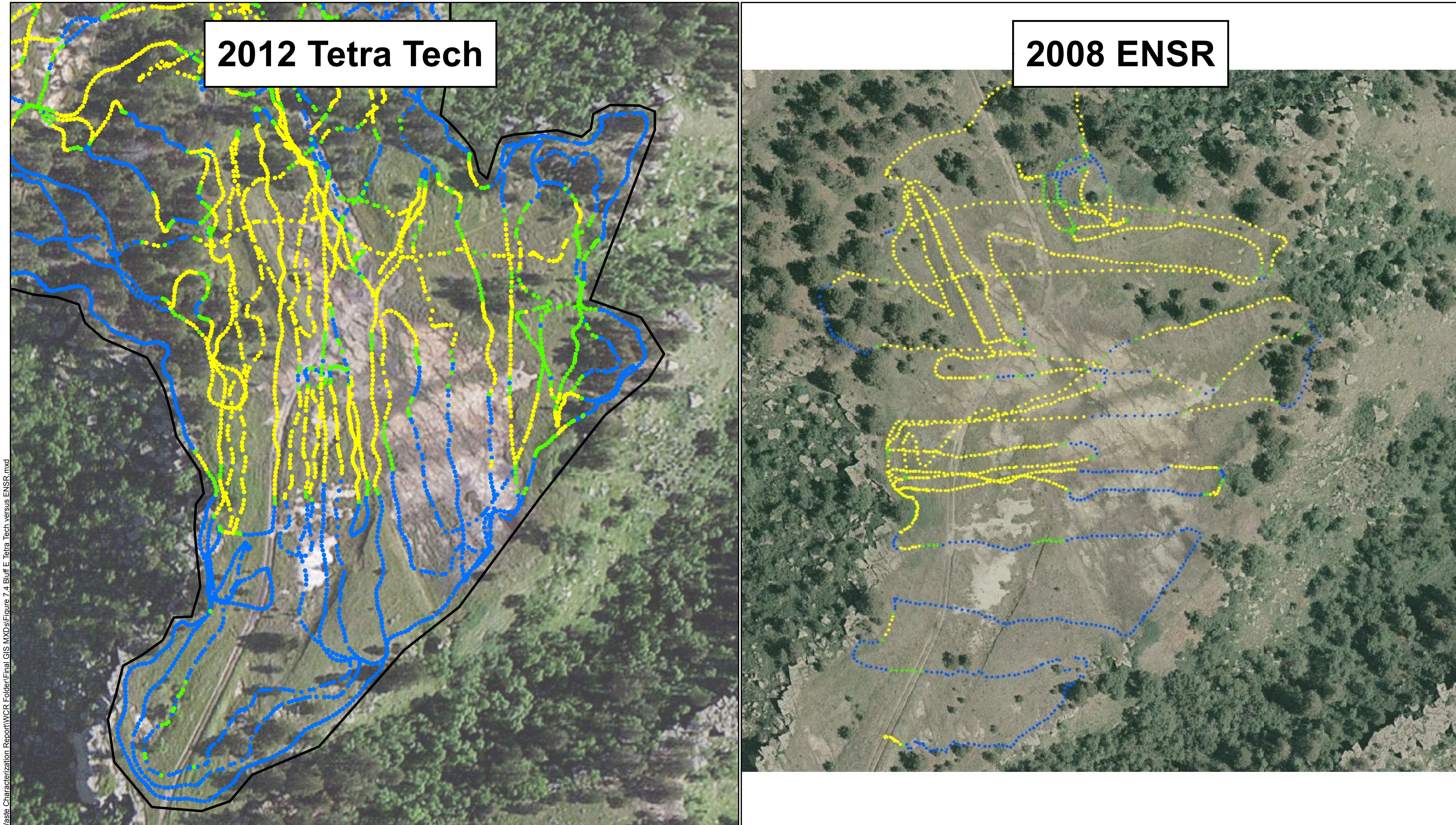
Bluff D Radium-226 Survey Map
Tetra Tech and ENSR Studies

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 7-3	
Location: HARDING COUNTY COUNTY, SD	June 2013		

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 7.3 Bluff D Tetra Tech versus ENSR.mxd



Legend:

Soil Radium-226 Activity

- < 30 pCi/g
- ≥ 30 pCi/g and < 50 pCi/g
- > 50 pCi/g

0 50 100 200 Feet

N

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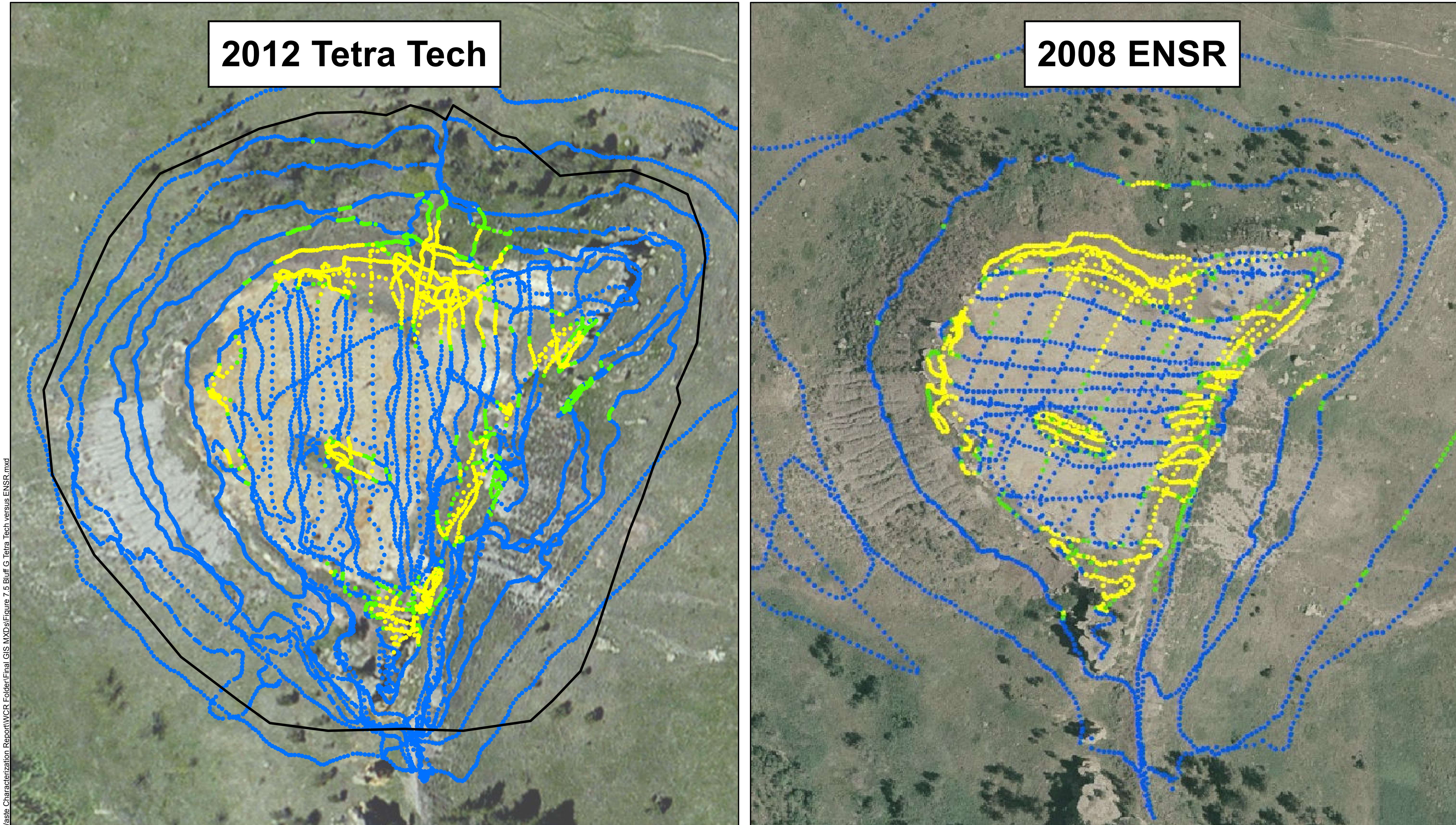
Bluff E Radium-226 Survey Map
Tetra Tech and ENSR Studies

Revision 3

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 7-4
Location: HARDING COUNTY COUNTY, SD	June 2013	

X:\551083 - Riley Pass\GIS\Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 7.4 Bluff E Tetra Tech versus ENSR.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Soil Radium-226 Activity

- < 30 pCi/g
- ≥ 30 pCi/g and < 50 pCi/g
- > 50 pCi/g

0 50 100 200 Feet

N

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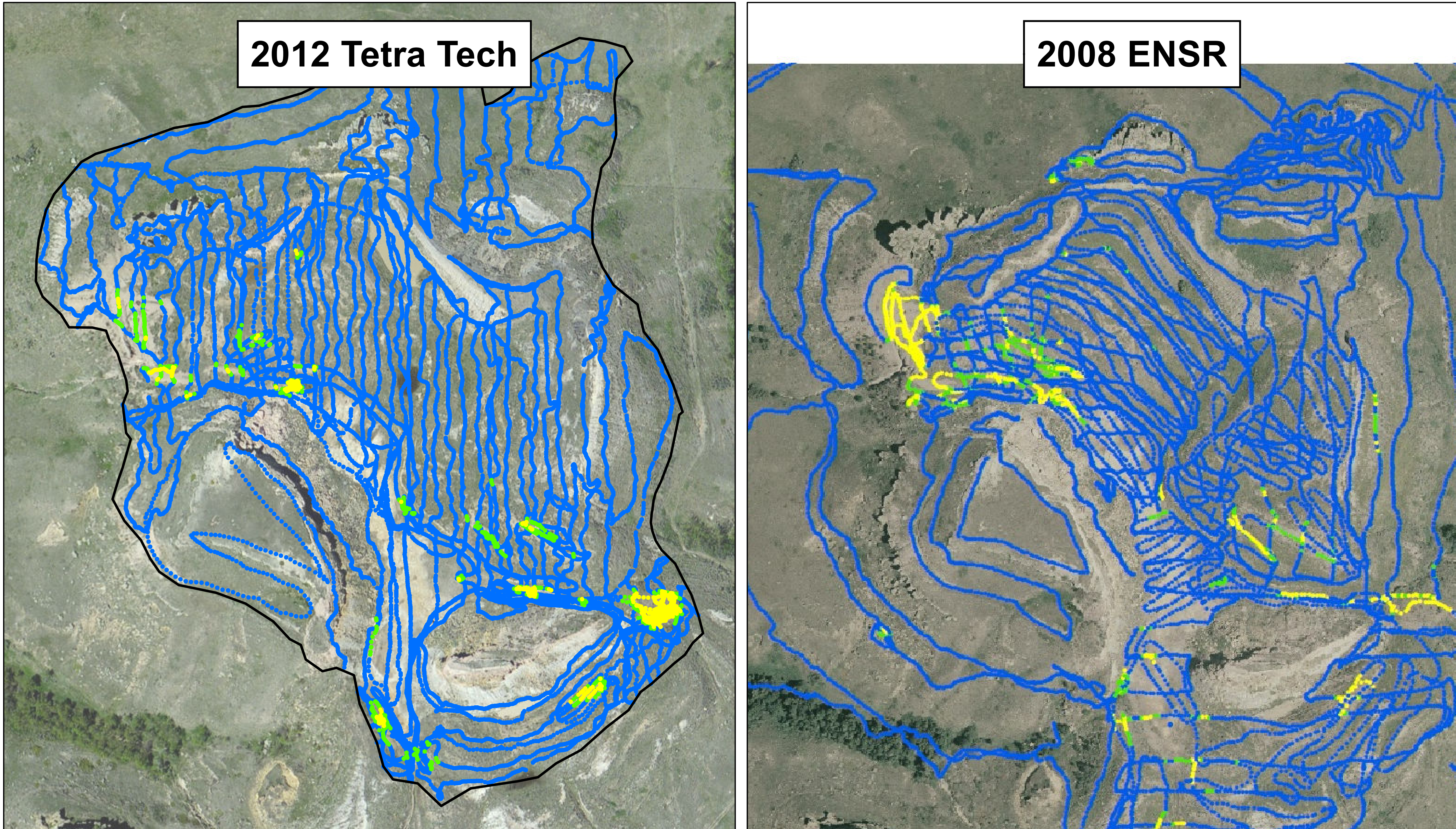
Bluff G Radium-226 Survey Map
Tetra Tech and ENSR Studies

3
Revision

Project: Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 7-5
Location: HARDING COUNTY COUNTY, SD	June 2013	

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 7.5 Bluff G Tetra Tech versus ENSR.mxd



Legend:

Soil Radium-226 Activity

- < 30 pCi/g
- ≥ 30 pCi/g and < 50 pCi/g
- > 50 pCi/g

0 125 250 500 Feet

N

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Bluff H Radium-226 Survey Map
Tetra Tech and ENSR Studies

3
Revision

Project: Riley Pass Tronox Bluffs

Project no.: 114-551083

Location: HARDING COUNTY COUNTY, SD

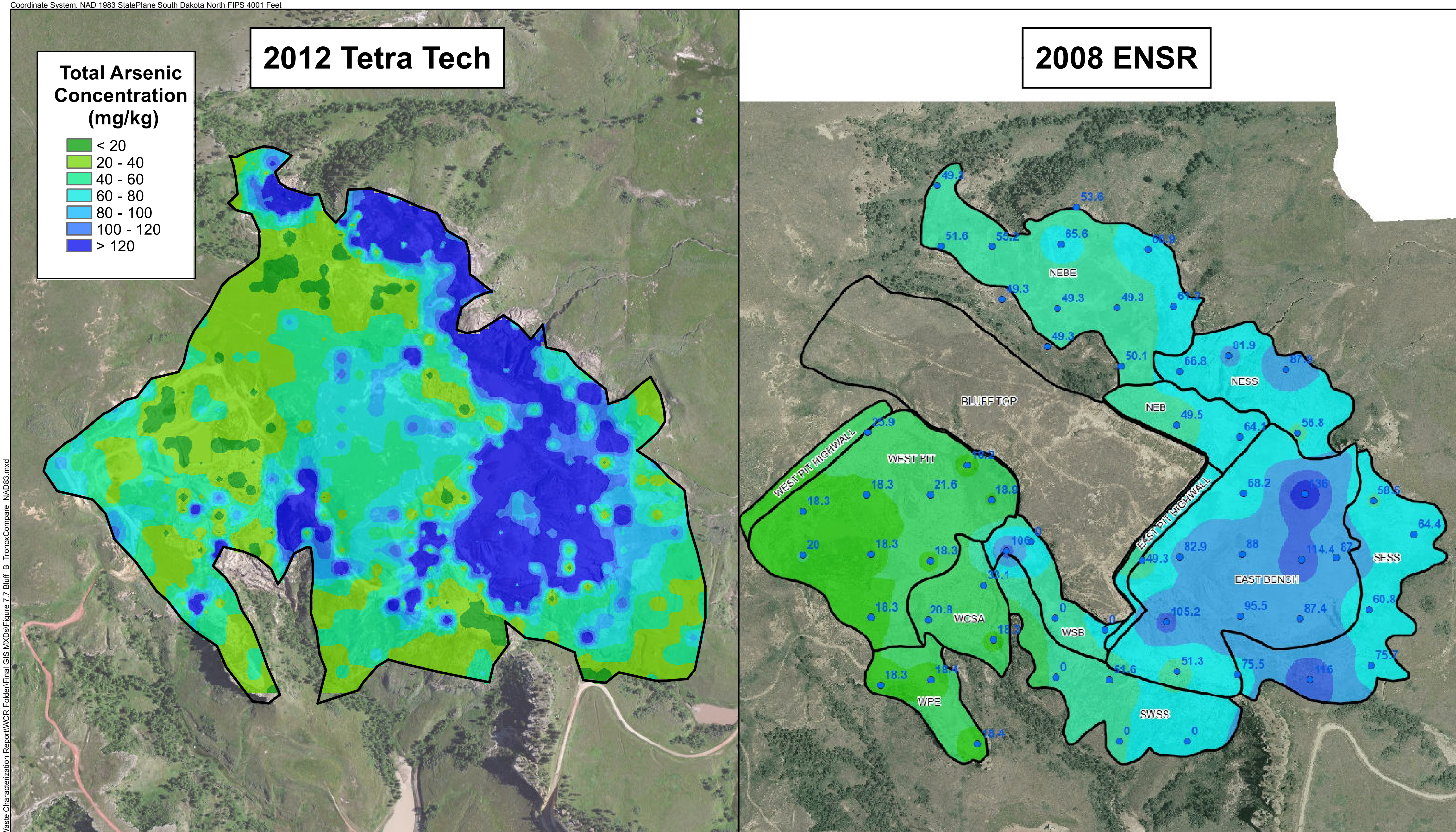
June 2013

Figure 7-6

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 7.6 Bluff H Tetra Tech versus ENSR.mxd

Coordinate System: NAD 1983 StatePlane South Dakota North FIPS 4001 Feet



Legend:

Bluff B Boundary

0 250 500 1,000 Feet

N

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Bluff B Total Arsenic
Survey Map
Tetra Tech and ENSR Studies

3
Revision

Project:	Riley Pass Tronox Bluffs	Project no.: 114-551083	Figure 7-7
Location:	HARDING COUNTY COUNTY, SD	June 2013	

X:\551083 - Riley Pass\GIS Waste Characterization Report\WCR Folder\Final GIS MXDs\Figure 7.7 Bluff_B_TronoxCompare_NAD83.mxd

8.0 CONCLUSIONS AND RECOMMENDATIONS

The 2012 Tronox Bluff waste characterization program was performed by Tetra Tech under contract with the USFS to collect and evaluate field data in support of the 2007 Action Memorandum and ongoing removal action design work being completed by Tetra Tech and the USFS. The data presented here includes information sufficient for engineering design and cost the removal actions at the Site.

8.1 Conclusions

The 2007 Action Memorandum specifies that the primary objectives for removal action at the Riley Pass Abandoned Uranium Mines will be to attain a degree of isolation, containment, and clean-up of hazardous substances assuring protection of public health and the environment. Prior to designing and initiating removal actions at the Site, the extent of hazardous substance contamination must be ascertained within an acceptable degree of certainty. The purpose of the 2012 Tronox Bluff waste characterization program was to perform field data collection and evaluation activities to identify removal areas to the extent practical, using acceptable scientific techniques. Tetra Tech performed a detailed, comprehensive, high-density gamma radiation survey, and an XRF field survey at each of the Tronox Bluffs B, CDE, G, and H as part of the program. In addition to the field surveys, sediment pond sampling, test pit sampling, erionite sampling, and SPLP analyses were performed.

The data Tetra Tech collected as part of the 2012 Tronox Bluffs waste characterization program are sufficient within a degree of certainty to estimate the areal extent of the mine waste removal action boundaries and provide mine waste volume estimates that will be used during the engineering design phase. A valid correlation was developed between gamma radiation and ^{226}Ra (R=0.96), and the results indicated that the soil ^{226}Ra activity at the Site can be estimated at a definitive level using the gamma exposure rate measurements. Similarly, a valid correlation was developed between total arsenic (R=0.95), total molybdenum (R=0.96), and natural uranium (R=0.98) laboratory reported soil concentrations and the *in-situ* XRF total arsenic measurements; therefore, these metal concentrations in surface soils were estimated to a definitive level using the field XRF measurement data that were collected at each bluff. The natural uranium metal concentrations were converted into the uranium decay radionuclides (^{238}U, ^{235}U, and ^{234}U) assuming secular equilibrium.

The conclusions from 2012 Tronox Bluff waste characterization program are as follows:

- The surface area of the Tronox Bluffs was previously estimated at approximately 204 acres (USFS, 2006). The boundaries were revised based on data collected during the 2012 Tronox Bluff waste characterization program for Bluff CDE, Bluff G, and Bluff H. The total area for the Tronox Bluffs based on the revised boundaries encompasses 240 acres, an increase in 36 acres (18 percent increase).

- Based on the final surveys, a total of 64.4 acres (27 percent) of the Site is classified as mine waste Criteria 1 Category III. The contaminated area is based on a combination of field data collected during the gamma radiation survey, including soil ^{226}Ra activity, and the XRF field survey, including total arsenic soil concentration, total molybdenum soil concentration, soil ^{238}U activity, soil ^{235}U activity, and soil ^{234}U activity. Bluff CDE has the largest areal extent of Category III materials (27.8 acres). Bluff B has the smallest areal extent by percentage (14 percent) of Category III materials, but the highest total volume (280,090 yd^3). Bluff G has the smallest area of Category III, but the highest density of overall contamination (including the sandstone area). Approximately 1.7 acres (0.7 percent) of the Site is classified as mine waste Criteria 1 Category II. A total of 172 acres (72 percent) of the Site had no exceedances of removal action criteria (Criteria 1 Category I).

- Bluff CDE was categorized based on both the 2007 Action Memorandum Criteria 1 and Criteria 2. In general, Bluff CDE has the most overall contamination of all the bluffs based on the field surveys and Criteria 1; however, based on Criteria 2 relatively few areas would need to be reclaimed.

- The elevated gamma exposure rates and XRF metals concentrations collected at Bluff CDE matched closely with the corresponding ^{226}Ra activity and metals concentrations measured in the test pit surface samples. In general, the test pit sampling at Bluff CDE indicates that the surface and subsurface contaminant levels were uniform and there was no apparent increasing or decreasing trends in contaminant concentration with depth. In each of the test pits analyzed, the deepest sample location had contaminant levels that exceeded the removal action cutoff levels.

- A volume estimate analysis was performed using a combination of LIDAR data, test pit sampling, historic aerial imagery, and geospatial techniques. The results of the volume analysis resulted in an estimated 2,089,868 yd^3 of Criteria Category I spoils material (no exceedances) that is pushed off the sides of the bluffs, an estimated 15,488 yd^3 of Category II materials, and an estimated 853,750 yd^3 of Category III materials.

- The SPLP results show that the proportion of soluble arsenic, uranium, copper, molybdenum, selenium, and zinc is consistently higher in the Bluff B soils compared to the remaining locations. Bluff G soils on the other hand, tend to have the lowest proportion of soluble constituents compared to their total concentrations.

- Erionite sampling indicates that PLM bulk analysis indicates percent sample composition by volume ranges from trace to 5 percent erionite in the road materials analyzed at Bluff B.

- Pond sediment sample analysis indicates that surface pond materials sampled are not classified as Criteria 1 Category II or Category III mine wastes. The results of the sediment sampling analysis indicated that the elevated SAR poses the greatest risk associated with use of sediment as a cover material and can only be corrected by blending of sediments with lower SAR material and/or by reclaiming the sediments with gypsum application followed by active leaching with good quality water, which may be impractical to implement. It is important to note that sediment sampling only concentrated on surface sediment. The geochemical sediment characteristics could potentially vary with depth.

Overall, the results of the waste characterization indicate that impacts of the mining activities related to the Riley Pass Abandoned Uranium Mines Tronox Bluffs vary in degrees of magnitude of radiological and metals concentrations between each bluff. The distribution of ^{226}Ra activity, total arsenic concentration, total molybdenum concentration, ^{238}U activity, ^{235}U activity, and ^{234}U activity in the surface soils was used to determine areal extents for each mine waste category at each bluff; this information can be used as part of the engineering removal design for the Site.

8.2 Recommendations

The data collected during the 2012 Tronox Bluff waste characterization program is sufficient to establish the nature and extent of environmental and radionuclide contamination due to the historic strip mining that occurred at the Tronox Bluffs. This WCR provides the necessary data and information to support the removal action engineering design in regard to identifying the overall areal extent of both radiological and metals contamination at the Site, specifically ^{226}Ra activity, total arsenic concentration, total molybdenum concentration, ^{238}U activity, ^{235}U activity, and ^{234}U activity in the surface soils at each bluff and provide estimates of the mine waste volumes. Tetra Tech's final recommendations are as follows:

1. A revised *Interpretation of Criteria for Waste Characterization Purposes* is detailed in WCR Section 2.2.3 and is recommended for characterization of on-site materials. This recommendation has been utilized throughout the WCR for characterization of total arsenic concentration, total molybdenum concentration, ^{238}U activity, ^{235}U activity, and ^{234}U activity in the surface soils at each bluff.

2. Due to the elevated levels of total arsenic, uranium decay products and ^{226}Ra present within the surface soils at Bluff CDE, it is recommended to apply the Criteria 1 waste characterization scheme in determining what removal actions should be applied.

3. It is recommended that after the removal engineering design has been established for the Tronox Bluffs, that a *"Tronox Bluff Removal Area Verification Sampling Plan"* be developed. This plan will identify environmental monitoring sampling procedures and statistical methods that will be used to evaluate the attainment of soil cleanup standards at the Site, based on USFS reclamation criteria and goals.

4. Test pit sampling was performed according to the SAP, but was limited to Bluff CDE only. Due to access constrains and ubiquitous non-uniformity of the mine waste materials at the Site, in addition to the excessive drilling budget that would likely be required for the USFS to perform the detailed subsurface characterization necessary to sufficiently characterize the depth of contamination and refine volume estimates at Bluff B, G and H; Tetra Tech does not recommend additional subsurface drilling or sampling at these bluffs. The current volume estimates provided in this WCR should be used for guidance purposes for costing and bidding on the removal construction activities.

5. Tetra Tech strongly recommends that removal action for arsenic, ^{226}Ra, and uranium contaminated soil at the 240 acre Site, be facilitated with the use of the XRF as a survey/screening tool and radiation detection equipment as a survey/screening tool. The combination of these survey screening tools in conjunction with permitted excavation to be guided by field GPS instruments should be performed by qualified field engineers and radiation control technicians during the removal action construction activities. The screening procedures for both the radiation detectors and XRF instruments will be detailed in the *"Tronox Bluff Removal Area Verification Sampling Plan."*

6. Tetra Tech collected gamma exposure rate and XRF data southeast of the original Bluff G boundary as part of the WCR characterization. This data collection indicates areas of elevated gamma exposure (Figure 5-21) and XRF points with elevated metals (Figures 5-25 to 5-27). The full extent of contamination of this area outside the Bluff G boundary was not fully identified because this was outside of the scope of the specified field activities for Bluff G. The USFS should consider conducting additional waste

characterization in this area if deemed necessary. If additional investigation is warranted, an amended report can be provided to characterize the area southeast of Bluff G. Similarly, this should also be considered at the western drainage of Bluff H, where the extent of contamination outside the boundary was not fully characterized.

7. It is recommended that the 3130 road surface within the vicinity of Bluff CDE area be sampled at depth to determine the extent of waste contamination, if any, exists under the road.

8. The simple random sampling data collected from the sediment ponds in this study were statistically adequate to characterize the surface sediment in the ponds; however, additional sampling should be conducted to characterize the subsurface contaminant levels or field screening methods should be applied as described in Recommendation #5.

9. The *in-situ* XRF correlations developed in this study are specifically applied to this model of XRF. Additional characterization studies or future verification work should employ the same model of XRF or newer; otherwise a new correlation should be developed if a different instrument is used.

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