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# DRAFT Waste Characterization Evaluation Report Revision 1

## Riley Pass Uranium Mines Site (North Cave Hills) Harding County, South Dakota

**Project No.: 114-560486A**

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# 1.0 INTRODUCTION

Tetra Tech Inc. prepared this report for the U.S. Forest Service (USFS) under Contract GS-10F-0268K, Task 1 and Task 3. This report presents the findings and recommendations of the waste characterization evaluation and document review performed by Tetra Tech for the Riley Pass Abandoned Uranium Mine site (Riley Pass) located in Custer Gallatin National Forest in Harding County, South Dakota. Additionally, this report presents the status update for all of the study areas within the Riley Pass site. The update involves a summary of the current reclamation status of each study area and provides maps of existing contaminant levels at each area using all data currently available for the site. Tetra Tech has developed a comprehensive geodatabase for all relevant characterization and reclamation data available at the site. Riley Pass consists of 10 primary study areas (A, B, CDE, F, G, H, I, J, K, and L) expanding 316 acres. This report provides data summaries and recommendations intended to support development of future work at the site, including the following: (1) 2015 Action Memorandum, (2) future reclamation design, and (3) Riley Pass Verification Sampling Plan.

Section 1.1 provides a site background. Section 1.2 presents the regulatory background. Section 1.3 summarizes the primary objectives. Section 2.0 provides a summary of the document review. Section 3.0 presents the review and findings of the risk-based soil cleanup criteria. Section 4.0 provides a technology review. Section 5.0 provides a status update of the site. Conclusions and recommendations are presented in Section 6.0 and Section 7.0, respectively.

## 1.1 SITE BACKGROUND

Uranium exploration began in the North Cave Hills in 1954 when the Atomic Energy Commission recorded high radiation anomalies over the North Cave Hills (Curtiss 1955; Stone et al. 2009). The first claims were staked in August 15, 1954; extensive mining started in the early 1960s in an effort to supply contracts for uranium, but all mining ceased in 1964. Riley Pass is part of the North Cave Hills complex contained within the Sioux Ranger District, Custer Gallatin National Forest, in Harding County, South Dakota, falling within Region 1 jurisdiction of the USFS. The site is located 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). The Riley Pass site was originally identified as 12 study areas referred to as Bluff A through Bluff L. In 2013, Bluff C, Bluff D, and Bluff E were categorized as “Bluff CDE.” The Riley Pass site consists of 10 study areas referred to as Bluff A, Bluff B, Bluff CDE, Bluff F, Bluff G, Bluff H, Bluff I, Bluff J, Bluff K, and Bluff L.

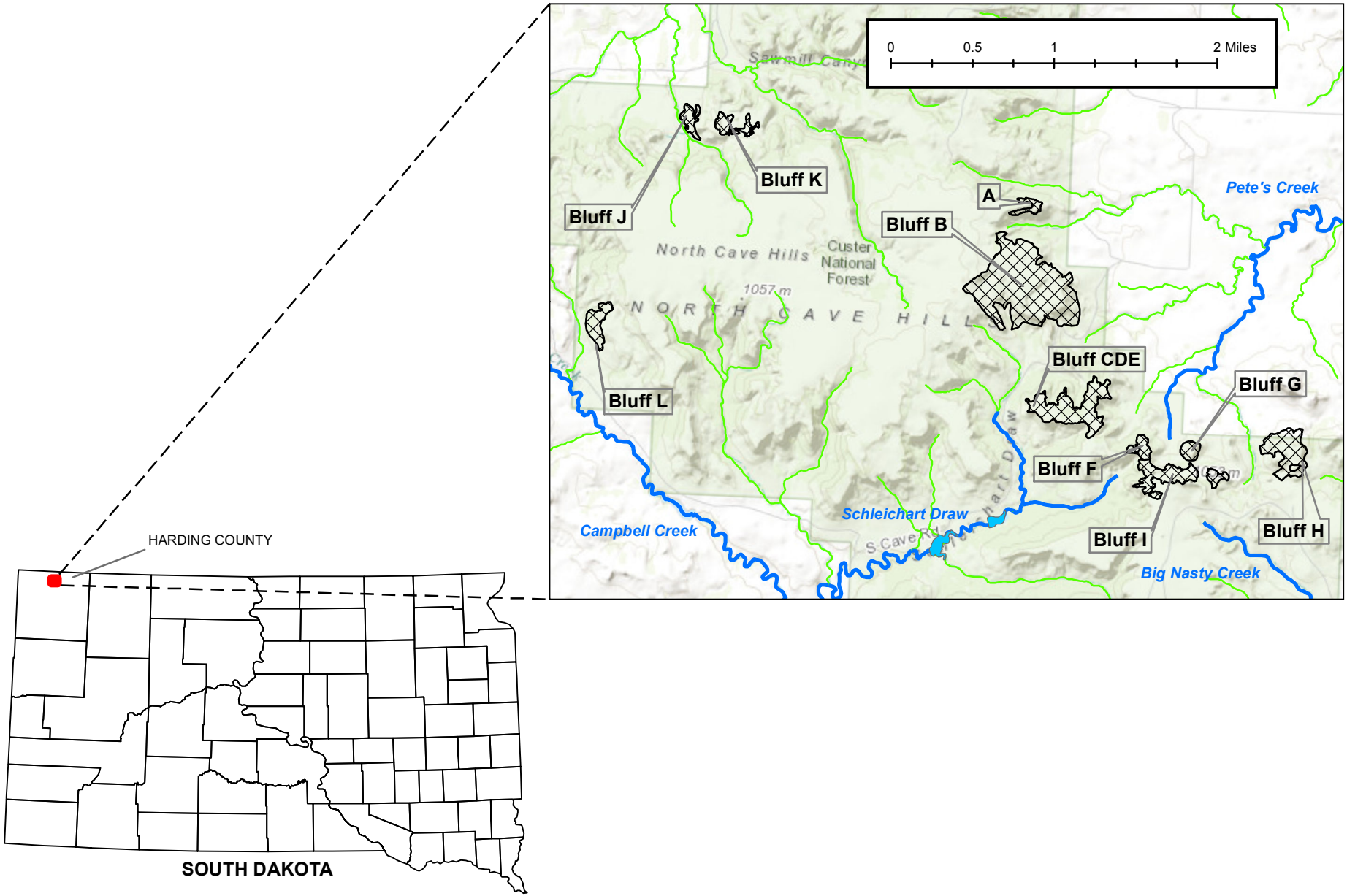
The North Cave Hills area serves as the headwaters of the South and North Forks of the Grand River which eventually flows into the Missouri River at Mobridge, South Dakota, over 200 miles away. There are four notable drainages or creeks within the vicinity of the site, including Pete’s Creek directly to the east of Bluff B, Campbell Creek to the southwest of the site, Schleichart Draw south of Bluff B, and Big Nasty Creek south of Bluff H. A site location map that incorporates these major drainages and their tributaries in presented in Figure 1.

The site includes steep-sided and flat-topped buttes that are rimmed with sandstone cliffs. From a geomorphic perspective, this area contains evidence of geologically rapid retreat (Stone et al. 2007). The climate in the region is intercontinental arid characterized by warm dry summers and cool dry winters, with an average precipitation of 12 inches per year. Snowfall does not typically contribute to the total precipitation amount. The uranium mines located in this region were lignite mines located on tops of the

buttes. Mining features include bluffs, overburden piles (spoils), and hazardous erosional openings and highwalls. Samples of spoils materials have been characterized as sandy clay and clayey sand. Within the North Cave Hills, documented mine sites, spoils, and exploration activities cover almost 1,000 acres. However, the estimated disturbed areas within the Riley Pass site include 316 acres of highwalls, pit floors, and spoils piles. Spoils were pushed over the edges of the buttes onto the steep slopes below the rimrocks during mining. Additional spoils have been deposited on these slopes by erosion.

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 removal of uranium-bearing lignite coal beds, with no requirements for environmental restoration or for establishing post-mining responsibility (USFS 2006). The nature of mining that took place resulted in acute environmental degradation and has eroded the soils and affected drainages and water supplies. Numerous site investigations conducted at the site have shown impacts of heavy metals and radionuclides releases associated with the mining.

The bluffs at the site have been delineated as either “Tronox” or “Non-Tronox,” relating each bluff to the potentially responsible party (PRP). Tronox, LLC, is the PRP for approximately 80 percent of the site. In 2008, Tronox informed the USFS that it was stopping all work on the project, in violation of the consent order Tronox had signed in the previous year. In 2009, Tronox filed Chapter 11 bankruptcy. The site was one of many included in a bankruptcy settlement agreement that created environmental response trusts and provided for Tronox to pay the trusts and Governmental Environmental Claimants. A series of court proceedings resulted in a payment to clean up the majority of the site. That settlement was announced by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Justice (DOJ) and approved by a judge in April 2014 (O’Sullivan 2014). The Tronox Bluffs previously referred to Bluff B, Bluff CDE, Bluff G, and Bluff H. The Non-Tronox Bluffs referred to Bluff A, Bluff F, Bluff I, Bluff J, Bluff K, and Bluff L. For this report, the title of “PRP” and, therefore, the “Tronox/Non-Tronox” designation has been removed for all of the study areas. The following section describes the regulatory background at Riley Pass.




NAD_1983_STATEPLANE
SOUTH_DAKOTA
NORTH_FIPS_4001_FEET

Riley Pass Site Location
Study Area Boundaries
Major Drainage
Minor Drainage

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Title:
RILEY PASS SITE LOCATION & MAJOR DRAINAGES

Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date: AUGUST 2015

Figure: Figure 1

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 1 Site Location.mxd August, 2015; Aaron.Orechwa

## 1.2 Regulatory Background

In 1996, the USFS sent Kerr McGee Corporation (predecessor to Tronox) a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Section 104 (e) letter notifying them of potential liability under CERCLA. The USFS began working at Riley Pass under its CERCLA authority at that time. Previously, the USFS had constructed five sedimentation ponds in 1989 under contract 43-003585-0-1001. The USFS cleaned the ponds in 1990 (contract number 43-0388-0-1152) and in 1997 (contract number 43-0355-6-0119). In 2004, USFS designated a time-critical removal action to minimize the impacts associated with sediment overflowing from the sedimentation ponds. As a result of this action memorandum three of the five sediment ponds were dredged in 2008. Time-critical actions are characterized by a need for a rapid response to address the immediate threat (EPA 2000a). Three existing action memorandums have been developed and approved (USFS 2004, 2007, and 2010) with varying degrees of time-based response actions for the site. The following action memorandums have been designated for the site, to date:

- *Time Critical Removal Action at Riley Pass Abandoned Uranium Mine Harding County, South Dakota* – dated September 7, 2004 [2004 Action Memorandum] (USFS 2004).
- *Riley Pass Uranium Mines Site Removal Action within the North Cave Hills Land Unit*- dated February, 2007 [2007 Action Memorandum] (USFS 2007).
- *Riley Pass Uranium Mines Site Non-Tronox Bluffs Removal Action within the North Cave Hills Land Unit*- dated April 27, 2010 [2010 Action Memorandum] (USFS 2010).

The Riley Pass site is primarily located on lands under the jurisdiction, custody, and control of the USFS. When abandoned mine waste sites are located on federal lands or a mixture of federal and private lands, federal land managers (USFS or the Bureau of Land Management [BLM], for example) will be the lead agency responsible for overseeing all or a portion of the cleanup using CERCLA authority (EPA 2000a). The USFS was delegated the lead authority at the Riley Pass site under Executive Order 12580 (Superfund Implementation, dated January 23, 1987), Executive Order 13016 (Amendment to EO 12580, dated August 28, 1996), and under 7 Code of Federal Regulations (CFR) 2.60(a)(40) (USFS 2004). The National Contingency Plan (NCP) recognizes this delegation when the source of the release or potential release of hazardous substance is from lands under the jurisdiction of the USFS. The Riley Pass site is listed in *Defense-Related Uranium Mines Assessment of Radiological Risk to Human Health and the Environment Topic Report* (DOE 2014), specifically under Section 2.4, "Risk Assessments Conducted for Various Inactive Uranium Mine Sites." Additionally, the Riley Pass site is mentioned in Volume II of the EPA's TENORM report (EPA 2008), Section 3 "Cancer Risks from On-site Exposure."

The 2007 Action Memorandum (USFS 2007) addressed the Tronox Bluffs so that Tronox could proceed with their cleanup work. In 2010, an Action Memorandum (USFS 2010) was developed for the Non-Tronox sites. This action memo had a different requirement for the categorization of waste, based on arsenic and radium-226 sample results at the site. Since these action memorandums were developed, additional comprehensive site characterization has been completed. Numerous action memorandums, general site actions, reclamation and verification reports, and major site investigations have been completed and published for the Riley Pass site. A detailed timeline documenting these items is provided in Figure 2. The following section describes the objectives of this report.

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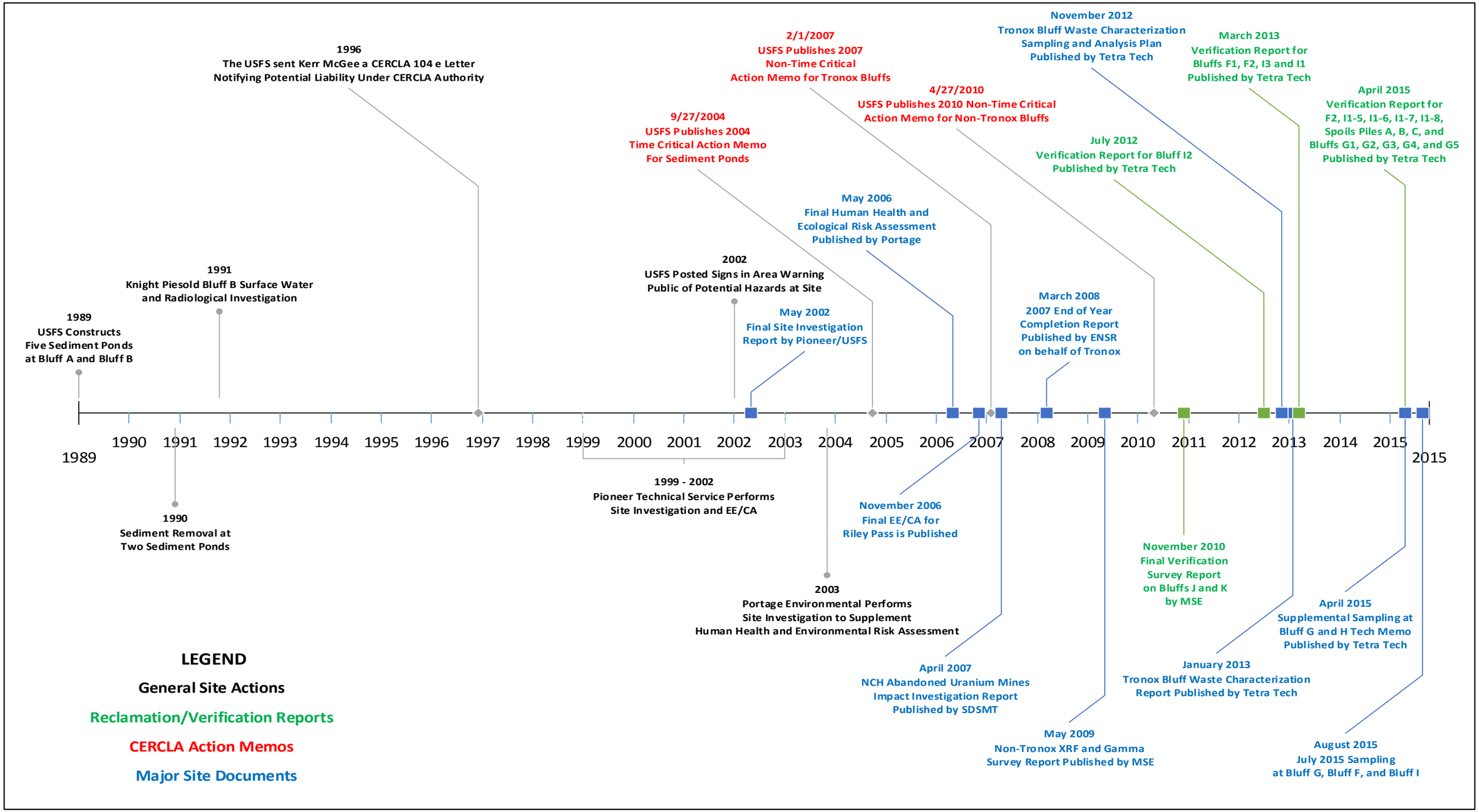


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**Figure 2**
**Historical Timeline of Activities (1989 to Present)**
**Riley Pass Abandoned Uranium Mines**

## 1.3 OBJECTIVES

This report provides data summaries and recommendations intended to support development of a 2015 Action Memorandum, reclamation design, and verification sampling design for future work at Riley Pass. The primary objectives of this report are as follows:

- Perform a detailed review and summarize all relevant historical environmental studies, action memorandums, and scientific reports related to the Riley Pass site.
- Review the Portage (2006) risk assessment, evaluate any risk-based soil cleanup criteria that have been developed at the site to date, and identify any new contaminants of potential concern.
- Evaluate the proposed risk-based cleanup levels to assess whether they are still applicable and appropriate to the site.
- Develop risk-based or background based soil cleanup criteria that will be used for all future characterization data collection, reclamation design, and verification sampling strategies.
- Provide an update of the current reclamation and characterization status for all Riley Pass study areas and provide maps of most recent data collected at each area.
- Determine if additional sampling is needed to fully characterize the study areas and provide recommendations as necessary.

# 2.0 SUMMARY OF REVIEW AND EVALUATION

A primary objective of this report was to perform a detailed review of and summarize all relevant historical environmental studies, action memorandums, and scientific reports related to the Riley Pass site. Tetra Tech reviewed 19 documents deemed most relevant to the Riley Pass site. A list of the documents reviewed and a summary of each document is provided in Table 1 and Table 2.

**Table 1 Summary of Documents Reviewed [Documents 1 through 7]**

| No. | Report Title | Year of Issue | Author | Document Summary |
|---|---|---|---|---|
| [1] | Time-Critical Removal Action Memorandum for sediment ponds and Schleichart Reservoir | 2004 | USFS | Selected time-critical removal action to minimize human health and environmental impacts associated with sediment overflowing containment ponds. |
| [2] | Final Engineering Evaluation and Cost Analysis (EE/CA) | 2006 | Pioneer/USFS | Presents response action alternatives, site background, waste characteristics, Applicable or Relevant and Appropriate Requirements (ARARs), and preliminary development and screening of response action alternatives. |
| [3] | Final Human Health and Environmental Risk Assessment for the Riley Pass Uranium Mines in Harding County, South Dakota | 2006 | Portage | Provides summary of human and ecological exposures and risks for site. Preliminary Remediation Goals (PRGs). |
| [4] | Final Report: North Cave Hills Abandoned Uranium Mines Impact Investigation | 2007 | SDSM | Determined extent of heavy metal and radionuclide concentrations on private property attributable to historical mining within the North Cave Hills. Uranium, arsenic, and molybdenum were above background in surface water, drainage sediment, and soil samples collected on private property. |
| [5] | 2007 Tronox Bluffs Action Memorandum | 2007 | USFS | Presents mine waste categorizations and selected non-time critical removal actions for Bluffs B, C, D, E, G and H and sediment ponds. |
| [6] | 2007 End-Of-Year Completion Report Riley Pass Uranium Mines Site | 2008a | AECOM | Phase 1 work completed by ENSR/AECOM for Tronox. Gamma surveys and soil sampling at Bluffs B, C, D, E, G, and H. Completed sediment ponds assessment and interim stabilization work at Bluff B. Arsenic and radium relationship evaluation. |
| [7] | Riley Pass Mines Site: 2008 Supplemental Field Sampling Report | 2008b | AECOM | Demonstrates there is no definitive correlation between arsenic and Ra-226 concentrations in soil [as presented in AECOM (2008a)] based on heterogeneity in spoils, waste, and soils at the site. |

**Table 2 Summary of Documents Reviewed [Documents 8 through 19]**

| No. | Report Title | Year of Issue | Author | Document Summary |
|---|---|---|---|---|
| [8] | Riley Pass Uranium Mines Site XRF and Gamma Surveys Report (Non-Tronox) | 2009 | MSE | X-ray fluorescence (XRF) and Gamma Survey results for Bluffs A, F, I, J, K, and L. |
| [9] | 2010 Non-Tronox Bluffs Action Memorandum | 2010 | USFS | Presents mine waste categorizations and non-time critical removal actions for Bluffs A, F, I, J and K. |
| [10] | Verification Sampling Plan Riley Pass Uranium Mines Site Removal Action Non-Tronox Bluffs (A, F, I1, I2, I3, J1, J2, K1, K2) | 2010b | MSE | Provides methods for verification of successful reclamation at Riley Pass using XRF and gamma survey tools in conjunction with confirmatory soil sampling. |
| [11] | Final Cleanup Verification Survey Report Riley Pass Uranium Mines Site Bluffs J and K | 2010c | MSE | Post-reclamation verification of Bluff J and Bluff K. No elevated arsenic or Ra-226 measured at Bluff K. Small areas of elevated gamma detected at Bluff J were capped. Arsenic below soil cleanup (142 mg/kg) for both bluffs. |
| [12] | Cleanup Verification Survey Report for Riley Pass Uranium Mines Site Bluff I2 | 2012a | Tetra Tech | Removal action was deemed successful at Bluff I2 in reducing the residual concentrations of both Ra-226 and arsenic in the soils to below cleanup standards. |
| [13] | Tronox Bluffs Waste Characterization Sampling and Analysis Plan | 2012b | Tetra Tech | Detailed sampling and analysis plan for waste characterization of Bluffs B, C, D, E, G and H. |
| [14] | Cleanup Verification Survey Report for Riley Pass Abandoned Uranium Mines Site Non-Tronox Bluffs F1, F2, I3 and I1 | 2013a | Tetra Tech | Removal actions were successful in reducing the residual concentrations of Ra-226 and arsenic to acceptable levels in reclaimed areas Bluff F, I1-1, I3-1, Spoils Pile E, but were not successful at Bluff F2. Note: Bluff F2 was successfully reclaimed in 2014. |
| [15] | Tronox Bluffs Waste Characterization Survey Report | 2013b | Tetra Tech | Presentation of comprehensive waste characterization at Bluffs B, CDE, G and H. Provides Ra-226 and arsenic concentration in soil maps and removal boundaries as well as re-categorization of mine waste clean-up goals |
| [16] | Cleanup Verification Survey Report for Riley Pass Abandoned Uranium Mines Site Non-Tronox Bluffs F2, I1-5, I1-6, I1-7, and I1-8; Spoils Piles A, B, and C | 2015a | Tetra Tech | Removal action was deemed successful in reducing the residual concentrations in soil of Ra-226 and arsenic concentrations in surface soils below the cleanup standards at Bluff F2, Bluff I1-7, Bluff I1-8, and Spoils Pile A. Attainment of cleanup standards were not met at Bluff I1-5, Bluff I1-6, Spoils Pile B, and Spoils C. |
| [17] | Cleanup Verification Survey Report for Riley Pass Abandoned Uranium Mines Site Tronox Bluffs G1, G2, G3, G4, and G5 | 2015b | Tetra Tech | Removal action was deemed successful in reducing the residual concentrations in soil of arsenic and Ra-226 concentrations in surface soils below the cleanup standards at Bluffs G1, G2, G3, G4, and G5. |
| [19] | Bluff G and Bluff H Waste Characterization Supplemental Sampling Memo | 2015c | Tetra Tech | Summarizes additional XRF and gamma surveying characterization work at Bluff G and Bluff H. |
| [20] | Bluff F, Bluff G, and Bluff I Sampling Memo | 2015d | Tetra Tech | Data transmittal report for XRF and gamma surveying performed at Bluff F, Bluff G, and Bluff I in July 2015. |

# 3.0 REMOVAL ACTION CLEANUP STANDARDS

On-site soils removal and stabilization has been selected as the primary CERCLA response action for achieving a reduction in mine-related wastes affecting potential human and ecological receptors. In this approach, soils are permanently covered in place or moved to an engineered containment facility. A detailed engineering evaluation and cost analysis (EE/CA) of response action technologies and process options were presented in the Final EE/CA (USFS 2006). All of the reclamation alternatives evaluated in the EE/CA (USFS 2006) are applicable to the contaminated solid media; no reclamation alternatives for groundwater, surface water, or contaminated stream sediments are analyzed in detail. The rationale that alternatives for those media were not directly developed is based primarily on the assumption that reclaiming the contaminant sources (source control) will subsequently reduce any problems associated with groundwater, surface water, or stream sediments at a significantly reduced cost (USFS 2006). This assumption is assumed to hold true for this report.

Removal action objectives provide the foundation used to develop remedial cleanup alternatives (EPA 1995). Removal action cleanup levels and objectives have been established for the site in USFS (2007) and USFS (2010). However, significant data have been collected since the removal action determinations have been made and risk assessment has been performed. Therefore, it is necessary to reevaluate all waste characterization data collected at the site to date and established cleanup goals to make a final decision for removal action cleanup criteria for contaminants of potential concern (COPCs) in soils at the site. Tetra Tech has reviewed all available pertinent historical documents to assess the existing removal action levels and to evaluate alternative options for cleaning up CERCLA sites under applicable federal regulations.

This section presents a review of cleanup standards at CERCLA sites, a summary of existing cleanup standards established for the different study areas at the Riley Pass site, summarizes the results of the Portage (2006) risk assessment evaluation, and presents a final recommendation on cleanup standards to be used at the site in the future.

## 3.1 REVIEW OF CLEANUP STANDARDS AT CERCLA SITES

There are two primary methods for establishing soil removal action cleanup levels for CERCLA sites that are evaluated for this report: (1) background-based standard, and (2) risk-based standard. This subsection evaluates both of these cleanup standards and how they have been applied to the Riley Pass site.

### *3.1.1 Background Based Standard*

A background-based standard is based on the distribution of the pollutant in the background area (EPA 1996). Another standard is the background-plus-risk (BPR) standard, which states that “X units greater than background,” where X is a fixed risk-based standard and ”background” is some function or summary statistic of a data set of background measurements (EPA 1996). Subpart B of Title 40 CFR Part 192 establishes cleanup standards for uranium processing sites to 5 picocuries per gram (pCi/g) above background. This radium cleanup level has been used as a relevant and appropriate requirement to establish cleanup criteria at some Superfund sites. The radon flux standards in 40 CFR 192 limit the radon flux rate to 20 picocuries per square meter per second (pCi/m$^2$-s). Background values for all COPCs identified in the risk assessment (Portage 2006) are presented in the EE/CA (USFS 2006), including radium-226 (Ra-226) and arsenic. A background Ra-226 soil concentration of 2.3 pCi/g (95 percent upper confidence limit [UCL]) was established for Riley Pass in the EE/CA (USFS 2006) using historical data;

however, significant additional site-specific data have been collected since that background level was established. Similarly, a background value of 39 milligrams per kilogram (mg/kg) (95 percent UPL) of arsenic was estimated, also from historical data. The EE/CA (USFS 2006) stated that a reduction in concentrations of arsenic in soil to background (39 mg/kg) would result in a residual cancer risk at $2 \times 10^{-5}$ for the permit holder, above the target cancer risk of $1.0 \times 10^{-6}$. However, reducing the Ra-226 concentration in soil to the $1.0 \times 10^{-6}$ cancer risk results in concentrations in soil above the local background of 2.3 pCi/g for both the permit holder and recreational visitor (USFS 2006; Portage 2006).

After a review of the available site documents, Tetra Tech concluded that the additional information collected in recent years is more representative of the site overall and recommends a more comprehensive background determination analysis using all available data, if a background-based standard approach is to be considered.

### *3.1.2 Risk-Based Standard*

A risk-based standard for a contaminant is a specified fixed concentration value that is assumed to be known with certainty (EPA 1996). This standard is usually established on the basis of human health or ecological risk assessments. A risk-based approach has been used at the Riley Pass site to date (USFS 2007, 2010). As described in Section 3.1.1, 40 CFR 192 sets concentration limits for cleanup of Ra-226 and thorium at inactive uranium processing sites designated for remedial action; however, these standards are applicable only to Uranium Mill Tailings Radiation Control Act (UMTRCA) sites that are exempt from CERCLA. Two previous action memorandums established by the USFS (USFS 2007, 2010) specified removal cleanup criteria for soil using the risk-based approach. The EPA's target risk criterion for lifetime cancer risk is $1 \times 10^{-4}$ to $1 \times 10^{-6}$ carcinogenic range based on the reasonable maximum exposure for an individual (EPA 1997b).

Under EPA guidance, specifically Office of Solid Waste and Emergency Response (OSWER) 9355.7-04 (EPA 1995), a baseline risk assessment generally needs only to consider reasonably anticipated future land use; however, it may be valuable to evaluate risks associated with other land uses. A comprehensive risk assessment was performed by Portage Environmental Inc. (Portage) in 2006, and the results were presented in the *Final Human Health and Ecological Risk Assessment for the Riley Pass Uranium Mines in Harding County, South Dakota Revision 2* (Portage 2006). The Portage risk assessment is cited in Section 2.4 of DOE (2014) and in Section 3 of EPA (2008). The risk assessment was based on scientific and environmental data collected by Pioneer in 2002 and from supplemental characterization work performed by Portage in 2004 (USFS 2006; Portage 2006). The 2004 supplemental investigation focused on Bluff H and Bluff B because the data at that time showed that these bluffs represented the highest level of contamination (Bluff H) and the largest disturbance area (Bluff B).

Given the risk assessments completed, regulatory history, and removal actions that have been performed to date at the site, ***Tetra Tech recommends a risk-based approach for determining the extent of removal, guiding removal actions, and assessing attainment standards.*** The next subsection describes the existing risk-based cleanup standards that have been documented and approved for the Riley Pass site.

## 3.2 Summary of Existing Cleanup Standards

As described in Section 1.2, the USFS published two separate action memorandums (USFS 2007, 2010) summarizing removal action criteria for the non-PRP identified study areas (Non-Tronox Bluffs) and the PRP-identified study areas (Tronox Bluffs). This subsection summarizes the removal action criteria that were identified for each of those categories.

### *3.2.1 Tronox Bluffs Existing Removal Action Criteria*

The 2007 Action Memorandum (USFS 2007) requested and documented the approval of non-time critical removal actions as authorized by Section 104 (42 United States Code [U.S.C.] 9604) of CERCLA to address study areas Bluff B, Bluff CDE (previously referred to as Bluff C, Bluff D, and Bluff E), Bluff G, and Bluff H, as well as sedimentation ponds at the Riley Pass site. The 2007 Action Memorandum (USFS 2007) identified the removal action to be performed, provided specific risk reduction criteria (cleanup criteria), and set forth a statement of determination that these criteria are protective of human health and the environment.

The 2007 Action Memorandum (USFS 2007) specified that Criterion 1 is applicable to Bluffs B, G, and H and the sediment ponds, and Criterion 2 is applicable to Bluffs C, D, and E (now referred to as Bluff CDE). The criteria in the memo defined the reclamation and materials handling requirements for these bluffs, where there is demonstrable disturbance attributable to the past surface mining. At the time the memorandum was published, it was assumed that arsenic and Ra-226 were directly correlated, and that direct gamma measurements would be used to quantify Ra-226 concentrations in soil and subsequently allow for simultaneous verification of arsenic concentrations (USFS 2007). The following three Criterion 1 categories are described in the 2007 Action Memorandum (USFS 2007) as follows:

- **Category 1:** Material with less than or equal to 30 pCi/g Ra-226 activity in soil. 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 2:** Materials with Ra-226 activity in soil greater than 30 pCi/g, but less than or equal to 50 pCi/g. Mitigation efforts will be implemented to bring the average Ra-226 activity in soil down to less than or equal to 30 pCi/g by any practical combination in areas where these bluffs meet this criterion.

- **Category 3:** Materials with greater than 50 pCi/g of soil Ra-226 activity. Materials in this category will be excavated and placed in a designated disposal repository.

The 2007 Action Memorandum (USFS 2007) specified that Criterion 2 is applicable to Tronox Bluffs C, D, and E (now referred to as Bluff CDE) and is 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 as a result of 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.

The 2007 Action Memorandum (USFS 2007) was published using data available to the USFS at that time and relied heavily on the data presented in both the EE/CA (USFS 2006) and the risk assessment (Portage 2006). A more comprehensive and detailed site characterization was performed by Tetra Tech in 2012 (Tetra Tech 2013b) at study areas Bluff B, Bluff CDE, Bluff G, and Bluff H. The 2012 study involved characterization of significantly more data for metals and radionuclide concentrations in soil at the site than were previously collected at these study areas. Tetra Tech (2013b) recommended a reclassification of study areas to include concentrations of molybdenum and uranium isotopes in soil in addition to the previously established arsenic and Ra-226 cleanup criteria. Additionally, it was concluded in AECOM (2008b), MSE (2009), and Tetra Tech (2013b) that arsenic and Ra-226 were not directly correlated; based on this conclusion, the metals concentrations should be verified independently (by X-ray fluorescence [XRF]) to assess cleanup attainment standards. The Tetra Tech-recommended cleanup criteria for removal action are summarized in Table 3 below. Finally, Tetra Tech (2013b) recommended that the revised Criterion 1 standards be applied to Bluffs CDE in addition to Bluff B, Bluff G, and Bluff H because new information showed higher levels of contamination at Bluffs CDE than had previously been believed.

**Table 3 Summary of Cleanup Criteria Recommended in Tetra Tech (2013b)**

| Category | Ra-226 | Total Arsenic | Total Molybdenum* | U-238** | U-235 | U-234 | 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 Uranium-238 (U-238), Uranium-235 (U-235), and Uranium-234 (U-234) are based on Table 5-4 from Appendix D of the EE/CA (USFS 2006).*
****pCi/g = picocuries per gram*
*+mg/kg = milligrams per kilograms*

### *3.2.2 Non-Tronox Bluffs Removal Action Criteria*

The 2010 Action Memorandum (USFS 2010) requested and documented the approval of non-time critical removal actions as authorized by Section 104 (42 U.S.C. 9604) of CERCLA to address the study areas Bluff A, Bluff F, Bluff I, Bluff J, and Bluff K. The 2010 Action Memorandum (USFS 2010) substantiated the need for and type removal action to be performed, provided specific risk reduction criteria (cleanup criteria), and provided a statement of determination that these criteria are protective of human health and the environment.

The 2010 Action Memorandum (USFS 2010) specified that Criterion 1 is applicable to Bluff A, Bluff F, Bluff I, Bluff J, and Bluff K. The criteria in the memorandum defined the reclamation and materials handling requirements for these bluffs, where there is demonstrable disturbance attributable to the past surface mining. Contrary to the 2007 Action Memorandum (USFS 2007), the 2010 Action Memorandum (USFS 2010) acknowledges that the arsenic and Ra-226 concentrations are not always correlated and, therefore, these two constituents should be measured independently for characterization and verification that cleanup has been attained. However, in Section III.B.V.a.1 it also stated "measurements to confirm attainment of these criteria will be based on surface gamma radiation readings correlated to Ra-226 activity and arsenic concentrations and will be based on block averaging or another agreed to method." The following two Criterion 1 categories are described in the 2010 action memorandum (USFS 2010) as follows:

- **Category 2:** Materials with Ra-226 activity in soil greater than or equal to 30 pCi/g, but less than 50 pCi/g. Mitigation efforts will be implemented to bring the average soil Ra-226 activity down to less than to 30 pCi/g by any practical combination in areas where these bluffs meet this criteria.

- **Category 3:** Materials with greater than to 50 pCi/g of soil Ra-226 activity. Materials in this category will be excavated and placed in a designated disposal repository.

Criterion 2 as defined in the 2010 Action Memorandum (USFS 2010) is as follows:

- No reclamation will be required, if there are no elevated levels of Ra-226 in areas at these bluffs where minimal overburden was historically present and vegetation has stabilized the soils so that no significant erosion is occurring.

## 3.3 Risk Assessment Evaluation

Tetra Tech performed a comprehensive review of pertinent documents related to the Riley Pass site, as described in Section 2.0. Part of the comprehensive review process involved a review of the Portage (2006) risk assessment. The review included an evaluation of risk-based soil cleanup criteria developed at the site and was used to identify any new COPCs. Additionally, the proposed risk-based cleanup levels were evaluated to assess whether they are still applicable and appropriate to the site. A report detailing the risk assessment evaluation and risk-based soil cleanup criteria for the site is provided in Appendix A. This subsection summarizes the evaluation conducted by Tetra Tech in identifying any new COPCs and deciding which COPCs should be used to dominate cleanup decisions at the site.

### 3.3.1 Identification of New COPCs

A baseline human health and ecological risk assessment, titled *Final Human Health and Ecological Risk Assessment for the Riley Pass Uranium Mines in Harding County, South Dakota,* was published by Portage in May 2006 (Portage 2006). The baseline human health risk assessment was conducted in general accordance with the NCP and other EPA guidance (USFS 2006). Portage (2006) assessed human exposures for several different receptors for Bluffs B and H and lignite exposures to the COPCs identified in soils, which included the following:

- Arsenic
- Molybdenum
- Selenium
- Uranium (U) as U-238, U-234, and U-235
- Radium-226 (Ra-226)
- Thorium-230 (Th-230)

A screening level evaluation of potential ecological risks using concentrations in soil was presented in Table 2-4 of Portage (2006); based on this evaluation, copper and lead were removed from further consideration as potential COPCs. Furthermore, copper and lead are far below industrial preliminary remediation goals (PRGs) and slightly below ecological PRGs (60.0 mg/kg for copper, 40.5 mg/kg for lead); therefore, it was concluded that these parameters are not expected to dominate cleanup decisions at the site. During the 2012 characterization work presented in Tetra Tech (2013b), Tetra Tech collected 69 soil samples that represented a range of arsenic concentrations at the site. These samples were analyzed for copper and lead; copper ranged between 4.8 mg/kg and 110 mg/kg, with an average of 19.7 mg/kg, and lead ranged between 6.9 mg/kg and 89 mg/kg, with an average of 21.7 mg/kg.

***Tetra Tech concludes that no additional COPCs should be added to the list above that will dominate cleanup decisions at the site.***

### 3.3.2 Identification of COPCs Dominating Cleanup Decisions

All reclamation efforts and verification surveys conducted at the Riley Pass site to date (MSE 2010c; Tetra Tech 2012a, 2013a, 2015a, 2015b) have focused on soils removal based solely on arsenic and Ra-226 concentrations in soil. Similarly, all characterization and design work up until the 2012 site characterization by Tetra Tech had focused solely on arsenic and Ra-226 concentrations in soil. However, based on the assessment of risk and concerns at other bluffs, arsenic, molybdenum, Ra-226, and uranium (-234, -235, and -238) became the focus after the 2012 characterization by Tetra Tech to ensure removal action efforts achieved a reduction of the majority of risk for these additional COPCs. Per discussion with the on-scene coordinator (OSC) at the time and newly available technology, Tetra Tech incorporated the other COPCs (U-238, U-234, U-235, and molybdenum) into the waste categorization of the Tronox Bluff study areas presented in Tetra Tech (2013b). Selenium and Th-230 were not mapped or included in the mine waste categorization data presented in Tetra Tech (2013b). Selenium was excluded from the analysis because all 69 samples collected and analyzed in 2012 were well below (less than 2,000 mg/kg) the site-specific risk-based levels identified in Portage (2006). Thorium is a decay product of the U-238 series, and secular equilibrium of the uranium decay series was assumed to hold true (USFS 2006; Portage 2006; Tetra Tech 2013b); therefore, the removal or U-238 and Ra-226 would also remove Th-230.

The risk assessment indicated that the COPCs to be carried forward included arsenic, molybdenum, uranium isotopes, and Ra-226 (Portage 2006). The following cleanup goals for waste categorization were subsequently proposed in Tetra Tech (2013):

- Arsenic: 142 mg/kg
- Molybdenum: 2,775 mg/kg
- U-238: 42.8 pCi/g
- U-234: 44.6 pCi/g
- U-235: 2.03 pCi/g
- Ra-226: 30.0 pCi/g

Ra-226 soil concentrations can be directly estimated using site-specific gamma/Ra-226 correlations that have been developed for the site. Similarly, arsenic, uranium (U-234, U-235, U-238), and molybdenum can be measured using site-specific XRF correlations developed for the site. However, significant additional labor and costs are associated with characterization and verification when cleanup decisions are based on more than one contaminant using the XRF. Therefore, Tetra Tech performed a comprehensive analysis to determine if uranium (U-234, U-235, and U-238) and molybdenum concentrations in soil exceeding the cleanup standards would be contained in the arsenic and Ra-226 final removal boundaries. The analysis included Bluff B, Bluff CDE, and Bluff H. These study areas were used in the analysis because of the significant amount of uranium and molybdenum characterization data available at those study areas. The analysis of uranium and molybdenum cleanup attainment based on the boundaries of the arsenic/Ra-226 cleanup in soil is provided in Appendix B. The results of the analysis show that using arsenic and Ra-226 as the contaminants used as the basis for cleanup decisions at the site will result in removal of nearly all soils contaminated with uranium and molybdenum above the cleanup levels shown above. ***Tetra Tech concludes that using solely arsenic and Ra-226 soil cleanup concentrations as the driving force during all future characterization and cleanup verification efforts will satisfy the project objectives.***

## 3.4 Final Recommendation on Cleanup Standards

A critical objective of this report involved development of risk-based or background-based cleanup criteria for soil that will be used for all future characterization data collection, reclamation design, and verification sampling strategies. As concluded in Section 3.1, Tetra Tech recommends a risk-based approach for determining the extent of removal, guiding removal actions, and assessing attainment standards. No additional COPCs were identified in the evaluation of site documents and the risk assessment, as discussed in Section 3.3.1. Furthermore, in Section 3.3.2 it was concluded that using concentrations of arsenic and Ra-226 in soil as the driving force during all future characterization and cleanup verification efforts will satisfy the project objectives.

Tetra Tech recommends that a site-wide cleanup standard solely based on arsenic and Ra-226 concentrations in soil be applied for all future characterization and verification of cleanup attainment at the Riley Pass site. Based on the risk assessment evaluation, the proposed cleanup values presented in Section 3.3.2 and Appendix A appear to be protective of human health and should result in site-associated risks below $1 \times 10^{-4}$ and usually below $1 \times 10^{-5}$ in total, summed across COPCs and all exposure pathways, and including ingestion of deer meat or beef at the 10 percent fraction ingested assumption, at the exposure assumptions used for the calculations. Therefore, a waste management strategy focused on reduction of those contaminants at the Riley Pass site to be within the target range ($1 \times 10^{-4}$ to $1 \times 10^{-6}$

cancer risk) deemed acceptable by EPA based on site-specific assumptions presented in the risk assessment.

***Tetra Tech recommends that the site cleanup standards be based on arsenic and Ra-226 concentrations in soil. A cleanup standard of 142 mg/kg for arsenic and 30 pCi/g for Ra-226 is recommended.***

# 4.0 TECHNOLOGY REVIEW

Much progress has been made in recent years in development and application of innovative technologies in assessing and characterizing anthropogenic environmental damage. Characterization and monitoring technologies typically help to characterize and monitor site conditions, delineate the nature of waste, and track progress toward achieving cleanup goals (EPA 2015). Frequently, two or more techniques may be available for measuring the amount of contaminant in an environmental sample (Gilbert 1987), referred to as "double sampling." Two forms of double sampling techniques previously used at the Riley Pass site included XRF and gamma surveying. EPA identifies both of these innovative tools as acceptable field analytical and site characterization technology EPA (1997a). This section summarizes a technology review of these survey methods and their applicability for use on future characterization and cleanup activities at the site.

## 4.1 X-RAY FLUORESCENCE

XRF field surveys are widely used in the field of environmental and mining engineering as a non-destructive, cost–effective, and rapid tool for screening soils or characterizing hazardous waste sites or sites contaminated with mine waste. XRF technology has been used at Riley Pass during both characterization studies (MSE 2009; Tetra Tech 2013b). Millennium Science and Engineering (MSE) performed an XRF correlation study presented in MSE (2009). Similarly, Tetra Tech performed an XRF correlation study presented in Tetra Tech (2013b) using newer instrument technology. The two correlations were compared and the results are presented in Appendix C. It was determined that similar arsenic cutoff levels are achieved using either correlation; however, Tetra Tech recommends using the correlation presented in Tetra Tech (2013b) and presented in Figure 3 and Equation 1, below, because this correlation provides a more conservative estimate of arsenic in soils.

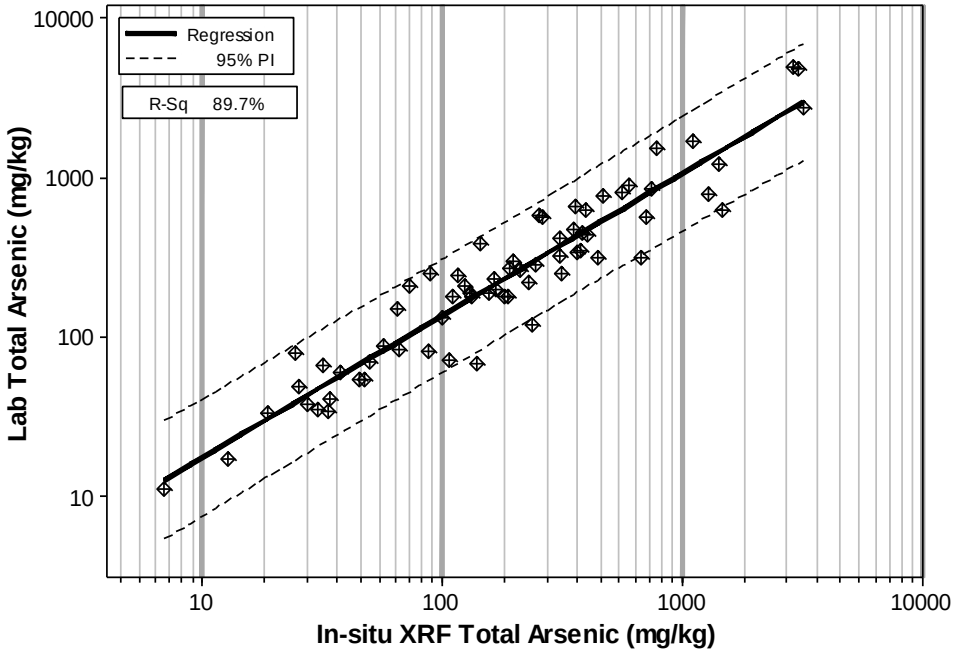



**Figure 3 In-situ XRF Total Arsenic Concentration Versus Laboratory-Reported Total Arsenic Concentration**

A strong correlation ($R^2$= 0.897 ; r = 0.947) exists between the in situ XRF arsenic measurements and the laboratory-reported total arsenic concentrations. The following equation can be used to convert the in situ XRF measurements to laboratory equivalent arsenic concentrations at the site:

Equation 1 $$Lab\ Arsenic\ = 10^{0.352+0.891log_{10}(\text{XRF Arsenic})}$$

Where:

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

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

***Tetra Tech recommends using Equation 1 to convert the in situ XRF measurements to laboratory equivalent arsenic concentrations at the site for future characterization and attainment of cleanup verification work at Riley Pass site.*** Using Equation 1, an in situ XRF concentration of 105 mg/kg corresponds to a laboratory-reported total arsenic concentration in soil of 142 mg/kg.

## 4.2 Gamma Radiation Surveying

Use of global positioning system (GPS)-based gamma radiation survey systems has become a mature methodology for characterizing the spatial distribution of gamma radiation caused by naturally occurring radioactive materials (NORM) in soils (Whicker et al. 2008; Whicker et al. 2015; Johnson et al. 2006; Meyer et al. 2005; Vitkus et al. 2007). NORM includes primarily natural uranium, thorium-232 (Th-232), and potassium-40 (K-40) and their decay products. Using gamma radiation to estimate radionuclides is a common approach at sites contaminated with windblown uranium tailings (such as former uranium mills) and at abandoned uranium mines. The success of this approach depends on whether radionuclides of interest have gamma emissions, potential contamination is located on the ground surface and, most importantly, acquiring regulatory approval of the technique (Albequist 2000). All soils and rock exhibit differing levels of radioactivity, depending on varying levels of naturally occurring potassium, uranium, thorium, and radium. On open ground, about two-thirds of the measured gamma radiation dose comes from radionuclides contained in the top 15 centimeters (cm) of soil (NRC 1994). The objective of the continuous gamma radiation survey is to characterize the spatial distribution of gamma radiation emanating from surface soils at the site. Using soil correlation methods, the gamma data can then be used to predict the radionuclide concentrations in surface soils. Gamma surveys have been performed by Tetra Tech at Riley Pass during both characterization studies (MSE 2009; Tetra Tech 2013b).

Tetra Tech developed a site-specific and site-wide gamma/Ra-226 correlation using 2009 and 2012 soil correlation data as presented in Tetra Tech (2013b). Tetra Tech recommends using the correlation presented in Tetra Tech (2013b) and presented in Figure 4 and Equation 2, below.

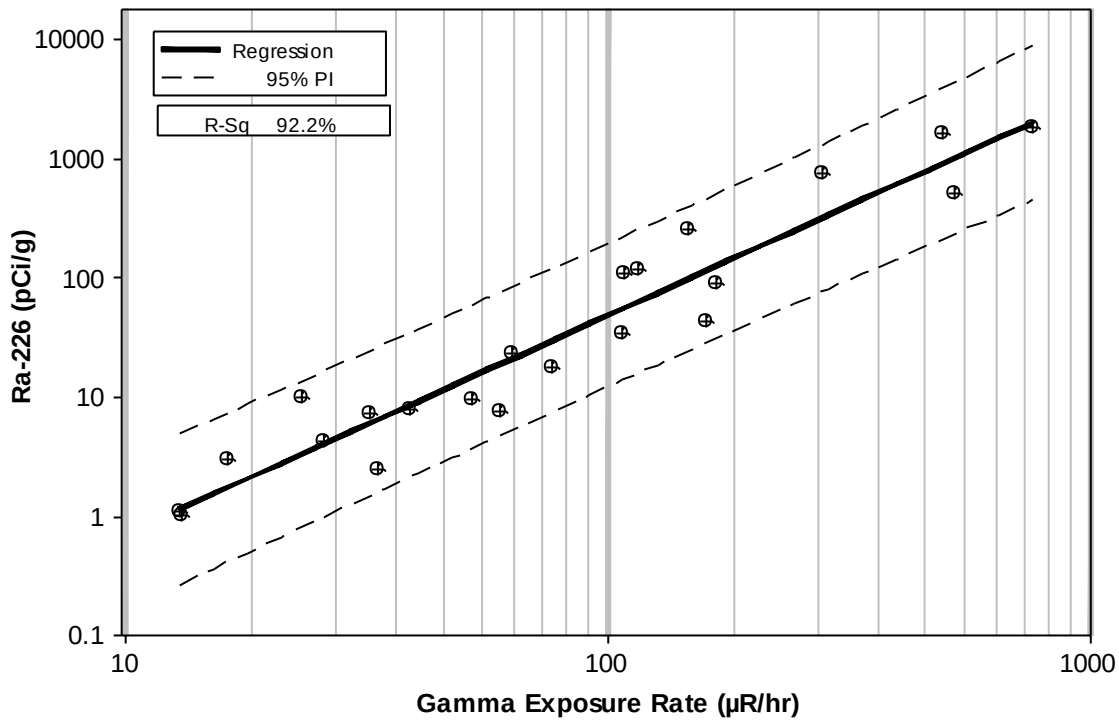



**Figure 4 Gamma Exposure Rate Versus Soil Ra-226 Mass Activity Concentration**

A strong correlation ($R^2$ = 0.922, r = 0.960) was established between gamma exposure rate and the Ra-226 concentration in soil. The following equation can be used to convert the gamma radiation measurements collected at the site to laboratory-equivalent Ra-226 concentrations in soil:

Equation 2 $$\text{Lab Ra} - 226 = 10^{-1.979+1.835\ log_{10}(Gamma)}$$

Where:

Lab Ra-226 = laboratory equivalent soil radium-226 concentration (pCi/g).

Gamma = Gamma exposure rate measurement (µR/hr)

***Tetra Tech recommends using Equation 2 to convert gamma exposure rates to laboratory-equivalent Ra-226 concentrations at the site for all future characterization and attainment of cleanup verification work at Riley Pass site.*** Using Equation 2, a gamma exposure rate of 76.5 microroentgen per hour (µR/hr) corresponds to a laboratory-reported Ra-226 concentration in soil of 30 pCi/g.

# 5.0 RILEY PASS STATUS UPDATE

## 5.1 OVERVIEW

The Riley Pass site consists of 10 primary study areas ranging in size from 3.8 acres (Bluff G) to 153 acres (Bluff B) as shown in Table 4. The level and range of contamination vary between study areas. To date, the soils within all of the study areas have been characterized for arsenic and Ra-226 using the methods outlined in Section 4.0. The effectiveness of characterization varies between the study areas. The Non-Tronox Bluffs (Bluffs A, F, I, J, K, and L) were characterized in 2008 by MSE and Tetra Tech (MSE 2009). The Tronox Bluffs (Bluffs B, CDE, G, and H) were characterized in 2012 by Tetra Tech (Tetra Tech 2013b). Three of the 10 study areas have been partially reclaimed, and two study areas have been fully reclaimed.

**Table 4 Summary of Riley Pass Study Area Size and Reclamation Status**

| Study Area | Surface Area (acres) | Surface Area ($ft^2$) | Original Characterization Date | Reclamation Status |
|---|---|---|---|---|
| Bluff A | 6.2 | 270,072 | 2009 | Not Reclaimed |
| Bluff B | 153.1 | 6,667,729 | 2012 | Not Reclaimed |
| Bluff CDE | 48.0 | 2,092,884 | 2012 | Not Reclaimed |
| Bluff F | 7.5 | 328,346 | 2009 | Partially Reclaimed |
| Bluff G | 7.1 | 309,276 | 2012 | Partially Reclaimed |
| Bluff H | 33.7 | 1,466,553 | 2012 | Not Reclaimed |
| Bluff I | 30.8 | 1,342,509 | 2009 | Partially Reclaimed |
| Bluff J | 8.8 | 381,150 | 2009 | Reclaimed |
| Bluff K | 10.6 | 460,892 | 2009 | Reclaimed |
| Bluff L | 10.0 | 435,600 | 2009 | Not Reclaimed |
| **All Bluffs** | **316** | **13,755,011** | **-** | **-** |

Tetra Tech performed a comprehensive review on all available data from both the MSE (2009) and the Tetra Tech (2013b) characterization studies. A site-wide geodatabase has been generated that includes all of the XRF and gamma surveying characterization and reclamation data for all of the study areas at the site. Figure 2-1 of the EE/CA (USFS 2006) presented a bluff identification data map for the Riley Pass site. This map was generated prior to characterization of these study areas and the boundaries do not necessarily reflect the actual boundaries. Tetra Tech generated revised study area boundaries for each bluff based on the characterization data available after the EE/CA was published. The study area acreages presented in Table 4 reflect these updated boundaries. Appendix D shows the historical and revised study area boundaries. Appendix E provides assorted photos taken at Riley Pass. A data gap analysis was performed at each study area and recommendations are provided based on the findings of this analysis.

This section provides an overview, characterization status, reclamation status, and recommendations for each study area at the Riley Pass site. Status update maps are provided in this section for each study area; the maps show the most recent data sets. In some cases where reclamation has occurred, geographic information systems (GIS) analysis was used to remove older characterization data and replace them with verification data that has been collected more recently.

## 5.2 BLUFF A

### 5.2.1 Overview

The Bluff A study area shown in Figure 1 encompasses 6.2 acres. Using all available data, the Bluff A study area boundary was revised from the historical boundary provided to Tetra Tech which previously encompassed 4.1 acres. Appendix D shows the historical and revised study area boundaries. Bluff A is located approximately 0.25 miles north of Bluff B in Township 22 North, Range 5 East, Sections 22 and 23. The EE/CA (USFS 2006) stated that Bluff A encompasses 3 acres of disturbed area, of which 1 acre is unvegetated spoils. A major characteristic of Bluff A is the peninsula-like rimrock oriented in an east-west direction (MSE 2009). Spoils materials are located on the south side of Bluff A and drain toward a dry draw that adjoins a large spoils pile area associated with Bluff B. The spoils are extremely steep (approximately 1.5 horizontal [H]: 1 vertical [V]) with very little vegetation. The remaining areas of Bluff A are also disturbed and exhibit poor vegetative growth. Significant erosion can be observed from remote sensing information off the southern boundary of Bluff A.

### 5.2.2 Characterization Status

Bluff A was first studied by Pioneer in a 1999 and 2000 field sampling investigation (USFS 2002). Pioneer's 1999/2000 sampling investigation indicated that molybdenum, uranium, and Ra-226 soil concentrations exceeded background concentrations greater than three times (USFS 2006). The EE/CA (USFS 2006) specified that before the response action be designed, the study area should be re-sampled and the results should be reevaluated to confirm soil amendments and nutrients required to establish vegetation. Bluff A was subsequently characterized by XRF field and gamma survey in 2008 by MSE (MSE 2009). A total of 37 surface XRF readings were taken to characterize the distribution of arsenic, along with five surface confirmatory soil samples. Twelve XRF arsenic readings were above 142 mg/kg. A gamma survey of Bluff A indicated Ra-226 concentrations above 30 pCi/g in the northern and southeastern sections of the study area, where a majority of the high arsenic results were obtained. However, high levels of arsenic were also detected in surface and subsurface samples collected from an area where Ra-226 was estimated to be below 30 pCi/g (MSE 2009). Arsenic concentrations ranged from 38 mg/kg to 345 mg/kg. The EE/CA (USFS 2006) stated the estimated spoils volume is 25,250 cubic yards ($yd^3$). Organic matter content on Bluff A was 8.4 percent (USFS 2006). MSE (2009) reported waste volumes based on removal action cleanup standards from the 2010 Action Memorandum. MSE (2009) reported a mine waste volume of 1,961 $yd^3$. These volumes will need to be recalculated based on the new waste categorization criteria presented in this report.

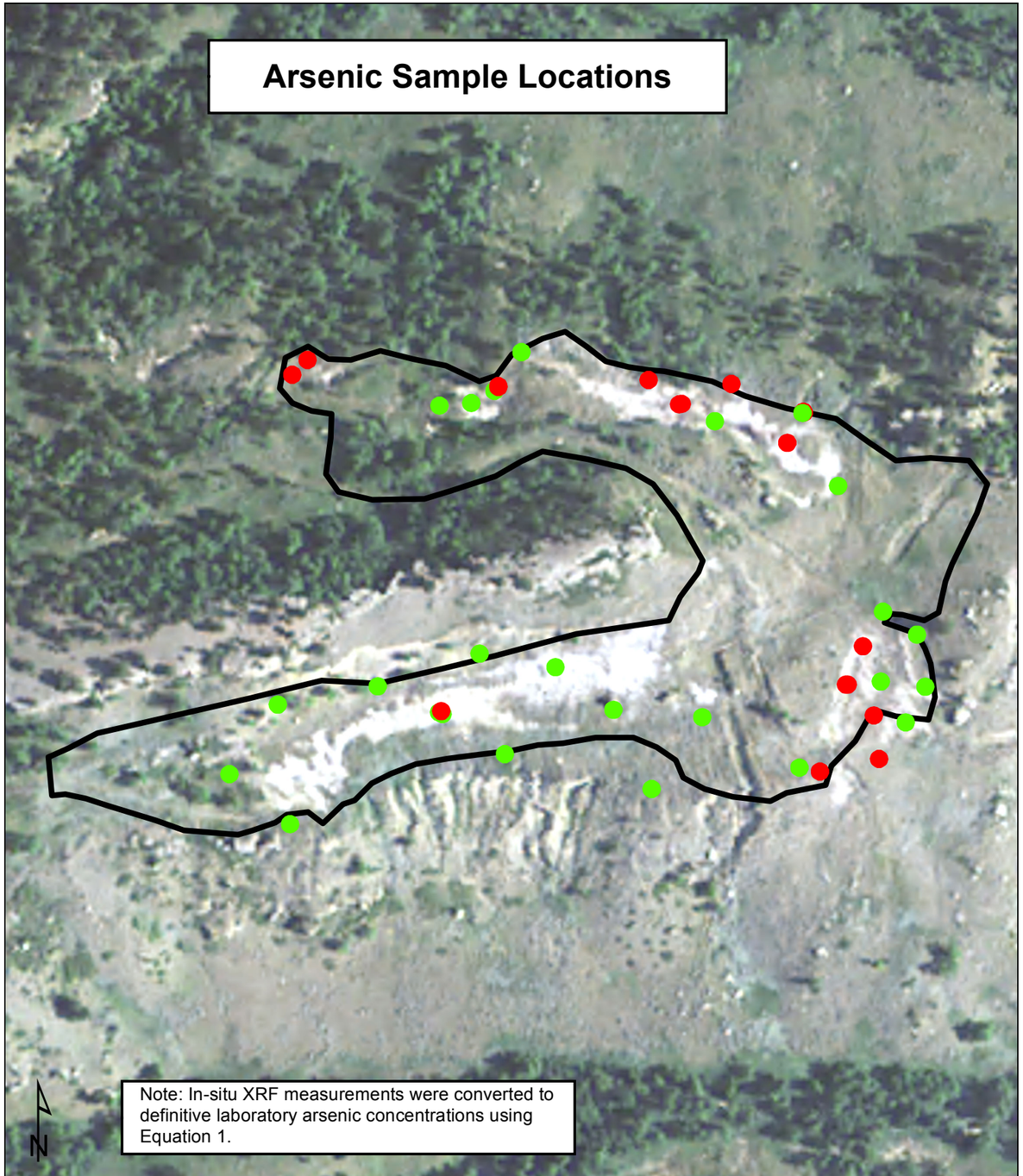
### 5.2.3 Reclamation Status

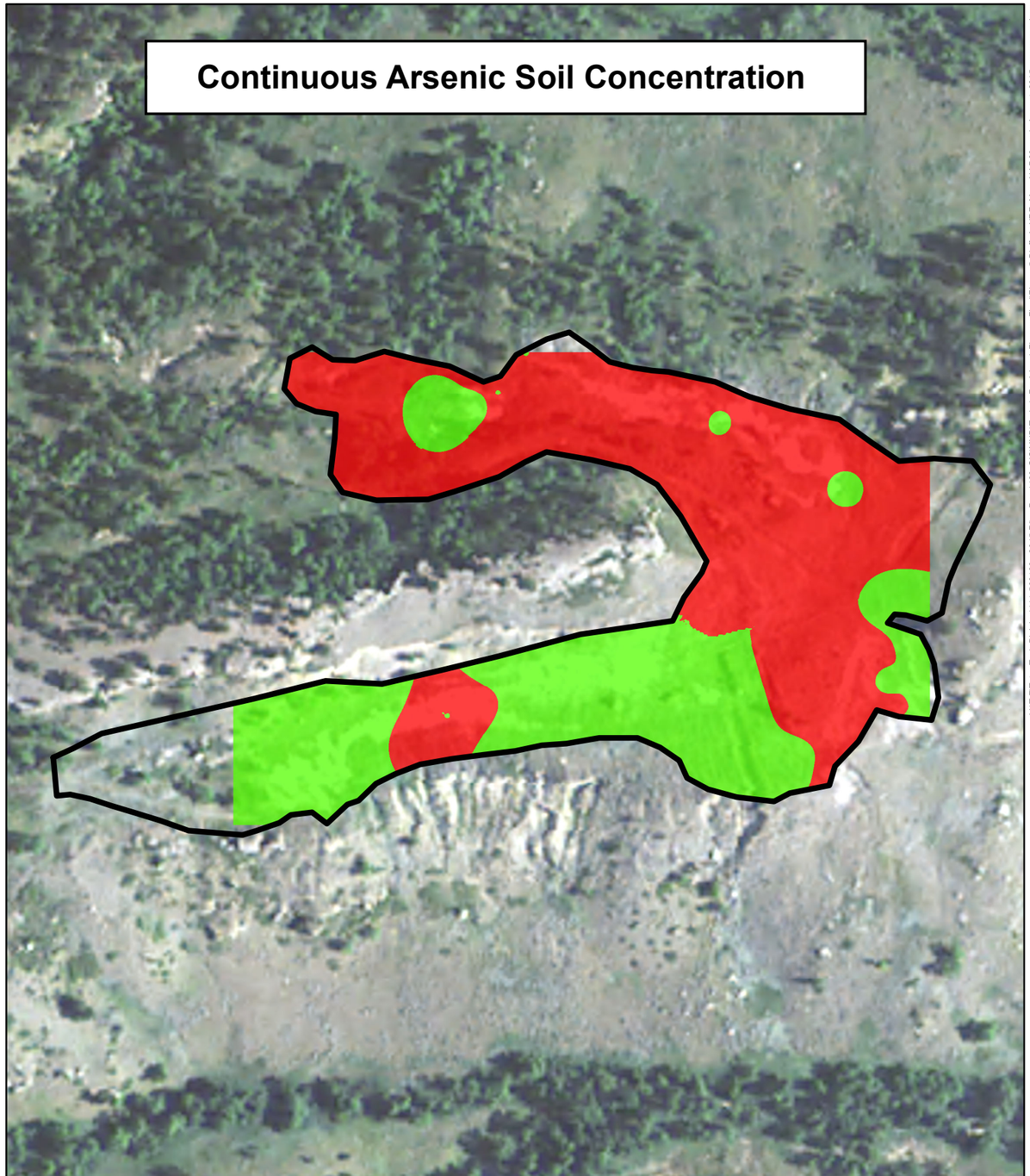
No reclamation has been performed to date at Bluff A.

### 5.2.4 Recommendations

Tetra Tech utilized all available characterization survey data to generate status update maps of Bluff A based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff A is provided in Figure 5. A status update map showing the Ra-226 soil concentrations at Bluff A is provided in Figure 6. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial

interpolation methods. The status update maps reflect the current conditions at the study area using all available data. Dispersed areas of arsenic and Ra-226 soil contamination remain at Bluff A. Tetra Tech recommends removal action at Bluff A to reduce the arsenic and Ra-226 concentrations below the soil cleanup levels. Before a detailed removal action design for Bluff A is completed, Tetra Tech recommends that additional characterization be conducted at Bluff A to further discretize hot spots of contamination needed for removal action design.




SCALE IN FEET

0 100 200

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**

< 142 ≥ 142

Prepared For:

Prepared By:

TETRA TECH
3501 Automation Way, Suite 100
Fort Collins, CO 80525
970-223-9600

Title:

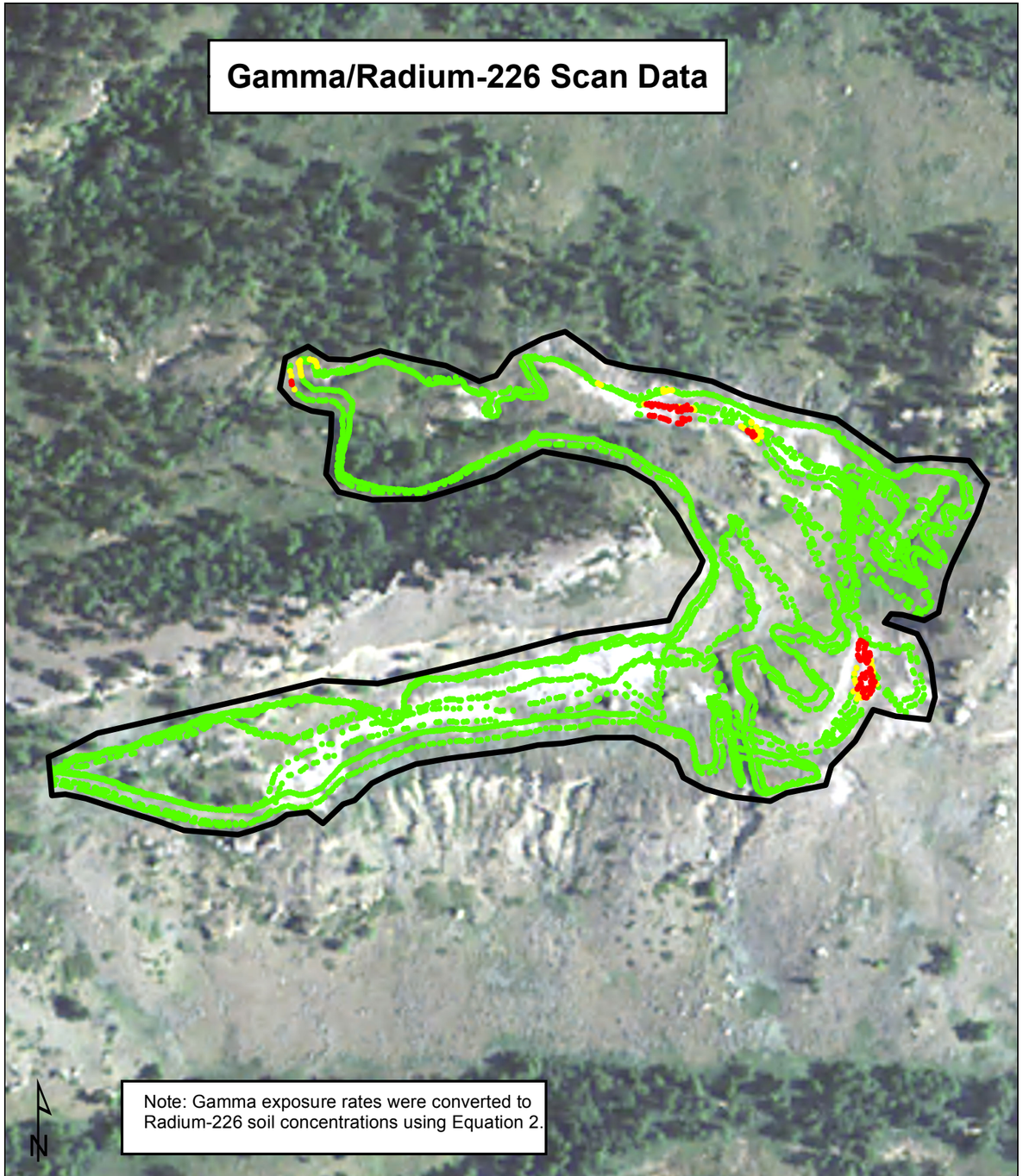
**FIGURE 5 BLUFF A**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

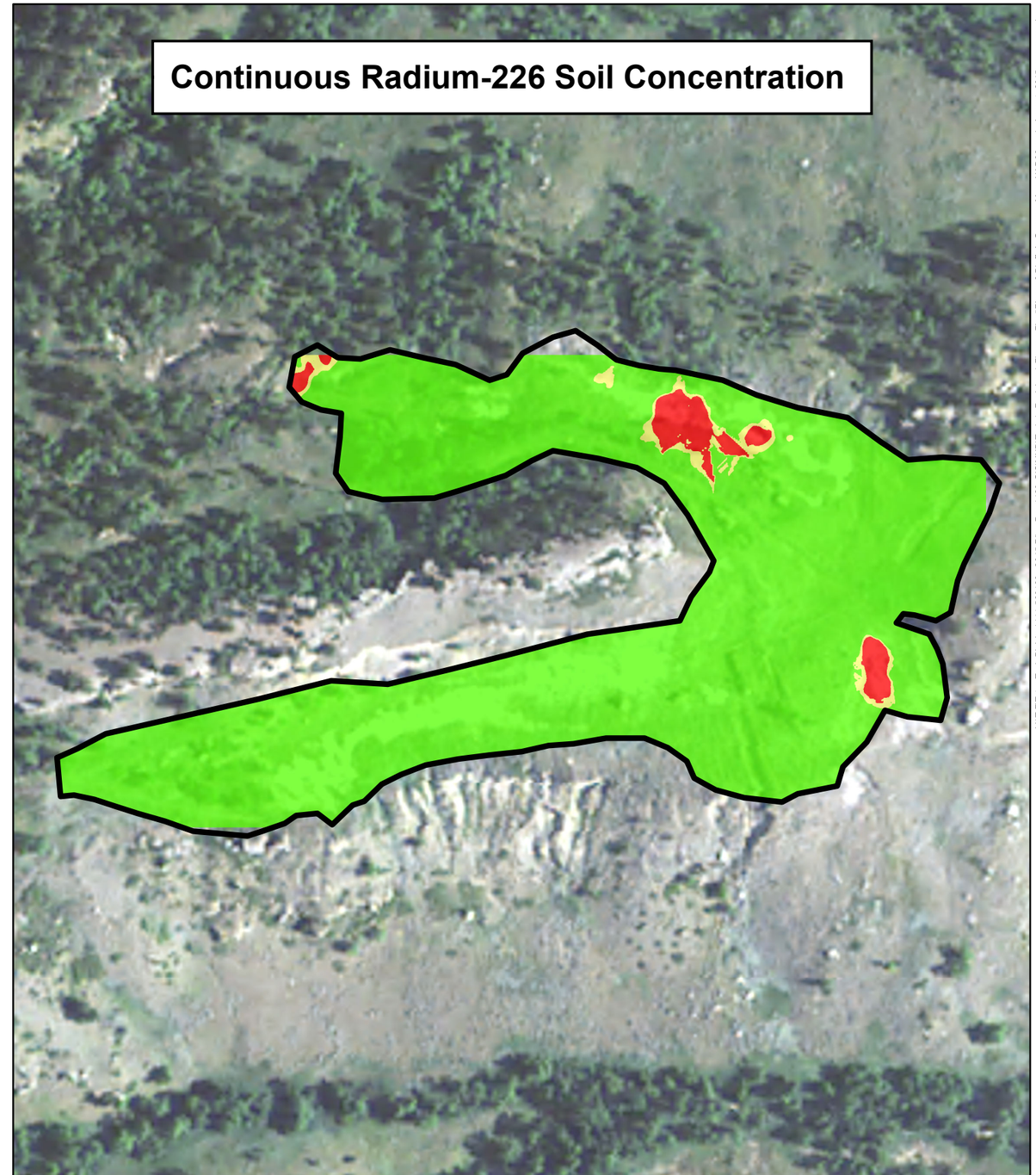
Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 - Revision 1 Figures Final\Figure 5 Bluff_A_XRF_Map_NAD83.mxd August, 2015; aaron.orechwa




SCALE IN FEET

0 100 200

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**

< 30 | 30 - 50 | ≥ 50

Prepared For:

Prepared By:

TETRA TECH
3501 Automation Way, Suite 100
Fort Collins, CO 80525
970-223-9600

Title:

**FIGURE 6 BLUFF A**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 6 Bluff_A_Gamma_Map_NAD83.mxd August, 2015: aaron.orechwa

## 5.3 BLUFF B

### 5.3.1 Overview

The Bluff B study area shown in Figure 1 encompasses approximately 153 acres of spoils piles (overburden), highwalls, and open pits. Using all available data, the Bluff B study area boundary was revised from the historical boundary provided to Tetra Tech which previously encompassed 138 acres. Appendix D shows the historical and revised study area boundaries. Bluff B is located in parts of Township 22 North, Range 5 East, Sections 22,23,26 and 27. A significant historical pioneer wagon route during the 1890s is located within approximately 500 feet of the study area. Bluff B is the largest study area at Riley Pass and the waste materials (spoils and overburden) have been a major source of sedimentation to Pete's Creek to the east of Bluff B and Schleichart Draw to the southeast. A majority of the bluff is either barren or sparsely vegetated and shows signs of severe erosion by wind and surface water. Sediment from the east half of the site is currently being carried approximately 0.75 mile and deposited on the main access road to Riley Pass and the adjoining private property. Sedimentation ponds have been installed and maintained by the USFS in Upper Pete's Creek and Schleichart Draw. However, as a result of the amount of sediment eroding from the site, frequent maintenance of the sedimentation ponds is required. Because of the predominant soil type present — sandy clay and silty clay — soil piping and tunneling with occasional sink holes are present. Piping and large gullies are most prevalent in areas where the overburden was placed along or below the rimrocks. Some of the pipes that have formed are 10 feet to 15 feet in diameter, and gullies up to 25 feet in depth have formed in places. The mined pit floors are generally at or near bedrock. Some spoils have been placed along the edges that erode to the land below Bluff B. Small, shallow ponds have formed in some of the areas, creating small retention basins, which during snowmelt and small storm events assist in controlling some of the surface water erosion. Water from these ponds most likely evaporates or seeps through the bedrock during the summer. Aerial photos of Bluff B are provided in Appendix E.

### 5.3.2 Characterization Status

Bluff B was first studied by Knight Piesold in 1990 and 1991 to evaluate existing conditions, develop plausible response action alternatives, and provide a cost estimate for each alternative (USFS 2006). Knight Piesold's 1990/1991 studies consisted of water quality analysis and collection of radiological measurements. Additional characterization was performed by Pioneer in 1999 and 2000 (USFS 2002). Concentrations greater than three times background of Ra-226 and U-235 were documented from sample RP-SS-B1 during Pioneer's 1999/2000 sampling investigation. Low organic matter content was observed during that investigation (1.2 percent). Information from the Pioneer study was used to identify COPCs by comparing with background concentrations to be used in the risk assessment (Portage 2006). A supplemental sampling investigation was performed by Portage in 2004. Information from the 2004 investigation was used in development of the risk assessment and EE/CA (USFS 2006; Portage 2006). The EE/CA recommended that Bluff B should be re-sampled before a detailed response action design be completed. Bluff B was characterized in 2007 as part of the Phase 1 work executed by AECOM on behalf of Tronox, the results are summarized in AECOM (2008a). The estimated total arsenic concentrations were derived from robust correlations between total and plant available arsenic concentrations, none of these estimated total arsenic concentrations in soil exceeded 142 mg/kg AECOM (2008a). Multiple areas exceeding Ra-226 soil cleanup levels were identified based on results of a gamma radiation survey AECOM (2008a). No XRF field surveys were performed during the 2007 investigation by AECOM.

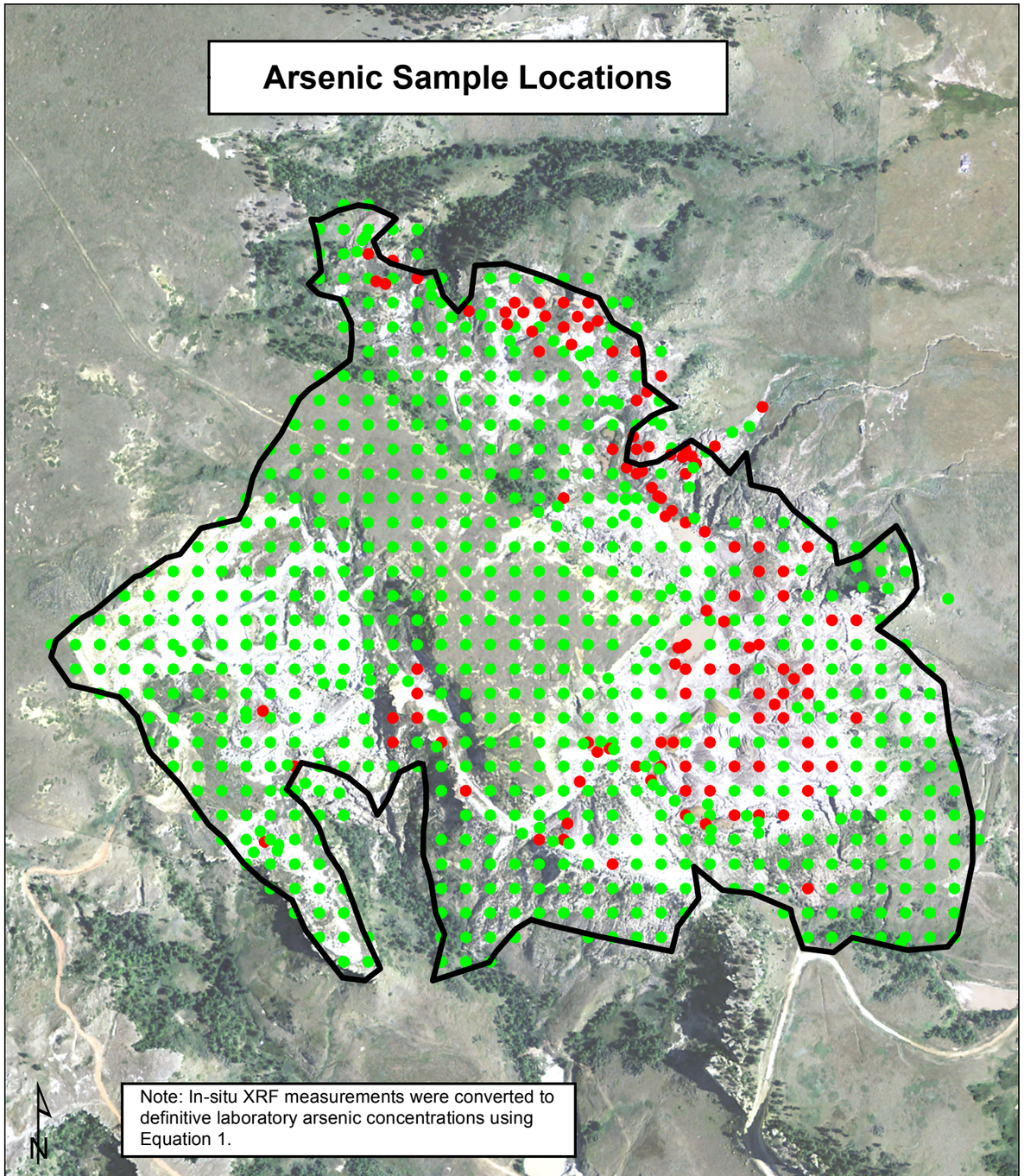
The Action Memorandum (USFS 2007) presented removal action cleanup standards for Bluff B and all other Tronox bluffs in 2007. Numerous investigations had been performed at the study area; however, no study has characterized the spatial extent of contamination in extreme detail until 2012. In 2012, a comprehensive characterization (Tetra Tech 2013b) was conducted on behalf of the USFS. A total of 804 XRF measurements and 34 soil confirmation samples along with 67,000 gamma exposure rate measurements were collected at Bluff B. The Ra-226 activity ranged from 0.56 pCi/g to 1,846 pCi/g with an average of 11.8 pCi/g. Arsenic concentrations ranged from 3 mg/kg to 2,838 mg/kg. Approximately 14 percent (22 acres) of Bluff B was identified as exceeding one of the COPCs and requiring removal action in Tetra Tech (2013b). The estimated spoils volume at Bluff B is 1,140,000 $yd^3$ (USFS 2006). Tetra Tech (2013b) provided an estimate of 1,908,512 $yd^3$ total waste material volume at Bluff B. These volumes will need to be recalculated based on the new waste categorization criteria presented in this report.

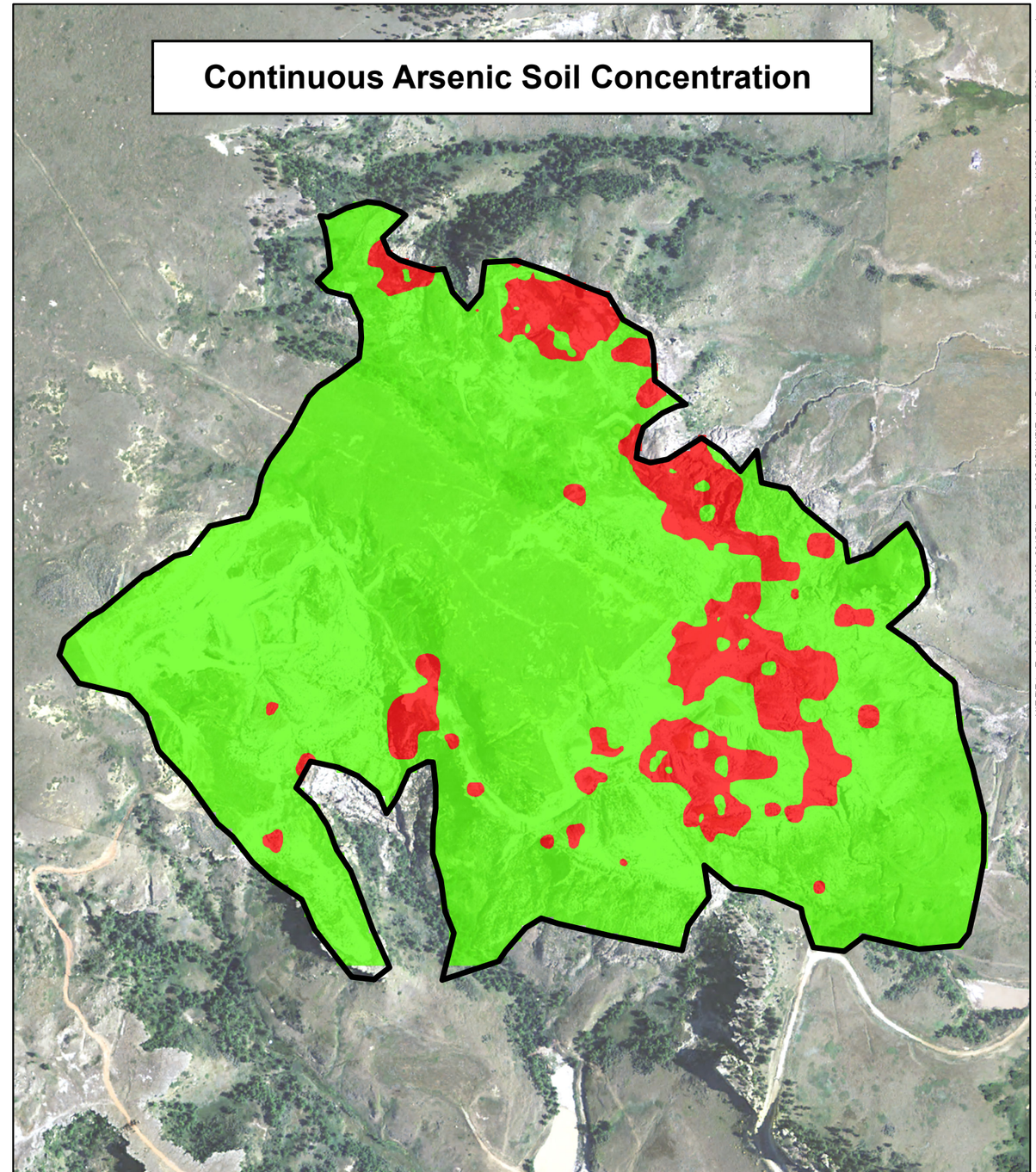
### *5.3.3 Reclamation Status*

Numerous erosion prevention actions have been conducted at Bluff B by the USFS and Tronox; however, no specific removal action has been conducted to date.

### *5.3.4 Recommendations*

Tetra Tech utilized all available characterization survey data to generate status update maps of Bluff B based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff B is provided in Figure 7. A status update map showing the Ra-226 soil concentrations at Bluff B is provided in Figure 8. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial interpolation methods. The status update maps reflect the current conditions at the study area using all available information. Dispersed areas of arsenic and Ra-226 soil contamination remain at Bluff B. A hydrologic analysis was performed on Bluff B to identify critical areas where drainages affect the contaminated zones (Appendix F). Bluff B has the highest density of potential stream networks of all the study areas evaluated. The hydrologic analysis identified numerous drainages that are directly affecting existing waste boundaries and have transported sediment off site. Additional XRF and gamma surveying within the affected drainages is recommended. Tetra Tech recommends removal action at Bluff B to reduce the arsenic and Ra-226 concentrations below the soil cleanup levels. Before a detailed removal action design for Bluff B is completed, Tetra Tech recommends that additional characterization be conducted to further discretize hot spots of contamination needed for removal action design particularly areas on the northeast and eastern boundary of the study area.

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SCALE IN FEET

0 500 1,000

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**

< 142 ≥ 142

Prepared For:

Prepared By:

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970-223-9600

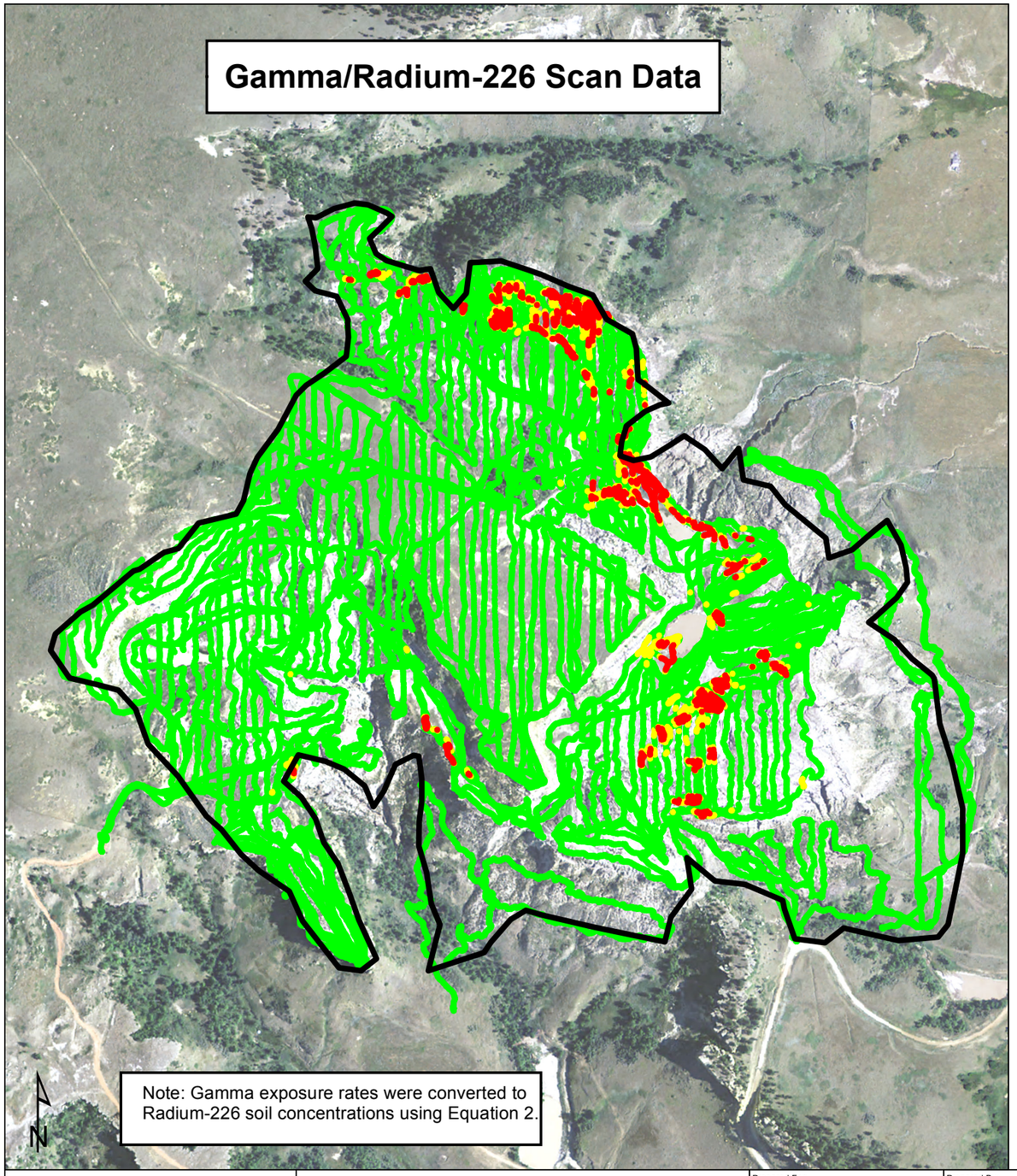
Title:

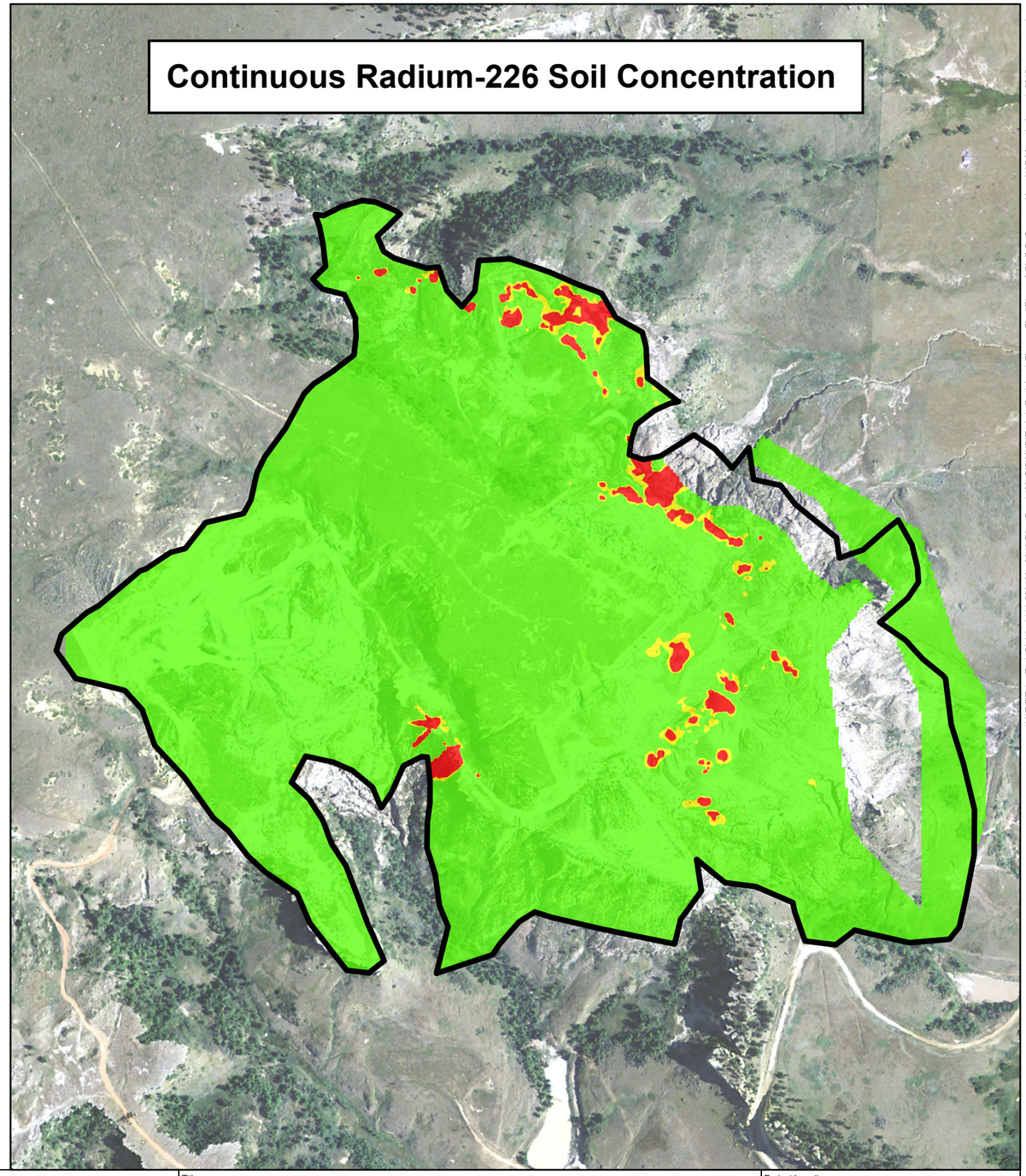
**FIGURE 7 BLUFF B**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015




SCALE IN FEET

0 500 1,000

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**

< 30 | 30 - 50 | ≥ 50

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Prepared By:

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Title:

**FIGURE 8 BLUFF B**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

V:\IT-2\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 8 Bluff_B_Gamma_Map_NAD83.mxd August, 2015: aaron.orechwa

## 5.4 BLUFF CDE

### 5.4.1 Overview

The Bluff CDE study area shown in Figure 1 encompasses 48.1 acres. Using all available data, the Bluff CDE study area boundary was revised from the historical boundaries provided to Tetra Tech. Bluff CDE was originally delineated by the USFS as three separate study areas (Bluff C, Bluff D, and Bluff E). The original boundary extents of Bluff C, Bluff D, and Bluff E were 11.3 acres, 5.02 acres, and 0.935 acre, as presented in Tetra Tech (2013b). The EE/CA (USFS 2006) speculated that minimal response action work was deemed necessary at these original areas given the existing stable vegetation. However, during the 2012 investigation (Tetra Tech 2013b), it was discovered that these study areas are all interconnected and a change order was approved to fully delineate the extent of contamination outside of the previously delineated boundaries of the study area. Based on the results of that investigation, Tetra Tech revised these three individual study areas into one larger area referred to as "Bluff CDE." Appendix D shows the historical and revised study area boundaries. Bluff CDE is located approximately 0.8 miles southeast of Bluff B in Township 22 North, Range 5 East, Section 26.

### 5.4.2 Characterization Status

The EE/CA (USFS 2006) specified that mining-related disturbance was relatively small at Bluff C, Bluff D, and Bluff E. However, a detailed waste characterization investigation had not been performed at these areas when that statement was made. Additionally, the risk assessment (Portage 2006) stated that Bluff H generally represented the highest levels of contamination from all of the study areas. These statements were made based on limited data. Prior to 2012, Bluff C, Bluff D, and Bluff E were characterized during the Pioneer 1999 and 2000 field sampling investigation (USFS 2002).

Tetra Tech performed a comprehensive investigation at Bluff CDE in 2012 and concluded that the waste was more prominent than been previously expected (Tetra Tech 2013b). A total of 293 XRF measurements and 19 soil confirmation samples along with 22,000 gamma exposure rate measurements were collected at Bluff CDE. The Ra-226 activity ranged from 1.5 pCi/g to 3,699 pCi/g with an average of 86.8 pCi/g. Arsenic concentrations ranged from 5.2 mg/kg to 2,953 mg/kg with an average of 230 mg/kg. Bluff CDE also had the largest removal area of Category II mine waste (0.99 acre) and Category III mine waste (27.8 acres) as stated in Tetra Tech (2013b) of all study areas.

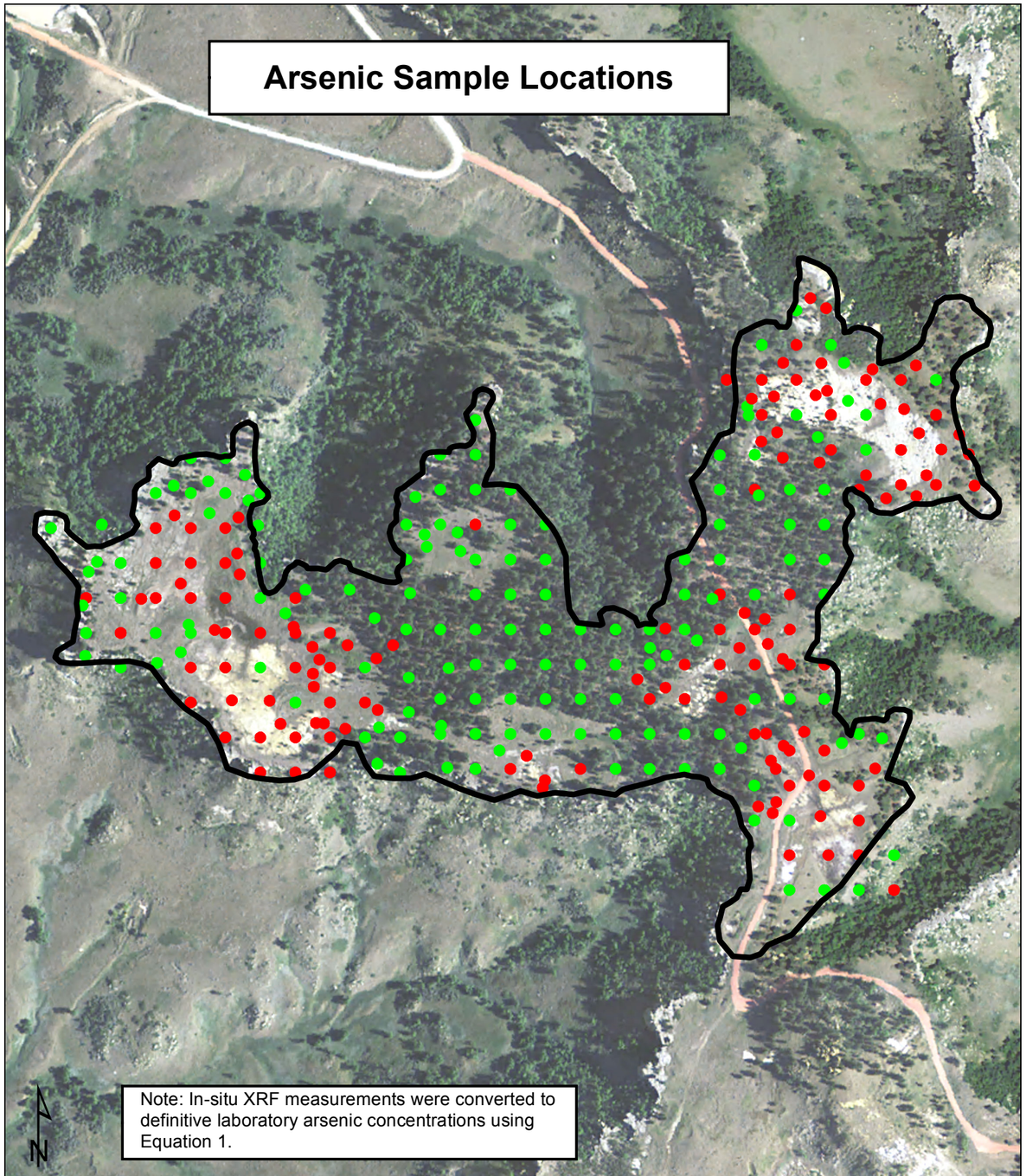
### 5.4.3 Reclamation Status

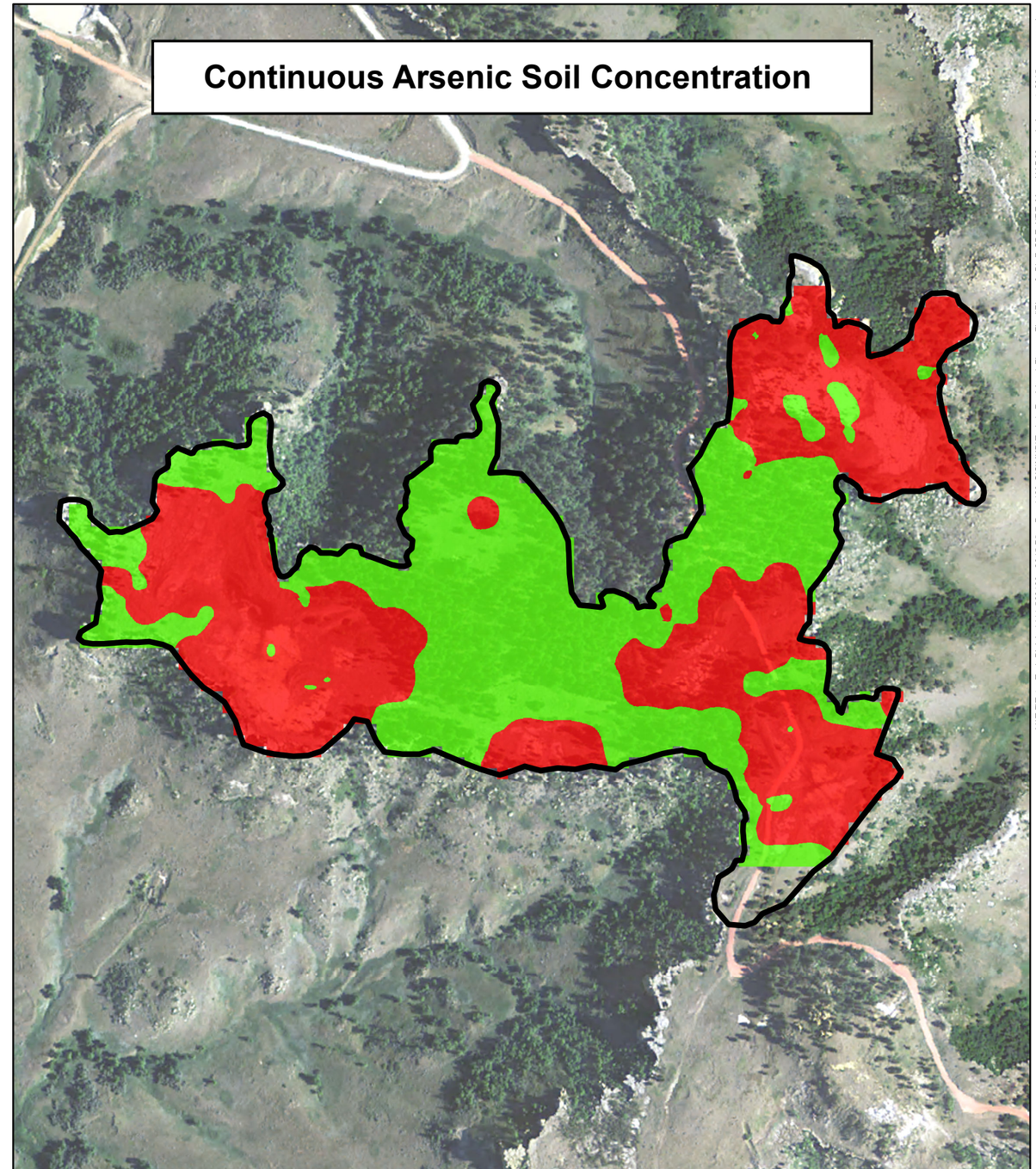
No reclamation has been performed to date at Bluff CDE.

### 5.4.4 Recommendations

Reclamation was not recommended in the EE/CA (USFS 2006) based on the data available and the stable vegetation observed at Bluff CDE. The results of the Tetra Tech (2013b) study at Bluff CDE discovered arsenic and Ra-226 soil concentrations were the highest observed at the site. Tetra Tech utilized all available characterization and verification survey data to generate status update maps of Bluff CDE based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff CDE is provided in Figure 9. A status update map showing the Ra-226 soil concentrations at Bluff CDE is provided in Figure 10. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial interpolation

methods. The status update maps reflect the current conditions at the study area using all available information. Dispersed areas of arsenic and Ra-226 soil contamination remain at Bluff CDE. While erosion is not a concern for most of the bluff area, the high concentrations in soil of radionuclides and heavy metals necessitate a removal action to reduce the exposure to these contaminants below the risk-based cleanup criteria. Tetra Tech recommends removal action at Bluff CDE to reduce the arsenic and Ra-226 concentrations below the soil cleanup levels. The transport of materials over the bluff edge from the bluff top is not known, Tetra Tech recommends further investigation to determine if any material has moved outside the study area.




SCALE IN FEET
0 250 500
NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**
< 142 ≥ 142

Prepared For:

Prepared By:
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Title:
**FIGURE 9 BLUFF CDE**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD
Project no.: 114-560486A
Date of Issue: AUGUST 2015

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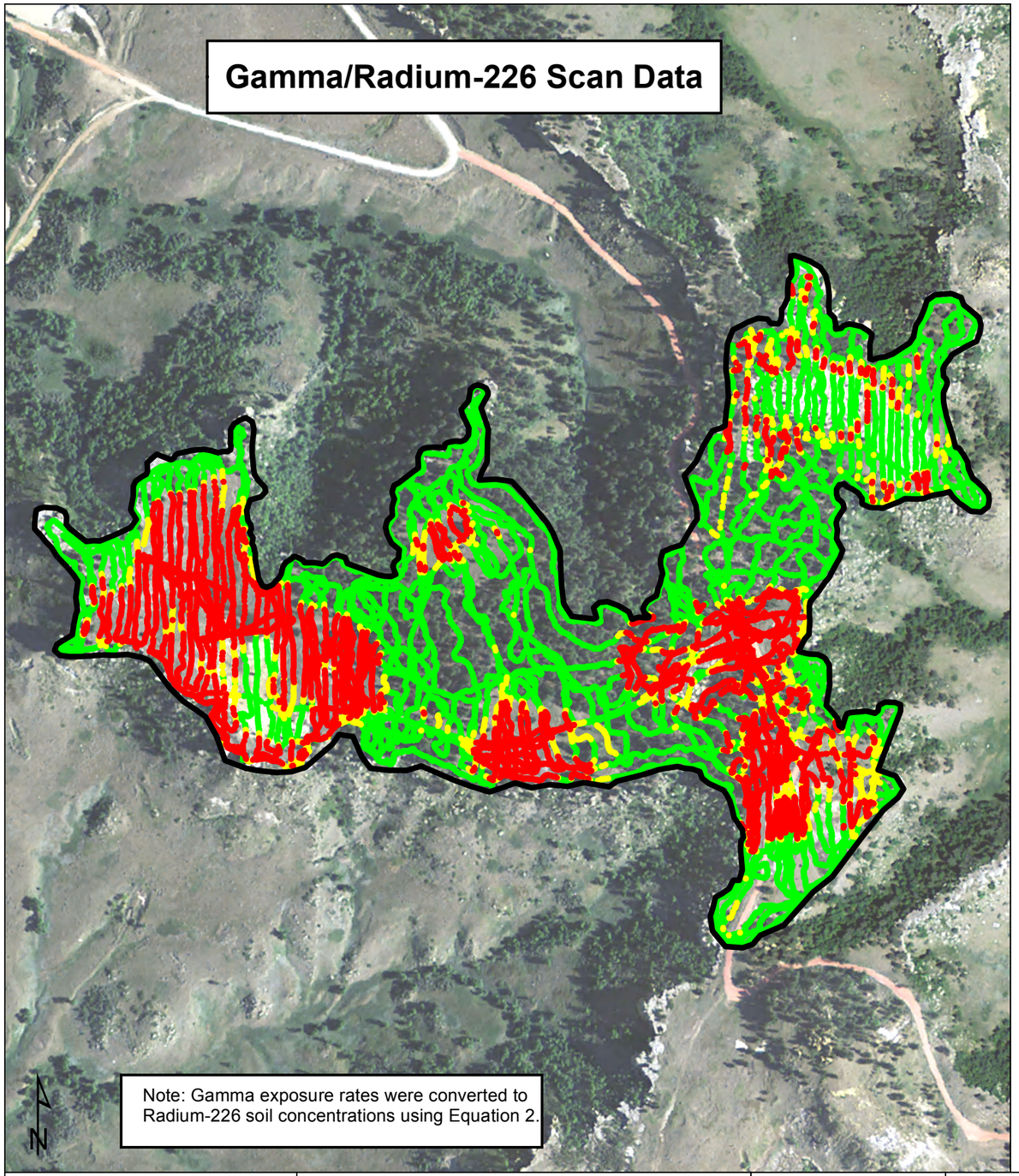


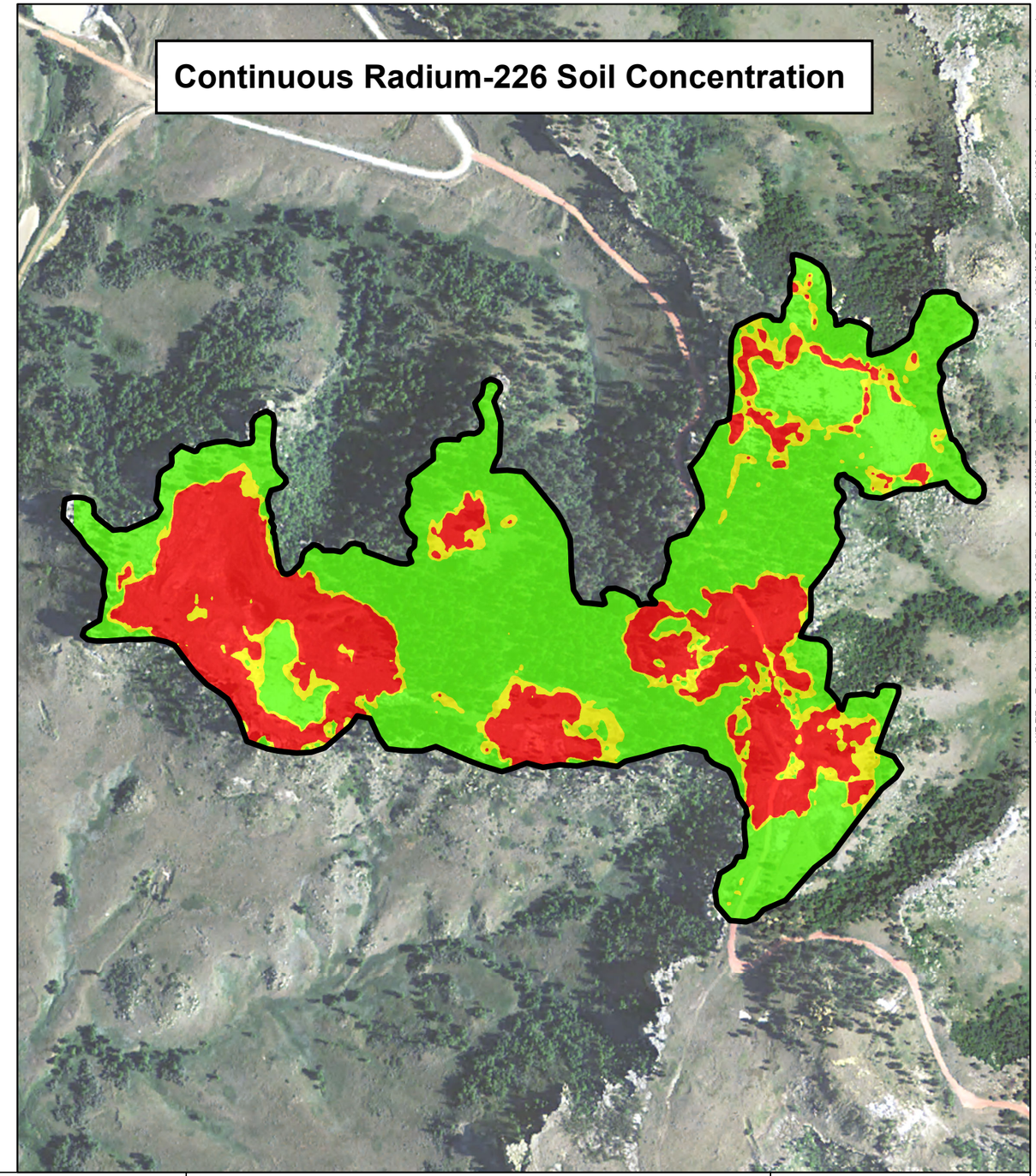


SCALE IN FEET
0 250 500

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**

< 30 | 30 - 50 | ≥ 50

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970-223-9600

Title:

**FIGURE 10 BLUFF CDE**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

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## 5.5 BLUFF F

### 5.5.1 Overview

The Bluff F study area shown in Figure 1 encompasses 7.5 acres and has established vegetation of the spoils piles and berms. Some areas of exposed bedrock are located within the study area. There are no signs of erosion from the berms or spoils piles, and vegetation cover at the site is approximately 90 percent to 95 percent (USFS 2006). Using all available data, the Bluff F study area boundary was revised from the historical boundary provided to Tetra Tech which previously encompassed 2.1 acres. Appendix D shows the historical and revised study area boundaries. Bluff F is located 1.2 miles southeast of Bluff B in Township 22 North, Range 5 East, Section 35. Aerial photos of Bluff F are provided in Appendix E.

### 5.5.2 Characterization Status

Bluff F was first studied by Pioneer in a 1999 and 2000 field sampling investigation (USFS 2002). Concentrations greater than three times background of molybdenum, Ra-226, and U-235 were documented for Bluff F during Pioneer's 1999/2000 field sampling investigation. Bluff F was characterized by MSE in 2008 (MSE 2009).

In May 2015, Tetra Tech reviewed all available data at Bluff F and identified areas where additional data gaps were still present, including an area with Ra-226 concentrations in soil exceeding the risk-based cleanup criteria presented in Section 3.4 with no arsenic data available for that same location. The USFS requested Tetra Tech perform XRF field surveys and gamma radiation surveys at Bluff F under Modification #1 for contract AG-02-02NV-D-15-0004 dated June 9, 2015. The additional characterization surveys were performed by Tetra Tech field engineers in July 2015 and the results of this investigation are presented in Tetra Tech (2015d). The data collected in July 2015 was validated and incorporated into the final project geodatabase.

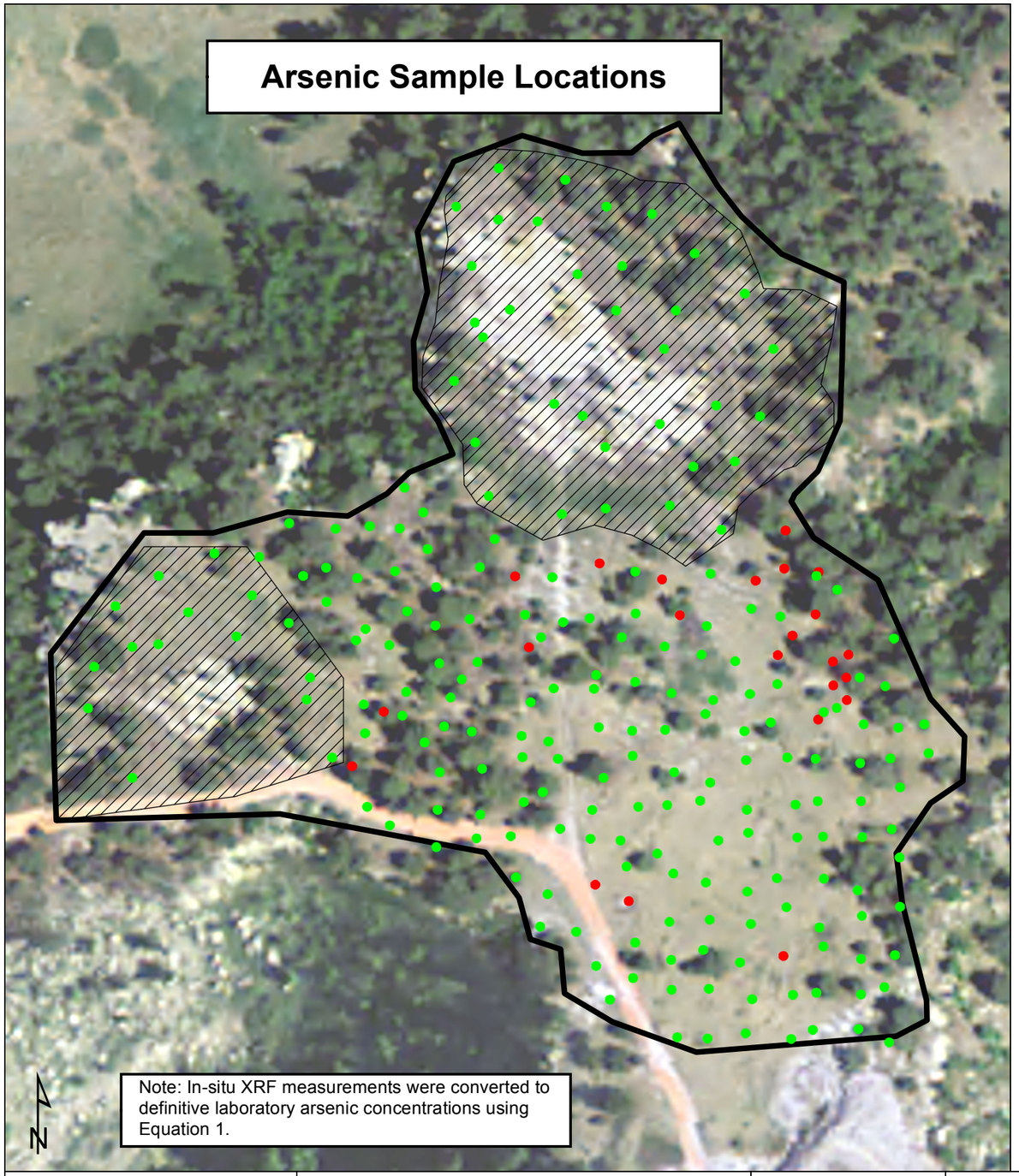
### 5.5.3 Reclamation Status

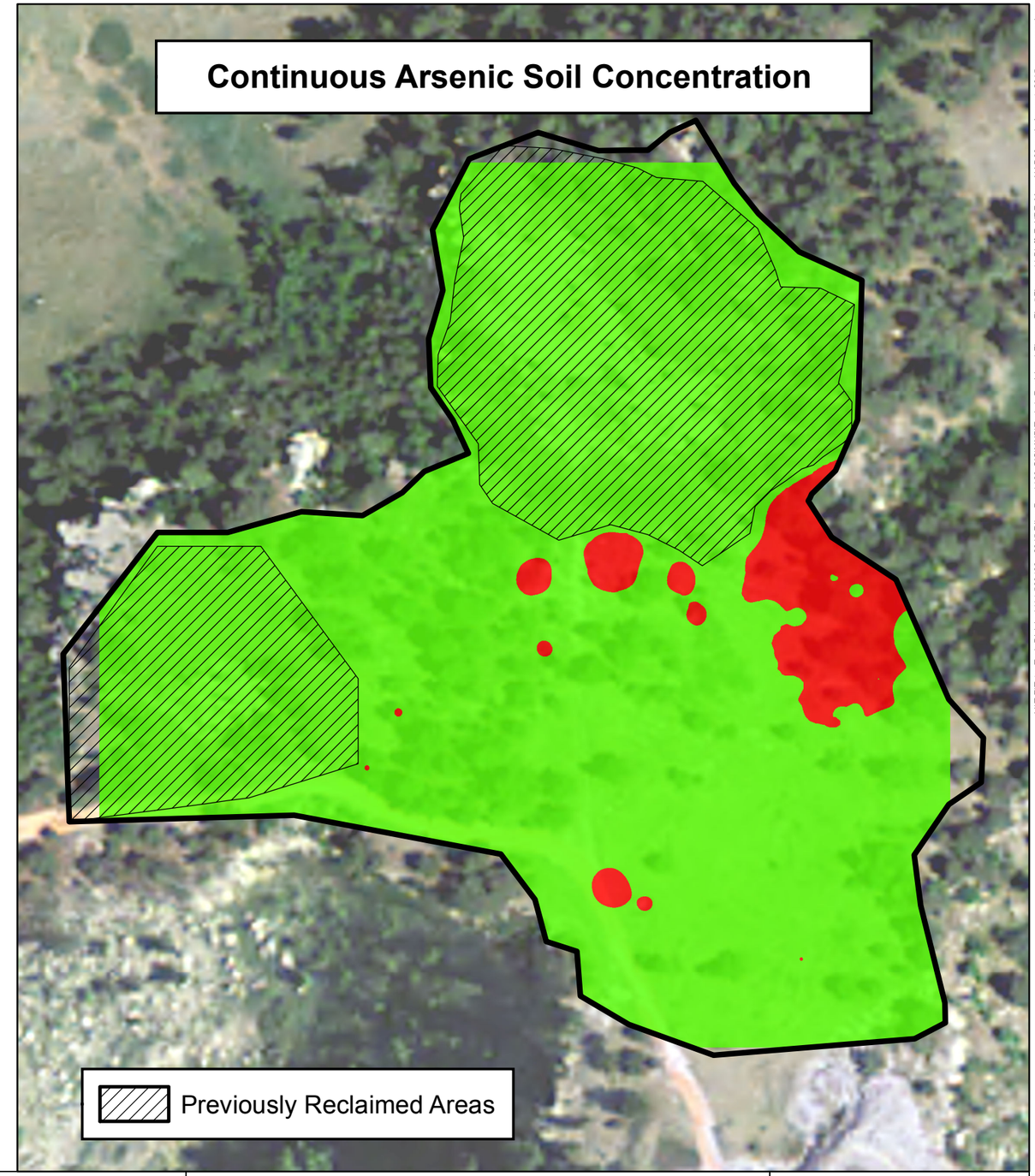
The USFS reclaimed two separate areas at Bluff F in 2012 under Federal Contract Number GS-10F-0268K and Task Order AG-0355-D-11-0011. A verification survey report outlining the removal action efforts during 2012 is presented in Tetra Tech (2013a). Removal action was successful at the western portion of Bluff F; however, cleanup attainment was not achieved at the northeastern portion of Bluff F (Tetra Tech 2013a), and further areas were identified during the verification surveys that required removal at Bluff F. In 2014, under Federal Contract Number GS-10F-0268K and Task Order AG-0355-D-14-0010, final removal action and attainment of cleanup standards was achieved at Bluff F, as summarized in Tetra Tech (2015a); however, additional areas designated as Bluff F will require additional reclamation.

### 5.5.4 Recommendations

Tetra Tech utilized all available characterization and verification survey data to generate status update maps of Bluff F based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff F is provided in Figure 11. A status update map showing the Ra-226 soil concentrations at Bluff F is provided in Figure 12. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial interpolation methods. The status update maps provide the boundaries of previously reclaimed areas and reflect the current conditions at the study area using all available information. The results of

the 2015 sampling showed there are areas exceeding arsenic and Ra-226 soil cleanup levels outside of the reclamation boundaries at Bluff F, and some areas exceeding the Ra-226 soil cleanup values within the existing reclamation boundaries. Attainment of the Ra-226 soil cleanup objectives within the reclaimed areas at Bluff F were previously determined to be successful (Tetra Tech 2013a; Tetra Tech 2015a); however, these were based on the correlation available at that time presented in MSE (2009). The Ra-226 data presented in Figure 12 was evaluated using the more conservative Equation 2 in Section 4.2 of this report. Because the areas at Bluff F were reclaimed to the cleanup objectives available at that time, Tetra Tech recommends no further action within the reclaimed areas at Bluff F. Tetra Tech recommends removal action at Bluff F outside of the previously reclaimed areas to reduce the arsenic and Ra-226 concentrations below the soil cleanup levels.




SCALE IN FEET
0 50 100
NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**
< 142 ≥ 142

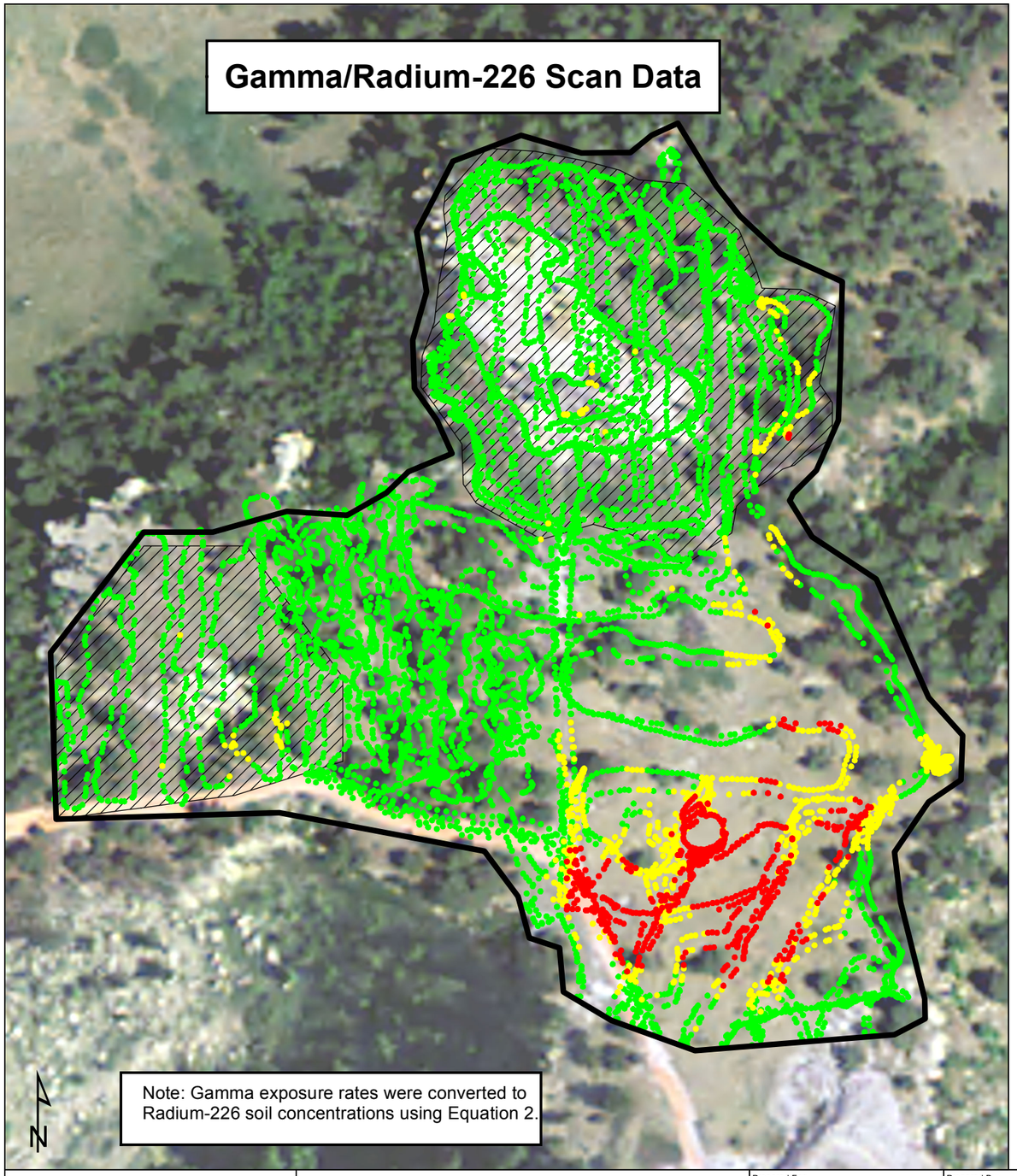
Prepared For:

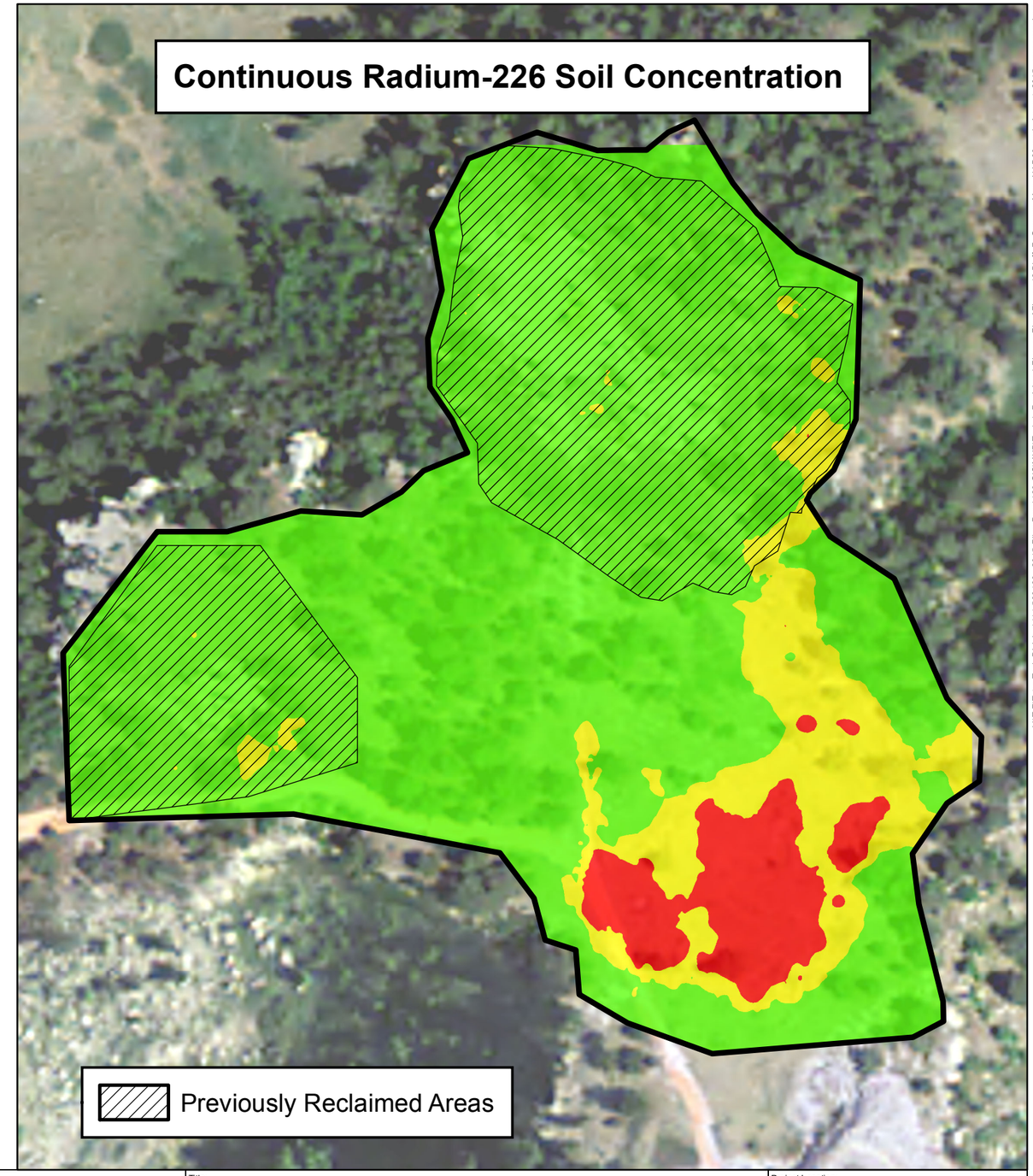
Prepared By:
3501 Automation Way, Suite 100
Fort Collins, CO 80525
970-223-9600

Title:
**FIGURE 11 BLUFF F**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD
Project no.: 114-560486A
Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 11 Bluff_F_XRF_Map_NAD83.mxd August, 2015: aaron.orechwa




SCALE IN FEET
0 50 100

NAD_1983_STATEPLANE_SOUTH_DAKOTA
NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**

< 30 | 30 - 50 | ≥ 50

Prepared For:

Prepared By:

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970-223-9600

Title:

**FIGURE 12 BLUFF F**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

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## 5.6 BLUFF G

### 5.6.1 Overview

The Bluff G study area shown in Figure 1 encompasses 7.1 acres, of which approximately 2 acres consist of exposed bedrock. Using all available data, the Bluff G study area boundary was revised from the historical boundary provided to Tetra Tech which previously encompassed 3.6 acres. Appendix D shows the historical and revised study area boundaries. Bluff G is located approximately 1.5 miles southeast of Bluff B in Township 22 North, Range 5 East, Section 36. There are several bare and eroding steep (l.5H: 1V) slopes, where the materials have been pushed off the rimrock. Aerial photos of Bluff G are provided in Appendix E.

### 5.6.2 Characterization Status

Bluff G was first studied by Pioneer in a 1999 and 2000 field sampling investigation (USFS 2002). Pioneer's 1999/2000 sampling results indicated one acutely contaminated area (RP-SS-G2 [lignite sample]) that has been left on top of the bluff. The greater portion of the top of the bluff has been excavated down to bedrock with very little vegetation present (USFS 2006). Vegetation is present on some of the less steep slopes. There are several berms and spoils piles along the north and east side of the bluff. Surface erosion is localized to two areas on the berms and spoils piles on the north side of the bluff. Access to Bluff G is gained by traveling over Bluff I; the EE/CA (USFS 2006) recommended that reclamation of Bluff G should be completed before any response actions at Bluff I. Concentrations greater than three times background of arsenic, molybdenum, uranium, and Ra-226 were documented for Sample RP-SS-G 1 during Pioneer's 1999/2000 sampling investigation (USFS 2002).

Bluff G was more comprehensively studied by Tetra Tech in 2012 (Tetra Tech 2013b). A total of 54 XRF measurements and 9,000 gamma exposure rate measurements were collected at Bluff G. The Ra-226 activity ranged from 1.35 pCi/g to 1,493 pCi/g with an average of 42.4 pCi/g. Arsenic concentrations ranged from 14.8 mg/kg to 1,483 mg/kg with an average of 256 mg/kg. Arsenic or Ra-226 soil concentrations in approximately 5 acres of Bluff G are above the risk-based cleanup criteria (Tetra Tech 2013b). Per the recommendations in Tetra Tech (2013b), a supplemental field investigation was performed east of Bluff G. The results of the supplemental sampling investigation are presented in a technical memorandum to the USFS (Tetra Tech 2015c).

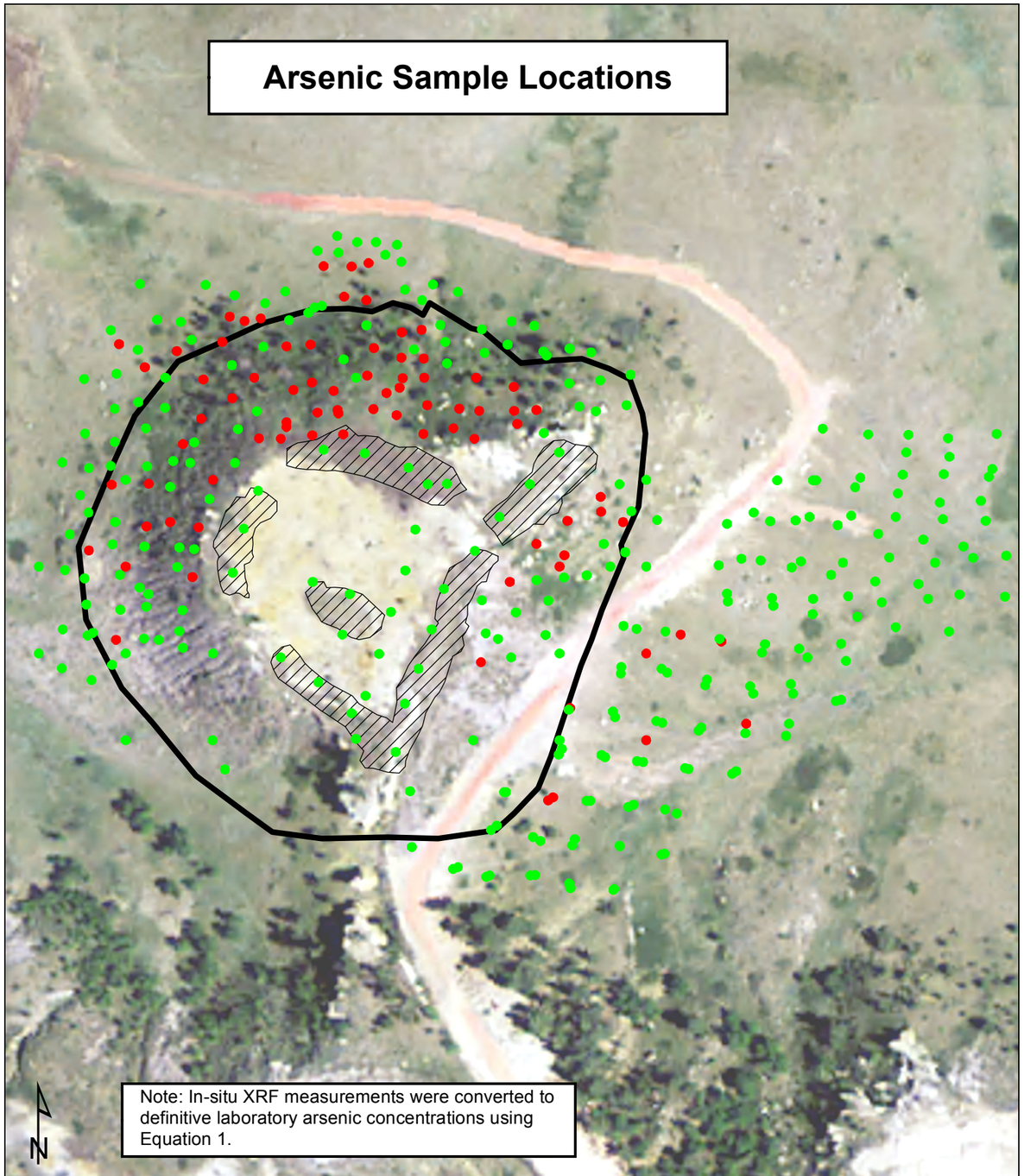
In May 2015, Tetra Tech reviewed all available data at Bluff G and identified areas where additional data gaps were still present. The USFS requested Tetra Tech perform XRF field surveys and gamma radiation surveys at Bluff G under Modification #1 for contract AG-02-02NV-D-15-0004 dated June 9, 2015. The additional characterization surveys were performed by Tetra Tech field engineers in July 2015 and the data transmittal report is presented in Tetra Tech (2015d). The data collected in July 2015 was validated and incorporated into the final project geodatabase. Tetra Tech (2013b) provided an estimate of 72,395 $yd^3$ total waste material volume at Bluff G. These volumes will need to be recalculated based on the 2015 characterization data and new waste categorization criteria presented into this report.

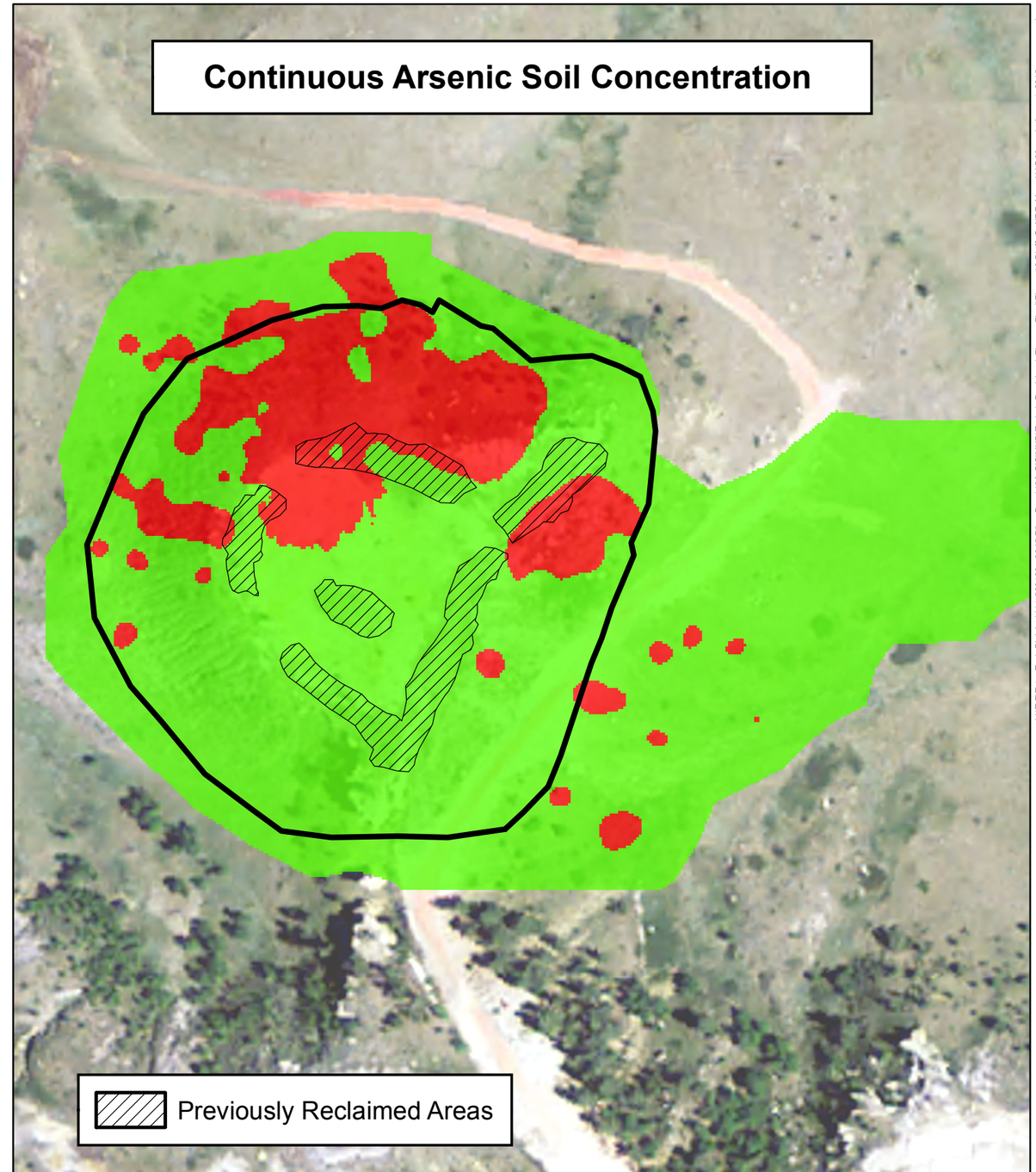
### 5.6.3 Reclamation Status

The USFS reclaimed five separate areas at Bluff G under Federal Contract Number GS-10F-0268K and Task Order AG-0355-D-14-0010. The verification arsenic XRF/soil sampling performed at the Bluff G reclaimed areas indicated that all the levels collected within these areas were below 142 mg/kg of arsenic. However, using geospatial interpolation techniques with all available data at Bluff G there are areas displayed within the reclaimed areas that exceed arsenic soil concentrations of 142 mg/kg. Attainment of the Ra-226 soil cleanup objectives at the reclaimed areas at Bluff G were previously determined to be successful (Tetra Tech 2015b).

### 5.6.4 Recommendations

Tetra Tech utilized all available characterization and verification survey data to generate status update maps of Bluff G based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff G is provided in Figure 13. A status update map showing the Ra-226 soil concentrations at Bluff G is provided in Figure 14. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial interpolation methods. The status update maps provide the boundaries of previously reclaimed areas and reflect the current conditions at the study area using all available information. Dispersed areas of arsenic and Ra-226 soil contamination remain at Bluff G. Tetra Tech recommends removal action at Bluff G to reduce the arsenic and Ra-226 concentrations below the soil cleanup levels.




SCALE IN FEET
0 100 200

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**

< 142 ≥ 142

Prepared For:

Prepared By:

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Title:

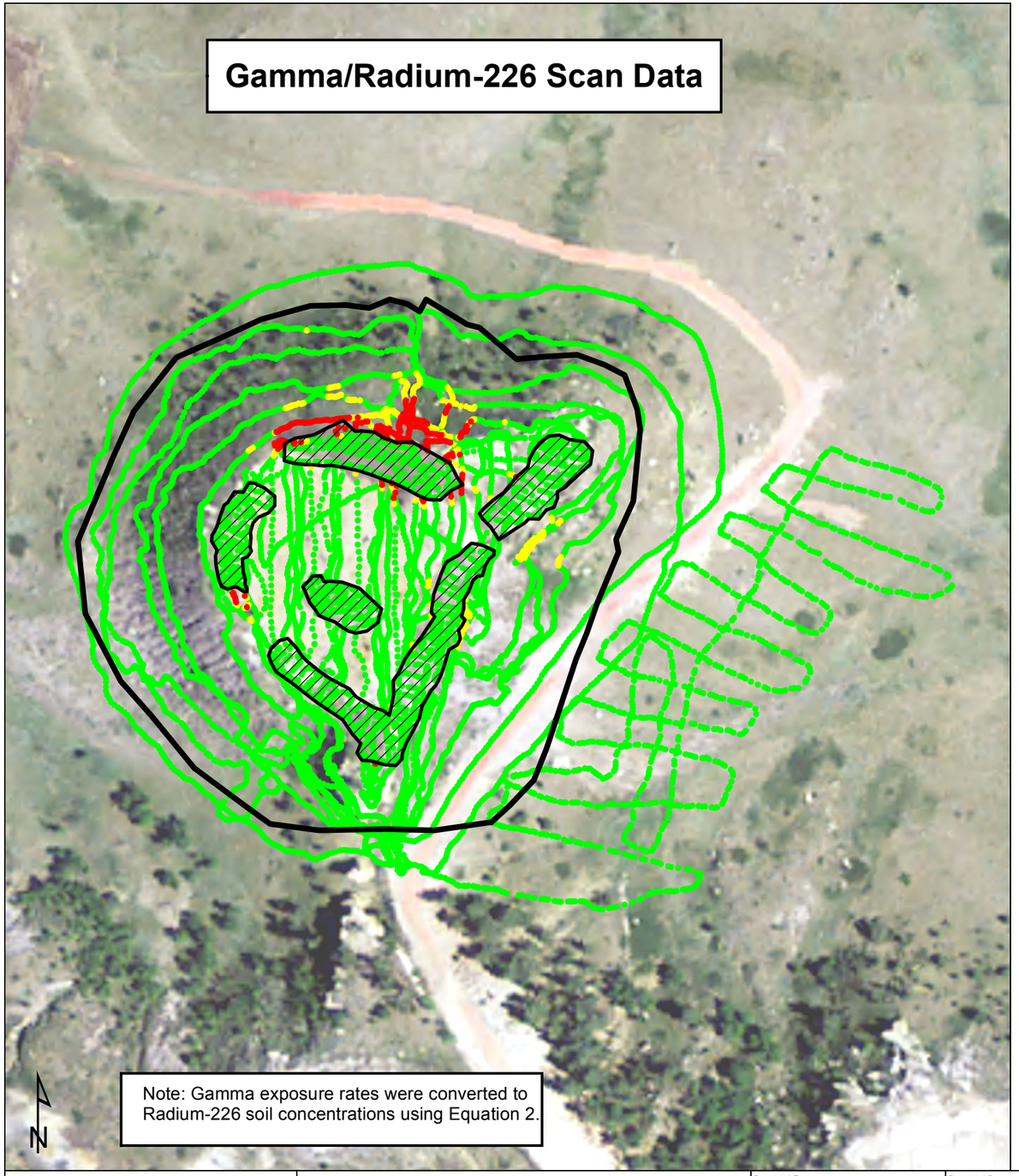
**FIGURE 13 BLUFF G**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

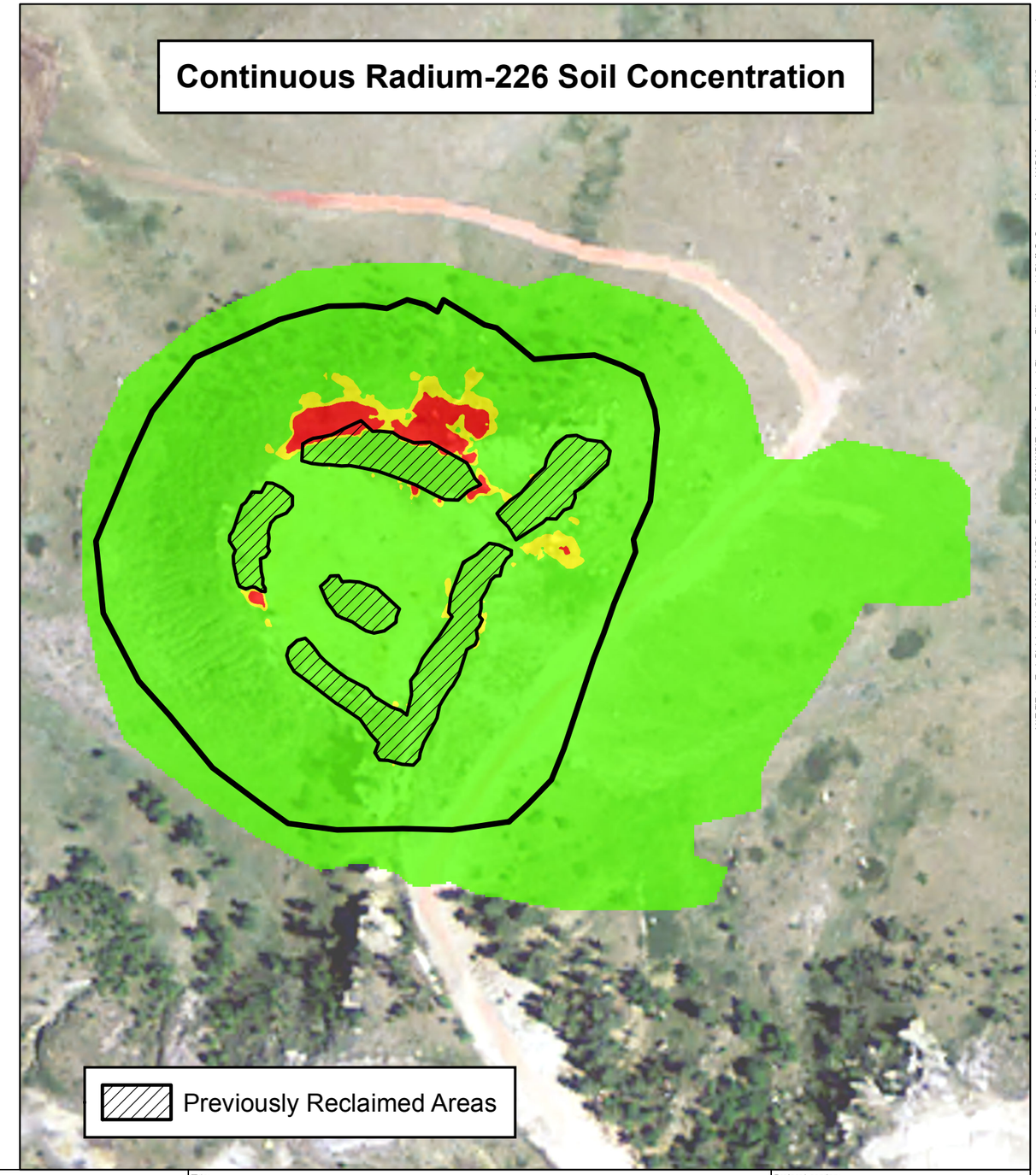
Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 13 Bluff_G_XRF_Map_NAD83.mxd August, 2015; aaron.orechwa




SCALE IN FEET
0 100 200
NAD_1983_STATEPLANE_SOUTH_DAKOTA
NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**
< 30 | 30 - 50 | ≥ 50

Prepared For:

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970-223-9600

Title:
**FIGURE 14 BLUFF G**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD
Project no.: 114-560486A
Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 14 Bluff_G_Gamma_Map_NAD83.mxd August, 2015: aaron.orechwa

## 5.7 BLUFF H

### 5.7.1 Overview

The Bluff H study area shown in Figure 1 encompasses approximately 33.7 acres. Using all available data, the Bluff H study area boundary was revised from the historical boundary provided to Tetra Tech which previously encompassed 29.8 acres. Appendix D shows the historical and revised study area boundaries. Bluff H is located approximately 1.9 miles southeast of Bluff B in Township 22 North, Range 5 East, Sections 25 and 36. The Bluff H study area consists of several spoils piles that have been placed along and over the rimrock edges; these slopes are generally very steep (1.5H : 1 V) and show signs of severe water erosion, especially on the northwest and northeast spoils piles (USFS 2006). Vegetation growth on the side slopes is limited. There is a pit area with unstable highwalls on the southwestern portion of the site. A portion of the spoils piles on the north and northeast side of the bluff is currently located on private property. A spoils pile of approximately 1.1 acres is located on the northwest comer of the bluff (USFS 2006), and the slope is extremely steep (l.5H : 1V) and barren of vegetation. One large erosion gully is located on the south portion of the spoils pile. The water and sediment from this gully flow into an intermittent dry draw and drainage. However, some of the sediments are being deposited on private property adjacent to Bluff H. The spoils pile located on the northeast end of the bluff is moderately vegetated. Erosion gullies and rills are transporting sediment onto private property and into an intermittently dry draw and drainage. Approximately one-third of this spoils pile is currently situated on private property. A large spoils pile located on the west side of the bluff encompasses 3 acres (USFS 2006). The spoils are sparsely vegetated, with numerous erosion gullies and rills. One large erosion gully (approximately 12 feet deep) is located on the south end of the spoils pile and drains into an intermittent dry draw and drainage. A spoils pile containing encompassing 4 acres is located on the southern end of the bluff. This spoils pile is moderately vegetated with limited signs of surface erosion.

### 5.7.2 Characterization Status

Bluff H was first studied by Pioneer in a 1999 and 2000 field sampling investigation (USFS 2002). Pioneer's 1999/2000 sampling results indicated concentrations greater than three times background of arsenic, molybdenum, uranium, and Ra-226 in Sample RP-SS-H1. Concentrations were less than three times background for all metals analyzed in Sample RP-SS-H2. Pioneer personnel identified one hot spot (RP-SS-H3 [lignite sample at the base of the northwest high wall on Bluff H) (USFS 2006). The EE/CA (USFS 2006) recommended that it should be resampled, and the results reevaluated to confirm amendments and nutrients required to establish vegetation before the detailed response action design for Bluff H was completed.

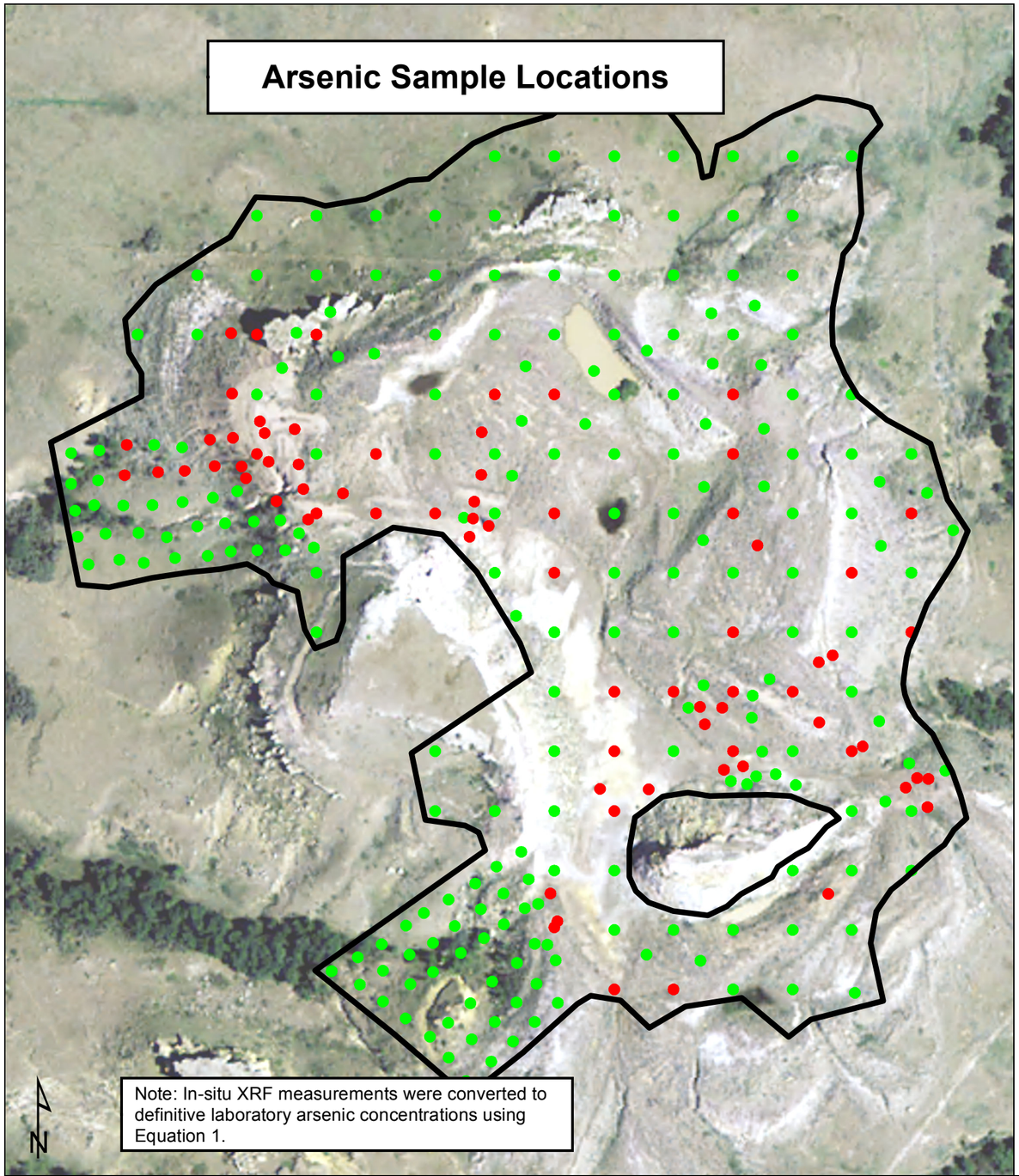
Bluff H was more comprehensively studied by Tetra Tech in 2012 (Tetra Tech 2013b). A total of 199 in situ XRF measurements and 18,000 gamma exposure rate measurements were collected at Bluff H. Arsenic concentrations ranged from 9.1 mg/kg to 1,431 mg/kg with an average of 136 mg/kg. The Ra-226 soil concentrations ranged from 1.11 pCi/g to 1,367 pCi/g with an average of 12.1 pCi/g. Arsenic or Ra-226 soil concentrations in approximately 10 acres were above risk-based cleanup criteria. Per the recommendations in Tetra Tech (2013b), a supplemental field investigation was performed west of Bluff H. The results of the supplemental sampling investigation were presented in a technical memorandum to the USFS (Tetra Tech 2015c). Tetra Tech (2013) provided an estimate of 699,513 $yd^3$ total waste material volume at Bluff H. These volumes will need to be recalculated based on the new waste categorization criteria presented in this report.

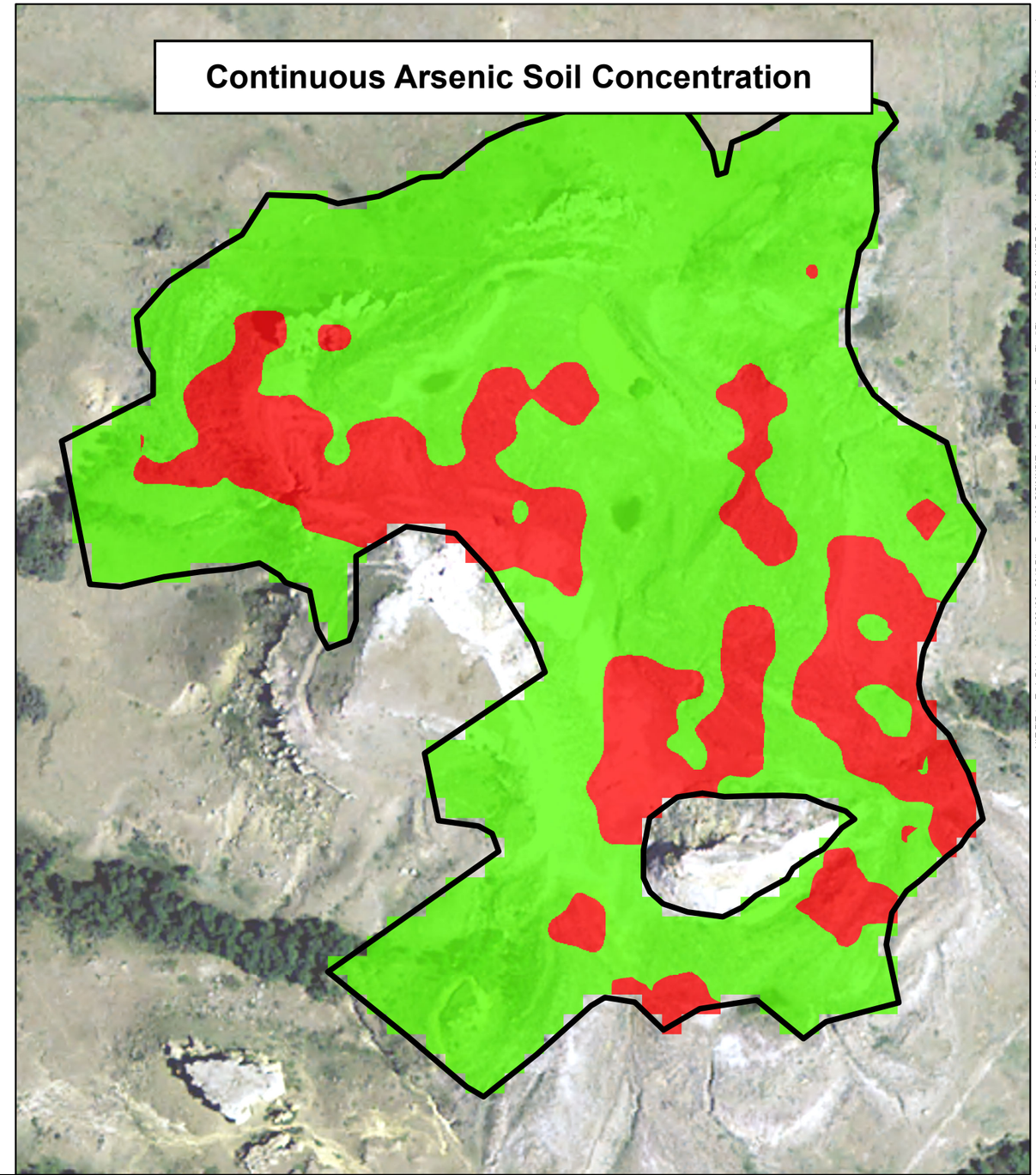
### 5.7.3 Reclamation Status

No reclamation has been performed to date at Bluff H.

### 5.7.4 Recommendations

Tetra Tech utilized all available characterization survey data to generate status update maps of Bluff H based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff H is provided in Figure 15. A status update map showing the Ra-226 soil concentrations at Bluff H is provided in Figure 16. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial interpolation methods. The status update maps reflect the current conditions at the study area using all available information. A hydrologic analysis was performed on Bluff H to identify critical areas where drainages affect the contaminated zones (Appendix F). The hydrologic analysis identified numerous drainages that are directly affecting existing waste boundaries and have transported sediment off site. Additional XRF and gamma surveying within the affected drainages is recommended, specifically within the drainage on the western boundary. Dispersed areas of arsenic and Ra-226 soil contamination remain at Bluff H. Tetra Tech recommends removal action at Bluff H to reduce the arsenic and Ra-226 concentrations below the soil cleanup levels. Before a detailed removal action design for Bluff H is completed, Tetra Tech recommends that additional characterization be conducted to further discretize hot spots of contamination needed for removal action design particularly areas on the northeast and eastern boundary of the study area.




SCALE IN FEET
0 100 200

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**

< 142 ≥ 142

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Title:

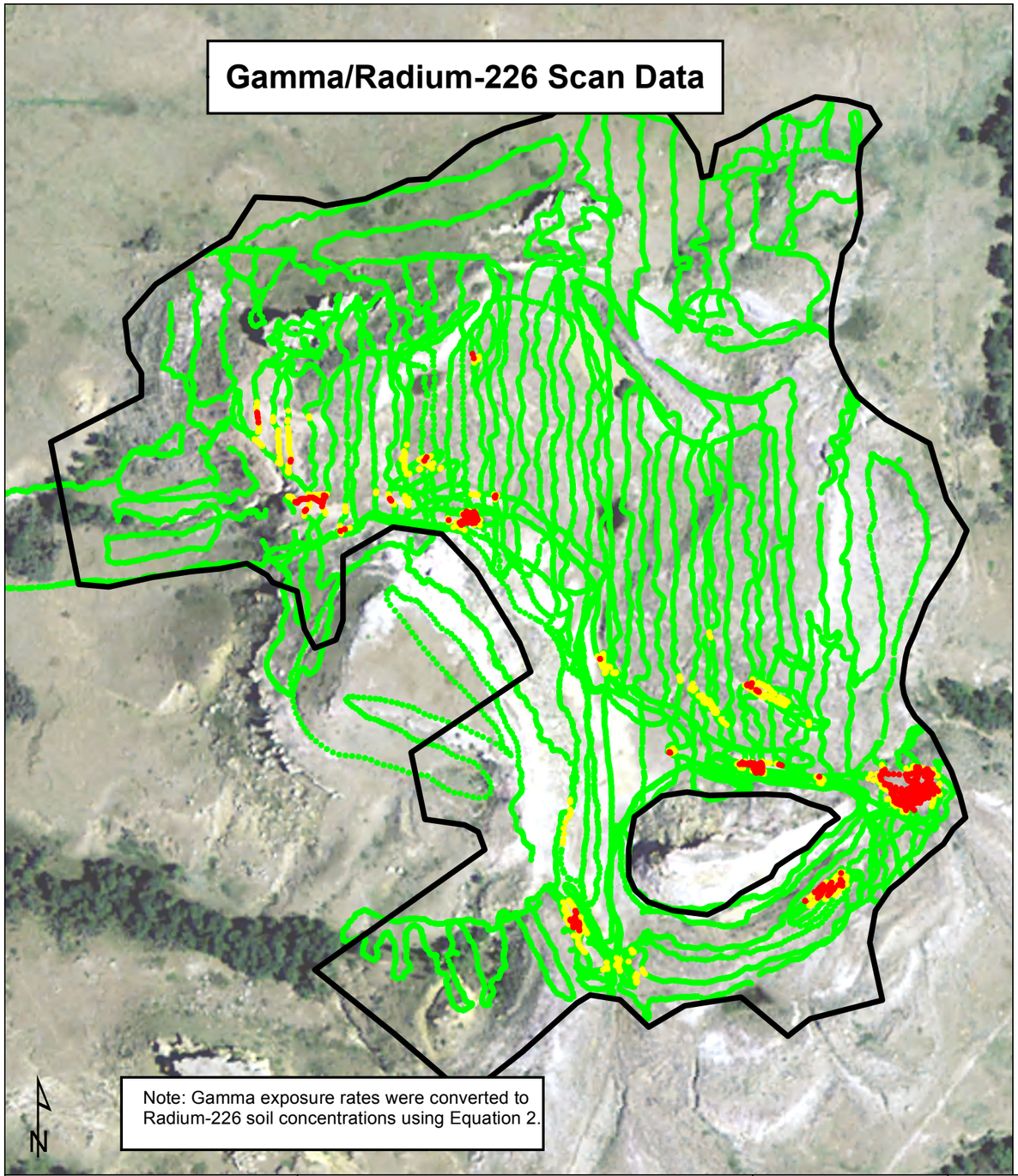
**FIGURE 15 BLUFF H**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

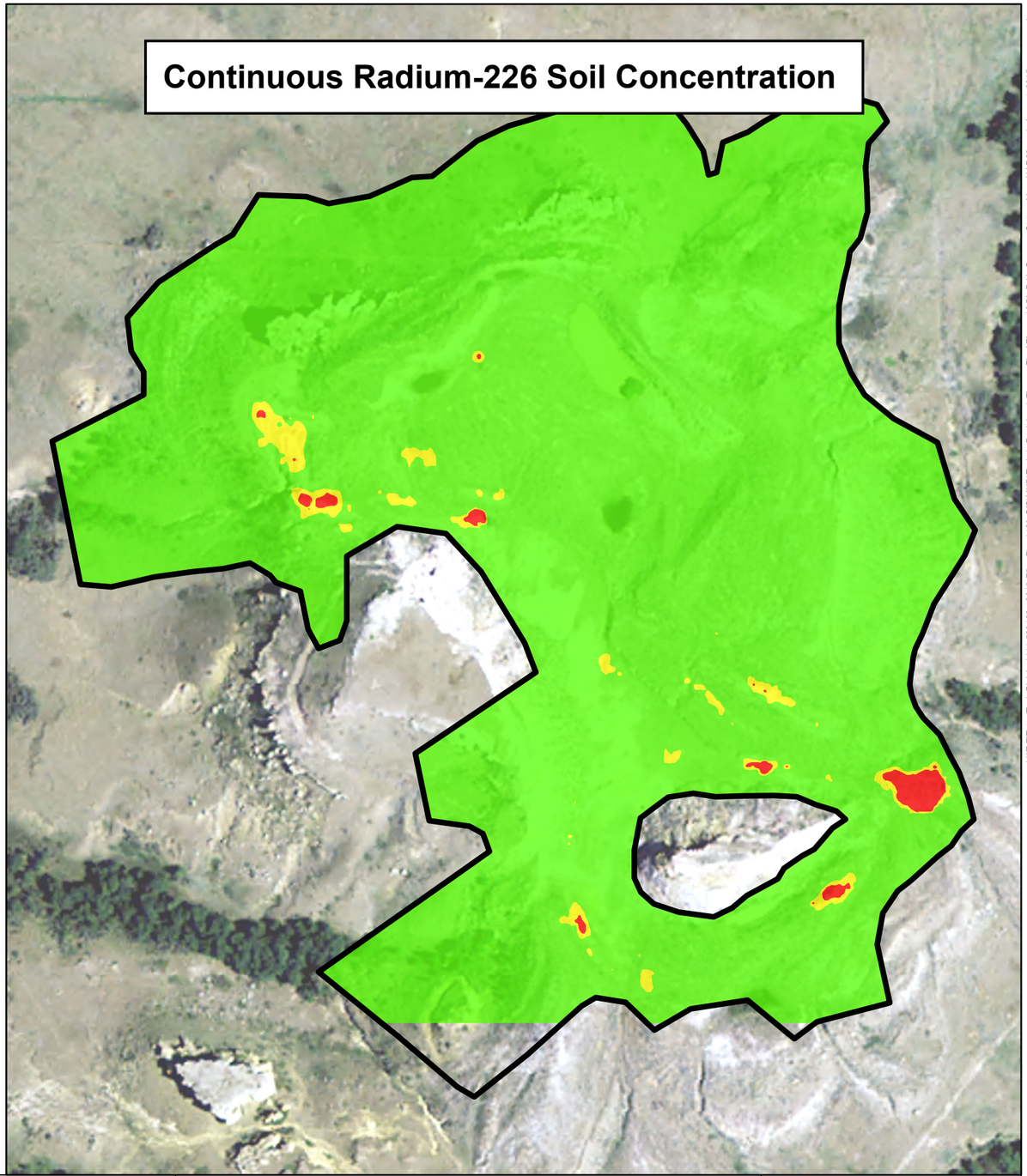
Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 - Revision 1 Figures Final\Figure 15 Bluff_H_XRF_Status_Map_NAD83.mxd August, 2015; aaron.orechwa




SCALE IN FEET

0 100 200

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**

< 30 | 30 - 50 | ≥ 50

Prepared For:

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Title:

**FIGURE 16 BLUFF H**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 16 Bluff_H_Gamma_Status_Map_NAD83.mxd August, 2015: aaron.orechwa

## 5.8 BLUFF I

### 5.8.1 Overview

The Bluff I study area shown in Figure 1 encompasses 30.8 acres. Using all available data, the Bluff I study area boundary was revised from the historical boundary provided to Tetra Tech which previously encompassed 22.2 acres. Appendix D shows the historical and revised study area boundaries. Bluff I is located approximately 0.25 miles south of Bluff F along an unmarked USFS road in Township 22 N, Range 5 East, Sections 35 and 36. The majority of the waste materials are unvegetated and eroding into an intermittently dry draw north of the bluff (USFS 2006). Vegetation has established along the southern highwalls and moderately within the pit areas. The spoils piles and waste materials have been placed on and over the northern edge of the rimrock and are considered the primary source of sedimentation of the draw north of the bluff. Aerial photos of Bluff I are provided in Appendix E.

### 5.8.2 Characterization Status

Bluff G was first studied by Pioneer in a 1999 and 2000 field sampling investigation (USFS 2002). Two soil samples (RP-SS-I1 and RP-SS-I2) were collected from Bluff I. A more comprehensive characterization study was performed by MSE and Tetra Tech in 2008, and the results are presented in MSE (2009). The 2008 investigation consisted of in situ XRF field surveys, gamma radiation surveys, and soil sampling at Bluff I. The XRF field survey results indicated a number of the surface soil XRF readings resulted in arsenic concentrations above 142 ppm (MSE 2008). The gamma survey results revealed that Ra-226 soil concentrations greater than 30 pCi/g occur intermittently throughout the Bluff I study area (MSE 2008).

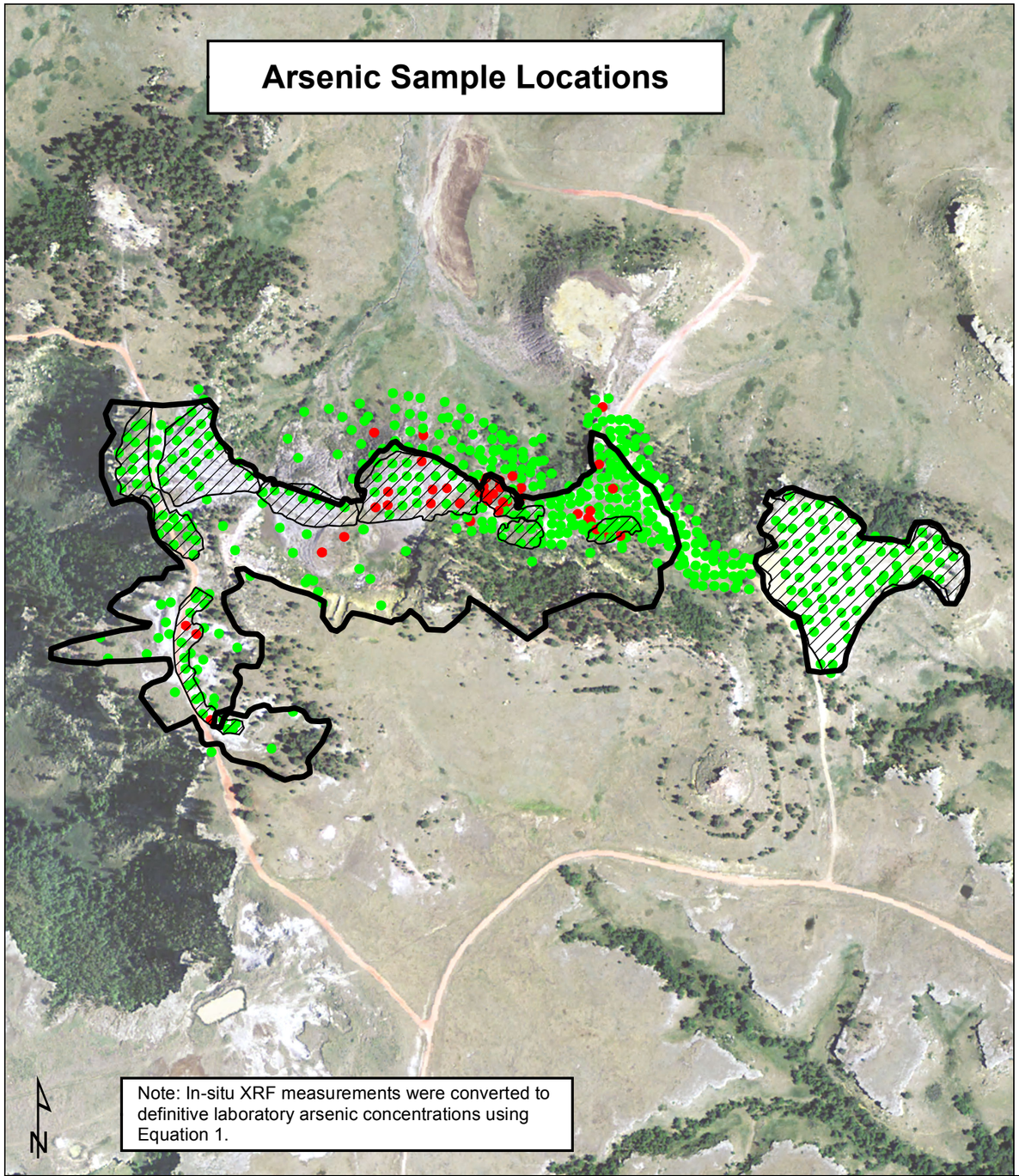
In May 2015, Tetra Tech reviewed all available data at Bluff I and identified areas where additional data gaps were still present. The USFS requested Tetra Tech perform XRF field surveys and gamma radiation surveys at Bluff I under Modification #1 for contract AG-02-02NV-D-15-0004 dated June 9, 2015. The additional characterization surveys were performed by Tetra Tech field engineers in July 2015 and the data transmittal report is presented in Tetra Tech (2015d). The data collected in July 2015 was validated and incorporated into the final project geodatabase.

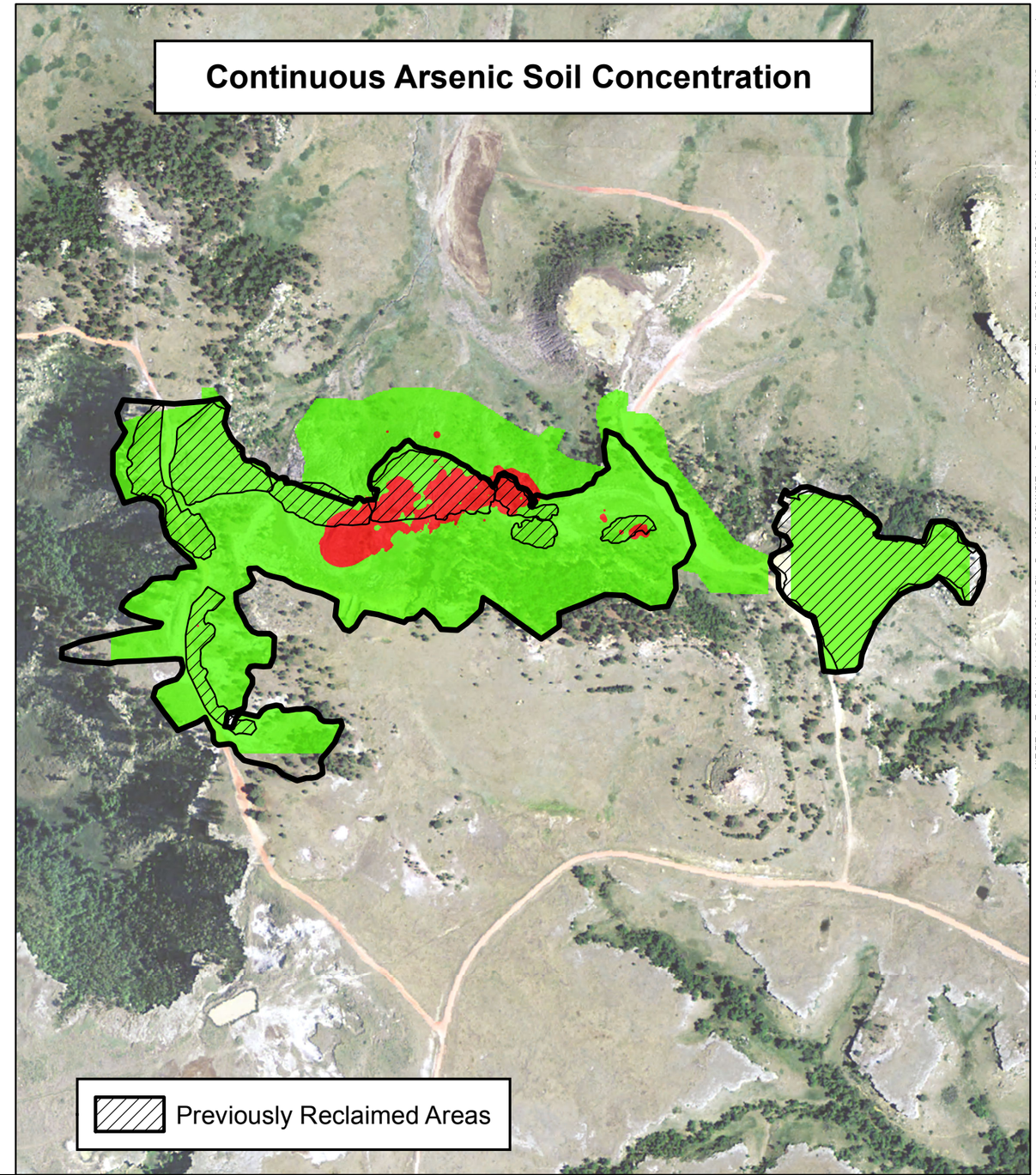
### 5.8.3 Reclamation Status

Numerous reclamation activities have been conducted by the USFS at Bluff I, to varying degrees of success. Successful removal action at the eastern section of Bluff I was conducted in 2012 under Federal Contract Number GS-10F-0268K and Task Order AG-0355-D-11-0011, and the verification results are presented in Tetra Tech (2012a and 2012c). Additional removal action activities were conducted in 2013 and 2015 at the western and southern portions of Bluff I under Federal Contract Number GS-10F-0268K and Task Order AG-0355-D-11-0011, and the results are presented in Tetra Tech (2013a) and Tetra Tech (2015a). The degree of success varies within the previously reclaimed areas as discussed in Tetra Tech (2013a and 2015a).

### 5.8.4 Recommendations

Tetra Tech utilized all available characterization and verification survey data to generate status update maps of Bluff I based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff I is provided in Figure 13. A status update map showing the Ra-226 soil concentrations at Bluff I is provided in Figure 14. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial interpolation methods. The status update maps provide the boundaries of previously reclaimed areas and reflect the current conditions at the study area using all available information. Dispersed areas of arsenic and Ra-226 soil contamination remain at Bluff I. Tetra Tech recommends removal action at Bluff I to reduce the arsenic and Ra-226 concentrations below the soil cleanup levels.

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SCALE IN FEET

0 250 500

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**

< 142 ≥ 142

Prepared For:

Prepared By:

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970-223-9600

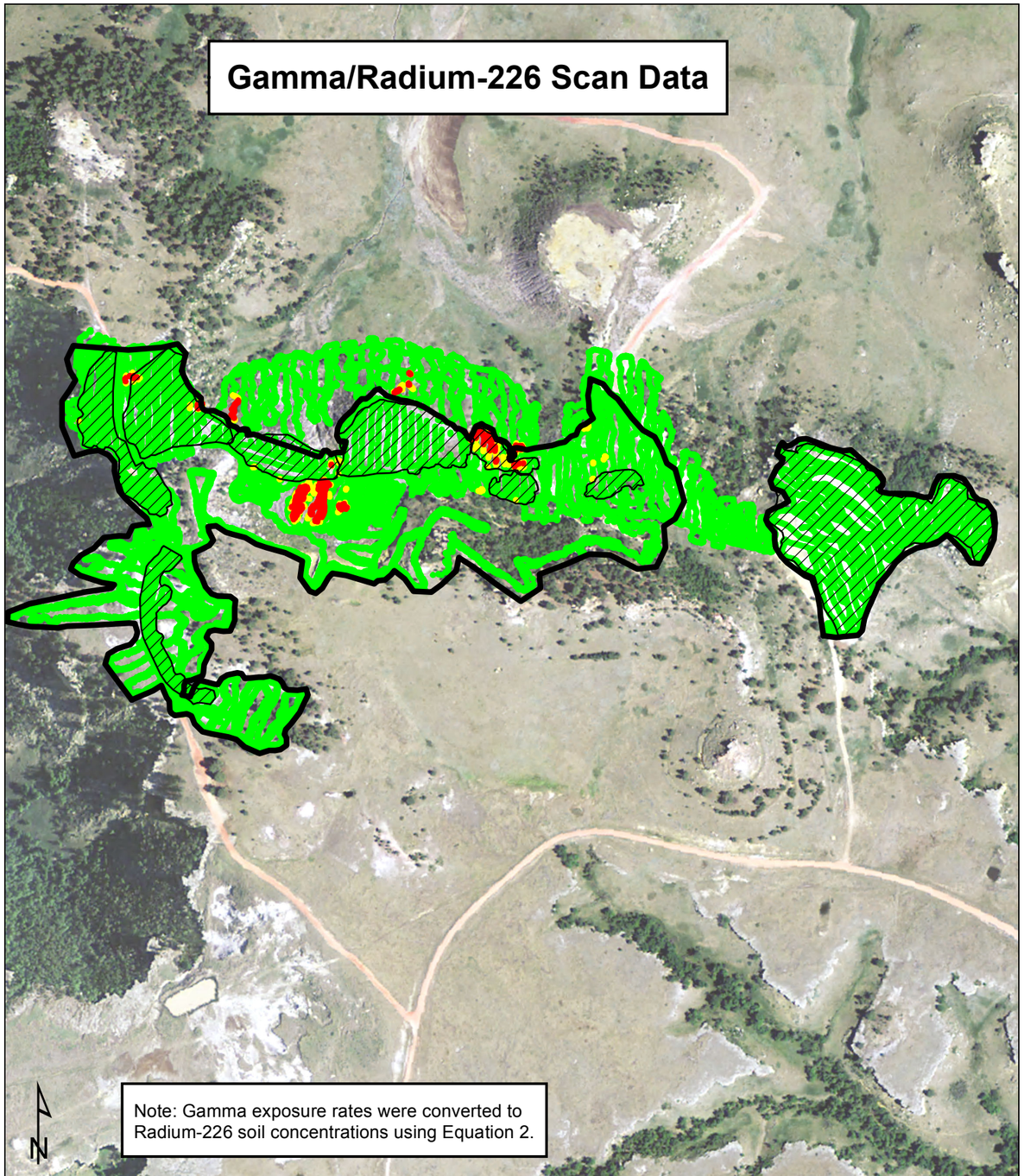
Title:

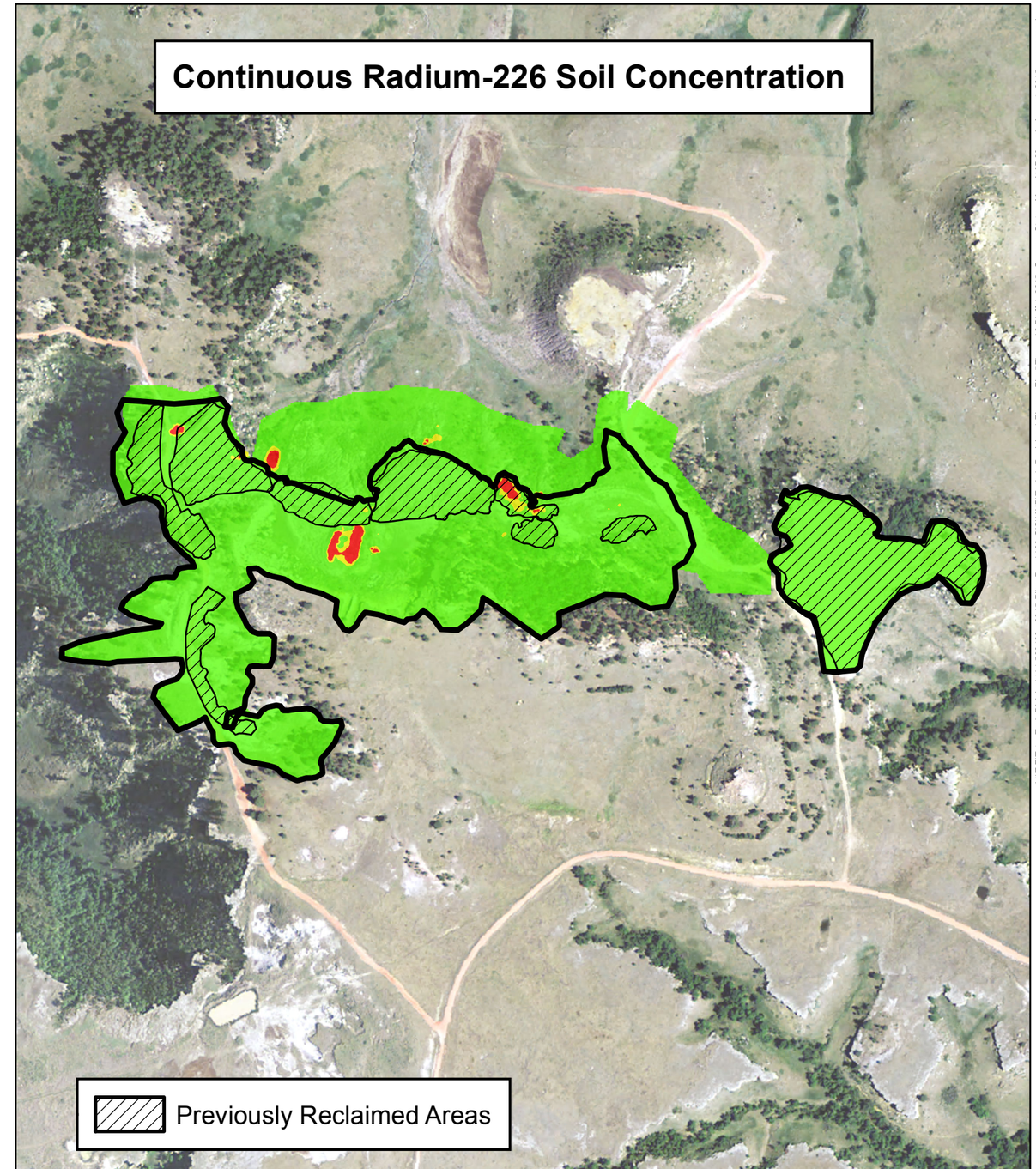
**FIGURE 17 BLUFF I**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015




SCALE IN FEET

0 250 500

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**

< 30 | 30 - 50 | ≥ 50

Prepared For:

Prepared By:

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Title:

**FIGURE 18 BLUFF I**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

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## 5.9 BLUFF J

### 5.9.1 Overview

The Bluff J study area shown in Figure 1 encompasses 8.75 acres consisting of highwalls, spoils piles, berms, and road cuts into the side of the bluff (USFS 2006). Using all available data, the Bluff J study area boundary was revised from the historical boundary provided to Tetra Tech which previously encompassed 4.2 acres. Appendix D shows the historical and revised study area boundaries. Bluff J is located in Township 22 North, Range 5 East, Section 20.

### 5.9.2 Characterization Status

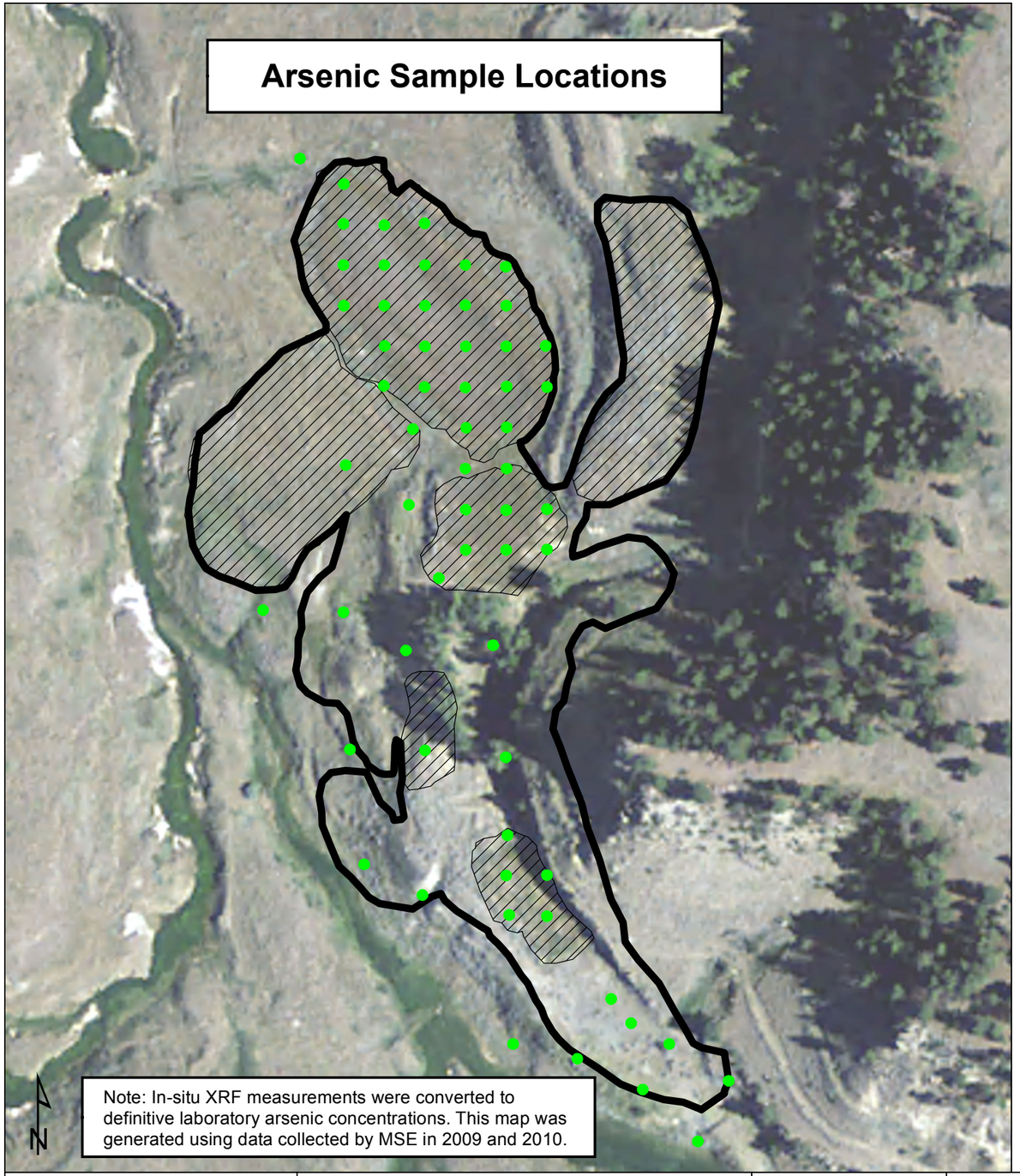
Bluff J was first studied by Pioneer in a 1999 and 2000 field sampling investigation (USFS 2002). Concentrations in soil greater than three times background for Ra-226 were documented (USFS 2002). A more comprehensive characterization study involving an XRF field survey and gamma radiation survey was performed at Bluff J by MSE and Tetra Tech in 2008, and the results are presented in MSE (2009).

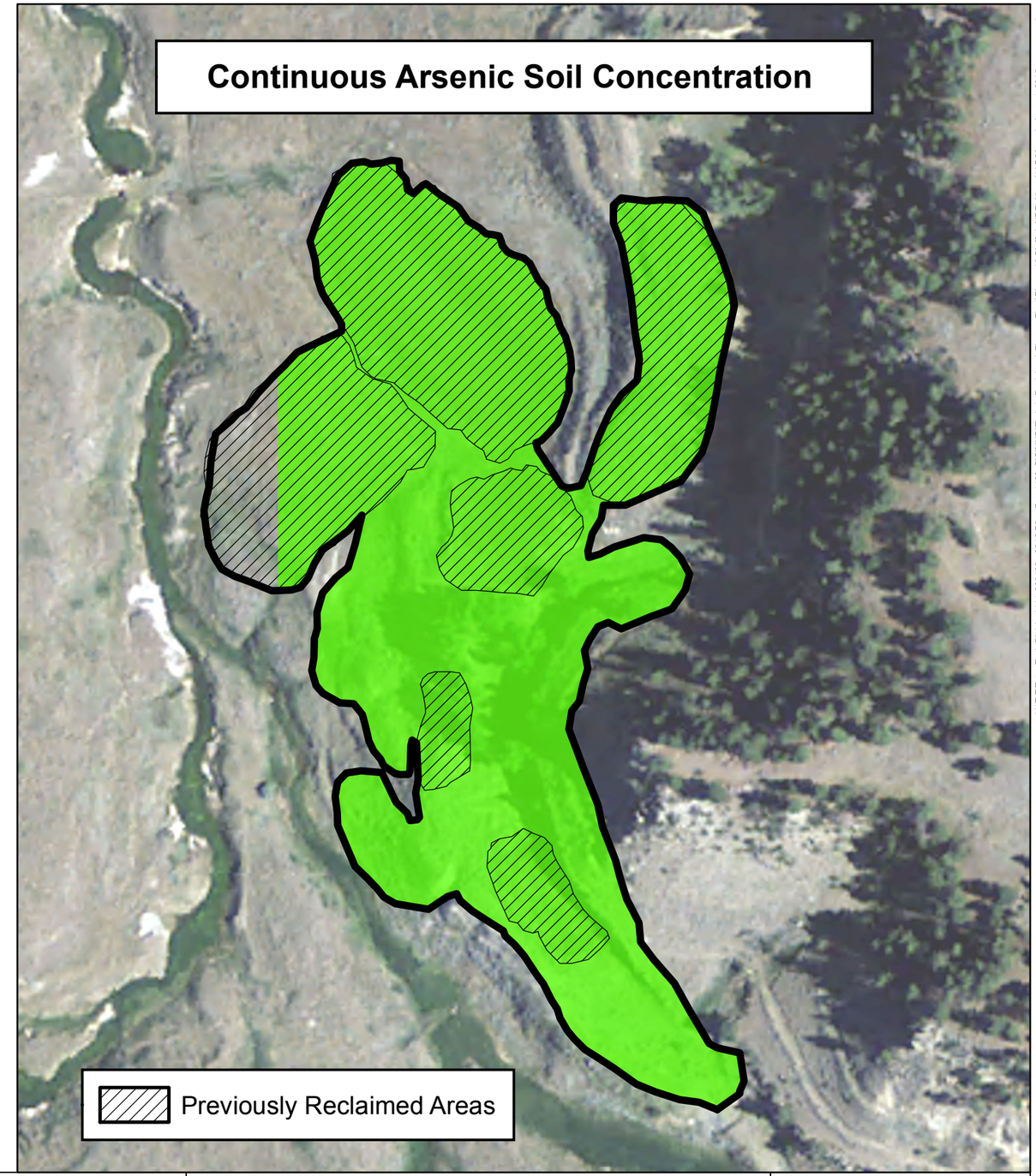
### 5.9.3 Reclamation Status

Reclamation of Bluff J was performed in 2010. Using the Ra-226 cutoff limit established at the time (90 µR/hr), a few relatively small areas were detected on Bluff J, which were in excess of the target concentration of 30 pCi/g Ra-226. In 2010, the USFS capped the radiation hot spots on the periphery of the Bluff J boundary with an average of 18 inches of cover soil. An elevated area of gamma and radium in the middle of a potential borrow area within Bluff J was not covered, as this area appeared undisturbed and was not likely to be used for soil borrow in the future. A total of 39 verification samples were collected at Bluff J as part of the 2010 verification survey. All samples were below the arsenic cleanup criteria. Consolidated mine waste and spoils materials on Bluffs J were sufficiently covered with clean borrow soil to reduce arsenic concentrations at the surface to less 142 mg/kg. Cleanup attainment was achieved at Bluff J after the 2010 reclamation, as summarized in MSE (2010c). The available data shows a remaining hot spot for Ra-226, Bluff J has been reclaimed based on the previously established verification sampling plan (MSE 2010b) and 2010 Action Memorandum (USFS 2010) cleanup criteria.

### 5.9.4 Recommendations

Tetra Tech utilized all available characterization and verification survey data to generate status update maps of Bluff J based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff J is provided in Figure 19. A status update map showing the Ra-226 soil concentrations at Bluff J is provided in Figure 20. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial interpolation methods. The status update maps provide the boundaries of previously reclaimed areas and reflect the current conditions at the study area using all available information. There is a hot spot of Ra-226 contamination remaining at Bluff J (Figure 20); however, this study areas was determined to meet the attainment objectives used at the time it was reclaimed (MSE 2010c). Tetra Tech recommends a reevaluation of the Ra-226 soil concentrations at Bluff J using the Riley Pass Verification Sampling Plan for the site.




SCALE IN FEET
0 100 200
NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**
< 142 ≥ 142

Prepared For:

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970-223-9600

Title:
**FIGURE 19 BLUFF J**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD
Project no.: 114-560486A
Date of Issue: AUGUST 2015

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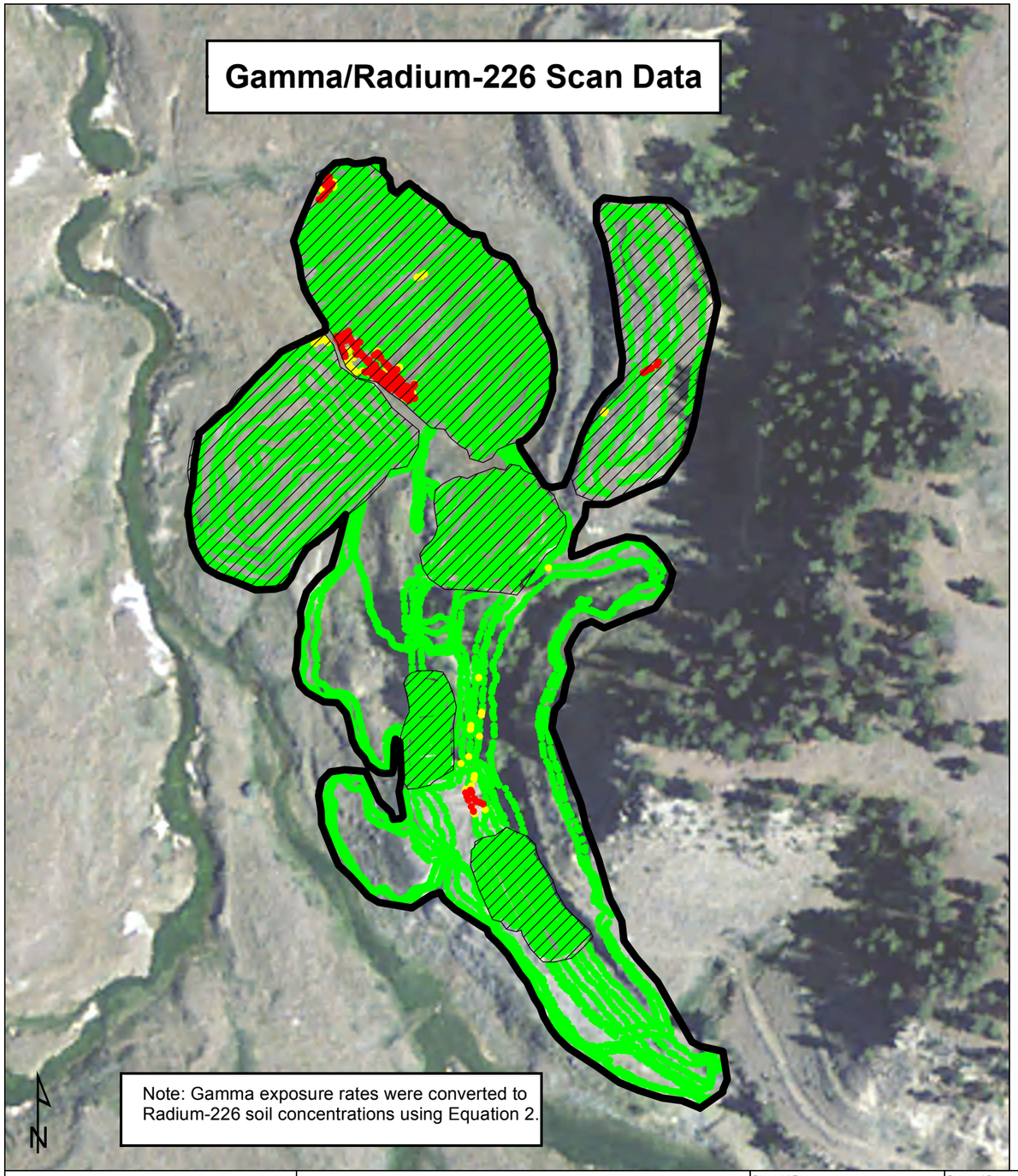


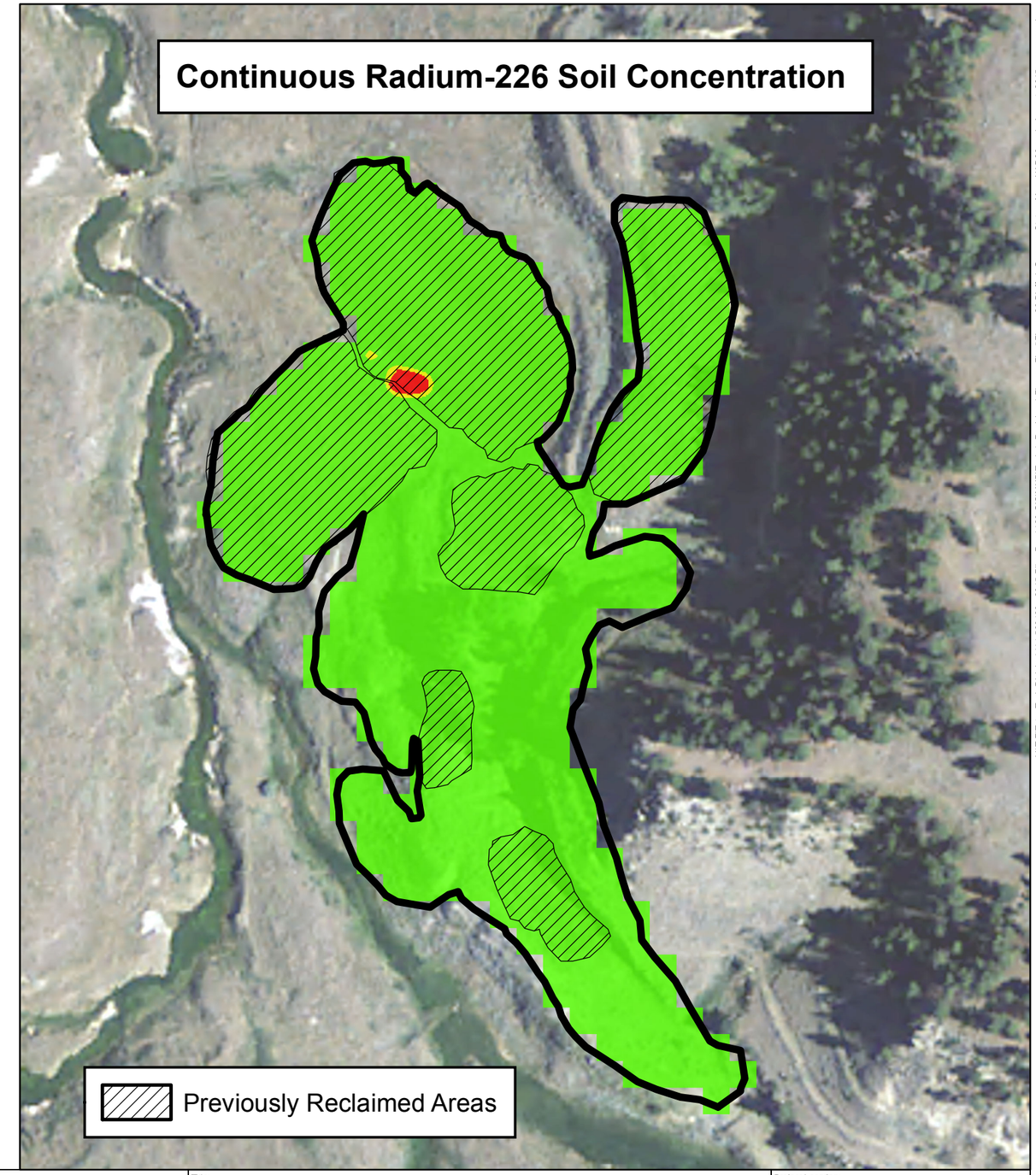


SCALE IN FEET
0 100 200
NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**
< 30 | 30 - 50 | ≥ 50

Prepared For:

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970-223-9600

Title:
**FIGURE 20 BLUFF J**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD
Project no.: 114-560486A
Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 20 Bluff_J_Gamma_Status_Map_NAD83.mxd August, 2015; aaron.orechwa

## 5.10 Bluff K

### 5.10.1 Overview

The Bluff K study area shown in Figure 1 encompasses 10.6 acres consisting of two spoils piles and berms within an open grass meadow in the middle of a bluff. There are no highwalls associated with this bluff. Using all available data, the Bluff K study area boundary was revised from the historical boundary provided to Tetra Tech which previously encompassed 6.1 acres. Appendix D shows the historical and revised study area boundaries. Bluff K is located in Township 22 North, Range 5 East, Section 21. There are no signs of erosion from the berms or spoils piles; vegetation at the site consists of approximately 90 percent vegetative cover (USFS 2006).

### 5.10.2 Characterization Status

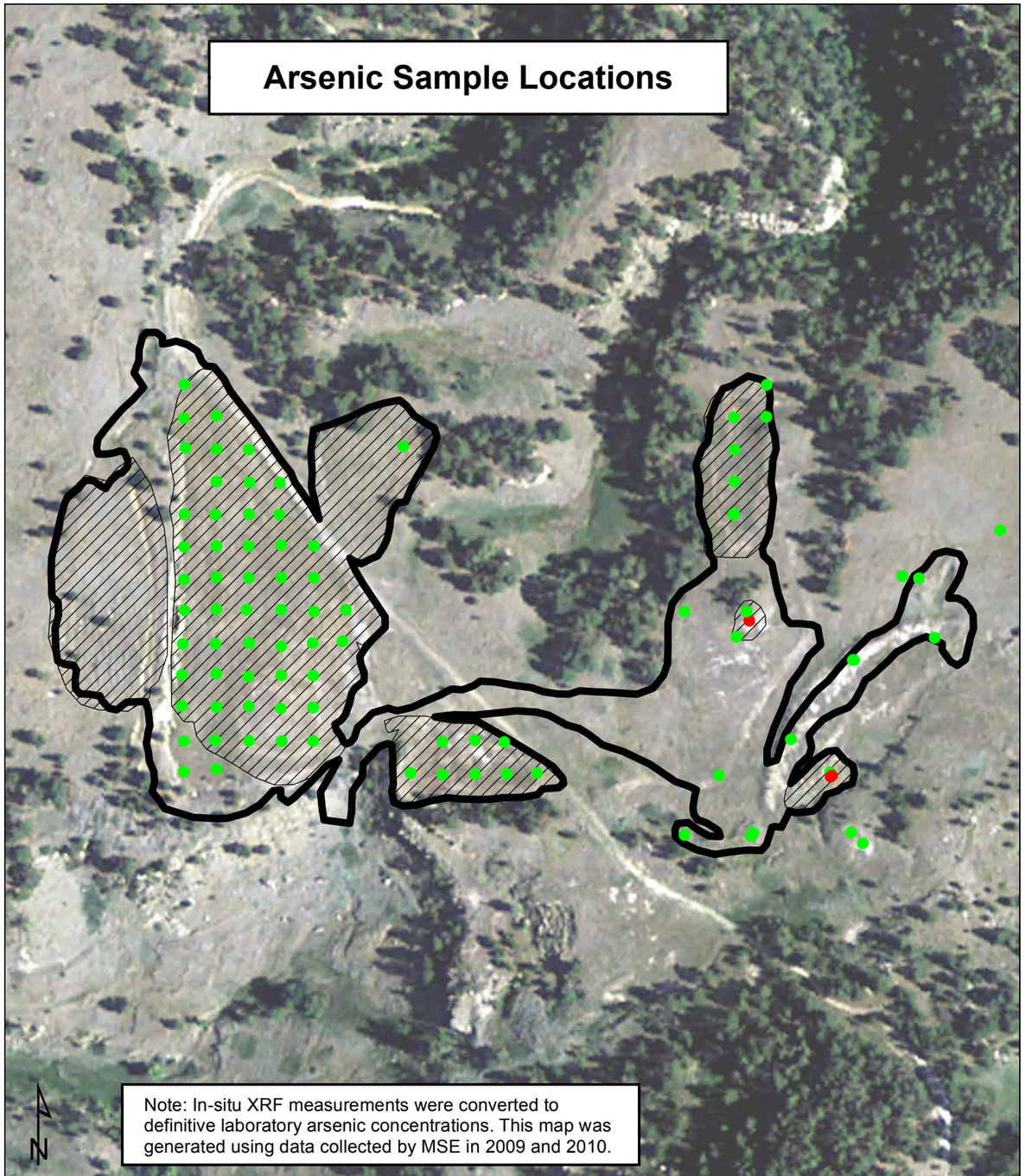
Bluff K was first studied by Pioneer in a 1999 and 2000 field sampling investigation (USFS 2002). One acutely contaminated area was observed during this sampling investigation. It is located at the end of a small dozer cut within the berm materials and is located on the southeastern portion of the site. A more comprehensive characterization study involving an in situ XRF field survey and gamma radiation survey was performed at Bluff K by MSE and Tetra Tech in 2008, and the results are presented in MSE (2009). During the 2008 investigation, soil samples were collected at Bluff K. One surface sample contained arsenic at 788 mg/kg, and one subsurface sample collected at 1.5 feet below ground surface had an arsenic concentration of 443 mg/kg. Another subsurface sample, which was collected from inside an animal burrow in a large mound, contained an arsenic concentration of 167 mg/kg (MSE 2009).

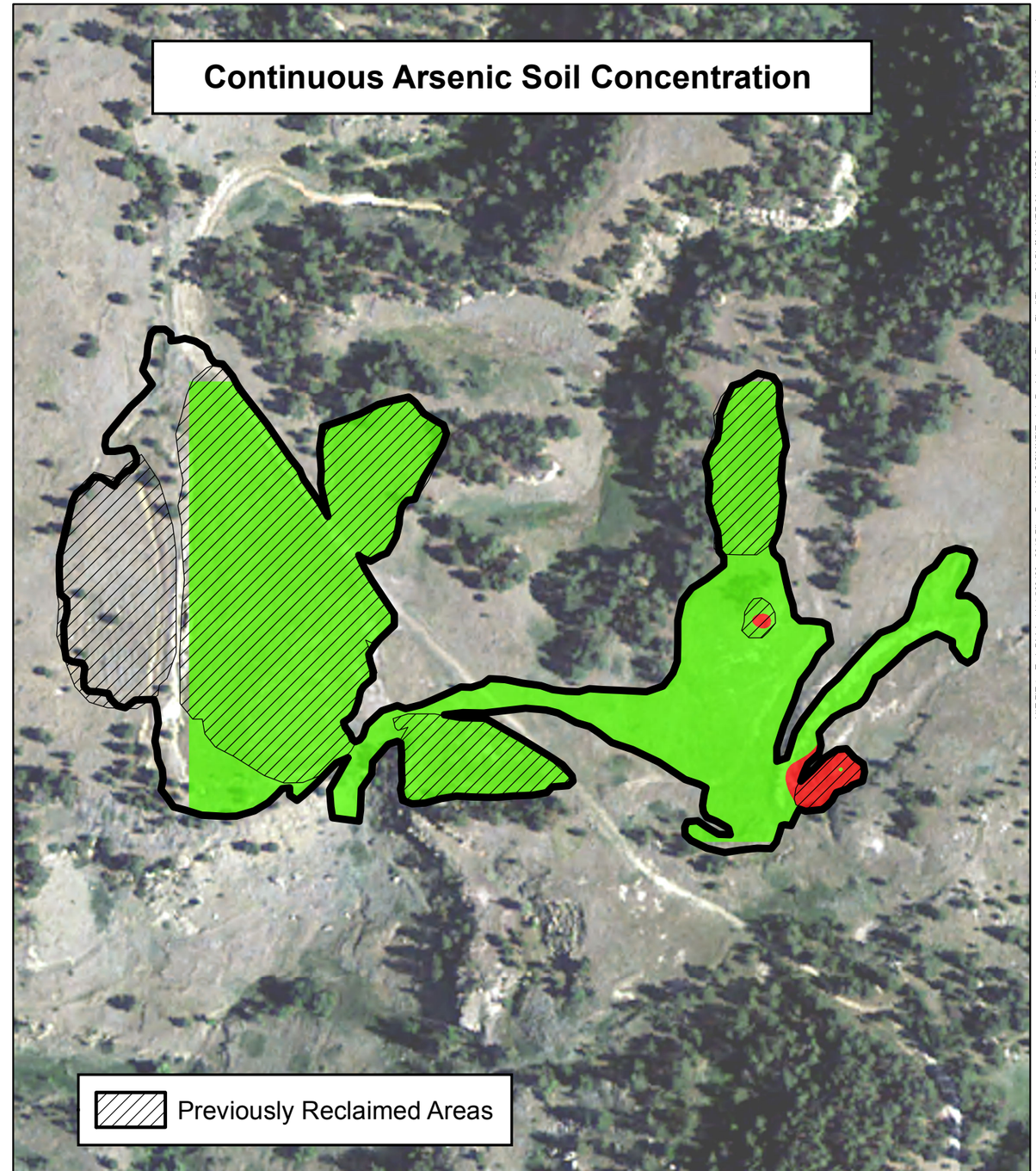
### 5.10.3 Reclamation Status

The USFS performed reclamation at Bluff K in 2010. Two small, slightly elevated areas bordering the south edge of the borrow area contained gamma measurements that exceeded 90 µR/hr. However, as mentioned above, these areas did not exceed the cleanup goal of 30 pCi/g; therefore, no cover soil was added to these areas. An XRF field survey was performed by MSE in 2010 to verify attainment of cleanups standards. The results of this verification survey showed that four point measurements of arsenic exceeded the cutoff value of 142 mg/kg; however, in general the cover soils appear to be below the cleanup goal established for arsenic at the site. Consolidated mine waste and spoils materials on Bluff K have been sufficiently covered with clean borrow soil to reduce arsenic concentrations at the surface to less than 142 mg/kg (MSE 2010c). Cleanup attainment was determined to be successful based on the criteria established at the time of verification survey was performed at Bluff K as summarized in (MSE 2010c).

### 5.10.4 Recommendations

Tetra Tech utilized all available characterization and verification survey data to generate status update maps of Bluff K based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff K is provided in Figure 21. A status update map showing the Ra-226 soil concentrations at Bluff K is provided in Figure 22. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial interpolation methods. The status update maps provide the boundaries of previously reclaimed areas and reflect the current conditions at the study area using all available information. The characterization and verification survey data at Bluff K is inadequate to determine if attainment of cleanup objectives for arsenic has been achieved. Tetra Tech recommends further investigation at Bluff K for arsenic.




SCALE IN FEET

0 100 200

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**

< 142 ≥ 142

Prepared For:

Prepared By:

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970-223-9600

Title:

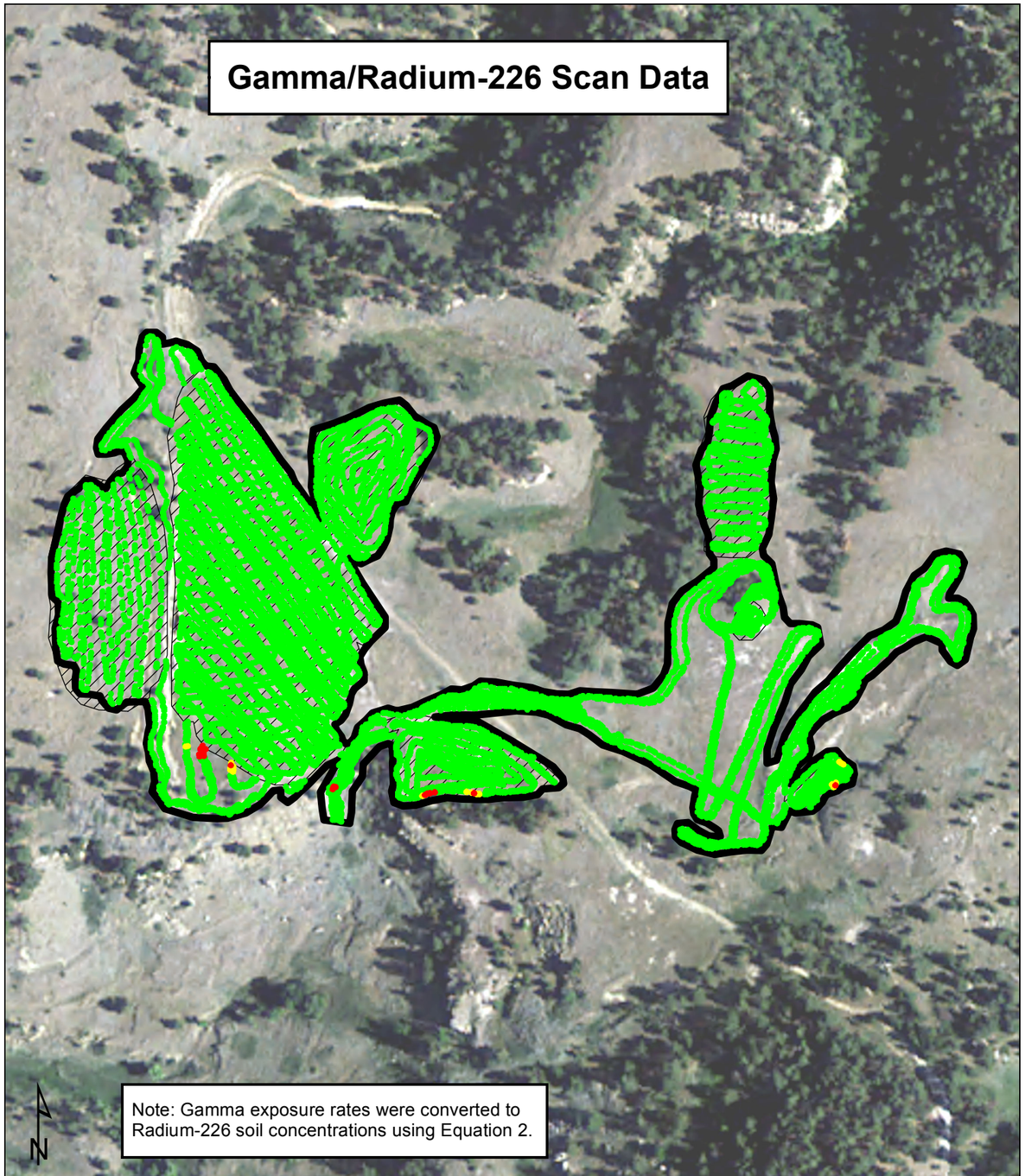
**FIGURE 21 BLUFF K**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

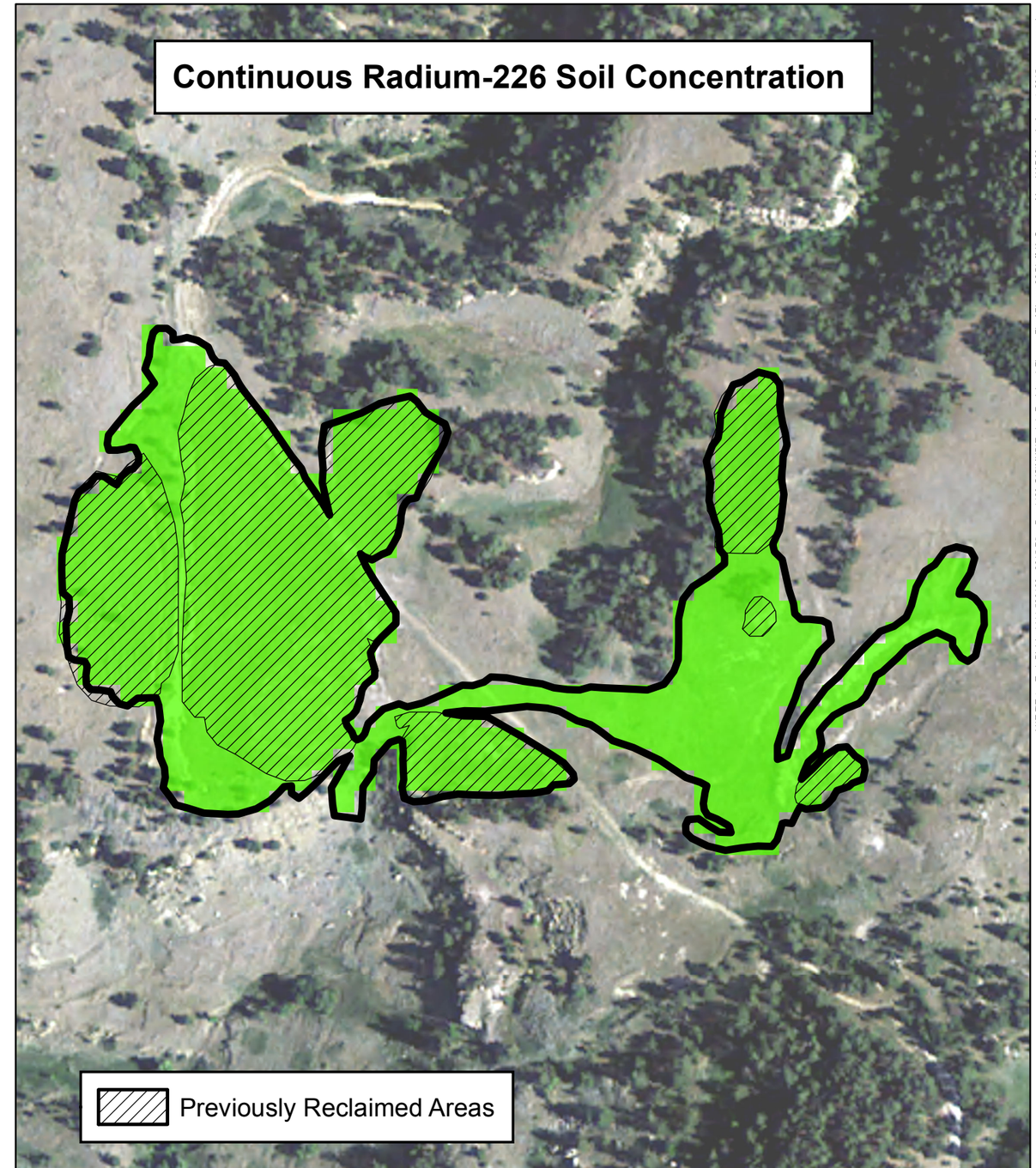
Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 21 Bluff_K_XRF_Map_NAD83.mxd August, 2015: aaron.orechwa




SCALE IN FEET
0 100 200

NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**

< 30 | 30 - 50 | ≥ 50

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Prepared By:

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Title:

**FIGURE 22 BLUFF K**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

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## 5.11 Bluff L

### 5.11.1 Overview

The Bluff L study area shown in Figure 1 encompasses 10.0 acres consisting of several small spoils piles, and old roads throughout the study area. Bluff L is located in Township 22 North, Range 5 East, Section 29. Using all available data, the Bluff L study area boundary was revised from the historical boundary provided to Tetra Tech which previously encompassed 8.2 acres. Appendix D shows the historical and revised study area boundaries. One larger spoils pile, approximately 44,100 $yd^3$, is located on the north end of the site in a dry draw. These volumes will need to be recalculated based on the new waste categorization criteria presented in this report. Several small erosion rills and gullies have formed on the face of this spoils pile. Vegetation at the site consists of approximately 85 percent to 90 percent vegetative cover in flatter areas and approximately 65 percent to 70 percent vegetative cover on the steeper faces of the spoils pile (USFS 2006). There is an exposed lignite coal seam on the eastern side of the large spoils pile.

### 5.11.2 Characterization Status

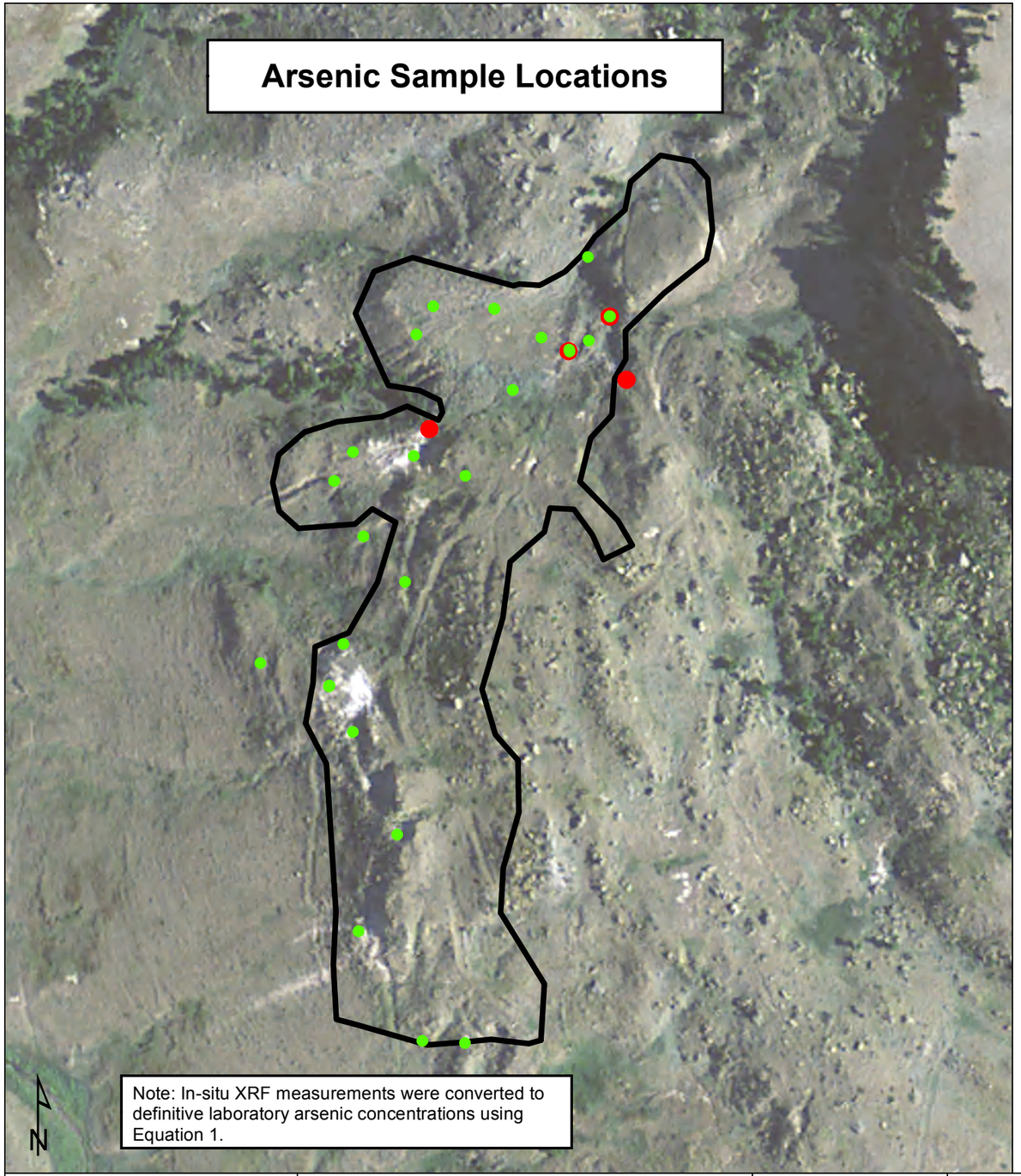
Bluff L was first studied by Pioneer in a 1999 and 2000 field sampling investigation (USFS 2002). No metal concentrations at the site were documented to be greater than three times the background concentrations. A more comprehensive characterization study involving an in situ XRF field survey and gamma radiation survey was performed at Bluff L by MSE and Tetra Tech in 2008, and the results are presented in MSE (2009). Four XRF arsenic measurements exceeded the cleanup criterion of 142 mg/kg.

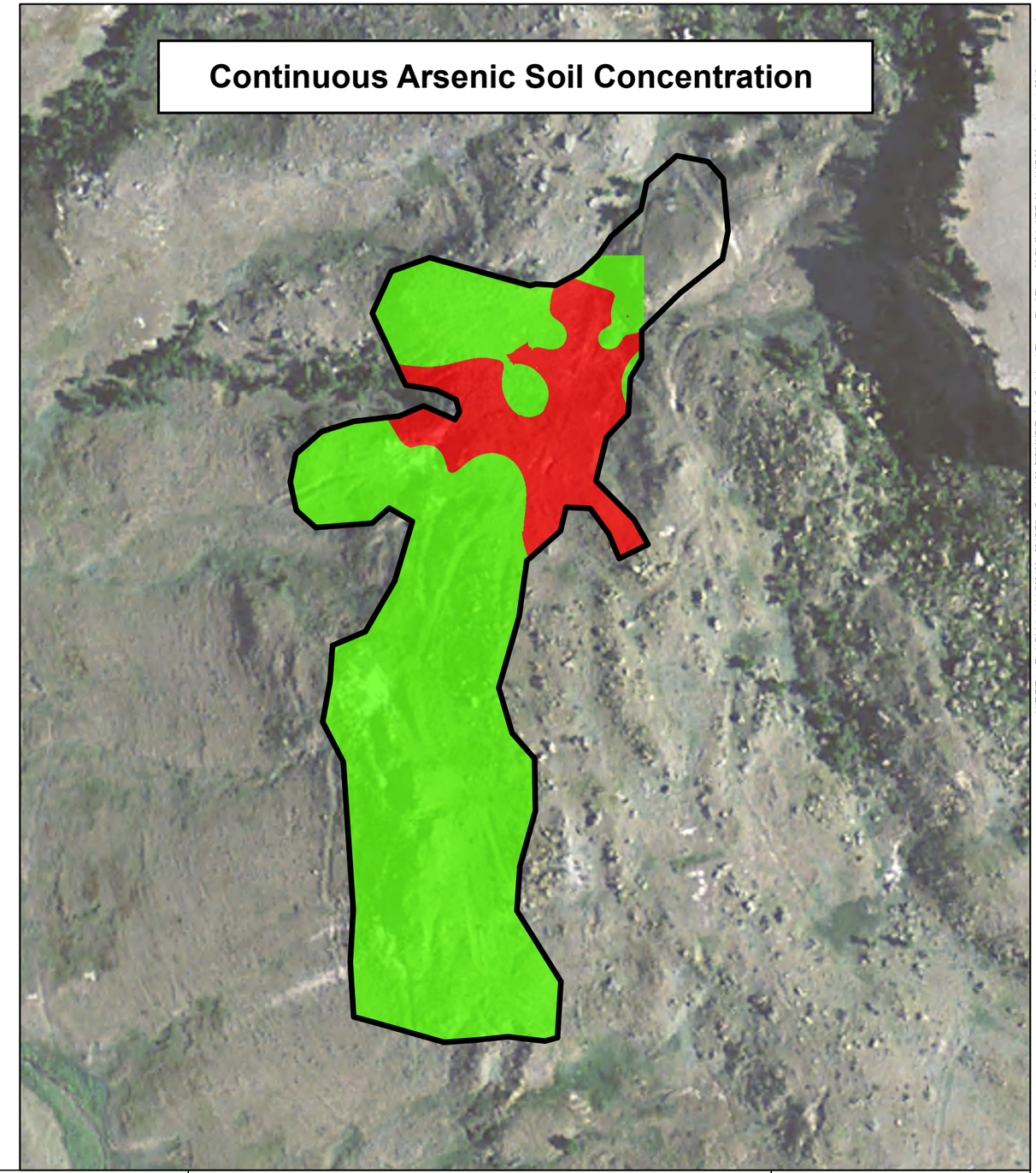
### 5.11.3 Reclamation Status

No reclamation has been performed to date at Bluff L.

### 5.11.4 Recommendations

Tetra Tech utilized all available characterization survey data to generate status update maps of Bluff L based on the risk-based cleanup standards proposed in this report (Section 3.4). A status update map showing the arsenic soil concentrations at Bluff L is provided in Figure 23. A status update map showing the Ra-226 soil concentrations at Bluff L is provided in Figure 24. The status update maps provide continuous surfaces for concentrations in soil on the right side that were generated using geospatial interpolation methods. The status update maps reflect the current conditions at the study area using all available information. Dispersed areas of arsenic and Ra-226 soil contamination remain at Bluff L. Tetra Tech recommends removal action at Bluff L to reduce the arsenic and Ra-226 concentrations below the soil cleanup levels. Before a detailed removal action design for Bluff L is completed, Tetra Tech recommends that additional characterization be conducted to further discretize hot spots of contamination needed for removal action design particularly areas on the northeast and eastern boundary of the study area.




SCALE IN FEET
0 100 200
NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Arsenic Soil Concentration (mg/kg)**
< 142 ≥ 142

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**FIGURE 23 BLUFF L**
**2015 STATUS UPDATE**
**ARSENIC SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD
Project no.: 114-560486A
Date of Issue: AUGUST 2015

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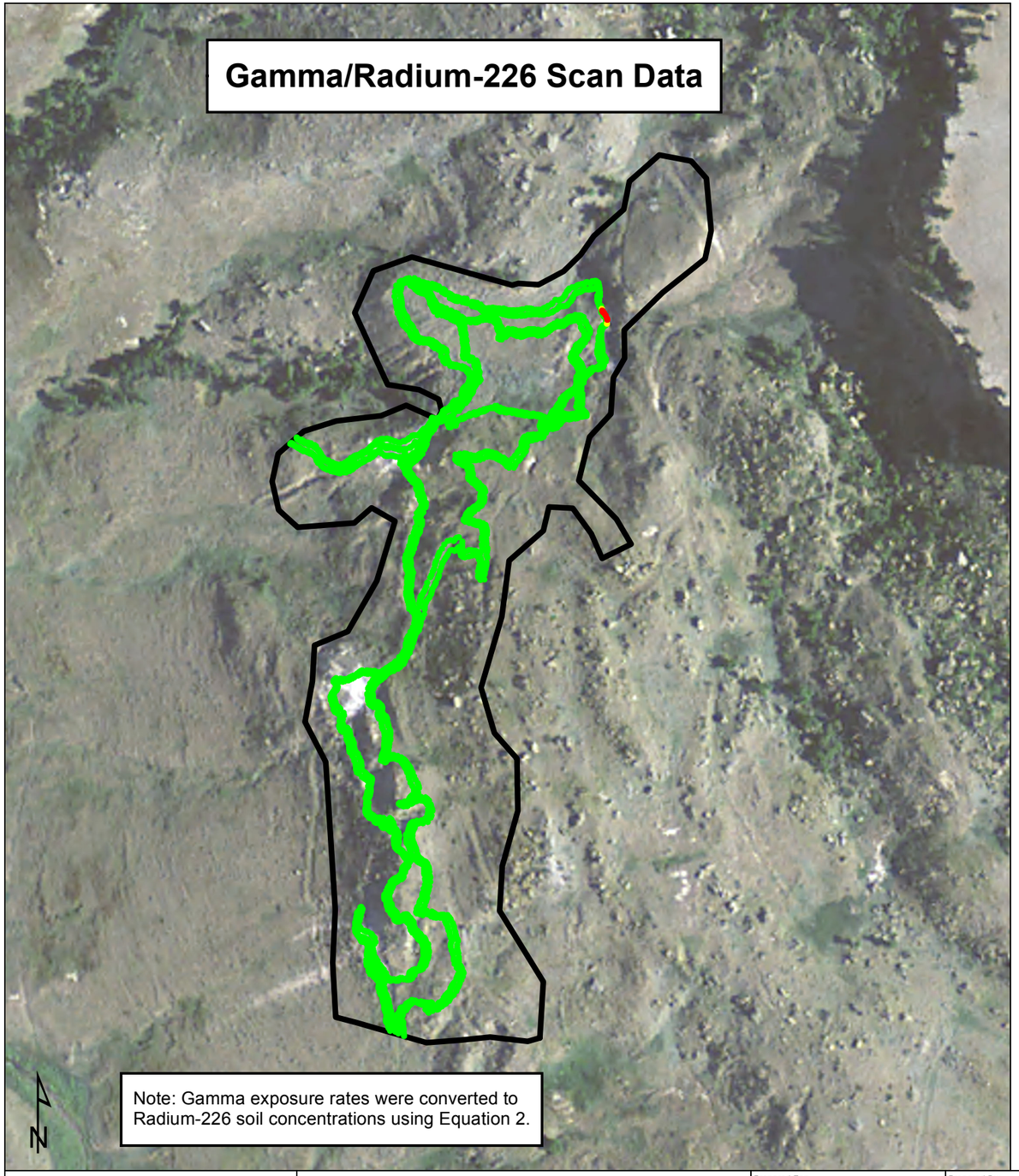


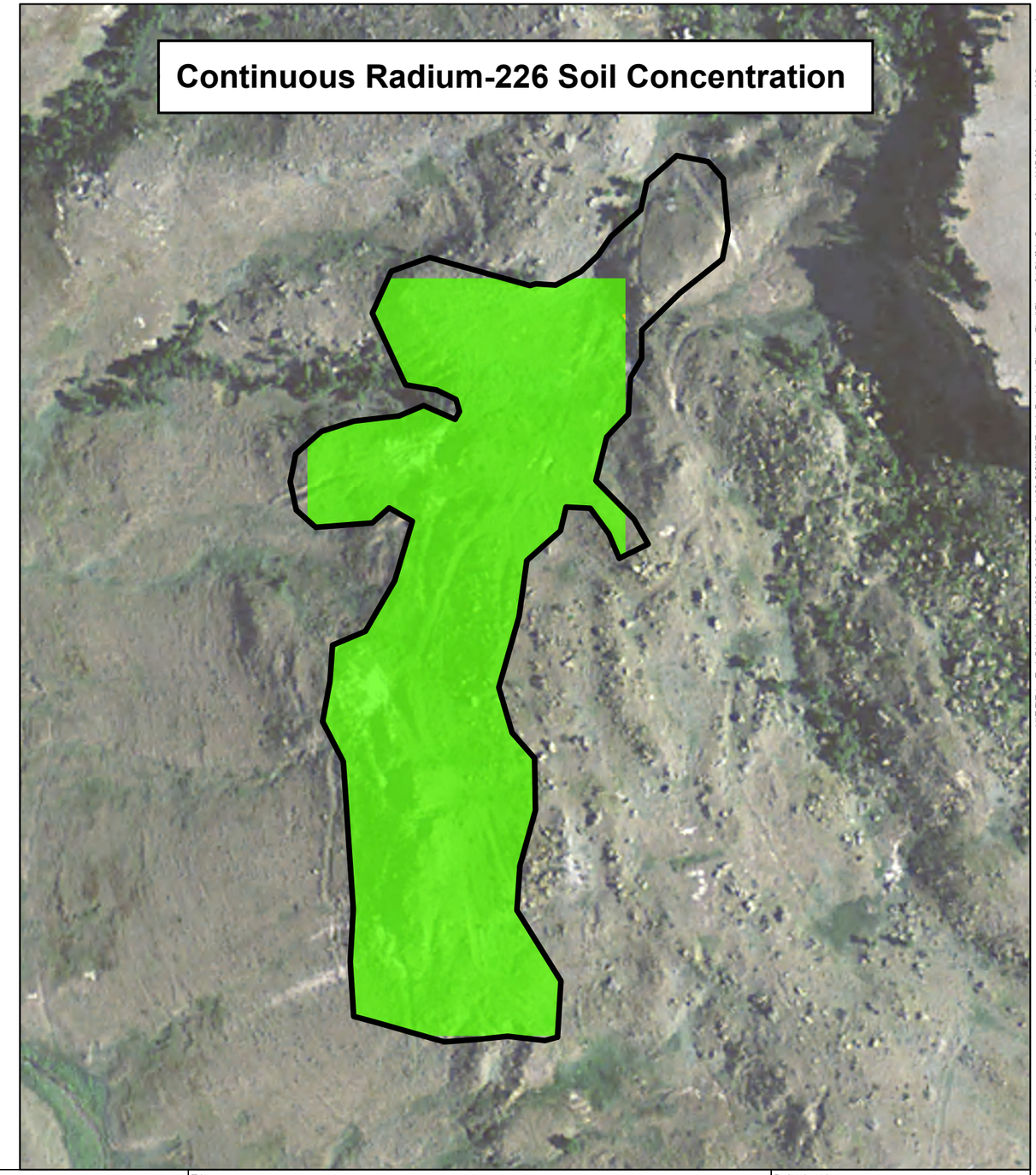


SCALE IN FEET
0 100 200
NAD_1983_STATEPLANE_SOUTH_DAKOTA NORTH_FIPS_4001_FEET

**Radium-226 Soil Concentration (pCi/g)**
< 30 | 30 - 50 | ≥ 50

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**FIGURE 24 BLUFF L**
**2015 STATUS UPDATE**
**RA-226 SOIL CONCENTRATION MAP**

Project Location: HARDING COUNTY, SD
Project no.: 114-560486A
Date of Issue: AUGUST 2015

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Task 1 Revision 1 Figures Final\Figure 24 Bluff_L_Gamma_Map_NAD83.mxd August, 2015: aaron.orechwa

# 6.0 CONCLUSIONS

This report presents the findings and recommendations of the waste characterization evaluation and document review performed by Tetra Tech for the Riley Pass Abandoned Uranium Mine site located in Custer Gallatin National Forest in Harding County, South Dakota. The environmental conditions at the site present an imminent and substantial endangerment to human health and the environment posed by the presence of elevated concentrations in soil of heavy metals and radionuclides (USFS 2004, 2006, 2007, 2010). These conditions met the criteria for initiating a removal action under 40 CFR Section 300.415 (b)(2) of the NCP. Executive Order 12580, Executive Order 13016, and 7 CFR 2.60(a)(39) delegate removal action authority to the USFS when the potential for release is on or from National Forest System lands. Significant amounts of information and scientific studies are available pertaining to the Riley Pass site. Tetra Tech performed a detailed review and summarized all relevant historical environmental studies, action memorandums, and scientific reports related to the Riley Pass site (Section 2.0). A detailed evaluation of the Portage (2006) risk assessment was conducted by a qualified senior toxicologist, as presented in Appendix A. The proposed cleanup levels for Riley Pass were evaluated for their potential risks (carcinogenic) and hazards (non-carcinogenic) to receptors who may be present at the site. No additional COPCs were identified for the site. The proposed cleanup values for the Riley Pass site are as follows:

- Arsenic: 142 mg/kg
- Molybdenum: 2,775 mg/kg
- U-238: 42.8 pCi/g
- U-234: 44.6 pCi/g
- U-235: 2.03 pCi/g
- Ra-226: 30.0 pCi/g
- Th-230: 39.8 pCi/g

Since most uranium locations are on federal lands, the primary exposure scenarios to technologically enhanced naturally occurring radioactive material (TENORM) wastes at uranium mines involve recreational use of the site, in which the abandoned mine is visited occasionally by hikers, campers, or driven through by ATVs. COPCs present in soil at current concentrations pose cancer risks to a recreational receptor (child and adult) from ingestion of soil, dermal contact or external exposure to soil, and inhalation of particulates totaling $1.2 \times 10^{-5}$ from these COPCs. Ingestion of deer meat is associated with a risk of $3.8 \times 10^{-6}$ (at 10 percent fraction ingested) at these concentrations in soil. The total cancer risk from all pathways would, therefore, be $1.6 \times 10^{-5}$ if all COPCs were present at the recommended cleanup values. Molybdenum is not carcinogenic. At a concentration of 2,775 mg/kg in soil, the hazard index to a recreational receptor from molybdenum would be approximately 0.16, below the threshold value of 1. The risks and hazards to the recreational receptor were calculated assuming an exposure frequency of 32 days per year for 30 years, for 4 hours per day at the site.

These cleanup concentrations identified above correspond to a risk of $1.3 \times 10^{-5}$ for a permit holder through soil ingestion, dermal exposure or external exposure to soil, and inhalation of particulates. The hazard index associated with molybdenum at the cleanup concentration would be approximately 0.004. The risk from ingestion of beef (at 10 percent fraction ingested from the site) is $6.1 \times 10^{-6}$ assuming that all COPCs are present at their cleanup values. In total, the maximum risk would total $1.9 \times 10^{-5}$ to the permit holder under these exposure assumptions. It is assumed that a permit holder is present at the site 60 days per year, for 30 years, for 2 hours each day.

Risk probabilities are compared to the generally acceptable risk range specified by the EPA. According to the revised NCP (EPA 1990), carcinogenic risks from exposures at Superfund sites are considered to be unacceptable at cancer risks greater than $1 \times 10^{-4}$, whereas cancer risks less than $1 \times 10^{-6}$ are considered to be minimal concern. Action may not be necessary in the cancer risk range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$. This is supported in the directive *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (EPA 1991), which indicates action is generally warranted at a site when the cumulative carcinogenic risk for any medium is greater than $1 \times 10^{-4}$ or the cumulative non-carcinogenic hazard index exceeds 1. The risk associated with the proposed risk-based cleanup values for soil at the Riley Pass site have been found to be within the acceptable range of lifetime cancer risk ($1 \times 10^{-4}$ to $1 \times 10^{-6}$) based on EPA guidance for the CERCLA remedial program and for ecological risks that were evaluated. If removal action objectives are met, the risks will likely be reduced significantly because the overall average concentrations in soil at the study areas will be significantly less than the risk-based cleanup criteria.

Exposure to uranium and radium and other contaminants in abandoned mine waste can increase a person's risk of cancer. The exposures associated with the highest risks at the Riley Pass site are ingestion of arsenic in soil and external radiation from radium. The combination of arsenic and radium produces very high cancer risks to potential on-site residents (EPA 2008). The costs associated with screening multiple contaminants during the removal action and the verification sampling will be greatly reduced if only arsenic and Ra-226 need to be measured. Therefore, Tetra Tech performed an analysis to evaluate the possibility of solely estimating cleanup boundaries based on arsenic and Ra-226 and assessing the potential removal of the other COPCs. Appendix B showed that all the COPCs (excluding Th-230, which was not evaluated) will be reduced below the cleanup criteria using only the arsenic and Ra-226 cleanup boundaries. A technology review was performed by Tetra Tech, showing that in situ XRF field surveys and gamma radiation surveys are practical, cost effective, and provide definitive results for measuring arsenic and Ra-226 in surface soils. These techniques should be relied on during the removal action to guide cleanup and during the post-reclamation verification sampling. **Tetra Tech recommends measuring attainment success based on the risk-based arsenic (142 mg/kg) and Ra-226 (30 pCi/g) concentrations in soil, and recommends using these criteria for all future characterization data collection, reclamation design, and verification sampling strategies.**

All of the site-wide data available were thoroughly reviewed and entered into a geodatabase by Tetra Tech. Status updates are provided in this report on all 10 study areas, and detailed maps showing both the point data and continuous surfaces of arsenic and concentrations in soil have been produced. Using the available information, data gaps were identified and additional sampling recommendations are provided in the following section.

Overall, the waste management strategies presented in this report will achieve reductions at the Riley Pass site within the target range ($10^{-4}$ to $10^{-6}$ cancer risk) deemed acceptable by the EPA based on site-specific assumptions presented in the risk assessment. The information provided in this report met the project objectives in full and provides data summaries and recommendations intended to support development of all future work at the site, including the following: (1) 2015 Action Memorandum (2) future reclamation design, and (3) Riley Pass Verification Sampling Plan.

# 7.0 RECOMMENDATIONS

One of the primary objectives of this report is determine if additional sampling is needed to adequately characterize the study areas and to provide recommendations. Tetra Tech performed a detailed review of all the useable available data collected at the Riley Pass site. Tetra Tech has developed a number of additional recommendations from the comprehensive review. The following items are recommended:

1. Development of a 2015 Action Memorandum;
2. Development of a Riley Pass Verification Sampling Plan;
3. Sampling and characterization of sediment transported outside of study area boundaries;
4. Additional characterization at Bluff A, Bluff B, Bluff CDE, Bluff H, Bluff K, and Bluff L; and
5. Subsurface investigations of Bluff B.

The rationale for each of these recommended items is discussed below:

Development of a 2015 Action Memorandum: A comprehensive summary analysis of the existing action memorandums is provided in Section 3.0 of this report. Tetra Tech recommends that a new action memorandum be developed by the USFS because of the following reasons:

- The 2007 Action Memorandum (USFS 2007) states a correlation exists between arsenic and Ra-226. Significant information has been collected since that disparages that statement, as presented in AECOM (2008b), MSE (2009), and Tetra Tech (2013b).

- Inconsistent language in the 2010 Action Memorandum (USFS 2010).

- Revised mine waste categorization criteria have been proposed [≥ 142 mg/kg and ≥ 30 pCi/g Ra-226].

Development of a Riley Pass Verification Sampling Plan: Tetra Tech recommends that a site-wide *Riley Pass Verification Sampling Plan* (VSP) be developed once a new action memorandum has been authorized.

Sampling and characterization of sediments outside of study area boundaries: Tetra Tech performed a comprehensive review of historical site documents related to the Riley Pass site. This review found that contamination was found in the Upper Pete's Creek watershed below and to the east of Bluff B (Stone et. al 2009). Uranium and arsenic concentrations were found to be 23 times and 89 times higher than background, respectively. This study found that background concentrations were achieved a distance of ~5 kilometers downstream of Bluff B. Similarly, contaminated sediments were observed in the eastern drainage of Bluff H. Tetra Tech performed a hydrologic analysis that is summarized in Appendix F of this report. The analysis showed that a number drainages are located directly through some of the soil cleanup areas and are likely impacting drainages coming off of the study areas. Tetra Tech recommends future sediment sampling outside of the study area boundaries in order to identify potential contaminant sources and to gain a better understanding of the existing conditions within these drainages. The existing conditions can be then be monitored in the future to assess how well removal action measures are being implemented at the site.

Additional characterization at Bluff A, Bluff B, Bluff H, and Bluff L: Tetra Tech performed a comprehensive review of all available data at each of the 10 study areas. A data gap analysis showed that additional sampling is needed to fully characterize the spatial extent of contamination and determine if removal action is needed at any of the study areas. Tetra Tech recommends the following additional sampling:

- Bluff A
  - Additional grid-based XRF and gamma surveys within the existing study area boundary.
  - Additional grid-based XRF and gamma surveys outside of the existing study area boundary to the north and south.
- Bluff B
  - Additional grid-based XRF and gamma surveys along the eastern and northeastern portions of the boundary.
  - Further grid-based XRF and gamma surveys within the existing boundary to discretize the hot spots in more detail.
- Bluff CDE
  - Tetra Tech recommends further investigation to determine if any material has moved outside the study area.
- Bluff H
  - Additional grid-based XRF and gamma surveys along the western and southern portions of the boundary.
  - Further grid-based XRF and gamma surveys within the existing boundary to discretize the hot spots in more detail.
- Bluff K
  - Additional grid-based XRF field surveys within the study area boundary.
- Bluff L
  - Additional grid-based XRF and gamma surveys within the existing study area boundary.
  - Additional grid-based XRF and gamma surveys outside of the existing study area boundary to the north and south.

Subsurface investigation: The information collected at the site and presented in this report focuses on surface contamination. Little information is known about the depth of contamination. Tetra Tech recommends consideration of a detailed subsurface investigation at all of the study areas.

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# APPENDIX A

# RISK ASSESSMENT EVALUATION FOR RILEY PASS ABANDONED URANIUM MINES

USDA Forest Service
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# Appendix A

# Risk Assessment Evaluation for Riley Pass Abandoned Uranium Mines

Tetra Tech Project No. 114-560486A

August 24, 2015

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# 1.0 PURPOSE

This appendix presents a review of the risk assessment (Portage 2006) and proposed risk-based cleanup goals for the Riley Pass Abandoned Uranium Mines Site in South Dakota. It is conducted under the U.S. Forest Service (USFS) Contract GS-10F-0268K in the current effort to fully characterize the site and implement removal action.

# 2.0 RISK ASSESSMENT REVIEW

As part of the comprehensive review of work performed and historical information on the Riley Pass Abandoned Uranium Mines site, the existing human health risk assessment was reviewed. A baseline human health and ecological risk assessment published by Portage Environmental, Inc. (Portage) in May 2006 (Portage 2006) assessed human exposures for several different receptors for Bluffs B and H and lignite exposures to the contaminants of potential concern (COPC) identified in soils, which included the following:

- Arsenic
- Molybdenum
- Selenium
- Uranium (U) as U-238, U-234, and U-235
- Radium-226 (Ra-226)
- Thorium-230 (Th-230)

Per the Portage report, the concentrations of these COPCs were found to be the highest relative to background and other screening values, including published risk-based preliminary remediation goals (PRGs). Uranium was assessed in the Portage document as U-234, U-235, and U-238. Some other radionuclides were also evaluated in this quantitative risk assessment (lead-210, protactinium-231, and actinium-227) but remediation assessments since that time have focused mainly on arsenic and radium.

The exposure assessment in Portage 2006 identified the following potential receptors for the site, based on uses of the site as documented by the Custer National Forest Sioux Ranger District:

- Cattle ranchers (permit holders);
- Recreationists;
- Native Americans; and
- U.S. Forest Service employees and contractors.

The following exposure parameters were identified from the documented site uses and were used in the risk assessment for a quantitative assessment of exposure:

- Permit Holder: 60 days per year, 2 hours per day. Exposure though inhalation of dust, direct contact with soil, incidental ingestion of soil, and ingestion of beef from cattle that have grazed at the site.

- Recreational Visitor (including a hunter): 32 days per year, 4 hours per day. Exposure through inhalation of dust, direct contact with soil, incidental ingestion of soil, and ingestion of deer that have grazed at the site.

- Native American Site User: 25 hours per year, or 1 hour per day for 25 days per year. Exposure through inhalation of dust, direct contact with soil, and incidental ingestion of soil.

- U.S. Forest Service employees and contractors: the evaluation of this pathway was limited to construction worker exposure, on the site for 12 days per year. Exposure through inhalation of dust, direct contact with soil, and incidental ingestion of soil.

Note that surface water and groundwater were not evaluated as media of concern to humans in the risk assessment (Portage 2006) document and discussions of such are not included in this appendix. Reclamation alternatives evaluated in the Final Engineering Evaluation and Cost Analysis [EE/CA] (USFS 2006) are applicable to the contaminated solid media; no reclamation alternatives for groundwater, surface water, or contaminated stream sediments are analyzed in detail. The rationale for not directly developing alternatives for those media is based primarily on the presumption that reclaiming the contaminant sources will subsequently reduce any problems associated with groundwater, surface water, or stream sediments at a significantly reduced cost (USFS 2006). Concentrations of the COPCs vary depending on the study area of concern, and each may not be a concern depending on location. However, the COPCs and the receptors identified in Portage (2006) are still considered most representative of site conditions and exposures.

# 3.0 REVIEW OF CLEANUP CRITERIA

Cleanup criteria for soil are generally based on two considerations: natural background conditions of an area, and risk-based considerations. Each of these considerations is described below. Risk-based cleanup criteria are based on predicted human or ecological receptor exposure to the affected media of interest, with the recognition that background values are the preferred cleanup goal if the background concentrations exceed the risk-based criteria.

## 3.1 BACKGROUND LEVELS

Background levels are defined by the U.S. Environmental Protection Agency (EPA) as "substances or locations that are not influenced by releases from a site," and naturally occurring background refers to "substances present in the environment in forms that have not been influenced by human activity" (EPA 2002).

Table 2-3 of the risk assessment (Portage 2006) identified the following background levels in soil for the COPCs evaluated in the risk assessment:

- Arsenic: 28.2 milligrams per kilogram (mg/kg)
- Molybdenum: 4.1 mg/kg
- Selenium: 4.6 mg/kg
- Uranium:
    - U-238: 0.9 picocuries per gram (pCi/g)
    - U-234: 1.0 pCi/g
    - U-235: 0.1 pCi/g
- Radium-226 (Ra-226): 1.8 pCi/g
- Thorium-230 (Th-230): 1.5 pCi/g

These values represent the calculated 95 percent upper confidence limit (UCL) of the mean concentration for radionuclides (results in pCi/g). *Note: Table 6-2 of the EE/CA (USFS 2006) states that the 95 percent UCL for Ra-226 is 2.3 pCi/g, not 1.8 pCi/g.* For other COPCs (results in mg/kg), they represent average concentrations from site-specific background data or from published sources for the conterminous United States. The COPCs identified are at concentrations higher than background in many locations and, therefore, were retained for the quantitative risk assessment by Portage.

## 3.2 RISK-BASED CLEANUP CRITERIA

The risk assessment (Portage 2006) found risks to permit holders to be the highest, based on their more frequent use of the site, their longer exposure times and durations, and through ingestion of beef cattle that had grazed on the site. Recreational exposure to the site was associated with the second-most risk, again because of the frequency and durations of exposures relative to the Native American site user and the U.S. Forest Service Worker/contractor scenarios.

Based on the assessment of risk and concerns at other bluffs, arsenic, molybdenum, Ra-226, and uranium (-234, -235, and -238) became the focus of the remediation efforts for reduction of the majority of the risk. The following cleanup goals were proposed, which differ from the PRGs in the risk assessment

(Portage 2006). These values were proposed in the 2010 Action Memorandum (USFS 2010), and are evaluated here:

- Arsenic: 142 mg/kg
- Molybdenum: 2,775 mg/kg
- U-238: 42.8 pCi/g
- U-234: 44.6 pCi/g
- U-235: 2.03 pCi/g
- Ra-226: 30 pCi/g

Portage conducted a comparison of site concentrations to risk-based ecological screening levels for terrestrial plants and animals for ecological receptors (2006). Table 1 presents the screening levels used for the ecological hazard assessment.

**Table 1. Summary of Ecological Hazard Assessment (Portage 2006)**

| COPC | Soil Biota Concentration Guides (mg/kg) | Toxicity Reference Values (mg/kg-day)(range of values)[1] |
|---|---|---|
| | Plants | Animals |
| Arsenic | 10 | 0.019 – 5.1 |
| Molybdenum | 2 | 0.04 – 3.5 |
| Selenium | 1 | 0.056 – 0.5 |
| COPC | Soil Biota Concentration Guides (pCi/g) | |
| Ra-226 | 300 | 50 |
| U-234 | 50,000 | 5,000 |
| U-235 | 30,000 | 3,000 |
| U-238 | 20,000 | 2,000 |

[1] The range of values represents the toxicity associated with the COPC for cattle, cottontail rabbits, deer, red fox, red tailed hawks, and robins. It is not a soil screening concentration.
mg/kg = milligrams/kilogram
pCi/g = picocuries per gram

In general, as summarized in the EE/CA for Bluff H (USFS 2006), the Portage risk assessment found that there was a low potential for impacts to ecological receptors through the presence of radionuclides and selenium (hazard quotients ranging from 0.3 to 2.1) and a greater hazard from arsenic and molybdenum (hazard quotients ranging from 50 to 300). Again, the risk evaluation for ecological receptors indicated that arsenic and molybdenum should be included in remediation considerations (Portage 2006).

## 3.3 Evaluation of Existing Cleanup Levels

This appendix re-evaluates the proposed risk-based cleanup levels to assess whether they are still applicable and appropriate to the site. The current proposed risk-based cleanup values were reevaluated using methodology presented in EPA 2008, currently published toxicity and reference values, and site-specific exposure assumptions, focusing on the recreational receptor and permit holder as the maximally exposed individuals to the site.

The receptors and site-specific exposure parameters identified have not, to the knowledge of Tetra Tech team members on this project, changed since the 2006 evaluation. They were assumed to be applicable to the site at this time. The permit holder and recreational receptor were selected for re-evaluation as these two receptors were associated with the highest estimated risks in the risk assessment (Portage 2006). In addition, the risk assessment (Portage 2006) indicated that the COPCs to be carried forward were Ra-226, uranium, arsenic, and molybdenum.

In 2008, the EPA published a review of potential health and environmental issues associated with abandoned uranium mines. This report provided recommended equations for evaluating risks and cleanup levels at abandoned uranium mines for radionuclides as well as arsenic. A recreational receptor with an exposure frequency of 1 to 350 days per year was evaluated with a range of target risks from $1 \times 10^{-4}$ to $1 \times 10^{-6}$. To evaluate the proposed cleanup levels for Riley Pass site, the methodology employed in the EPA (2008) document was used, as well as a qualitative comparison of Riley Pass results to those in EPA (2008) document.

# 4.0 QUANTITATIVE ASSESSMENT

EPA (2008) equations were entered into an Excel spreadsheet (Attachment 1) to assess the risks associated with the proposed cleanup levels. The cleanup levels are as follows:

- Arsenic: 142 mg/kg
- Molybdenum: 2,775 mg/kg
- U-238: 42.8 pCi/g
- U-234: 44.6 pCi/g
- U-235: 2.03 pCi/g
- Ra-226: 30 pCi/g
- Th-230: 39.8 pCi/g

The following exposure parameters were used in the equations for soil ingestion, external exposure, and inhalation of particulates for radionuclides. Ingestion of soil for arsenic was evaluated per the EPA (2008) document to include child and adult exposures; molybdenum was also evaluated for the soil ingestion pathway, and copper has been included as well based on more recent site characterization data. Table 2 presents the exposure parameters used to in the risk evaluation.

**Table 2. Exposure Parameters Used to Evaluate Risk**

| Parameter | Recreational | Permit Holder |
|---|---|---|
| Exposure Frequency (days/year) | 32 | 60 |
| Exposure Time (hours/day) | 4 | 2 |
| Exposure Duration (years) | 30 years | 30 |
| Soil Ingestion (mg/day) | 200 – child; 100 –adult | 100 |
| Target Risk | Variable | Variable |
| Arsenic GI absorption (unitless) | 80% | 80% |
| Body weight (kg) | 70 adult; 15 child (arsenic, copper, molybdenum) | 70 adult only |
| Averaging Time (arsenic only) | 70 years | 70 years (arsenic only) |

Note that the re-evaluation for exposure to copper and molybdenum focused on exposure of a child recreational receptor to account for the higher soil ingestion rate and lower body weight of children; this approach results in a more conservative estimate of hazards associated with non-carcinogenic chemicals. Conversely, arsenic is a more potent carcinogen, and exposure to arsenic was evaluated for adults and children in the recreational scenario over a lifetime of exposure. The permit holder is assumed to be an adult only. The adjusted soil ingestion rate for the recreational scenario used the exposure frequency of 32 days per, 200 mg/kg soil ingestion by a child for 6 years and 100 mg/kg for adults for 24 years, divided by the child body weight of 15 kilograms (kg) and the adult body weight of 80 kg (EPA 2015) as follows:

**IR adj = (32 days/year x 200 mg/kg x 6 years)/15 kg + (32 days/year x 100 mg/day x 24 years) / 80 kg =3, 520 mg/kg**

This methodology is different from that used in Portage (2006), as it includes child exposures.

No area correction factor was used for radionuclides because of the size the site (assumed value of 1.0). Exposure time represents outdoor time at the site; no indoor time was assumed, and no gamma shielding factor was used.

Uranium was assessed as U-238 plus daughter products (U-238+D), U-234, and U-235. Secular equilibrium has been determined to exist at the site (Tetra Tech 2013). Th-230 has been evaluated in this assessment although it was not the focus of the Engineering Evaluation/Cost Analysis performed by Pioneer (2006) Table 3 presents the toxicity factors (EPA 2001, 2015) used for assessing risks:

**Table 3. Toxicity Values**

| COPC | External | Soil Ingestion | Food Ingestion | Inhalation | Dermal Exposure |
|---|---|---|---|---|---|
| Ra-226+D | 8.49E-06 | 7.30E-10 | 5.15E-10 | 1.16E-08 | NA |
| U-238+D | 1.14E-07 | 2.10E-10 | 1.21E-10 | 9.35E-09 | NA |
| U-234 | 2.52E-10 | 1.58E-10 | 9.55E-11 | 1.14E-08 | NA |
| U-235 | 5.18E-07 | 1.57E-10 | 9.44E-11 | 1.01E-08 | NA |
| Th-230 | 8.19E-10 | 2.02E-10 | 1.19E-10 | 2.85E-08 | NA |
| Arsenic | NA | 1.5 $(mg/kg\text{-}day)^{-1}$ | 1.5 $(mg/kg\text{-}day)^{-1}$ | 0.0043 $(\mu g/m^3)^{-1}$ | 1.5 $(mg/kg\text{-}day)^{-1}$ |
| Copper | NA | 0.04 mg/kg-day | 0.04 mg/kg-day | NA | NA |
| Molybdenum | NA | 0.005 mg/kg-day | 0.005 mg/kg-day | NA | NA |

All radionuclide values from EPA (2001). All non-radionuclide values are from EPA 2015.
NA = Not Available
mg/kg = milligrams/kilogram

Note that copper and molybdenum are not evaluated for the dermal exposure pathway because they are not considered to be absorbed through the skin. They are also not evaluated for the inhalation pathway because no toxicity values are available for copper and molybdenum through the inhalation pathway at this time. External exposures are evaluated only for radionuclides.

# 5.0 RECREATIONAL EXPOSURE

Exposure through external radiation, soil ingestion, and particulate inhalation were included in the risk-based concentration for Ra-226, U-238+D, U-234, U-235, and Th-230. Dermal exposure, inhalation exposure, and soil ingestion, including a child, were included in the risk-based concentration calculations for arsenic. Only ingestion of soil by a child was included for copper and molybdenum. Table 4 presented the range of risk-based concentrations that were developed:

**Table 4. Calculated Risk-based Concentrations for Recreational Site Use Using USEPA 2008 methods**

| Target Risk[1] | Risk-Based Concentrations for All Pathways Combined – Recreational Exposure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ra-226+D[3] | U-238+D | U-234 | U-235 | Th-230 | Arsenic | Copper | Molybdenum |
| 1.00E-04 | 706 | 14,886 | 26,245 | 8,811 | 20,424 | 1,937 | | |
| 5.00E-05 | 353 | 7,443 | 13,123 | 4,405 | 10,212 | 968 | | |
| 1.00E-05 | 71 | 1,489 | 2,625 | 8,81 | 2,042 | 194 | | |
| 5.00E-06 | 35 | 744 | 1,312 | 441 | 1,021 | 96.8 | | |
| 1.00E-06 | 7 | 149 | 262 | 88 | 204 | 19.4 | | |
| Hazard[2] = 1.0 | NA | NA | NA | NA | NA | NA | 137,000 | 17,100 |

[1] for radionuclides and arsenic
[2] for copper and molybdenum
[3]Concentrations for Ra-226, U-238, U-234, U-235, and Th-230 are presented in picocuries per gram (pCi/g)
[4]Concentraitons for copper and molybdenum are presented in milligrams per kilogram (mg/kg)
NA = Not Available

The proposed cleanup value for Ra-226 of 30 pCi/g, therefore, corresponds to a risk of approximately 4.2 x $10^{-6}$. The proposed goal of 142 mg/kg for arsenic would equate to a risk of about 7.3 x $10^{-6}$. These estimates do not include ingestion of deer meat. The proposed cleanup goal for U-238 of 42.8 pCi/g is associated with a risk of 2.9 x $10^{-7}$. The proposed cleanup goal of 44.6 pCi/g for U-234 corresponds to a risk of 1.7 x $10^{-7}$, and the cleanup goal of 2.08 pCi/g for U-235 corresponds to a risk of 2.3 x $10^{-8}$. For Th-230, the proposed clean-up goal of 39.8 pCi/g corresponds to a risk of 4.9 x $10^{-9}$. The total risk, summed across cleanup goals, would total 1.2 x $10^{-5}$ if each COPC were to remain at a site at these cleanup levels. Furthermore, the proposed cleanup goal of 2,775 mg/kg for molybdenum corresponds to a hazard quotient of 0.16 for recreational receptors, well below the level of concern.

The cleanup goal was compared with the concentration used in the risk assessment (Portage 2006) to evaluate the approximate risk from ingestion of deer meat from the site. The risk assessment (Portage 2006) used the measured site concentrations to estimate intake by deer of soil and contaminated forage, as well as through drinking water. A predicted value for each COPC in the deer meat was then calculated. The difference between the cleanup goals presented here and the concentration used to produce the forward calculation of risk was assumed to equate to the same change in the concentration in meat. The ratio of measured concentration in soil to the predicted concentration in deer meat was used to estimate the concentration in deer meat from the proposed cleanup values. The new estimated concentration in meat was then used to estimate a revised risk associated with arsenic, U-238, U-234, U-235, Ra-226, and Th-230 from ingestion of deer meat.

Specifically, the concentrations used for radionuclides at Bluff B and from Bluff H for non-radionuclides in soil and in tissue were used to calculate a ratio that could be expected between the two media. The proposed cleanup goals were multiplied by this ratio to estimate a concentration in deer meat corresponding to the proposed cleanup value. Using the exposure parameters presented in the risk assessment (Portage 2006), the associated potential risk was then estimated. It was assumed that the change in soil value was directly proportionate to a change in concentration in meat, which is likely an overestimate, as it does not take into account the uptake fraction from soil to plants (forage). Table 5 presents the risk and hazard quotient values associated with the ingestion of deer meat.

**Table 5. Risk and Hazard Quotient associated with Ingestion of Deer Meat**

| COPC | Soil concentration in 2006 Risk Assessment | Deer Meat concentration corresponding to soil concentration (mg/kg) | Ratio | Proposed Cleanup Goal | Estimated deer meat concentration (Cd) using ratio [1] | Associated Risk at 10% ingestion[2] |
|---|---|---|---|---|---|---|
| Ra-226+D | 23.2 pCi/g | 3.65 pCi/kg | 0.157 | 30 pCi/g | 4.72 pCi/g | 3.75E-07 |
| U-238+D | 24 pCi/g | 0.773 pCi/kg | 0.032 | 42.8 pCi/g | 3.22 pCi/g | 2.57E-08 |
| U-234 | 25.7 pCi/g | 0.826 pCi/kg | 0.032 | 44.6 pCi/g | 1.433 pCi/g | 2.11E-08 |
| U-235 | 1.21 pCi/g | 0.0389 pCi/kg | 0.032 | 2.08 pCi/g | 0.0669 pCi/g | 9.74E-10 |
| Th-230 | 24.7 pCi/g | 0.219 pCi/kg | 0.009 | 39.8 pCi/g | 0.35 pCi/g | 6.48E-09 |
| Arsenic | 477.6 mg/kg | 0.146 mg/kg | 0.00023 | 142 mg/kg | 0.032 mg/kg | 3.33E-06 |
| Molybdenum | 617 mg/kg | 0.108 mg/kg | 0.00175 | 2,775 mg/kg | 4.86 mg/kg | 0.08 [3] |

[1]Calculated as (proposed cleanup goal x ratio)
[2]Calculated as Risk = Cd x Ingestion (0.147 kg/day) x 350 days/year x 30 years x Toxicity Value x Fraction Ingested; see Attachment 1
[3]Hazard Index; level of significance starts at 1.0.

Assuming a 10 percent ingestion of deer meat from the site, the risks to a hunter through this pathway would be approximately 3.8 x $10^{-6}$, assuming all COPCs are present at the proposed cleanup levels in soil. These proposed cleanup values would be protective of human health through the pathway of ingestion of deer meat as the site is unlikely to be a permanent source of deer meat for any one individual as well as because deer have a relatively large foraging area.

# 6.0 PERMIT HOLDER

Exposure through external radiation, soil ingestion, and particulate inhalation were included in the risk-based concentration calculations for U-238+D, U-234, U-235, Ra-226, and Th-230. Dermal exposure, soil ingestion and inhalation pathways for adults were included in the risk-based concentration calculations for arsenic. Only ingestion of soil can be quantitatively assessed for copper and molybdenum. Table 6 below provides the range of cleanup goals that were developed.

**Table 6. Risk-Based Concentrations for the Permit Holder Scenario**

| Target Risk | Risk-based Concentrations for All Pathways Combined – Permit Holder | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ra-226+D[1] | U-238+D | U-234 | U-235 | Th-230 | Arsenic | Copper | Molybdenum |
| 1.00E-04 | 362 | 2040 | 2726 | 2311 | 1999 | 663 | | |
| 5.00E-05 | 181 | 1020 | 1363 | 1156 | 1000 | 332 | | |
| 1.00E-05 | 36 | 204 | 273 | 231 | 2000 | 66 | | |
| 5.00E-06 | 18 | 102 | 136 | 116 | 100 | 33 | | |
| 1.00E-06 | 4 | 20 | 27 | 23 | 20 | 7 | | |
| Hazard = 1.0 | NA | NA | NA | NA | NA | NA | 170,333 | 638,750 |

[1]Concentrations for Ra-226, U-238, U-234, U-235, and Th-230 are presented in picocuries per gram (pCi/g)
[2]Concentraitons for copper and molybdenum are presented in milligrams per kilogram (mg/kg)

The proposed cleanup value for Ra-226 of 30 pCi/g, therefore, corresponds to a risk of approximately 7.5 x $10^{-6}$. Risks associated with the proposed cleanup goals for U-238, U-234, and U-235 correspond to risks to the permit holder of 2.14 x $10^{-6}$ for U-238, 1.65 x $10^{-6}$ for U-234, and 8.8 x $10^{-8}$ for U-235. The clean-up goal for Th-230 of 39.8 pCi/g corresponds to a risk of 1.6 x $10^{-6}$. The proposed goal of 142 mg/kg for arsenic would equate to a risk of about 2.03 x $10^{-5}$. These estimates do not include ingestion of beef from cattle grazed on the site.

The cleanup goal was compared with the concentration used in the risk assessment (Portage 2006) to evaluate the approximate risk from ingestion of beef from the site. The Portage estimate used the measured site concentrations to estimate intake by cattle of soil and contaminated forage as well as through drinking water. A predicted concentration in beef for each COPC was then calculated. The difference between the cleanup goals here and the concentration used to produce the forward calculation of risk was assumed to equate to the same change in the concentration in meat. The ratio of measured concentration in soil to the predicted concentration in beef was used to estimate the concentration in beef from the proposed cleanup values. The new estimated concentration in meat was then used to estimate a revised risk associated with arsenic, molybdenum, U-238, U-234, U-235, Ra-226, and Th-230 from ingestion of beef.

Specifically, the concentrations used for radionuclides at Bluff B and from Bluff H for non-radionuclides in soil and in tissue were used to calculate a ratio that could be expected between the two media. The proposed cleanup goals were multiplied by this ratio to estimate a concentration in beef corresponding to the proposed cleanup value. Using the exposure parameters presented in the risk assessment (Portage 2006), the associated potential risk was then estimated. It was assumed that the change in soil value was directly proportionate to a change in concentration in meat, which is likely an overestimate as it does not

take into account the uptake fraction from soil to plants (forage). Table 7 presents the risks from 10 percent beef ingestion.

**Table 7. Risks From Beef ingestion at 10 Percent Fraction Ingested**

| COPC | Soil concentration in 2006 Risk Assessment | Beef concentration corresponding to soil concentration (mg/kg) | Ratio | Proposed Cleanup Goal | Estimated beef concentration using ratio [1] | Associated Risk at 10% ingestion[2] |
|---|---|---|---|---|---|---|
| Ra-226+D | 23.2 pCi/g | 4.63 pCi/g | 0.19957 | 30 pCi/g | 5.99 pCi/g | 4.76E-07 |
| U-238+D | 24 pCi/g | 1.16pCi/g | 0.0483 | 42.8 pCi/g | 4.83 pCi/g | 3.86E-08 |
| U-234 | 25.7 pCi/g | 1.24 pCi/g | 0.0483 | 44.6 pCi/g | 2.15 pCi/g | 3.17E-08 |
| U-235 | 1.21 pCi/g | 0.0585 pCi/g | 0.0483 | 2.08 pCi/g | 0.101 pCi/g | 1.47E-09 |
| Th-230 | 24.7 pCi/g | 0.33 pCi/g | 0.013 | 39.8 pCi/g | 0.53 pCi/g | 9.77E-09 |
| Arsenic | 477.6 mg/kg | 0.189 mg/kg | 0.000396 | 142 mg/kg | 0.056 mg/kg | 5.82E-06 |
| Molybdenum | 617 mg/kg | 0.165 mg/kg | 0.0027 | 2775 mg/kg | 7.42 mg/kg | 0.13 (hazard) |

[1]Calculated as (proposed cleanup goal x ratio)
[2]Calculated as shown in Attachment 1
COPC = contaminant of potential concern
mg/kg = milligrams/kilogram
pCi/g = picocuries per gram

Assuming a 10 percent ingestion of beef from the site, the risks to a permit holder through this pathway would be approximately 6.1 x $10^{-6}$ or less. As the site cannot be used year-round, the cattle are unlikely to be exposed to the site COPCs for all food intake. Additionally, areas of the site are already below these proposed cleanup values. Furthermore, it was assumed that the change in soil value was directly proportionate to a change in the concentration in meat, which is likely an overestimate. However, assuming 100 percent ingestion of all beef comes from cattle exposed to the site, as estimated in the risk assessment (Portage 2006), the risks associated with arsenic in meat could exceed 1 x $10^{-4}$, and from Ra-226 the risks could approach 5 x $10^{-5}$.

# 7.0 ECOLOGICAL SCREENING LEVELS

In Portage (2006), soil screening levels for plants were presented and hazard quotients for ecological receptors (birds and terrestrial mammals) were calculated. A direct comparison to the screening levels for plants was conducted to evaluate the proposed cleanup levels for non-radionuclides, and a ratio comparison of hazard quotients associated with measured concentrations in soil to the proposed cleanup levels was conducted. This approach represents a reasonably conservative estimate of impacts without recalculation of soil exposures by terrestrial receptors. The soil biota concentration guides for plants and animals were used to assess potential hazards to ecological receptors for radionuclides. Table 8 provides the evaluation of impact of cleanup goals on ecological receptors.

**Table 8. Evaluation of Impact of Cleanup Goals on Ecological Receptors**

| Metals COPCs | Soil BCGs (mg/kg) | | Proposed Cleanup Concentration | Hazard Quotient |
|---|---|---|---|---|
| | Plants | Animals | (mg/kg) | |
| Arsenic | 10 | See discussion | 142 | 14.2 |
| Molybdenum | 2 | See discussion | 2,775 | 1388 |
| **Radionuclide COPCs** | **Soil BCGs (pCi/g)** | | **Proposed Cleanup Concentration** | **Hazard Quotient** |
| | **Plants** | **Terrestrial Animals** | **(pCi/g)** | |
| Ra-226 | 300 | 50 | 30 | 0.1 - 0.6 |
| U-234 | 50,000 | 5,000 | 100 | 0.005 – 0.05 |
| U-235 | 30,000 | 3,000 | 100 | 0.003 – 0.03 |
| U-238 | 20,000 | 2,000 | 100 | 0.002 – 0.02 |

COPC = contaminant of potential concern
BCGs = Biota concentration guides
mg/kg = milligrams/kilogram
pCi/g = picocuries per gram

Based on the ratios of proposed soil cleanup level to screening concentrations, the radionuclides do not appear to be of issue for terrestrial plants and animals at or above the proposed cleanup values. (Hazard indices are well below 1.0.) The cleanup concentration for arsenic exceeds the screening level for plants, but the background concentration for the site of 28 mg/kg also exceeds the screening level. These exceedances indicate that in some areas, even the background arsenic concentration may be too high to allow or encourage plant growth. The proposed cleanup goal for molybdenum is associated with a high hazard quotient that indicates impacts to plants would be likely.

A semi-quantitative assessment of the ratios of hazard quotients associated with measured soil concentrations to the proposed cleanup values was conducted to estimate impacts to terrestrial animals from arsenic and molybdenum. Results of this assessment are provided in Table 9 below.

**Table 9. Estimates of Hazard Quotients to Terrestrial Animals from Proposed Cleanup Concentrations**

| | COPC | | Ratio (Cleanup Value/Soil Concentration) | |
|---|---|---|---|---|
| | **Arsenic** | **Molybdenum** | **Arsenic** | **Molybdenum** |
| Measured Soil Concentration (mg/kg) | 447 | 617 | 0.32 | 4.5 |
| | **HQ for Soil ingestion [1]** | | **Predicted HQ for Soil Ingestion** | |
| HQ Rabbit | 105 | 67.8 | 33.4 | 304.94 |
| HQ Red Tailed Hawk | 0.915 | 0.00604 | 0.29 | 0.027 |
| HQ Red Fox | 25.7 | 16 | 8.16 | 71.96 |
| HQ Robin | 2.26 | 4.26 | 0.72 | 19.16 |
| HQ Deer | 38.7 | 23.7 | 12.29 | 106.59 |
| HQ Cattle | 11.7 | 7.15 | 3.72 | 32.16 |

[1] Hazard Quotient (HQ) for soil ingestion pathway as determined in Portage 2006 from statistical summary of measured concentrations in soil at Bluff H.
mg/kg = milligrams/kilogram

Based on this analysis, the overall hazard quotient from arsenic would decrease in areas where the concentration is above the proposed cleanup value of 142 mg/kg, but the cleanup concentration may still pose a hazard to rabbits, deer, and red-tailed fox. Similarly, the cleanup value of molybdenum of 2,775 mg/kg may present a hazard to rabbits, red fox, robins, deer, and cattle, but much of the site will be below the cleanup value and pose a much lesser hazard.

# 8.0 CONCLUSIONS

The proposed cleanup values appear to be protective of human health and should result in site-associated risks below $1 \times 10^{-4}$ and usually below $1 \times 10^{-5}$ in total, summed across COPCs and all exposure pathways. The risks remain in the range of acceptability even when including ingestion of deer meat or beef at the 10 percent fraction ingested assumption and at the exposure assumptions used to perform calculations. The cleanup goal for molybdenum is also below levels that would pose a hazard to humans in a recreational or permit holder scenario.

The proposed cleanup values are consistent with those presented in EPA (2008). The risk-based concentrations presented include ingestion of soil by a child and adults for the recreational scenario, which results in a lower overall concentration than presented in the EPA (2008) document. Molybdenum was not evaluated in EPA (2008). The radionuclide cleanup values are also consistent with those in the EPA (2008) document, but the values presented in this appendix are more directly applicable to the site because they incorporate site-specific exposure frequencies and durations.

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## External Exposure - Radionuclides only

$$SSL = \frac{TR}{SFE \times \frac{EF}{365} \times ED \times ACF \times [ETO + (ETI \times GSF)]}$$

Notes:
All values in agreement with EPA 2008 and Portage 2006. Some rounding differences with U nat
Also, USEPA used different slope factors than Riley Pass (purposeful).

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SFE | unitless | 8.49E-06 |
| EF | days/year | 14 |
| ED | years | 1 |
| ACF | unitless | 1 |
| ETO | unitless | 1 |
| ETI | unitless | 0 |
| GSF | unitless | 0 |

| | SFE |
|---|---|
| Radium-226 | 8.49E-06 |
| Thorium-232 | 1.23E-05 |
| U-nat | 2.14E-07 |

Riley Pass slope factors are the correct ones. to use for the site-specific assessment

This assumes a 24 hr/day exposure

SSL - external exposure

| | Ra-226 (pCi/g) | Th-232 | U-nat |
|---|---|---|---|
| TR | Scenario 1 | Scenario 1 | Scenario 1 |
| 5.00E-04 | 1535 | 1059.8 | 60914.6 |
| 1.00E-04 | 307 | 212.0 | 12182.9 |
| 5.00E-05 | 153.5 | 106.0 | 6091.5 |
| 1.00E-05 | 30.7 | 21.2 | 1218.3 |
| 5.00E-06 | 15.4 | 10.6 | 609.1 |
| 1.00E-06 | 3.07 | 2.1 | 121.8 |

## Soil Ingestion -Radionulcides

$$SSL = \frac{TR}{SFs \times EF \times ED \times IRs \times 1\,E-3}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SFE | unitless | 3.39E-09 |
| EF | days/year | 14 |
| ED | years | 1 |
| Irs | unitless | 120 |
| Conversion | g/mg | 0.001 |
| | | |
| | | |

| | SFs |
|---|---|
| Radium-226 | 3.39E-09 |
| Thorium-232 | 3.33E-09 |
| U-nat | 6.48E-10 |

SSL - soil ingestion

| | Ra-226 (pCi/g) | Th-232 | U-nat |
|---|---|---|---|
| TR | Scenario 1 | Scenario 1 | Scenario 1 |
| 5.00E-04 | 87793.23 | 89375.09 | 55115 |
| 1.00E-04 | 17558.65 | 17875.02 | 11023 |
| 5.00E-05 | 8779.32 | 8937.51 | 5511 |
| 1.00E-05 | 1755.86 | 1787.50 | 1102 |
| 5.00E-06 | 877.93 | 893.75 | 551 |
| 1.00E-06 | 175.59 | 178.75 | 919 |

## Inhalation of Dust -Radionulcides

$$SSL = \frac{TR}{SFs \times EF \times ED \times IRs \times 1\,E-3}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SF i | unitless | 2.55E-08 |
| INH | m3/day | 20 |
| 1/PEF | 1/(m3/kg) | 1.32E+09 |
| EF | days/year | 350 |
| ED | years | 1 |
| | | |
| Conversion | g/kg | 1000 |

| | SFs |
|---|---|
| Radium-226 | 2.55E-08 |
| Thorium-232 | 1.92E-07 |
| U-nat | 6.14E-08 |

checked USEPA 2008 - consistent

SSL - soil ingestion

| | Ra-226 (pCi/g) | Th-232 | U-nat |
|---|---|---|---|
| TR | Scenario 1 | Scenario 1 | Scenario 1 |
| 5.00E-04 | 3697478.99 | 491071.43 | 1535597.95 |
| 1.00E-04 | 739495.80 | 98214.29 | 307119.59 |
| 5.00E-05 | 369747.90 | 49107.14 | 153559.80 |
| 1.00E-05 | 73949.58 | 9821.43 | 30711.96 |
| 5.00E-06 | 36974.79 | 4910.71 | 15355.98 |
| 1.00E-06 | 7394.96 | 982.14 | 3071.20 |

## Dermal Exposure - Nonradionuclides only

Arsenic is the only nonradionulcide at Riley Pass evaluated for this pathway
Other metals are not assessed for this pathway
The equation is for children; a different one is needed for child +adult exposures

$$SSL = \frac{TR\ x\ AT\ x\ 365\ x\ BW}{SFo \times EF \times ED \times SA \times AF\ x\ ABS\ x\ 1E{-}6}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| AT | years | 70 |
| BW | unitless | 15.0 |
| SF o | unitless | 1.5 |
| EF | days/year | 14 |
| ED | years | 1 |
| SA | cm2 | 2800 |
| AF | mg/cm2 | 0.2 |
| ABS | unitless | 0.03 |

| TR | Arsenic (mg/kg) Scenario 1 |
|---|---|
| 5.00E-04 | 543154.8 |
| 1.00E-04 | 108631.0 |
| 5.00E-05 | 54315.5 |
| 1.00E-05 | 10863.1 |
| 5.00E-06 | 5431.5 |
| 1.00E-06 | 1086.3 |

## Soil Ingestion -Non- Radionulcides

Arsenic:

$$SSL = \frac{TR\ x\ AT\ x\ 365}{SFo \times EF \times 1E-6 \times IRadj - s}$$

Arsenic - Carcinogenic

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| Sfo | 1/(mg/kg-day) | 1.50E+00 |
| AT | years | 70 |
| EF | days/year | 14 |
| IR adj-s | mg/kg-day | 13.33333333 |
| Conversion | unitless | 1.00E-06 |
| | | |
| | | |

Copper and Molybdenum

$$SSL = \frac{THQ\ x\ ED\ x\ 365\ x\ BW}{\left(\frac{1}{RfDo}\right) \times EF \times EDx\ 1E-6 \times IR}$$

Copper and Manganese

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| BW | kg | 15.0 |
| AT | years | 1 |
| EF | days/year | 14 |
| IR | mg/kg-day | 200 |
| Conversion | unitless | 1.00E-06 |
| RfD | 1/(mg/kg-day) | chem specific |
| ED | years | 1 |

| | RfD |
|---|---|
| Cu | 4.00E-02 |
| Mo | 5.00E-03 |

| TR | Arsenic (mg/kg) Scenario 1 | |
|---|---|---|
| 5.00E-04 | 45625.0 | |
| 1.00E-04 | 9125.0 | |
| 5.00E-05 | 4562.5 | |
| 1.00E-05 | 912.5 | |
| 5.00E-06 | 456.3 | does not agree with USEPA 2008 but it is close (10% difference) |
| 1.00E-06 | 91.3 | USEPA may have a typo in their ingestion rate |

| Copper Scenario 1 | Molybdenum Scenario 1 |
|---|---|
| 78214 | 9777 |

## Inhalation of Dust - Non-Radionulcides

$$SSL = \frac{TR\ x\ AT\ x\ 365}{SFo \times EF \times ED \times ET\ x\ \left(\frac{1}{PEF}\right) x\ \ 1\ E3}$$

Arsenic Only - no toxicity values for copper and manganese

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| Sfo | 1/(ug/m3) | 4.30E-03 |
| AT | years | 70 |
| EF | days/year | 14 |
| ET | hrs exp/24 hours | 0.083333333 |
| Conversion | ug/mg | 1.00E+03 |
| PEF | years | 161047637 |
| | | |

| TR | Arsenic (mg/kg) Scenario 1 |
|---|---|
| 5.00E-04 | 410109680.3 |
| 1.00E-04 | 82021936.1 |
| 5.00E-05 | 41010968.0 |
| 1.00E-05 | 8202193.6 |
| 5.00E-06 | 4101096.8 |
| 1.00E-06 | 820219.4 |

## Permit Holder - Adult Exposure Parameters
## External Exposure - Radionuclides only

$$SSL = \frac{TR}{SFE \times \frac{EF}{365} \times ED \times ACF \times [ETO + (ETI \times GSF)]}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SFE | unitless | 8.49E-06 |
| EF | days/year | 5 |
| ED | years | 1 |
| ACF | unitless | 1 |
| ETO | unitless | 1 |
| ETI | unitless | 0 |
| GSF | unitless | 0 |

SFE (Riley Pass)

| | | | |
|---|---|---|---|
| Radium-226 | 8.49E-06 | | |
| Thorium-230 | 8.19E-10 | U-234 | U-235 |
| U-nat | 1.14E-07 | 2.52E-10 | 5.18E-07 |

EF = # days/year x # hours/day/24 hours

**ENTER DATA HERE**

| | | |
|---|---|---|
| EF = | 60 | days/year |
| Time | 2 | hours day |
| ED | 30 | years |

SSL - external exposure

| | Ra-226 (pCi/g) | Th-232 | U-nat | U-234 | U-235 |
|---|---|---|---|---|---|
| TR | Scenario 1 | Scenario 1 | Scenario 1 | | |
| 5.00E-04 | 4299 | 44566545 | 320175 | 144841270 | 70463 |
| 1.00E-04 | 860 | 8913309 | 64035 | 28968254 | 14093 |
| 5.00E-05 | 430 | 4456654 | 32018 | 14484127 | 7046 |
| 1.00E-05 | 86 | 891331 | 6404 | 2896825 | 1409 |
| 5.00E-06 | 43 | 445665 | 3202 | 1448413 | 705 |
| 1.00E-06 | 9 | 89133 | 640 | 289683 | 141 |

## Soil Ingestion -Radionulcides

$$SSL = \frac{TR}{SFs \times EF \times ED \times IRs \times 1\,E-3}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SFE | unitless | 7.30E-10 |
| EF | days/year | 60 |
| ED | years | 30 |
| Irs | unitless | 120 |
| Conversion | g/mg | 0.001 |
| | | |
| | | |

| | SFs |
|---|---|
| Radium-226 | 7.30E-10 |
| Thorium-230 | 2.02E-10 |
| U-238+D | 2.10E-10 |
| U-234 | 1.58E-10 |
| U-235 | 1.57E-10 |

SSL - soil ingestion

| | Ra-226 (pCi/g) | Th-230 | U-238+D | U-234 | U-235 |
|---|---|---|---|---|---|
| TR | Permit Holder | Permit Holder | Permit Holder | | |
| 5.00E-04 | 3171 | 11459 | 11023 | 14651 | 14744 |
| 1.00E-04 | 634 | 2292 | 2205 | 2930 | 2949 |
| 5.00E-05 | 317 | 1146 | 1102 | 1465 | 1474 |
| 1.00E-05 | 63 | 229 | 220 | 293 | 295 |
| 5.00E-06 | 32 | 115 | 110 | 147 | 147 |
| 1.00E-06 | 6 | 23 | 22 | 29 | 29 |

## Inhalation of Dust -Radionulcides

$$SSL = \frac{TR}{SFi \times X\ IRa\ x\ PEF \times EF \times ED \times 1000}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SF i | unitless | 1.16E-08 |
| IR a | m3/day | 20 |
| PEF | m3/kg | 1.61E+08 |
| EF | days/year | 60 |
| ED | years | 30 |
| | | |
| Conversion | g/kg | 1000 |

| | SFs |
|---|---|
| Radium-226 | 1.16E-08 |
| Thorium-230 | 2.85E-08 |
| U-238+D | 9.35E-09 |
| U-234 | 1.14E-08 |
| U-235 | 1.01E-08 |

SSL - soil ingestion

| | Ra-226 (pCi/g) | Th-230 | U-238+D | U-234 | U-235 |
|---|---|---|---|---|---|
| TR | Permit Holder | Permit Holder | Permit Holder | Permit Holder | Permit Holder |
| 5.00E-04 | 192825 | 78483 | 239227 | 196208 | 221463 |
| 1.00E-04 | 38565 | 15697 | 47845 | 39242 | 44293 |
| 5.00E-05 | 19283 | 7848 | 23923 | 19621 | 22146 |
| 1.00E-05 | 3857 | 1570 | 4785 | 3924 | 4429 |
| 5.00E-06 | 1928 | 785 | 2392 | 1962 | 2215 |
| 1.00E-06 | 386 | 157 | 478 | 392 | 443 |

## Combined Pathway SSLs - without beef

| TR | Ra-226 (pCi/g) | Th-230 (pCi/g) | U-238+D (pCi/g) | U-234 (pCi/g) | U-235 (pCi/g) |
|---|---|---|---|---|---|
| 5.00E-04 | 1808 | 9997 | 10202 | 13631 | 11557 |
| 1.00E-04 | 362 | 1999 | 2040 | 2726 | 2311 |
| 5.00E-05 | 181 | 1000 | 1020 | 1363 | 1156 |
| 1.00E-05 | 36 | 200 | 204 | 273 | 231 |
| 5.00E-06 | 18 | 100 | 102 | 136 | 116 |
| 1.00E-06 | 4 | 20 | 20 | 27 | 23 |

## Dermal Exposure - Nonradionuclides only

Arsenic is the only nonradionulcide at Riley Pass evaluated for this pathway
Other metals are not assessed for this pathway
The equation is for adults; a different one is needed for child +adult exposures

$$SSL = \frac{TR\ x\ AT\ x\ 365\ x\ BW}{SFo \times EF \times ED \times SA \times AF\ x\ ABS\ x\ 1E{-}6}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| AT | years | 70 |
| BW | unitless | 70.0 |
| SF o | unitless | 1.5 |
| EF | days/year | 60 |
| ED | years | 30 |
| SA | cm2 | 3300 |
| AF | mg/cm2 | 0.2 |
| ABS | unitless | 0.03 |

| TR | Arsenic (mg/kg) Scenario 1 |
|---|---|
| 5.00E-04 | 16727 |
| 1.00E-04 | 3345 |
| 5.00E-05 | 1673 |
| 1.00E-05 | 335 |
| 5.00E-06 | 167 |
| 1.00E-06 | 33 |

## Soil Ingestion -Non- Radionulcides

**Arsenic:**

$$SSL = \frac{TR\ x\ AT\ x\ 365\ x\ BW}{SFo \times EF \times ED\ x\ 1E-6 \times IRs}$$

**Copper and Molybdenum**

$$\mathrm{SSL} = \frac{THQ\ x\ ED\ x\ 365\ x\ BW}{\left(\frac{1}{RfDo}\right) \times EF \times ED x\ 1E-6 \times IR}$$

**Arsenic - Carcinogenic**

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| Sfo | 1/(mg/kg-day) | 1.50E+00 |
| AT | years | 70 |
| EF | days/year | 60 |
| IR adj-s | mg/kg-day | 100 |
| Conversion | unitless | 1.00E-06 |
| ED | years | 30 |
| BW | kg | 70 |

**Copper and Manganese**

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| BW | kg | 70.0 |
| AT | years | 30 |
| EF | days/year | 60 |
| IR | mg/kg-day | 100 |
| Conversion | unitless | 1.00E-06 |
| RfD | 1/(mg/kg-day) | chem specific |
| ED | years | 30 |

| | RfD |
|---|---|
| Cu | 4.00E-02 |
| Mo | 5.00E-03 |

| TR | Arsenic (mg/kg) Permit Holder | Arsenic (mg/kg) 80% GI absorption | Copper Permit Holder 170333 | Molybdenum Permit Holder 638750 |
|---|---|---|---|---|
| 5.00E-04 | 3312 | 4140.0 | | |
| 1.00E-04 | 662 | 828.0 | | |
| 5.00E-05 | 331 | 414.0 | | |
| 1.00E-05 | 66 | 82.8 | | |
| 5.00E-06 | 33 | 41.4 | | |
| 1.00E-06 | 7 | 8.3 | | |

## Inhalation of Dust - Non-Radionulcides

$$SSL = \frac{TR \; x \; AT \; x \; 365}{SFi \times EF \times ED \times ET \; x \; \left(\frac{1}{\;}\right) \; x \; 1000}$$

Arsenic Only - no toxicity values for copper and manganese

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SF i | 1/(ug/m3) | 4.30E-03 |
| AT | years | 70 |
| EF | days/year | 60 |
| ET | hrs exp/24 hours | 0.083333333 |
| Conversion | ug/mg | 1.00E+03 |
| PEF | years | 161047637 |
| ED | years | 30 |

| TR | Arsenic (mg/kg) Permit Holder |
|---|---|
| 5.00E-04 | 3189742 |
| 1.00E-04 | 637948 |
| 5.00E-05 | 318974 |
| 1.00E-05 | 63795 |
| 5.00E-06 | 31897 |
| 1.00E-06 | 6379 |

## Combined Pathway SSLs - without beef

| TR | Arsenic (mg/kg) | | | |
|---|---|---|---|---|
| 5.00E-04 | 3315 | | | |
| 1.00E-04 | 663 | | | |
| 5.00E-05 | 332 | | | |
| 1.00E-05 | 66 | | | |
| 5.00E-06 | 33 | Copper | HI = | Molybdenum |
| 1.00E-06 | 7 | 170333 | 1 | 638750 |

## External Exposure - Radionuclides only - Annual

$$SSL = \frac{TR}{SFE \times \frac{EF}{365} \times ED \times ACF \times [ETO + (ETI \times GSF)]}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SFE | unitless | 8.49E-06 |
| EF - full day | days/year | 5 |
| ED | years | 1 |
| ACF | unitless | 1 |
| ETO | unitless | 1 |
| ETI | unitless | 0 |
| GSF | unitless | 0 |

SFE (Riley Pass)

| | | | |
|---|---|---|---|
| Radium-226 | 8.49E-06 | | |
| Thorium-230 | 8.19E-10 | U-234 | U-235 |
| U-238+D | 1.14E-07 | 2.52E-10 | 5.18E-07 |

EF = # days/year x # hours/day/24 hours

**ENTER DATA HERE**

| | | |
|---|---|---|
| EF = | 32 | days/year |
| Time | 4 | hours day |
| ED | 30 | years |

SSL - external exposure

| | Ra-226 (pCi/g) | Th-230 | U-238+D | U-234 | U-235 |
|---|---|---|---|---|---|
| TR | Rec Scenario | Rec Scenario | Rec Scenario | Rec Scenario | Rec Scenario |
| 5.00E-04 | 4030 | 41781135.5 | 300164.5 | 135788690.5 | 66059.4 |
| 1.00E-04 | 806 | 8356227.1 | 60032.9 | 27157738.1 | 13211.9 |
| 5.00E-05 | 403.0 | 4178113.6 | 30016.4 | 13578869.0 | 6605.9 |
| 1.00E-05 | 80.6 | 835622.7 | 6003.3 | 2715773.8 | 1321.2 |
| 5.00E-06 | 40.3 | 417811.4 | 3001.6 | 1357886.9 | 660.6 |
| 1.00E-06 | 8.06 | 83562.3 | 600.3 | 271577.4 | 132.1 |

## Soil Ingestion -Radionulcides

$$SSL = \frac{TR}{SFs \times EF \times ED \times IRs \times 1\,E-3}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SFE | unitless | 7.30E-10 |
| EF | days/year | 32 |
| ED | years | 30 |
| Irs | unitless | 100 |
| Conversion | g/mg | 0.001 |
| Time spent on site | unitless (25%) | 0.25 |
| | | |

| | SFs |
|---|---|
| Radium-226 | 7.30E-10 |
| Thorium-230 | 2.02E-10 |
| U-238+D | 2.10E-10 |
| U-234 | 1.58E-10 |
| U-235 | 1.57E-10 |

SSL - soil ingestion adjusted for 25% exposure time

| | Ra-226 (pCi/g) | Th-230 | U-238+D | U-234 | U-235 |
|---|---|---|---|---|---|
| TR | Rec Scenario | Rec Scenario | Rec Scenario | Rec Scenario | Rec Scenario |
| 5.00E-04 | 28538.81 | 103135.31 | 99206.35 | 131856.54 | 132696.39 |
| 1.00E-04 | 5707.76 | 20627.06 | 19841.27 | 26371.31 | 26539.28 |
| 5.00E-05 | 2853.88 | 10313.53 | 9920.63 | 13185.65 | 13269.64 |
| 1.00E-05 | 570.78 | 2062.71 | 1984.13 | 2637.13 | 2653.93 |
| 5.00E-06 | 285.39 | 1031.35 | 992.06 | 1318.57 | 1326.96 |
| 1.00E-06 | 57.08 | 206.27 | 198.41 | 263.71 | 265.39 |

## Inhalation of Dust -Radionulcides

$$SSL = \frac{TR}{SFi \times X\ IRa\ x\ PEF \times EF \times ED \times 1000}$$

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SF i | unitless | 1.16E-08 |
| IR a | m3/hr | 1.6 |
| PEF | m3/kg | 1.61E+08 |
| EF | days/year | 32 |
| ED | years | 1 |
| ET | hours/day | 4 |
| Conversion | g/kg | 1000 |

| | SFs |
|---|---|
| Radium-226 | 1.16E-08 |
| Thorium-230 | 2.85E-08 |
| U-238+D | 9.35E-09 |
| U-234 | 1.14E-08 |
| U-235 | 1.01E-08 |

SSL - soil ingestion

| | Ra-226 (pCi/g) | Th-230 | U-238+D | U-234 | U-235 |
|---|---|---|---|---|---|
| TR | Rec Scenario | Rec Scenario | Rec Scenario | Rec Scenario | Rec Scenario |
| 5.00E-04 | 4236882.62 | 13795884.47 | 42051626.47 | 34489711.19 | 38928980.94 |
| 1.00E-04 | 847376.52 | 2759176.89 | 8410325.29 | 6897942.24 | 7785796.19 |
| 5.00E-05 | 423688.26 | 1379588.45 | 4205162.65 | 3448971.12 | 3892898.09 |
| 1.00E-05 | 84737.65 | 275917.69 | 841032.53 | 689794.22 | 778579.62 |
| 5.00E-06 | 42368.83 | 137958.84 | 420516.26 | 344897.11 | 389289.81 |
| 1.00E-06 | 8473.77 | 27591.77 | 84103.25 | 68979.42 | 77857.96 |

## Combined Pathway SSLs - without beef

| | Ra-226 | Th-230 | U-238+D | U-234 | U-235 |
|---|---|---|---|---|---|
| TR | (pCi/g) | (pCi/g) | (pCi/g) | (pCi/g) | (pCi/g) |
| 5.00E-04 | 3529 | 102120 | 74431 | 131227 | 44054 |
| 1.00E-04 | 706 | 20424 | 14886 | 26245 | 8811 |
| 5.00E-05 | 353 | 10212 | 7443 | 13123 | 4405 |
| 1.00E-05 | 71 | 2042 | 1489 | 2625 | 881 |
| 5.00E-06 | 35 | 1021 | 744 | 1312 | 441 |
| 1.00E-06 | 7 | 204 | 149 | 262 | 88 |

## Dermal Exposure - Nonradionuclides only

Arsenic is the only nonradionulcide at Riley Pass evaluated for this pathway

Other metals are not assessed for this pathway

The equation is for adults to be consistent with Portage 2006; a different one is needed for child +adult exposures.

$$SSL = \frac{TR\ x\ AT\ x\ 365\ x\ BW}{SFo \times EF \times ED \times SA \times AF\ x\ ABS\ x\ 1E{-}6}$$

Note that this is a conservative equation as a higher adherence factor is used, and upper-end surface area.

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| AT | years | 70 |
| BW | unitless | 70.0 |
| SF o | unitless | 1.5 |
| EF | days/year | 32 |
| ED | years | 30 |
| SA | cm2 | 3300 |
| AF | mg/cm2 | 0.2 |
| ABS | unitless | 0.03 |

| TR | Arsenic (mg/kg) Rec Scenario |
|---|---|
| 5.00E-04 | 31364.0 |
| 1.00E-04 | 6272.8 |
| 5.00E-05 | 3136.4 |
| 1.00E-05 | 627.3 |
| 5.00E-06 | 313.6 |
| 1.00E-06 | 62.7 |

## Soil Ingestion -Non- Radionulcides

Arsenic:

$$SSL = \frac{TR\ x\ AT\ x\ 365}{SFo \times 1E-6 \times IRadj-s}$$

Arsenic - Carcinogenic

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| Sfo | 1/(mg/kg-day) | 1.50E+00 |
| AT | years | 70 |
| EF | days/year | 32 |
| IR adj-s | mg/kg-day | 3520 |
| Conversion | unitless | 1.00E-06 |
| ED | years | 30 |
| % Time on site | | 0.25 |

Note that ED and EF are included in the IR adj

| TR | Arsenic (mg/kg) Rec Scenario | Arsenic using 80% abs |
|---|---|---|
| 5.00E-04 | 9678.0 | 12097.5 |
| 1.00E-04 | 1935.6 | 2419.5 |
| 5.00E-05 | 967.8 | 1209.8 |
| 1.00E-05 | 193.6 | 242.0 |
| 5.00E-06 | 96.8 | 121.0 |
| 1.00E-06 | 19.4 | 24.2 |

Copper and Molybdenum

$$SSL = \frac{THQ\ x\ BW\ x\ AT\ x\ 365}{\left(\frac{1}{RfDo}\right) \times EF \times EDx\ 1E-6 \times IR}$$

Copper and Manganese

| Parameter | Units | Scenario 1 |
|---|---|---|
| THQ | hazard | *1* |
| BW | kg | 15.0 |
| AT | years | 30 |
| EF | days/year | 32 |
| IR | mg/kg-day | 200 |
| Conversion | unitless | 1.00E-06 |
| RfD | 1/(mg/kg-day) | chem specific |
| ED | years | 30 |
| % Time on site | | 0.25 |

AT is equal to ED in this equation

| | RfD |
|---|---|
| Cu | 4.00E-02 |
| Mo | 5.00E-03 |

| Copper Rec Scenario | Molybdenum Rec Scenario |
|---|---|
| 1.37E+05 | 1.71E+04 |

Irs adj-s = (32 day/yr x 200 mg/day x 6 years)/15 kg + (32 day/yr x 100 mg/day x 24 years)/80 kg

3520

## Inhalation of Dust - Non-Radionulcides

$$SSL = \frac{TR\ x\ AT\ x\ 365}{SFi \times EF \times ED \times ET\ x\ \left(\frac{1}{PEF}\right) x\ \ 1000}$$

Arsenic Only - no toxicity values for copper and manganese

| Parameter | Units | Scenario 1 |
|---|---|---|
| TR | unitless | *variable* |
| SF i | 1/(ug/m3) | 4.30E-03 |
| AT | years | 70 |
| EF | days/year | 32 |
| ET | hrs exp/24 hours | 0.166666667 |
| Conversion | ug/mg | 1.00E+03 |
| PEF | m3/kg | 161047637 |
| ED | years | 30 |

| TR | Arsenic (mg/kg) Rec Scenario |
|---|---|
| 5.00E-04 | 2990383.1 |
| 1.00E-04 | 598076.6 |
| 5.00E-05 | 299038.3 |
| 1.00E-05 | 59807.7 |
| 5.00E-06 | 29903.8 |
| 1.00E-06 | 5980.8 |

## Combined Pathway SSLs - without beef

| TR | Arsenic (80% GI absorption) (mg/kg) | | | |
|---|---|---|---|---|
| 5.00E-04 | 8705 | | | |
| 1.00E-04 | 1741 | | | |
| 5.00E-05 | 870 | | | |
| 1.00E-05 | 174 | Copper | | Molybdenum |
| 5.00E-06 | 87 | | | |
| 1.00E-06 | 17 | 1.37E+05 | HI =1.0 | 1.71E+04 |

**Beef Ingestion**
**Radium -226**

| | | | | | |
|---|---|---|---|---|---|
| at proposed cleanup values of | 30 | pCi/g Radium 226 | | | |
| | | 5.987069 | pCi/g in beef (cleanup value * ratio) | | |
| concentration in meat at 23.2 pCi/g soil = | | 4.63 | | ratio = 4.63/23.2 is | 0.199569 |

assuming that 30 pCi/g in soil equates to 6 pCi/g in beef:
and that the following apply:

| | | | | |
|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 |
| Slope Factor | 5.15E-10 | | 5.15E-10 | 5.15E-10 |
| Risk = | 4.76E-07 | | 2.38E-06 | 4.76E-06 |

**Thorium-230**

| | | | | | |
|---|---|---|---|---|---|
| at proposed cleanup values of | 39.8 | pCi/g Radium 226 | | | |
| | | 0.53 | pCi/g in beef (cleanup value * ratio) | | |
| concentration in meat at 24.7 pCi/g soil = | | 0.33 | | ratio = 0.33/24.7 is | 0.0133603 |

assuming that 100 pCi/g in soil equates to 1.33 pCi/g in beef:
and that the following apply:

| | | | | |
|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 |
| Slope Factor | 1.19E-10 | | 1.19E-10 | 1.19E-10 |
| Risk = | 9.77E-09 | | 4.88E-08 | 9.77E-08 |

**Uranium**

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | U-234 | U-235 | |
| at proposed cleanup values of | | 42.8 | pCi/g U-238 | 44.6 | 2.08 | |
| | | 2.07 | pCi/g in beef (cleanup value * ratio) | 2.15 | 0.10 | |
| concentration in meat at 24 pCi/g soil = | | | 1.16 | | ratio = 1.16/24 is: | 0.048333 |
| U-234 | 25.7 | | 1.24 | | | 0.048249 |
| U-235 | 1.21 | | 0.0585 | | | 0.048347 |

assuming that 100 pCi/g in soil equates to 4.8 pCi/g in beef:
and that the following apply:

| | | | | | U-234 | U-235 |
|---|---|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 | 0.1 | 0.1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 | 30 | 30 |
| Slope Factor | 1.21E-10 | | 1.21E-10 | 1.21E-10 | 9.55E-11 | 9.44E-11 |
| Risk = | 3.86E-08 | | 1.93E-07 | 3.86E-07 | 3.17E-08 | 1.47E-09 |

**Arsenic**

| | | | | | |
|---|---|---|---|---|---|
| at proposed cleanup values of | | 142 | mg/kg | | |
| | | | 0.06 | mg/kg in beef (cleanup value * ratio) | |
| concentration in meat at 477.6 mg/kg soil = | | | 0.189 | ratio = .189/477.6 is | 0.000396 |

assuming that 142 mg/kg in soil equates to 0.056 mg/kg in beef:
and that the following apply:

| | | | | |
|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 |
| Slope Factor | 1.50E+00 | | 1.50E+00 | 1.50E+00 |
| Body weight | 70 | | 70 | 70 |
| AT | 25550 | | 25550 | 25550 |
| As absorption | 0.8 | | 0.8 | 0.8 |
| Risk = | 5.82E-06 | | 2.91E-05 | 4.65E-02 |

**Molybdenum**

| | | | | | |
|---|---|---|---|---|---|
| at proposed cleanup values of | 2775 | mg/kg | | | |
| | | | 7.42 | mg/kg in beef (cleanup value * ratio) | |
| concentration in meat at 617 mg/kg soil = | | | 0.165 | ratio = .165/617 is | 0.002674 |

assuming that 142 mg/kg in soil equates to 0.056 mg/kg in beef:
and that the following apply:

| | | | | |
|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 |
| RfD | 5.00E-03 | | 5.00E-03 | 5.00E-03 |
| Body weight | 70 | | 70 | 70 |
| AT | 25550 | | 25550 | 25550 |
| As absorption | 1 | | 1 | 1 |
| Risk = | 1.28E-01 | | 6.40E-01 | 1.28E+00 |

**Deer Ingestion**
**Radium -226**

| | | | | | |
|---|---|---|---|---|---|
| at proposed cleanup values of | 30 | pCi/g Radium 226 | | | |
| | | | 4.72 | pCi/g in deer (cleanup value * ratio) | |
| concentration in meat at 23.2 pCi/g soil = | | | 3.65 | ratio = 3.65/23.2 is | 0.157327586 |

assuming that 30 pCi/g in soil equates to 4.7 pCi/g in deer:
and that the following apply:

| | | | | |
|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 |
| Slope Factor | 5.15E-10 | | 5.15E-10 | 5.15E-10 |
| Risk = | 3.75E-07 | | 1.88E-06 | 3.75E-06 |

**Thorium-230**

| | | | | | |
|---|---|---|---|---|---|
| at proposed cleanup values of | 39.8 | pCi/g Radium 226 | | | |
| | | | 0.35 | pCi/g in deer (cleanup value * ratio) | |
| concentration in meat at 24.7 pCi/g soil = | | | 0.219 | ratio = 0.219/24.7 is | 0.008866397 |

assuming that 100 pCi/g in soil equates to 0.89 pCi/g in deer:
and that the following apply:

| | | | | |
|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 |
| Slope Factor | 1.19E-10 | | 1.19E-10 | 1.19E-10 |
| Risk = | 6.48E-09 | | 3.24E-08 | 6.48E-08 |

**Uranium**

| | | | | | | |
|---|---|---|---|---|---|---|
| at proposed cleanup values of | | 42.8 | pCi/g U-238 | U-234 | U-235 | |
| | | 1.38 | pCi/g in deer (cleanup value * ratio) | 1.43 | 0.07 | Ratio |
| concentration in meat at 24 pCi/g soil = | | | 0.773 | ratio = 0.773/24 is: | | 0.032208 |
| U-234 | 25.7 | | 0.826 | | | 0.03214 |
| U-235 | 1.21 | | 0.0389 | | | 0.032149 |

assuming that 100 pCi/g in soil equates to 3.22 pCi/g in deer:
and that the following apply:

| | | | | | U-234 | U-235 |
|---|---|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 | 0.1 | 0.1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 | 30 | 30 |
| Slope Factor | 1.21E-10 | | 1.21E-10 | 1.21E-10 | 9.55E-11 | 9.44E-11 |
| Risk = | 2.57E-08 | | 1.29E-07 | 2.57E-07 | 2.11E-08 | 9.74E-10 |

**Arsenic**

| | | | | | |
|---|---|---|---|---|---|
| at proposed cleanup values of | | 142 | mg/kg | | |
| | | | 0.03 | mg/kg in deer (cleanup value * ratio) | |
| concentration in meat at 477.6 mg/kg soil = | | | 0.146 | ratio = .108/477.6 is | 0.000226 |

assuming that 142 mg/kg in soil equates to 0.032 mg/kg in deer:
and that the following apply:

| | | | | |
|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 |
| Slope Factor | 1.50E+00 | | 1.50E+00 | 1.50E+00 |
| Body weight | 70 | | 70 | 70 |
| AT | 25550 | | 25550 | 25550 |
| Absorption | 0.8 | | 0.8 | 0.8 |

| | | | | |
|---|---|---|---|---|
| | | | Deer Meat Ingestion | |
| Risk = | 3.33E-06 | | 1.66E-05 | 3.33E-05 |

**Molybdenum**

at proposed cleanup values of 2775 mg/kg

4.86 mg/kg in beef (cleanup value * ratio)

concentration in meat at 617 mg/kg soil = 0.108 ratio = .108/617 is 0.00175

assuming that 2775 mg/kg in soil equates to 4.86 mg/kg in beef:
and that the following apply:

| | | | | |
|---|---|---|---|---|
| Fraction ingested = 10%, 50%, 100% | 0.1 | | 0.5 | 1 |
| Ingestion Rate | 0.147 | kg/day | 0.147 | 0.147 |
| Exposure Freq | 350 | days/ year | 350 | 350 |
| Exposure Duration | 30 | years | 30 | 30 |
| RfD | 5.00E-03 | | 5.00E-03 | 5.00E-03 |
| Body weight | 70 | | 70 | 70 |
| AT | 25550 | | 25550 | 25550 |
| As absorption | 1 | | 1 | 1 |
| Risk = | 8.38E-02 | | 4.19E-01 | 8.38E-01 |

Ecological Receptors

Proposesd Cleanup Conc:
As - 142 mg/kg; Mo - 2775 mg/kg

| Measured Soil Conc (mg/kg) | Arsenic | Molybdenum | **Ratio measured/proposed** Arsenic | Molybdenum | |
|---|---|---|---|---|---|
| | 447 | 617 | 0.32 | 4.50 | |
| HQ Rabbit | 105 | 67.8 | 33.3557047 | 304.9351702 | |
| HQ Red Tailed Hawk | 0.915 | 0.00604 | 0.290671141 | 0.027165316 | |
| HQ Fox | 25.7 | 16 | 8.164205817 | 71.96110211 | **Estimated HQs** |
| HQ Robin | 2.26 | 4.26 | 0.717941834 | 19.15964344 | **(Ratio* HQ)** |
| HQ Deer | 38.7 | 23.7 | 12.29395973 | 106.5923825 | |
| HQ Cattle | 11.7 | 7.15 | 3.716778523 | 32.1576175 | |

# APPENDIX B

# ASSESSMENT OF MOLYBDENUM AND URANIUM CLEANUP LEVELS

# Appendix B - Assessment of Molybdenum and Uranium Cleanup Levels

## 1.0 PURPOSE

The purpose of this appendix is to present the analysis and assessment to determine if the arsenic and Ra-226 removal boundaries are inclusive of any molybdenum and uranium samples that exceed the risk-based cleanup criteria for the Riley Pass site. The risk-based cleanup values are as follows:

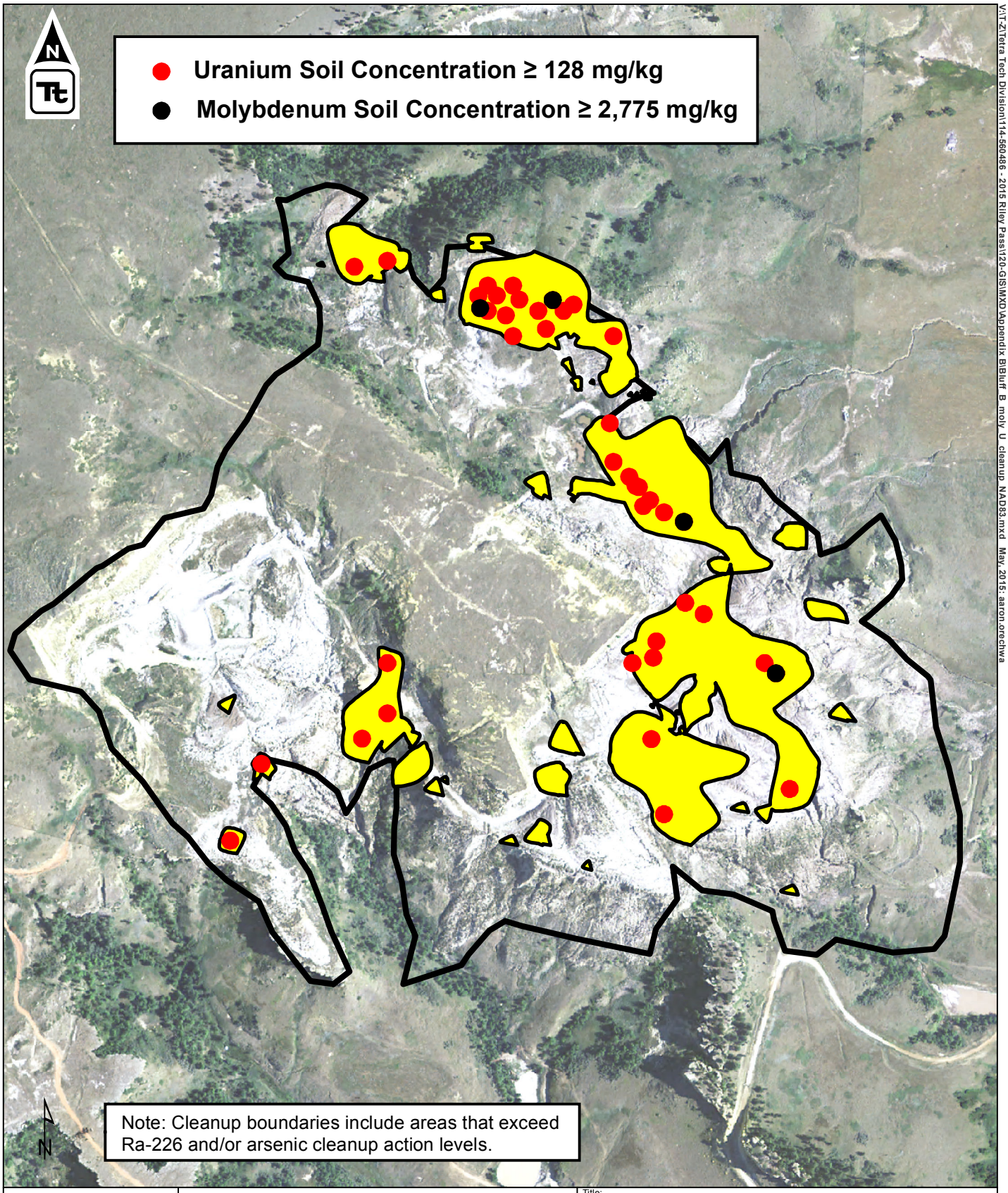
- Arsenic: 142 mg/kg
- Molybdenum: 2,775 mg/kg
- Natural Uranium: 128 mg/kg. Refer to Tetra Tech (2015) on development of natural uranium risk-based cleanup criteria from the following uranium isotopic risk-based cleanup concentrations:
    - U-238: 42.8 pCi/g
    - U-234: 44.6 pCi/g
    - U-235: 2.03 pCi/g
- Radium-226 (Ra-226): 30.0 pCi/g
- Thorium-230 (Th-230): 39.8 pCi/g *(This was not evaluated because Th-230 is assumed to be in secular equilibrium with Ra-226)*

## 2.0 METHODS

Cleanup removal boundaries were developed for Bluff B, Bluff CDE, and Bluff H using the in situ XRF field survey and gamma radiation survey data collected by Tetra Tech in 2013 and 2014 (Tetra Tech 2013; 2015). The in situ XRF arsenic measurements were converted to definitive arsenic laboratory concentrations using the methods outlined in EPA (2007) and Tetra Tech (2013). Similarly, the gamma exposure rate measurements were converted to equivalent Ra-226 soil concentrations using the methods outlined in Tetra Tech (2013). A rigorous geostatistical analysis was performed on the data sets. Geostatistical techniques (kriging, Inverse Distance Weighted [IDW], or Radial Basis Functions [RBF]) were then applied to the data sets to determine optimal removal boundaries for each study area. The molybdenum and natural uranium metals concentrations that exceed the risk-based cleanup criteria described above were then overlaid on the cleanup boundaries.

## 3.0 RESULTS

The removal boundaries for study areas Bluff B, Bluff CDE, and Bluff H were determined using the methods described above. Figure B-1 through Figure B-3 show the removal boundaries and the molybdenum and natural uranium soil concentrations that exceed risk-based cleanup criteria for Bluff B, Bluff CDE, and Bluff H, respectively.




FEET
0 100 200

NAD_1983_STATEPLANE
SOUTH_DAKOTA
NORTH_FIPS_4001_FEET

Bluff B Boundary
Cleanup Boundary

Title:

**BLUFF B EVALUATION OF MOLYBDNEUM AND URANIUM**

Prepared for:

Prepared by:

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

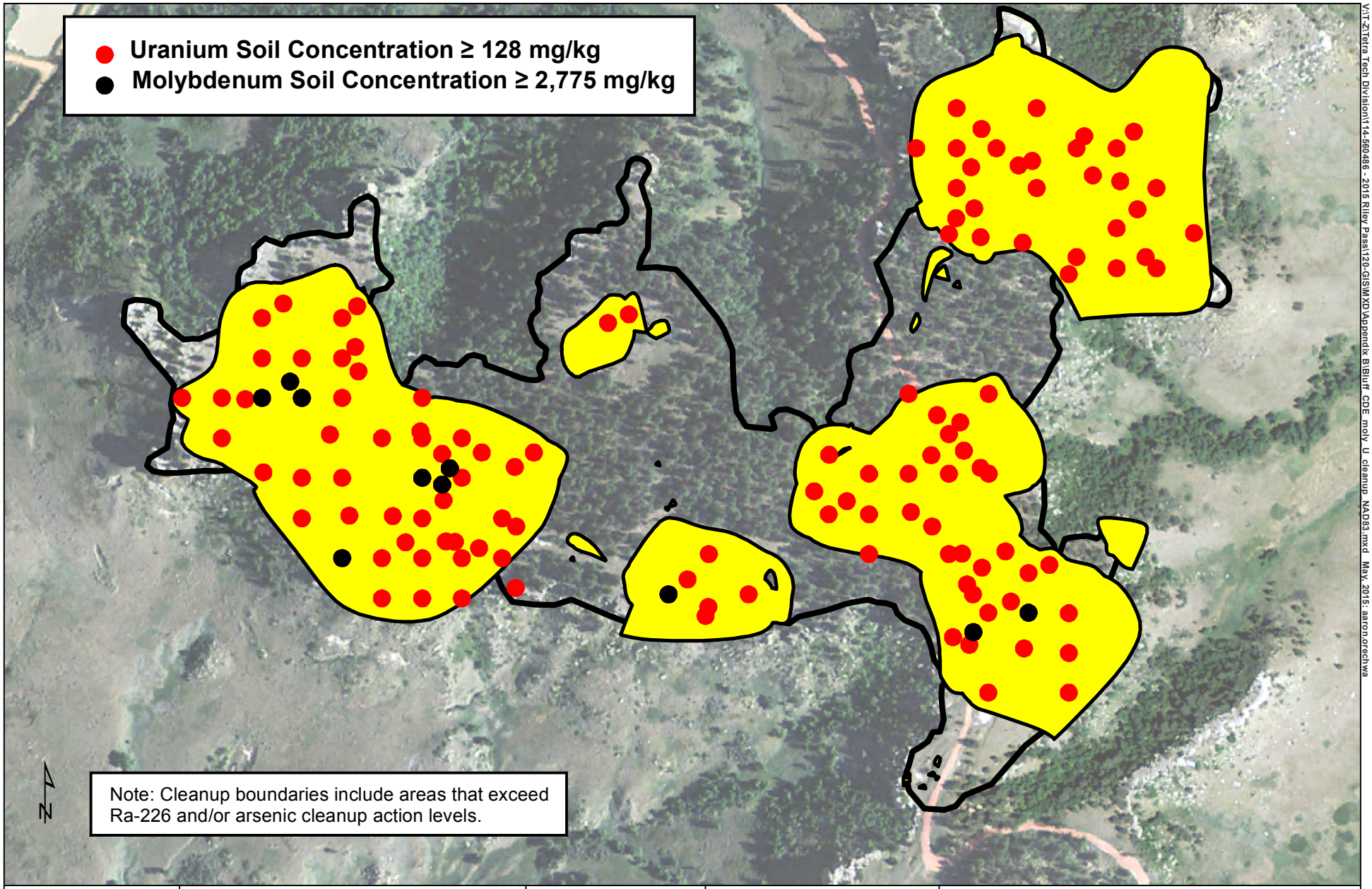
Location: HARDING COUNTY, SD

Project no.: 114-560486

Date: MAY 2015

Figure: **Figure B1**

Y:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Appendix B\Bluff_B_moly_U_cleanup_NAD83.mxd May, 2015; aaron.orechwa




FEET
0 50 100

NAD_1983_STATEPLANE
SOUTH_DAKOTA
NORTH_FIPS_4001_FEET

Bluff CDE Boundary
Cleanup Boundary

Prepared for:

Prepared by:

TETRA TECH
3501 Automation Way, Suite 100
Fort Collins, CO 80525
970-223-9600

Title: BLUFF CDE EVALUATION OF MOLYBDNEUM AND URANIUM

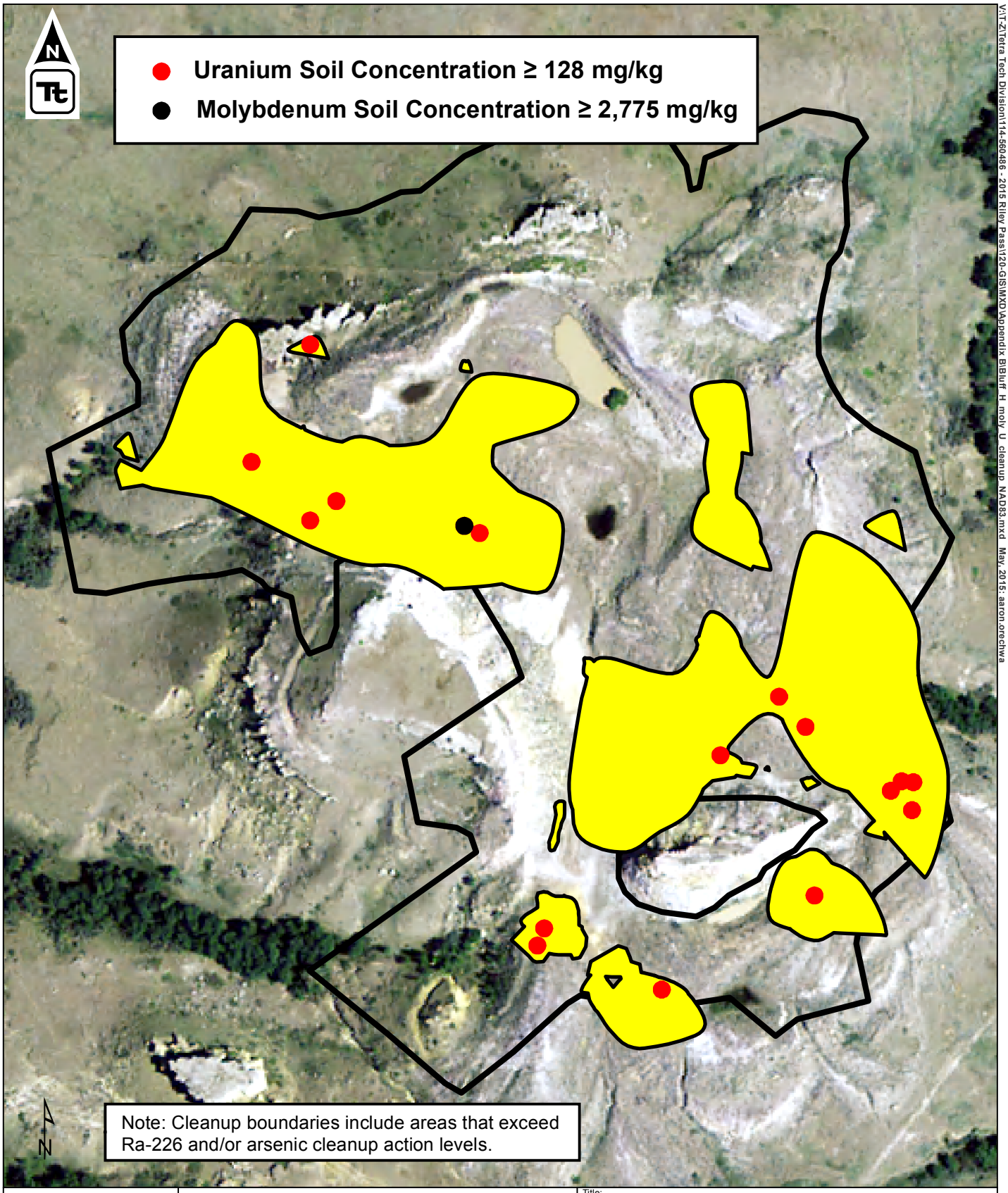
Location: HARDING COUNTY, SD

Project no.: 114-560486

Date: MAY 2015

Figure: Figure B2

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Appendix B\Bluff_CDE_moly_U_cleanup_NAD83.mxd May, 2015; aaron.orechwa




FEET
0 100 200

NAD_1983_STATEPLANE
SOUTH_DAKOTA
NORTH_FIPS_4001_FEET

Bluff H Boundary
Cleanup Boundary

Title:

**BLUFF H EVALUATION OF MOLYBDNEUM AND URANIUM**

Prepared for:

Prepared by:

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(970)223-9600 (970)223-7171 fax

Location: HARDING COUNTY, SD

Project no.: 114-560486

Date: MAY 2015

Figure: **Figure B3**

V:\T-Z\Tetra Tech Division\114-560486 - 2015 Riley Pass\120-GIS\MXD\Appendix B\Bluff_H_moly_U_cleanup_NAD83.mxd May, 2015; aaron.orechwa

# 4.0 CONCLUSIONS

The risk-based soil cleanup criteria for molybdenum is 2,775 mg/kg as determined in Portage (2006) and Tetra Tech (2013). The risk-based soil cleanup criteria for natural uranium was determined in Tetra Tech (2015) to be 128 mg/kg. All of the molybdenum soil samples that exceeded the risk-based cleanup criteria of 2,775 mg/kg were contained within the arsenic/Ra-226 removal boundaries. All but one of the natural uranium soil samples that exceeded the risk-based cleanup criteria of 128 mg/kg were contained within the arsenic/Ra-226 removal boundaries. This analysis indicates that using arsenic and Ra-226 to guide removal action will effectively removal soil with molybdenum and uranium occurrences above risk-based cleanup criteria.

Tetra Tech recommends that the site cleanup standards be based on arsenic and Ra-226 concentrations in soil. A cleanup standard of 142 mg/kg for arsenic and 30 pCi/g for Ra-226 is recommended.

# 5.0 REFERENCES

[EPA] United States Environmental Protection Agency. 2007. Field Portable XRF Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment. Method 6200. Washington, DC: EPA

[Portage] Portage Environmental, Inc. 2006. Final Human Health and Ecological Risk Assessment for the Riley Pass Uranium Mines in Harding County, South Dakota. Prepared for USDA Forest Service, Northern Regional Office. Portage. 88p.

[Tetra Tech] Tetra Tech. 2013. Tronox Bluff Waste Characterization Report, Riley Pass Abandoned Uranium Mines Site North Cave Hills, Harding County, South Dakota. June 27, 2013. Tetra Tech. 187p.

Tetra Tech. 2015. Bluff G and Bluff H Waste Characterization Supplemental Sampling Final Memo [Technical Memorandum]. April 20, 2015. Tetra Tech. 59p.

# APPENDIX C

# COMPARATIVE ANALYSIS OF THE 2009 AND 2012 XRF CORRELATIONS

TETRA TECH

# Appendix C - Comparative Analysis of the 2009 and 2012 XRF Correlation Studies

## 1.0 PURPOSE

The purpose of this appendix is to compare the 2009 XRF correlation data collected by Millennium Science and Engineering Inc. (MSE) with the 2013 correlation conducted by Tetra Tech in order to determine if the 2013 regression equation can be applied with reasonable certainty to the MSE in situ XRF measurements collected in 2008 (MSE 2009) and 2010 (MSE 2010a; 2010b). The results of MSE's 2009 XRF correlation are presented in MSE (2009) and the results Tetra Tech's 2012 XF correlation are presented in Tetra Tech (2013). The MSE data was obtained from the appendix of MSE (2009) and the correlation was re-created using the 54 correlation paired samples collected during that study. The Tetra Tech data was obtained from Appendix F of Tetra Tech (2013).

## 2.0 METHODS

Tetra Tech determined a strong relationship exists between the in-situ XRF samples and the arsenic laboratory confirmation samples as stated in Appendix F in Tetra Tech (2013). The final correlation for arsenic was based on 69 confirmation samples and followed the methodology of EPA Method 6200 (Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment) (EPA 2007). A log-transformation was done on the final correlation as recommended in EPA (2007). The final correlation presented in Tetra Tech (2013) included 67 of the 69 confirmation sample pairs of in situ XRF measurements and arsenic laboratory reported values. Tetra Tech evaluated a number of potential scenarios to determine the optimum correlation to be used for site characterization purposes. The final scenario evaluated (Scenario 3a, Figure F-7 in Appendix F of Tetra Tech [2013]) analyzed the log-transformed data pairs with the two outliers removed from the data set. The correlation coefficient for Scenario 3a was 0.947 and the $R^2$ is 0.897, both indicating a strong fitting model. Figure F-8 shows the standardized residual plots, indicating the residuals follow a normal distribution. All the standardized residuals are within the acceptable range of -3 to +3 standard deviations. Figure C1 provides the final correlation that was presented in Tetra Tech (2013), and the final equation used for site characterization purposes is as follows:

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

Where:

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

An evaluation was performed to determine if the 2009 MSE in situ XRF measurements and arsenic laboratory reported data pairs fit within the 2013 Tetra Tech 95 percent prediction limits as shown in Section 3.0.

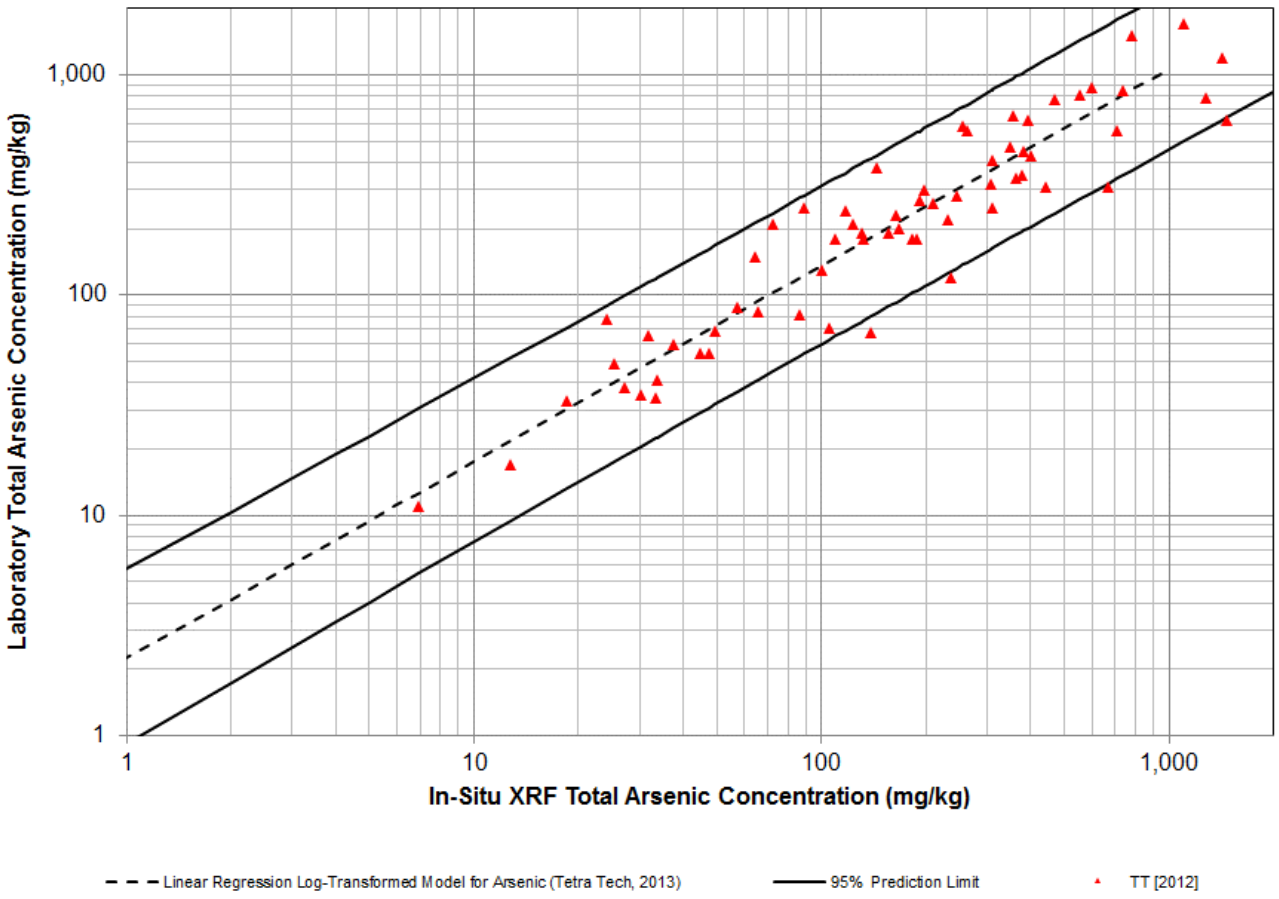



**Figure C-1 In Situ XRF Arsenic Measurements vs Lab Arsenic Correlation from Tetra Tech (2013)**

# 3.0 RESULTS

The MSE correlation pairs of in situ XRF measurements and arsenic laboratory reported concentrations were plotted onto the 2013 Tetra Tech correlation as shown in Figure C2. The blue data points show the 2009 MSE data pairs, as can be seen from this figure, all of the points except one data value fall within the specified prediction limits (95 percent), indicating a good fit with the Tetra Tech correlation model.

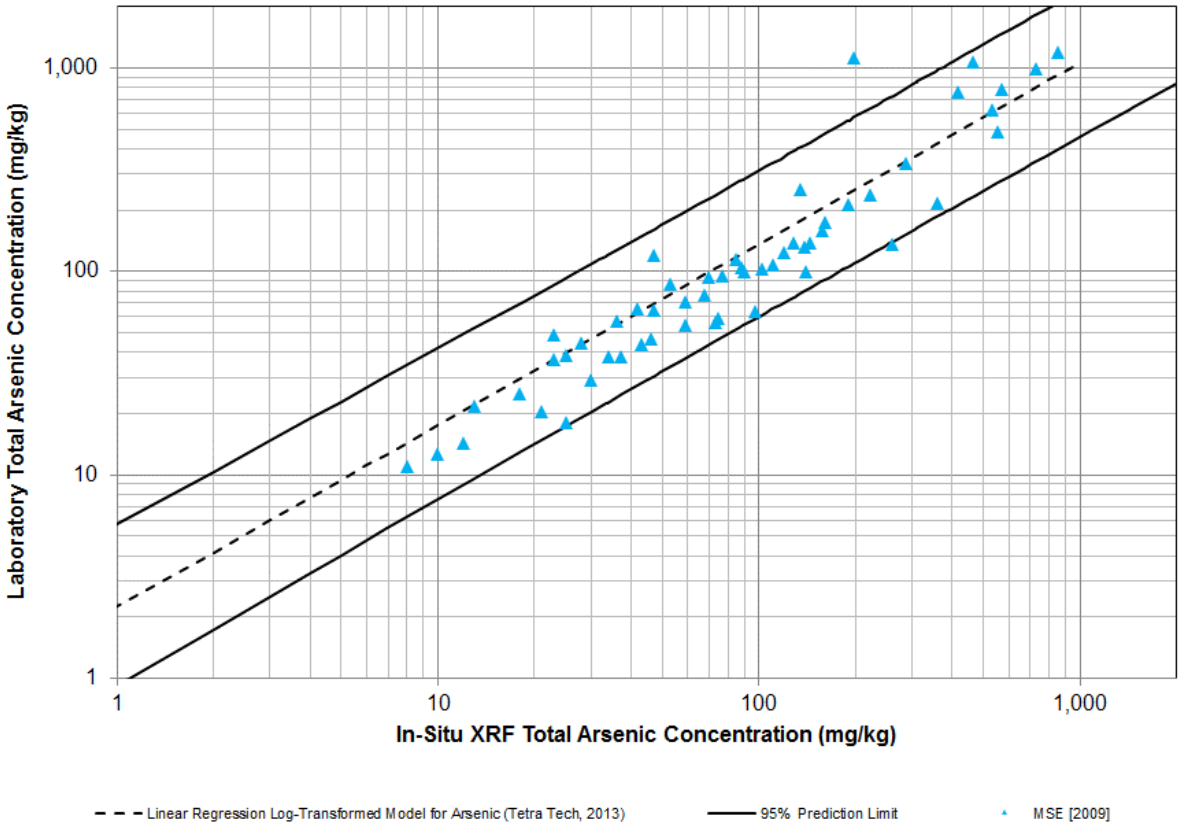



**Figure C-2 In Situ XRF Arsenic Measurement vs Lab Arsenic Concentrations from 2013 Tetra Tech with 2009 MSE Data Pairs**

A further comparison was done to show the similarity between the two data sets using a linear regression as opposed to the log-transformed regression used in Tetra Tech (2013). The MSE data had a lower range (< 1,200 mg/kg) and therefore the 2013 Tetra Tech data was truncated to remove the four points where the in situ XRF arsenic measurement or arsenic laboratory reported concentrations exceeded 1,200 mg/kg. Additionally, three outliers were removed from the 2013 Tetra Tech data set. A graph showing the comparison is provided in Figure C3. Using either of these equations, the in-situ XRF arsenic measurements corresponding to the risk-based cleanup criteria of 142 mg/kg is 106 mg/kg (MSE 2009) and 108 mg/kg (Tetra Tech 2013). Both of these are very similar to the log-transformed equivalent in-situ XRF measurement concentration of 105 mg/kg corresponding to the risk-based cleanup criteria of 142 mg/kg presented in Tetra Tech (2013).

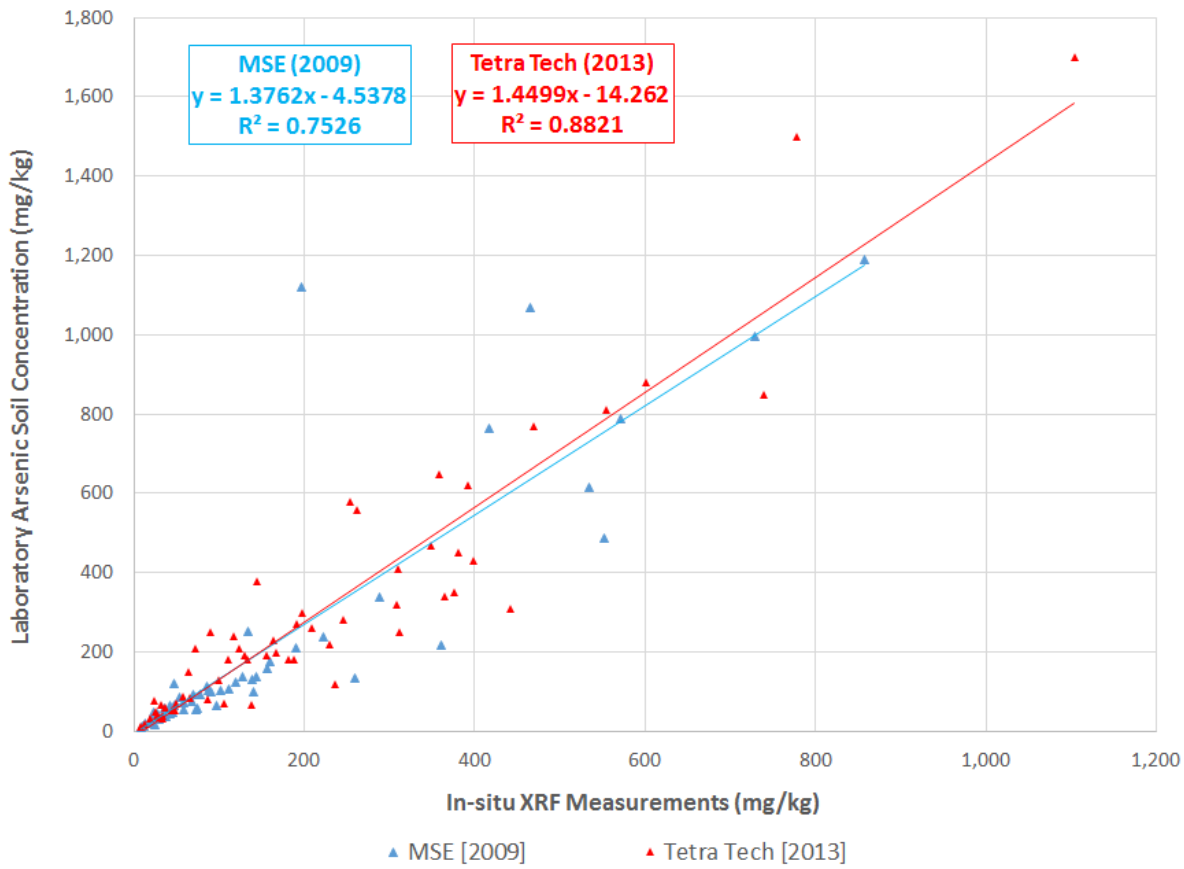



**Figure C-3 Comparison of Linear Regression of In-Situ XRF vs Lab Arsenic Correlation from 2013 Tetra Tech with 2009 MSE Data Pairs**

## 4.0 CONCLUSION

The results of this analysis show that the 2009 MSE and 2013 Tetra Tech XRF and lab correlations for arsenic show comparable results and the 2013 Tetra Tech log-transformed regression can be utilized to convert the 2008 MSE in-situ XRF arsenic measurements into laboratory equivalent arsenic concentrations at the Riley Pass site.

# 5.0 REFERENCES

[EPA] United States Environmental Protection Agency. 2007. Field Portable XRF Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment. Method 6200. Washington, DC: EPA

[MSE] Millennium Science and Engineering. 2009. Riley Pass Uranium Mines Site X-Ray Fluorescence (XRF) and Gamma Surveys Report, USDA Forest Service, Custer National Forest (North Cave Hills), Riley Pass Uranium Mines Site (Mine Bluffs I, F, J, K, L & A), Harding County, South Dakota. MSE. 32p.

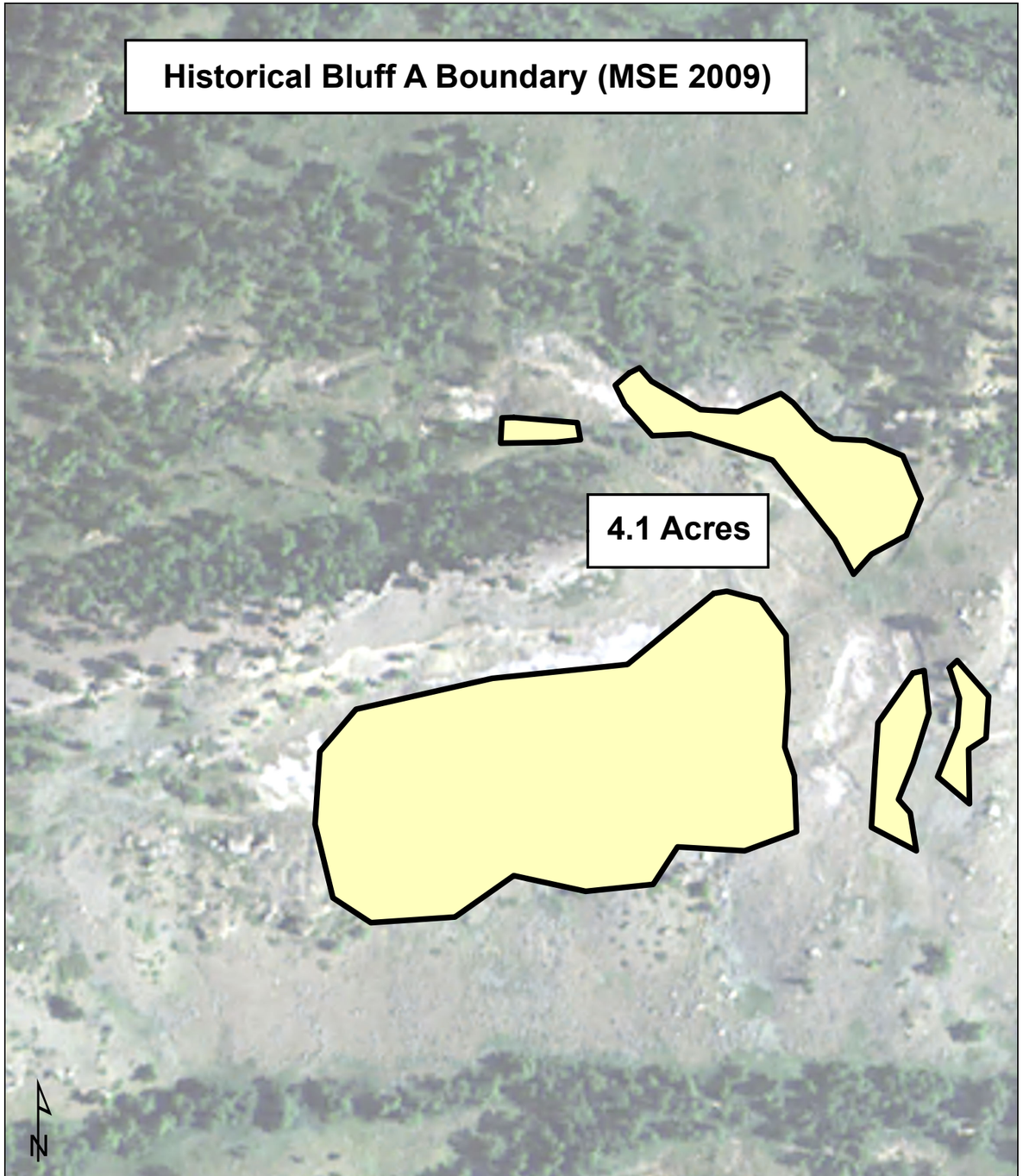
MSE. 2010a. Verification Sampling Plan, Riley Pass Uranium Mines Site Removal Action Non-Tronox Bluffs (A, F, I1, I-2, I3, J1, J2, K1, K2), USDA Forest Service, Custer National Forest (North Cave Hills), Harding County, South Dakota. MSE. 15p.

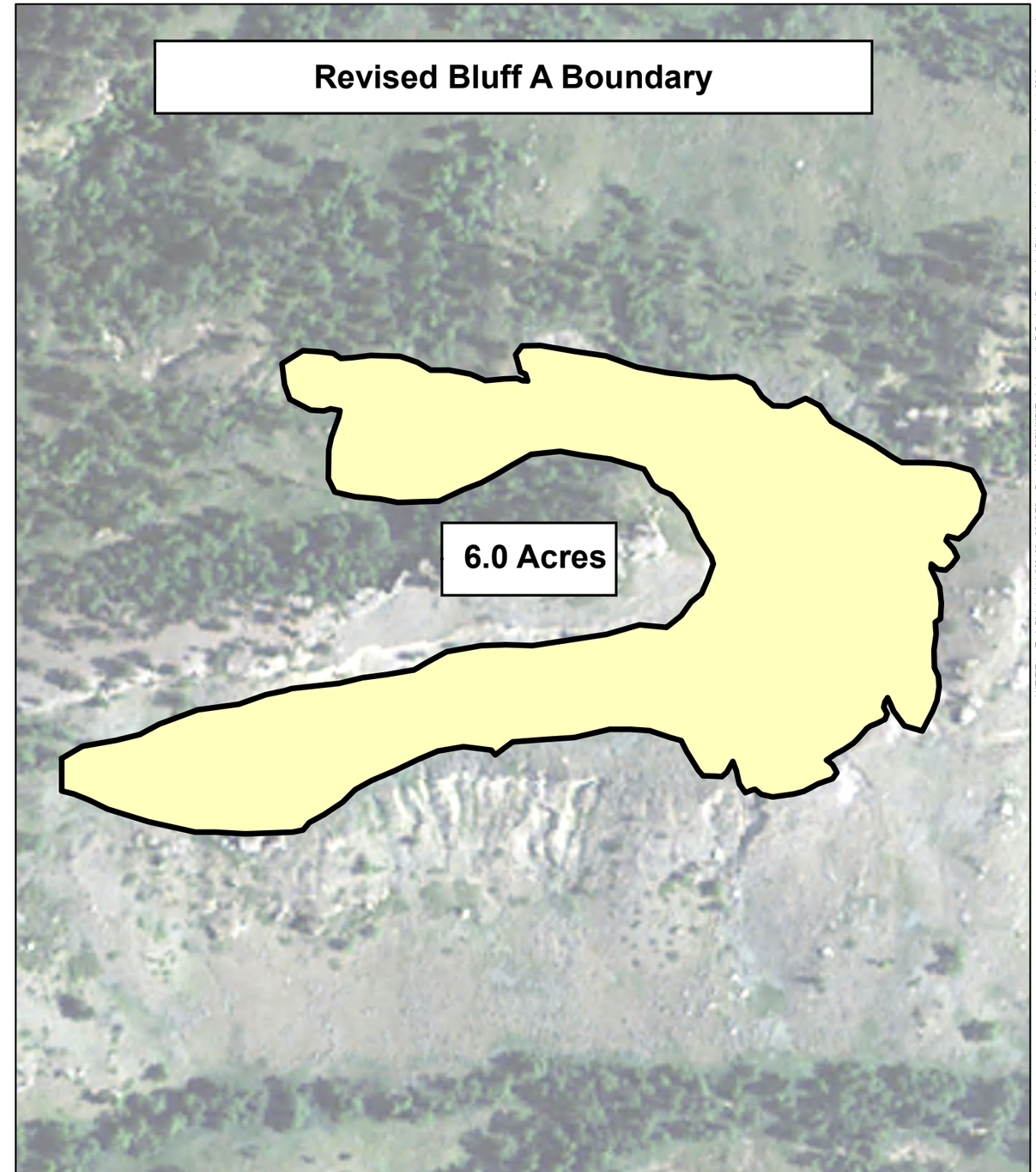
MSE. 2010b. Final Cleanup Verification Survey Report, Riley Pass Uranium Mines Site, Bluffs J and K, USDA Forest Service, Custer National Forest (North Cave Hills), Harding County, South Dakota. MSE. 22p.

[Tetra Tech] Tetra Tech. 2013. Tronox Bluff Waste Characterization Report, Riley Pass Abandoned Uranium Mines Site North Cave Hills, Harding County, South Dakota. June 27, 2013. Tetra Tech. 187p.

# APPENDIX D

# STUDY AREA BOUNDARY DEVELOPMENT

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NORTH_FIPS_4001_FEET

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Prepared By:

TETRA TECH
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Fort Collins, CO 80525
970-223-9600

Title:

**FIGURE D1**
**REVISED BLUFF A BOUNDARY**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

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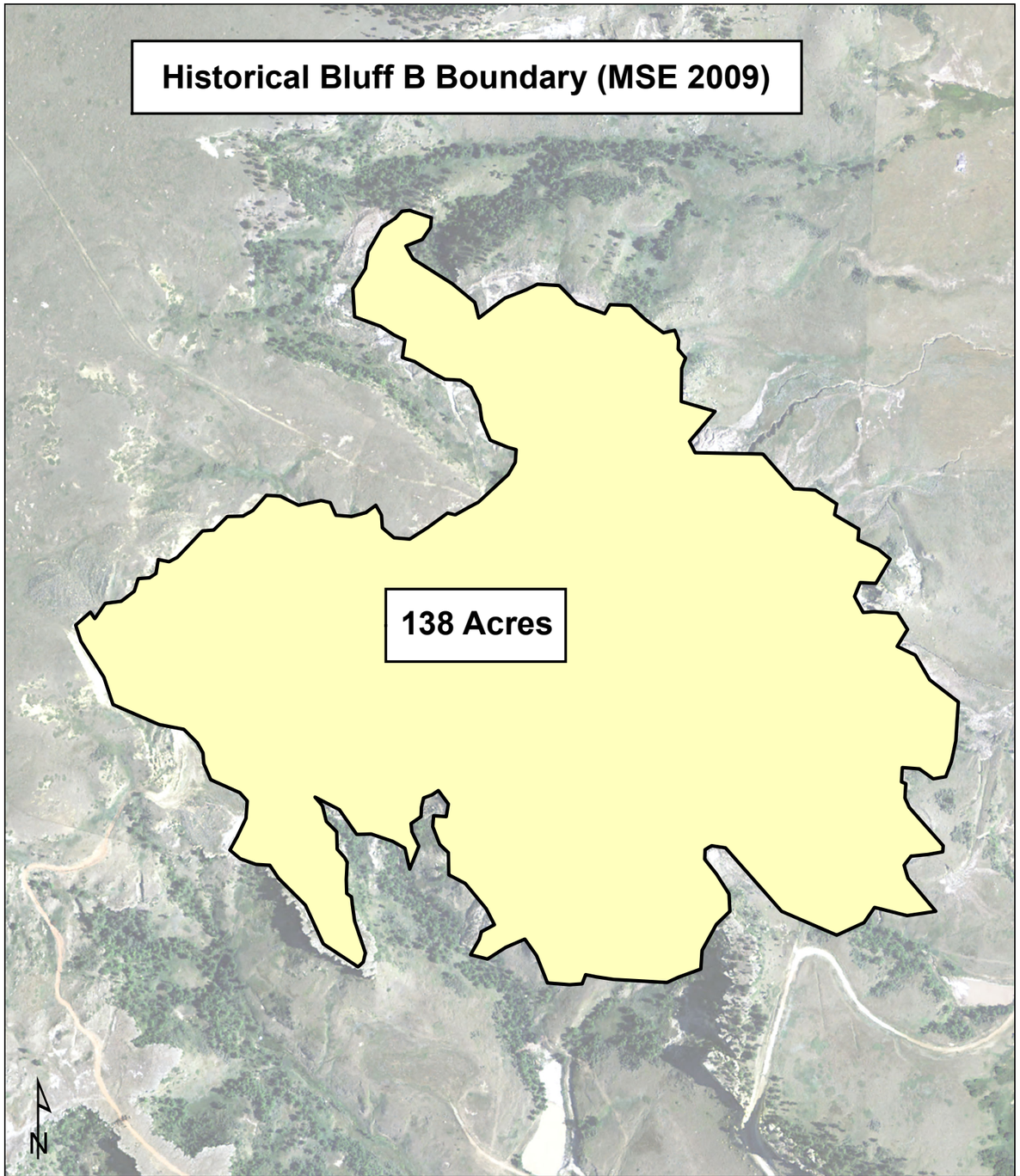


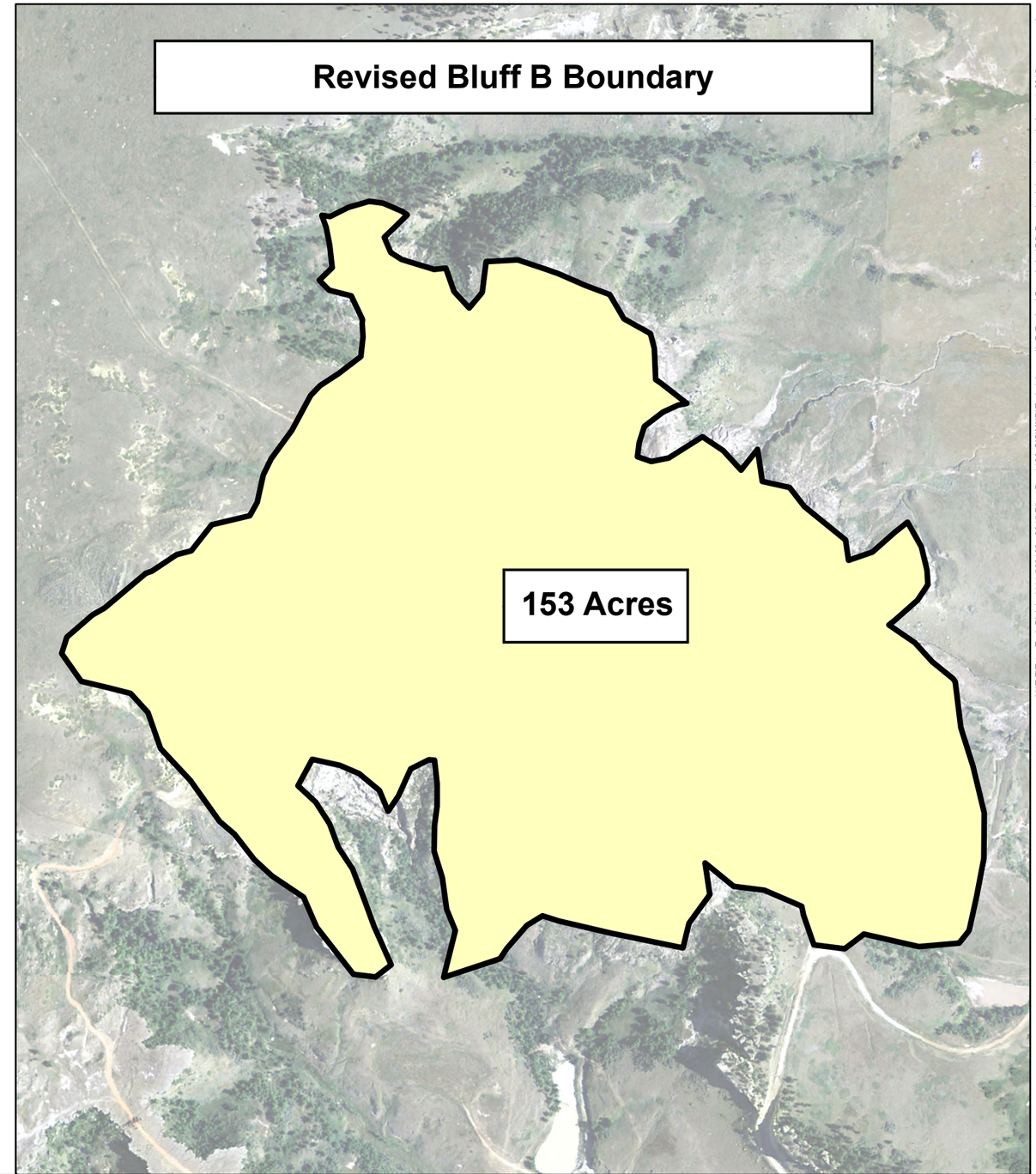


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**FIGURE D2**
**REVISED BLUFF B BOUNDARY**

Project Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date of Issue: AUGUST 2015

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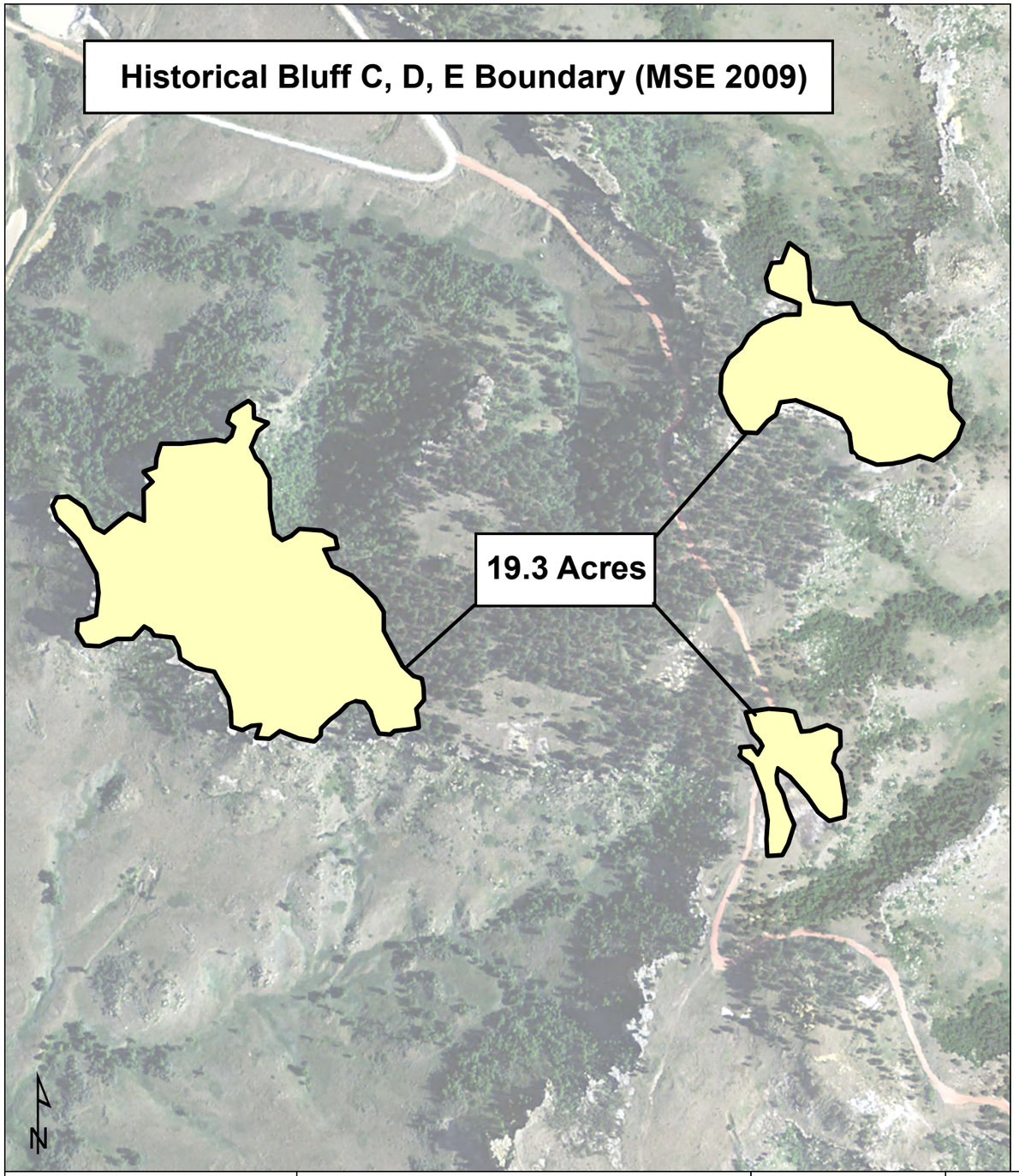


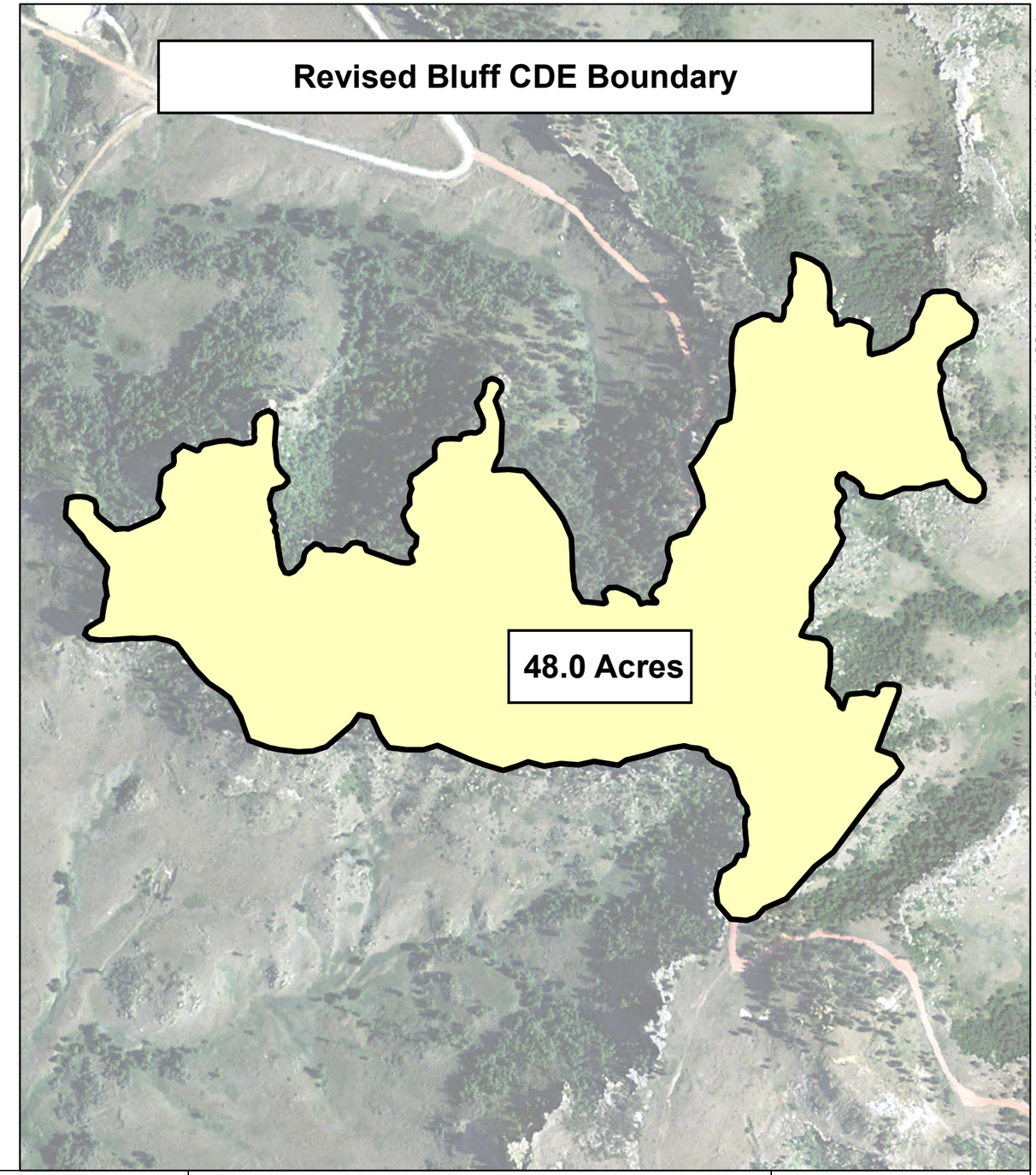


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**FIGURE D3**
**REVISED BLUFF CDE BOUNDARY**

Project Location: HARDING COUNTY, SD

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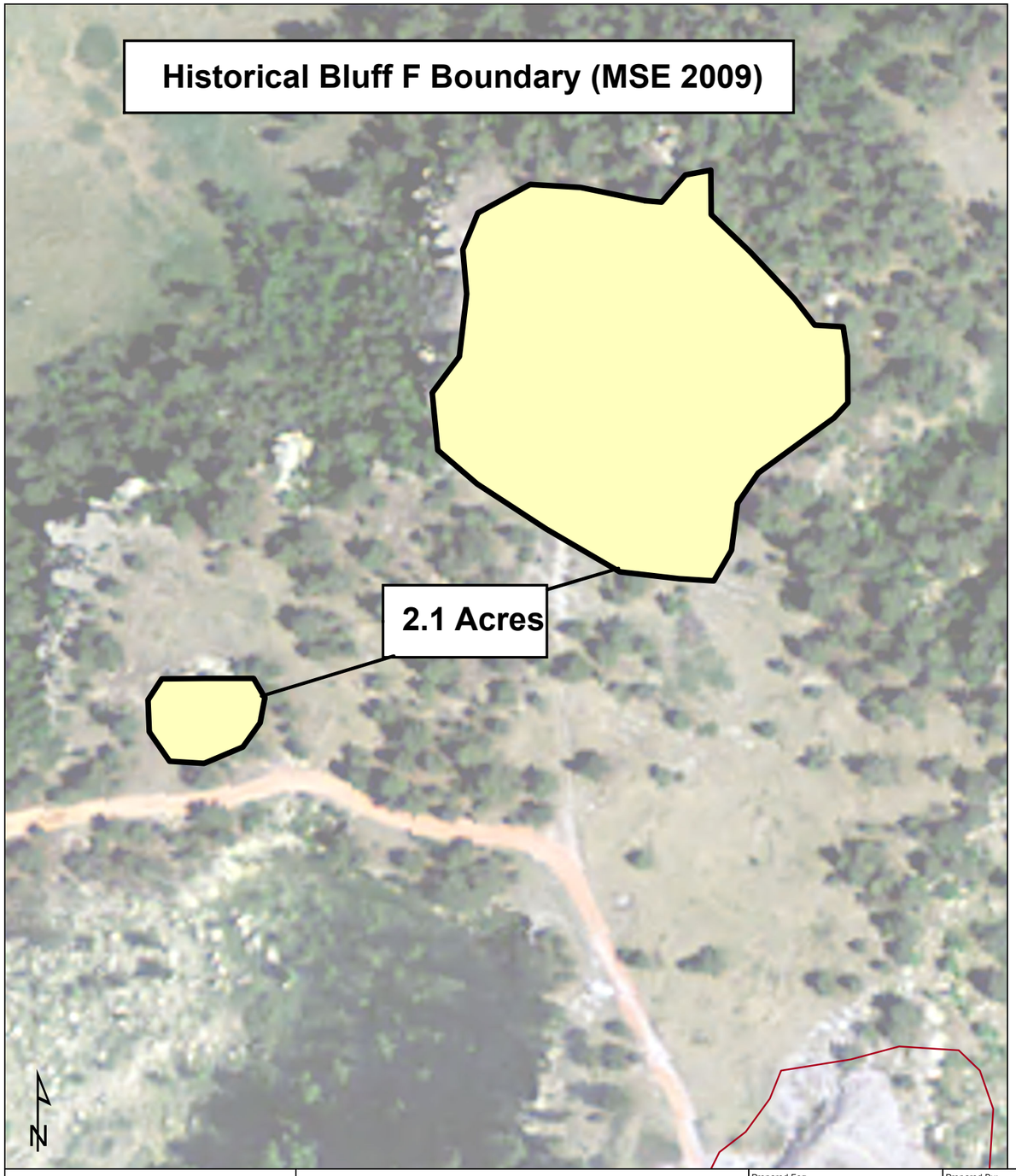
Date of Issue: AUGUST 2015



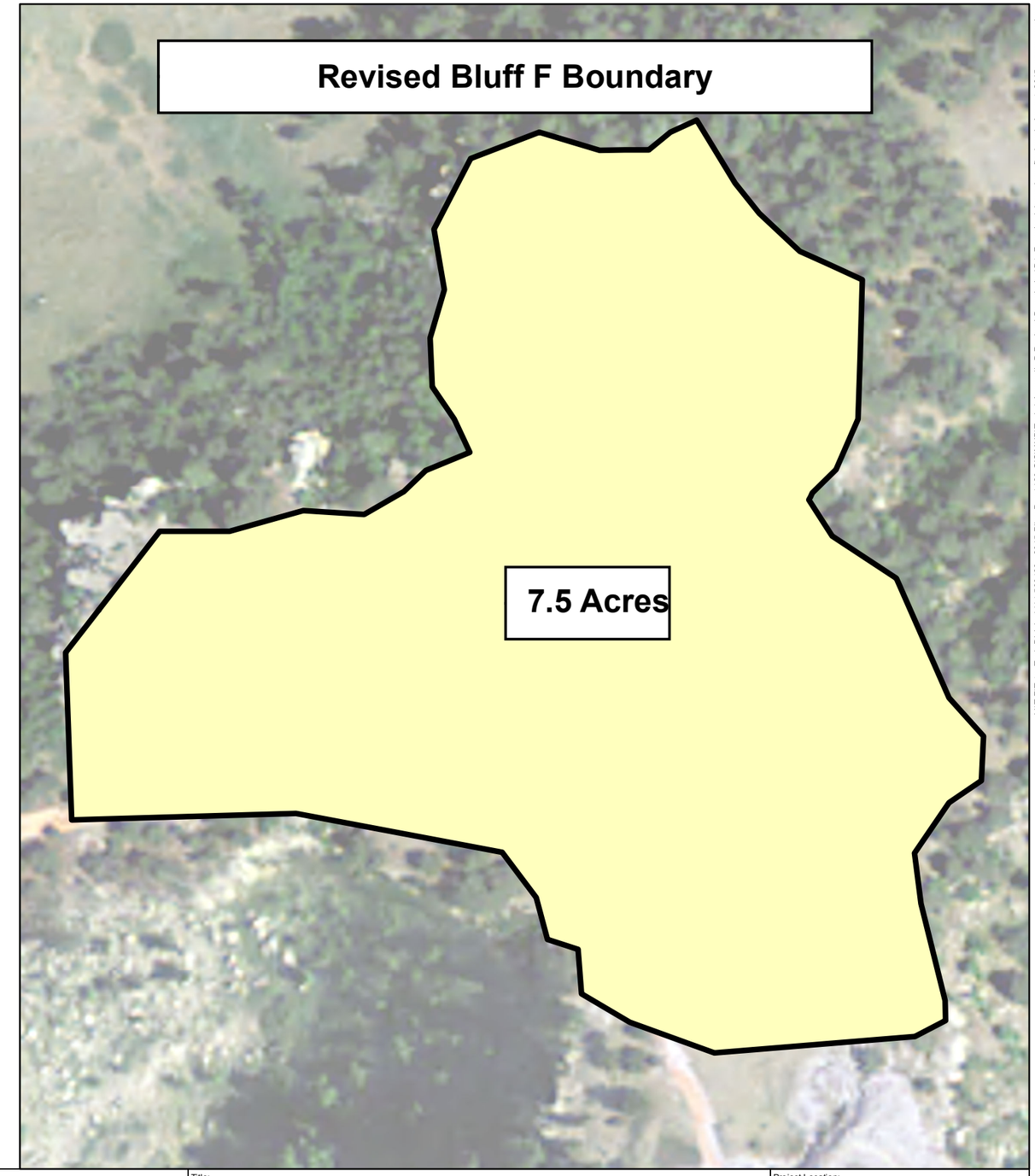




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**FIGURE D4**
**REVISED BLUFF F BOUNDARY**

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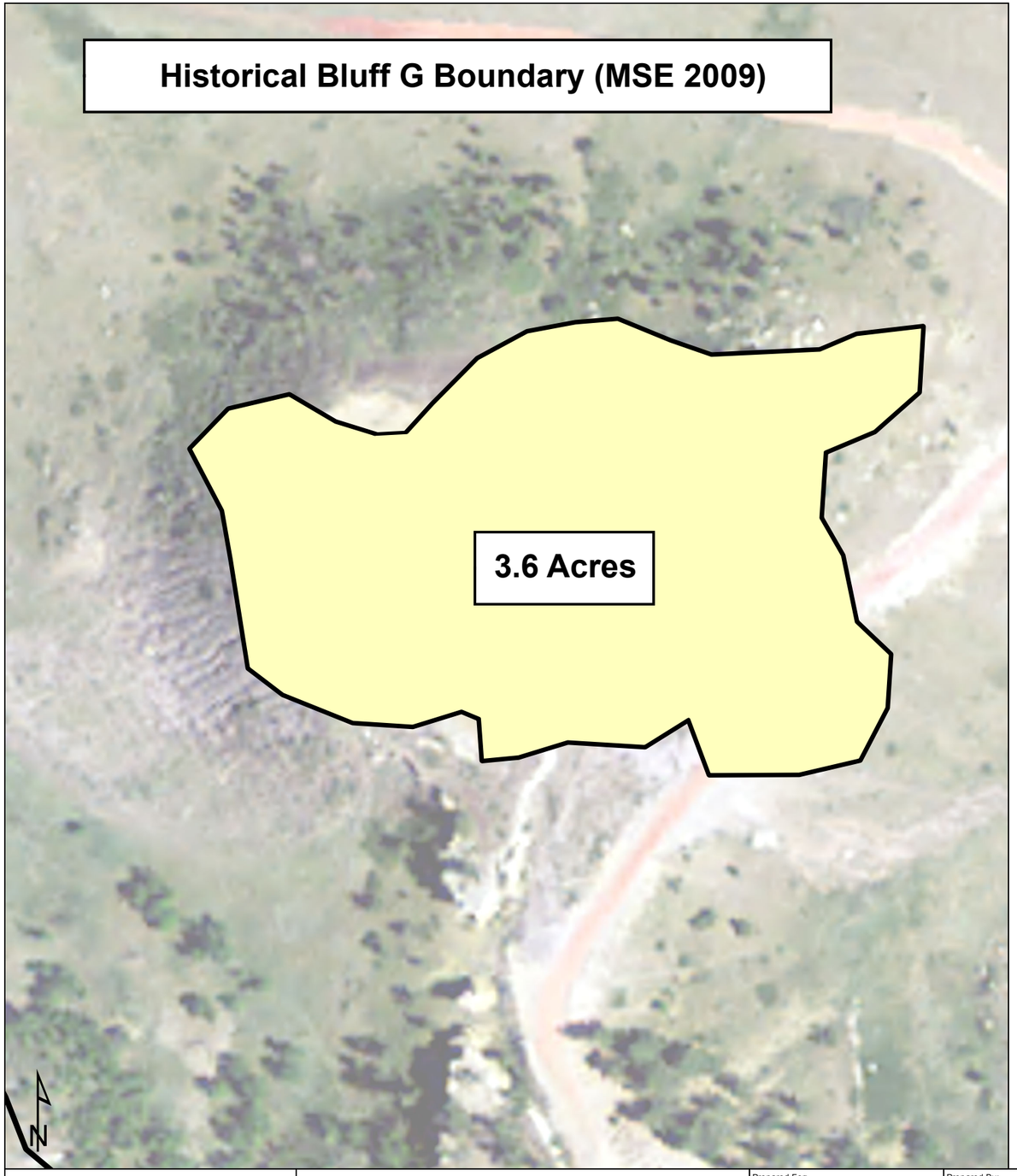


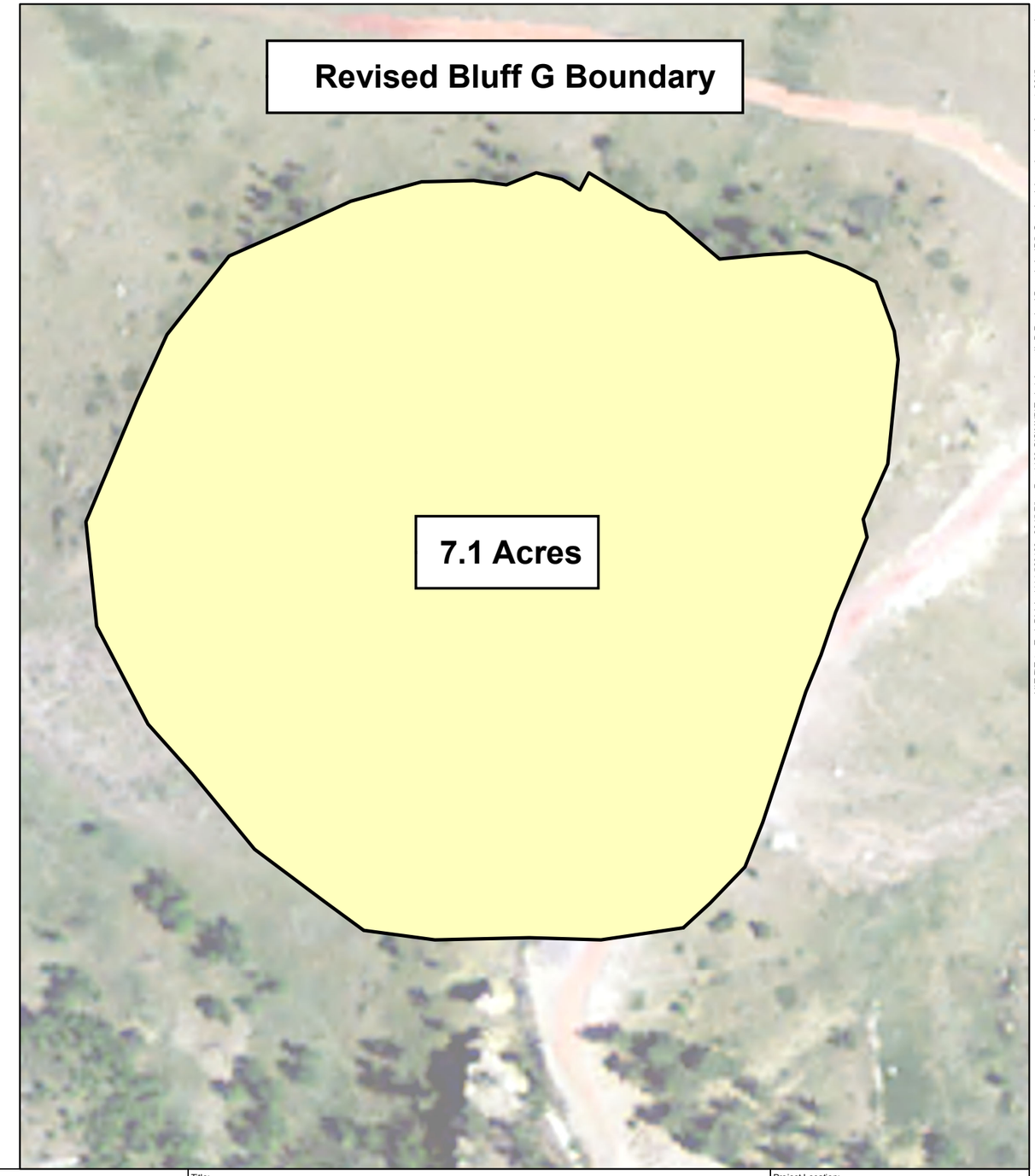


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**FIGURE D5**
**REVISED BLUFF G BOUNDARY**

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Date of Issue: AUGUST 2015

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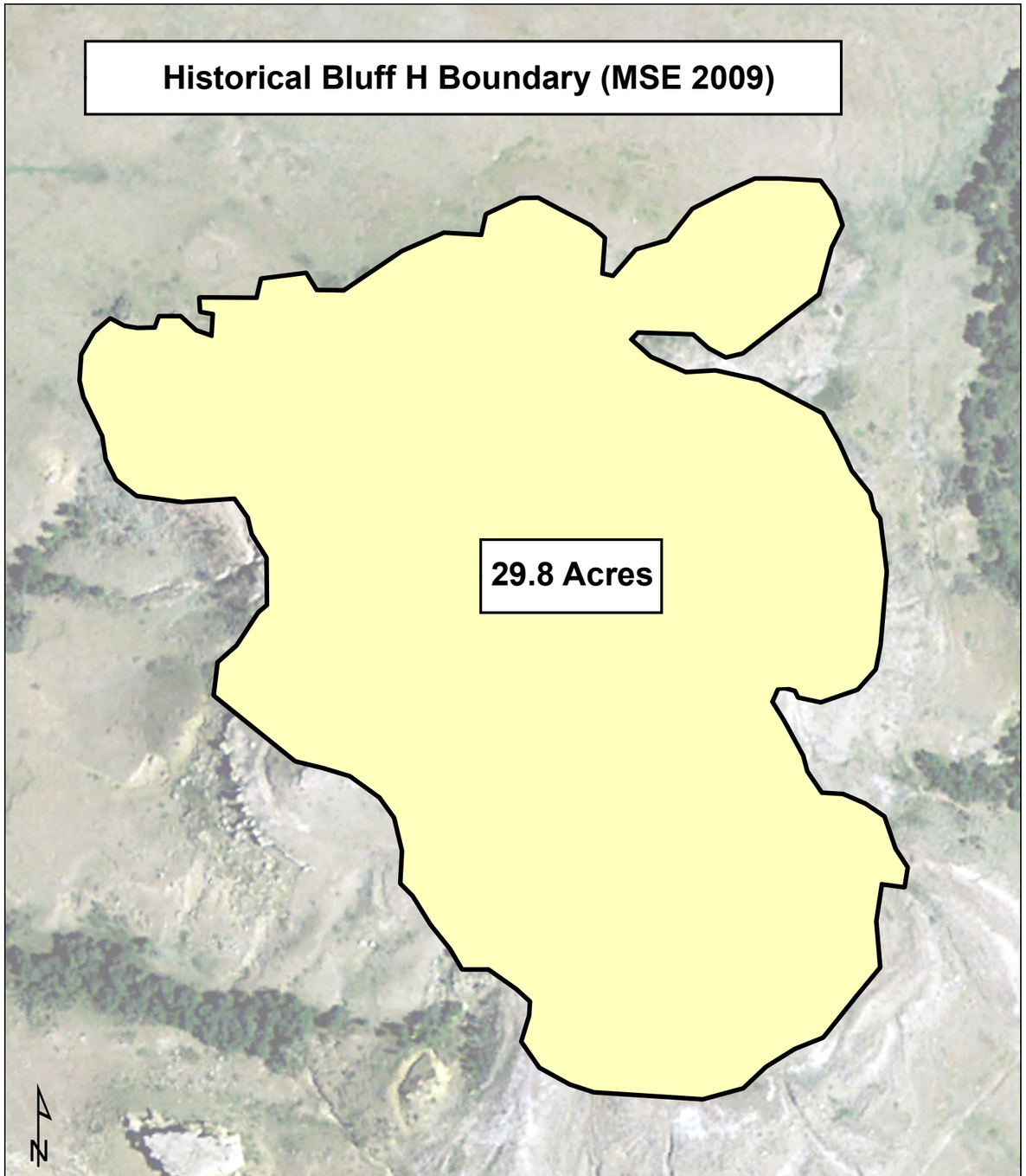


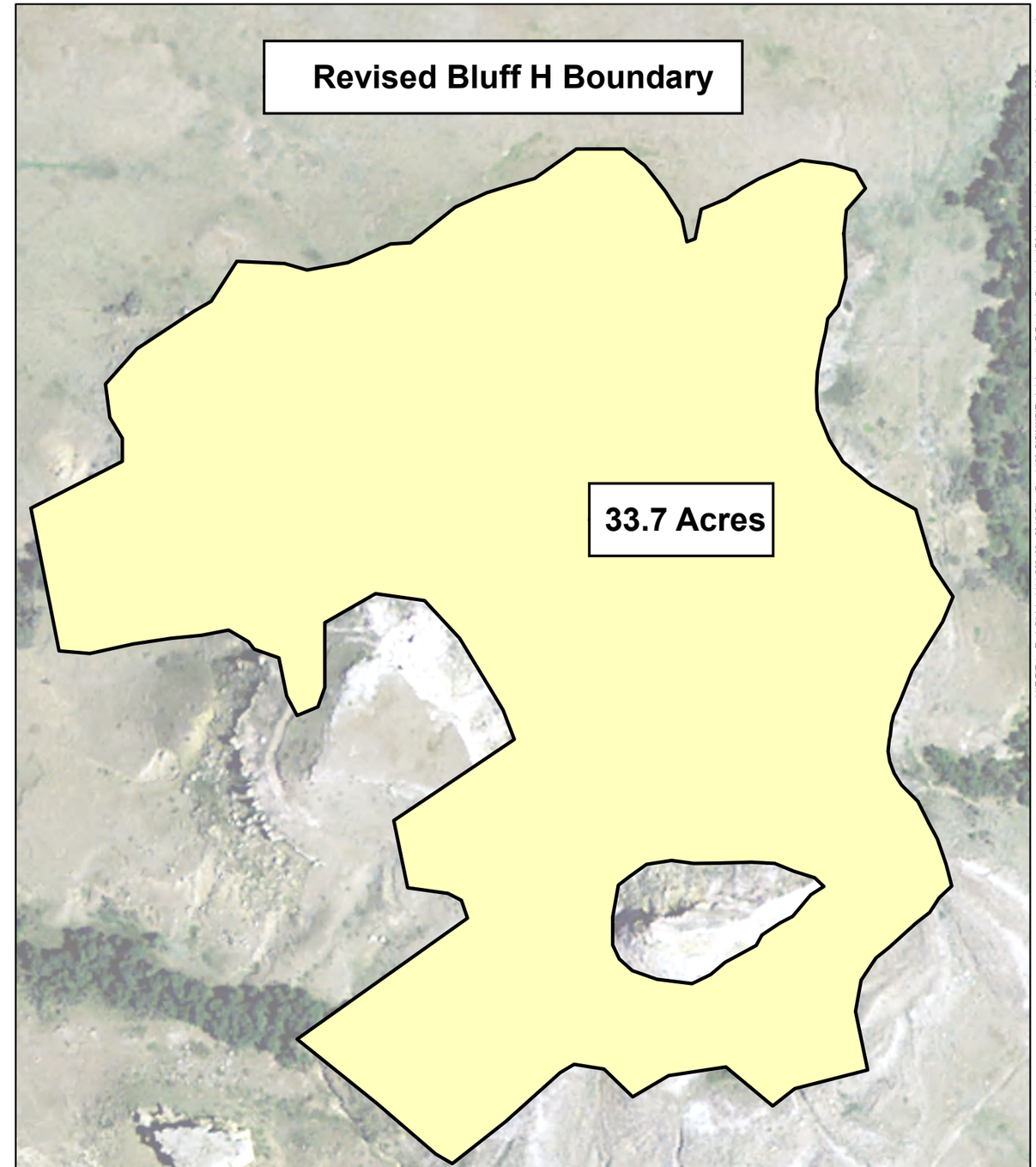


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**FIGURE D6**
**REVISED BLUFF H BOUNDARY**

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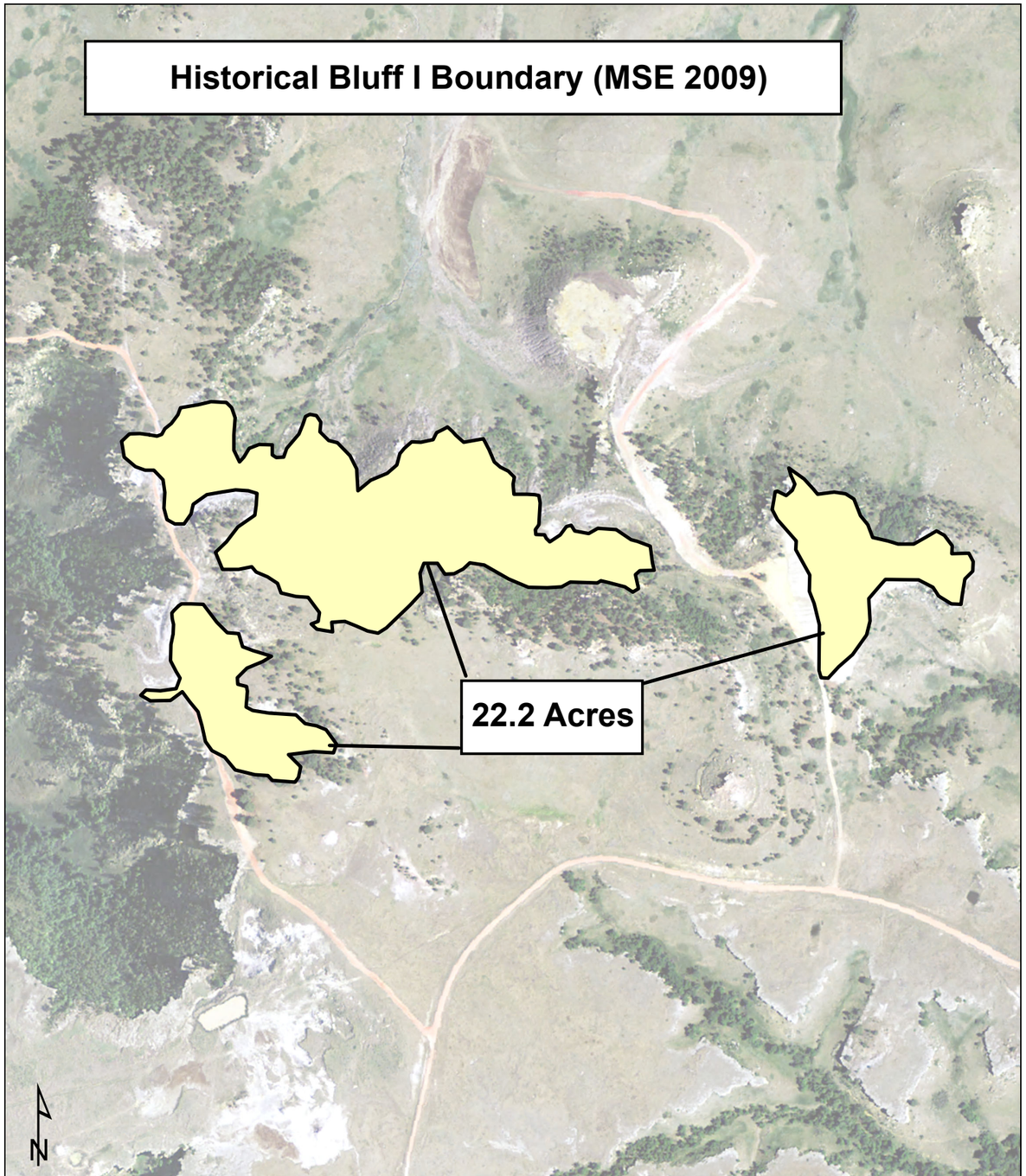


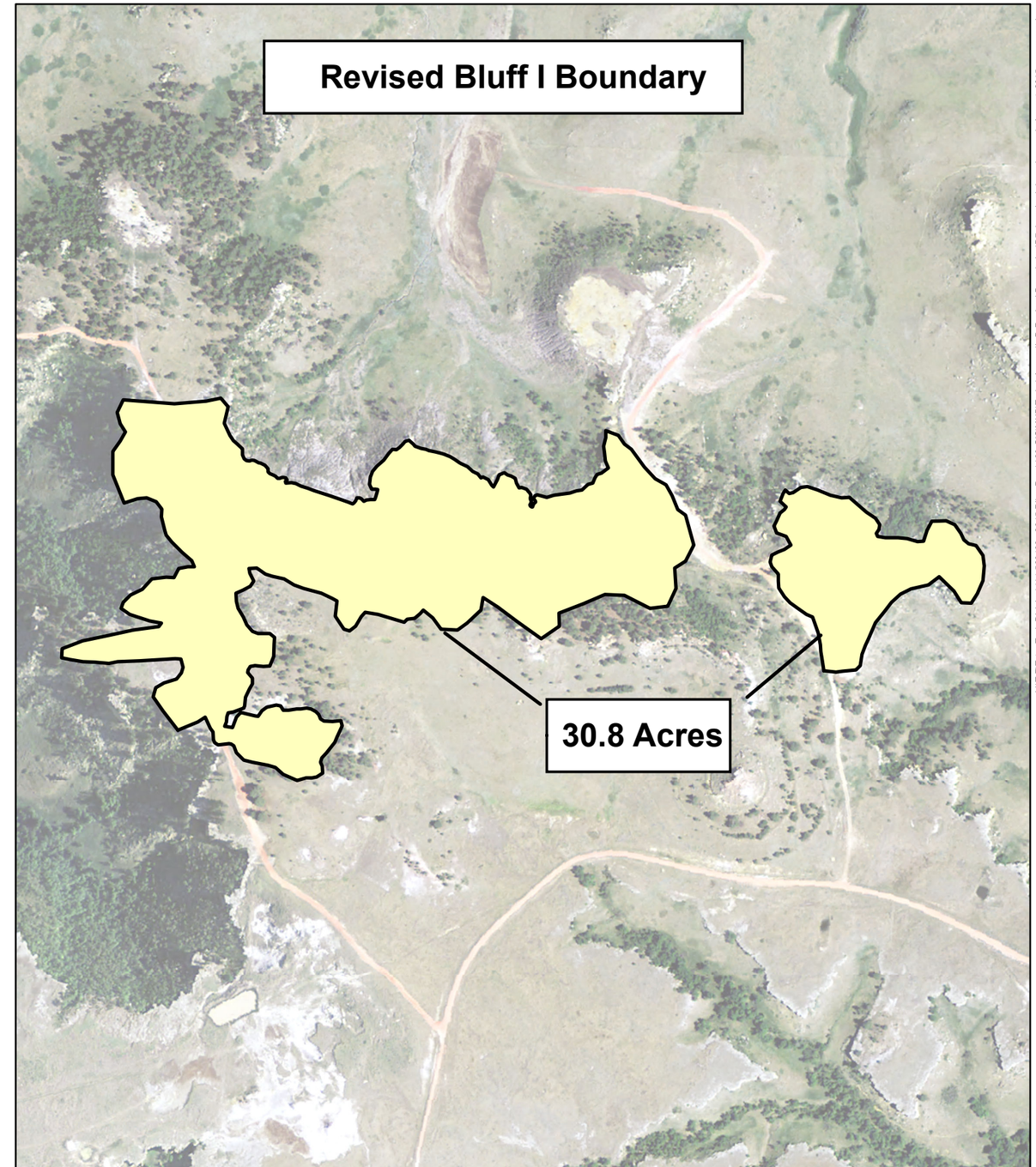


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**FIGURE D7**
**REVISED BLUFF I BOUNDARY**

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Date of Issue: AUGUST 2015

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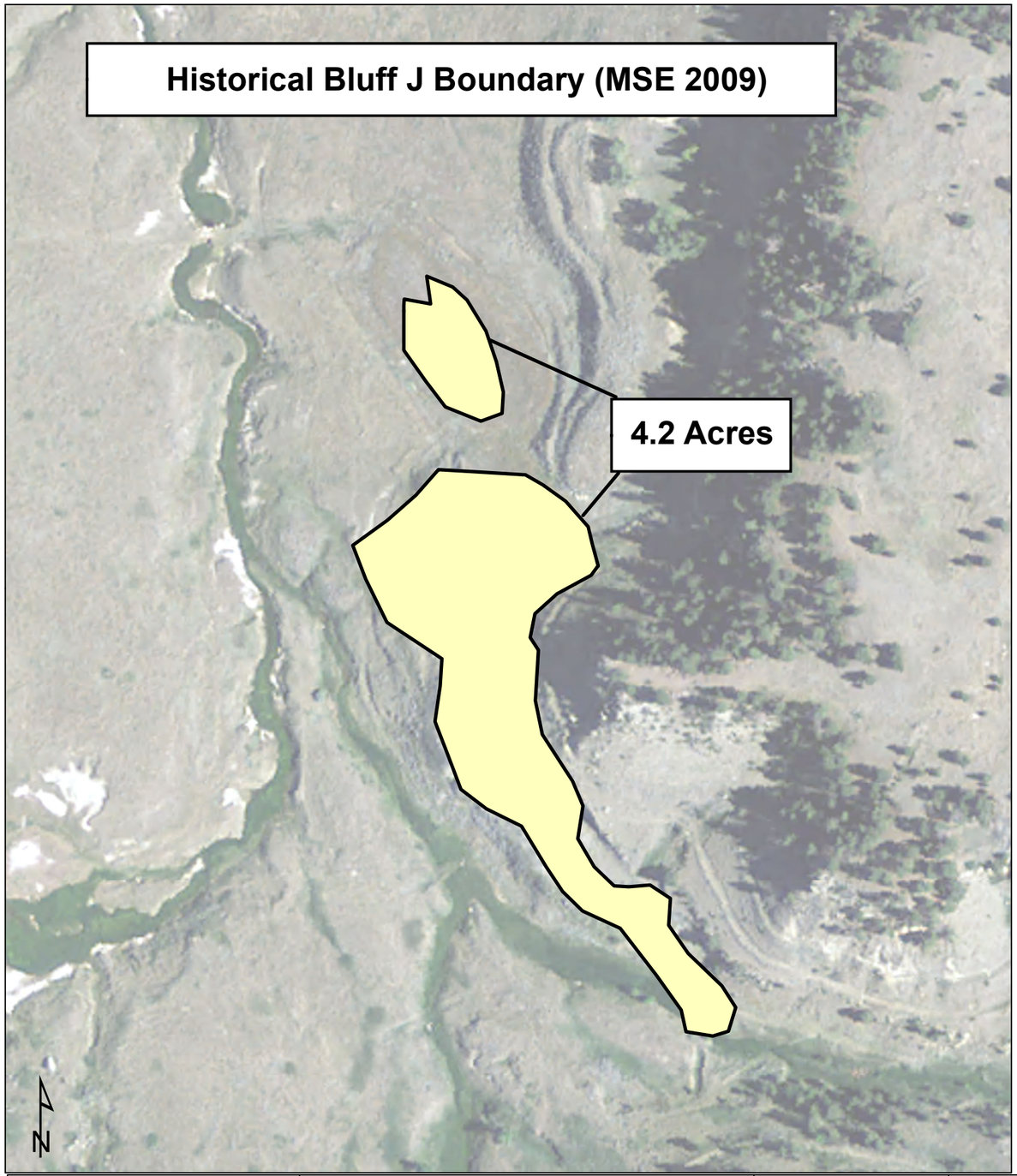


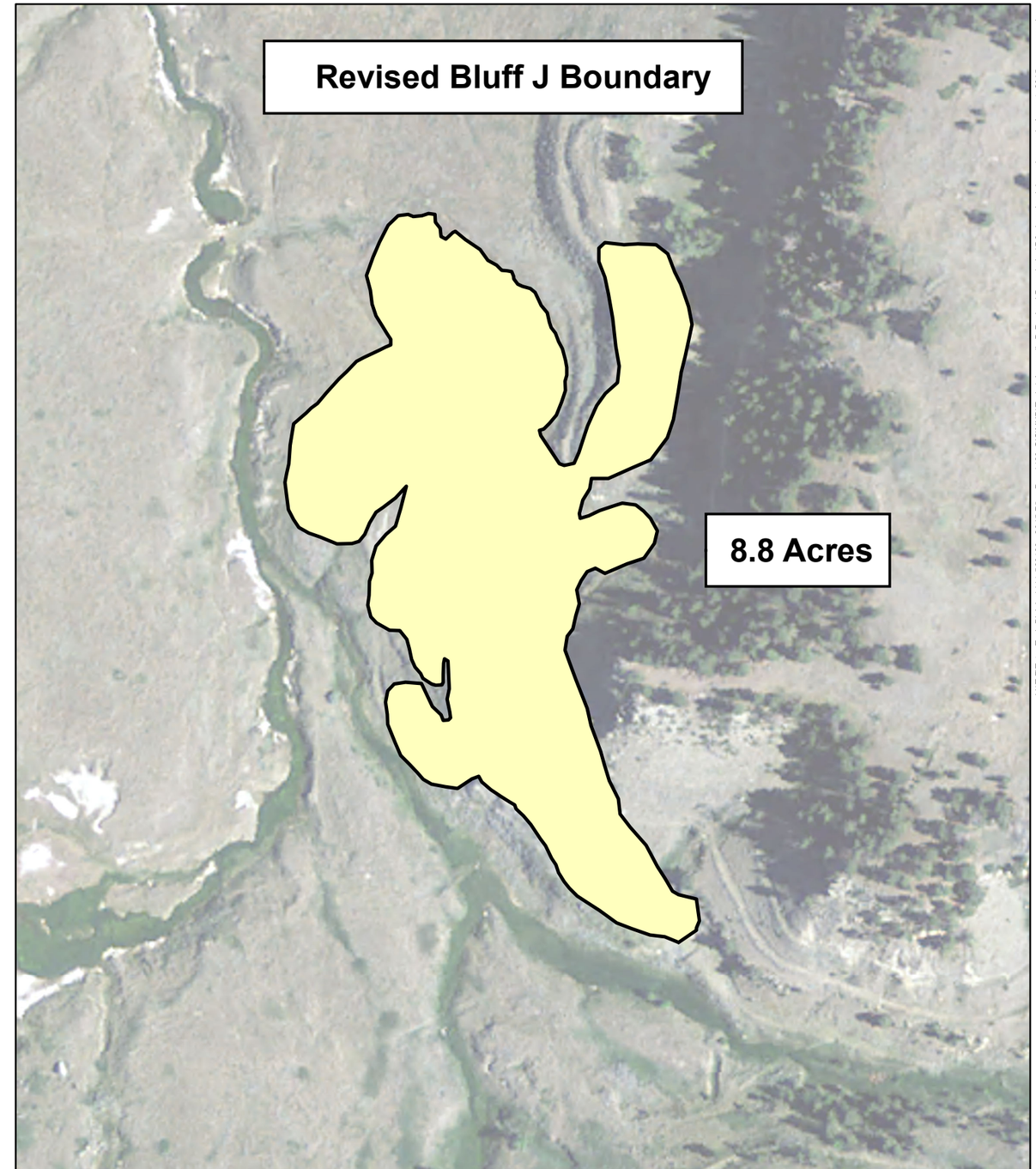


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**FIGURE D8**
**REVISED BLUFF J BOUNDARY**

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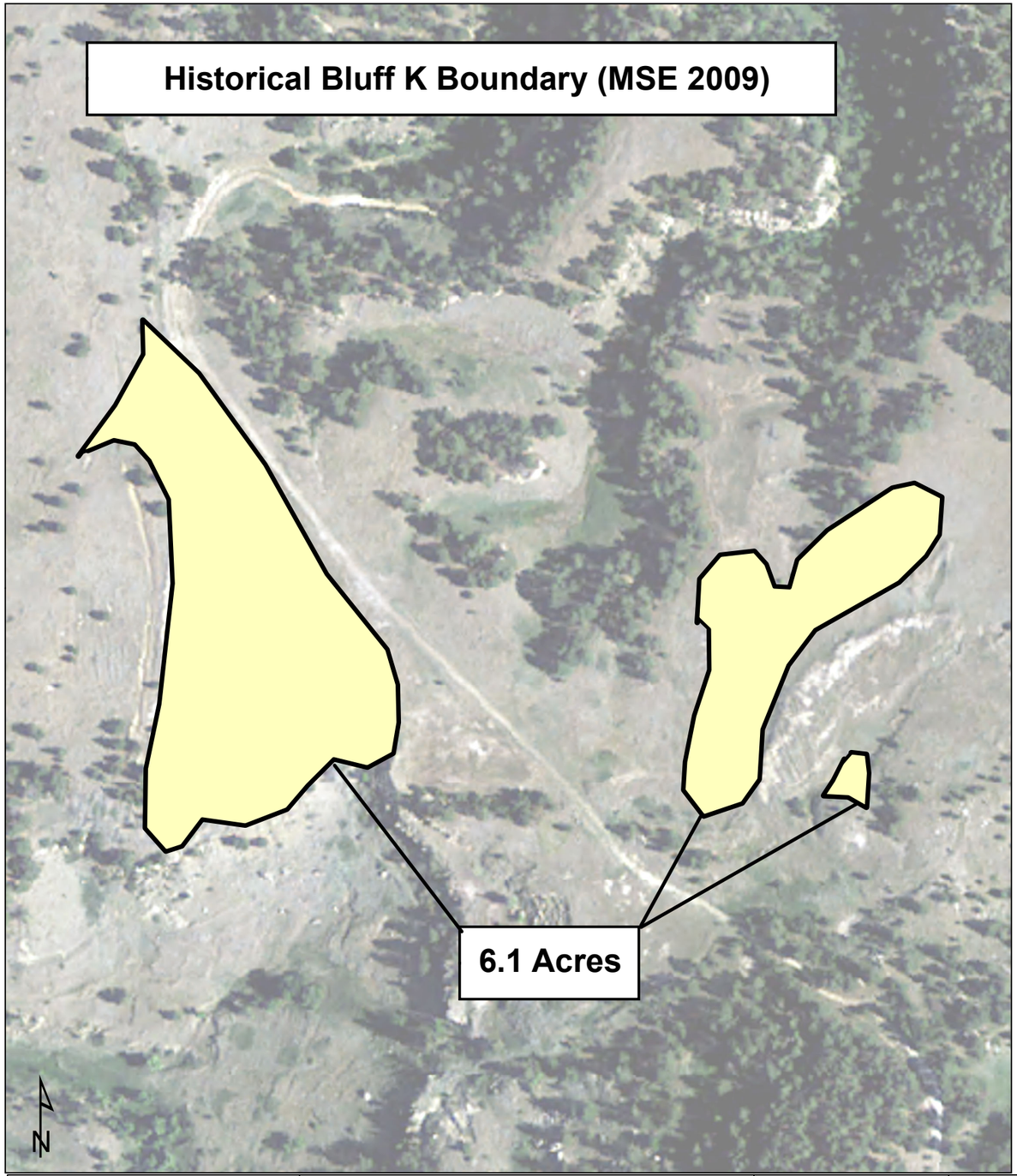


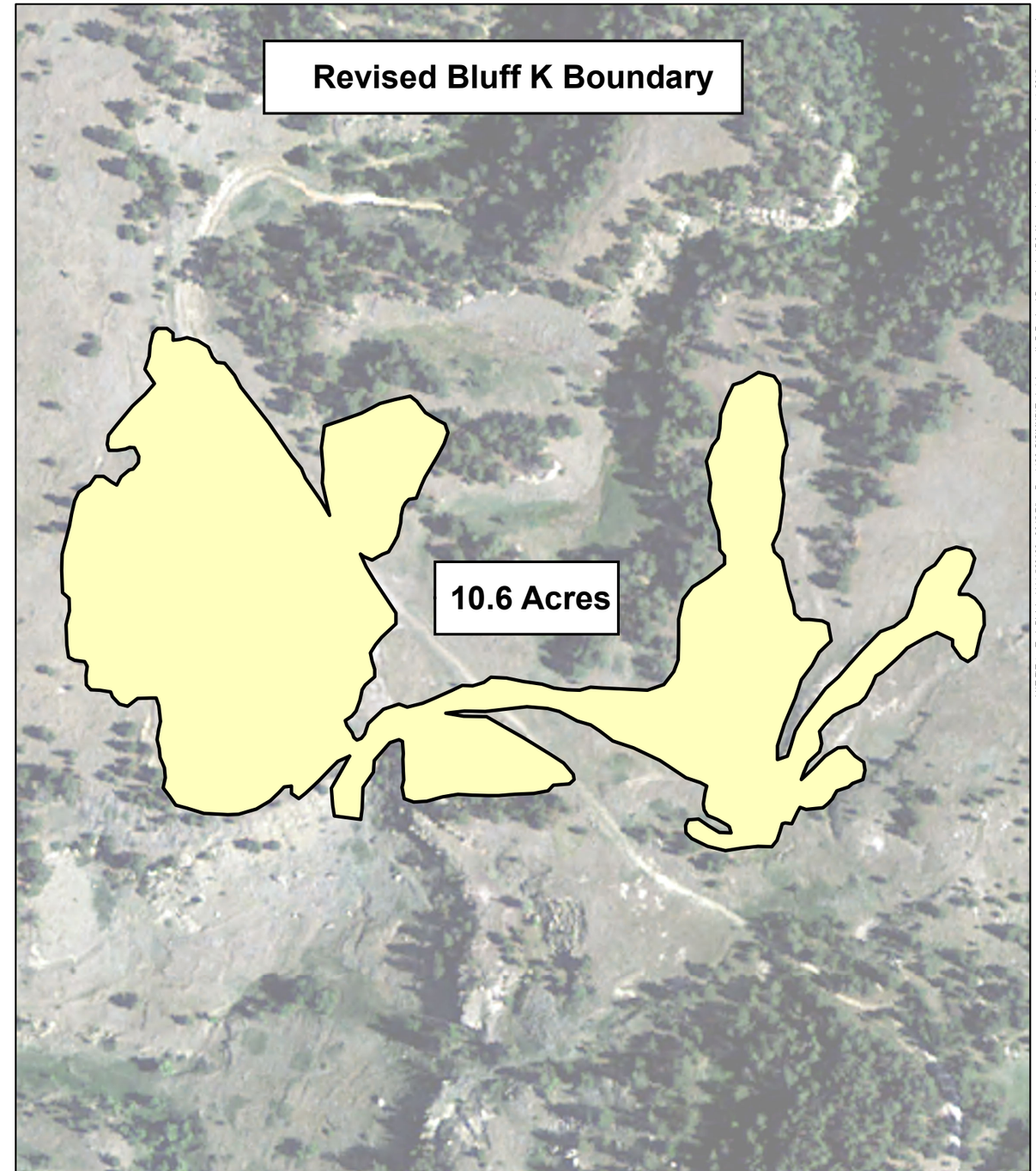


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**FIGURE D9**
**REVISED BLUFF K BOUNDARY**

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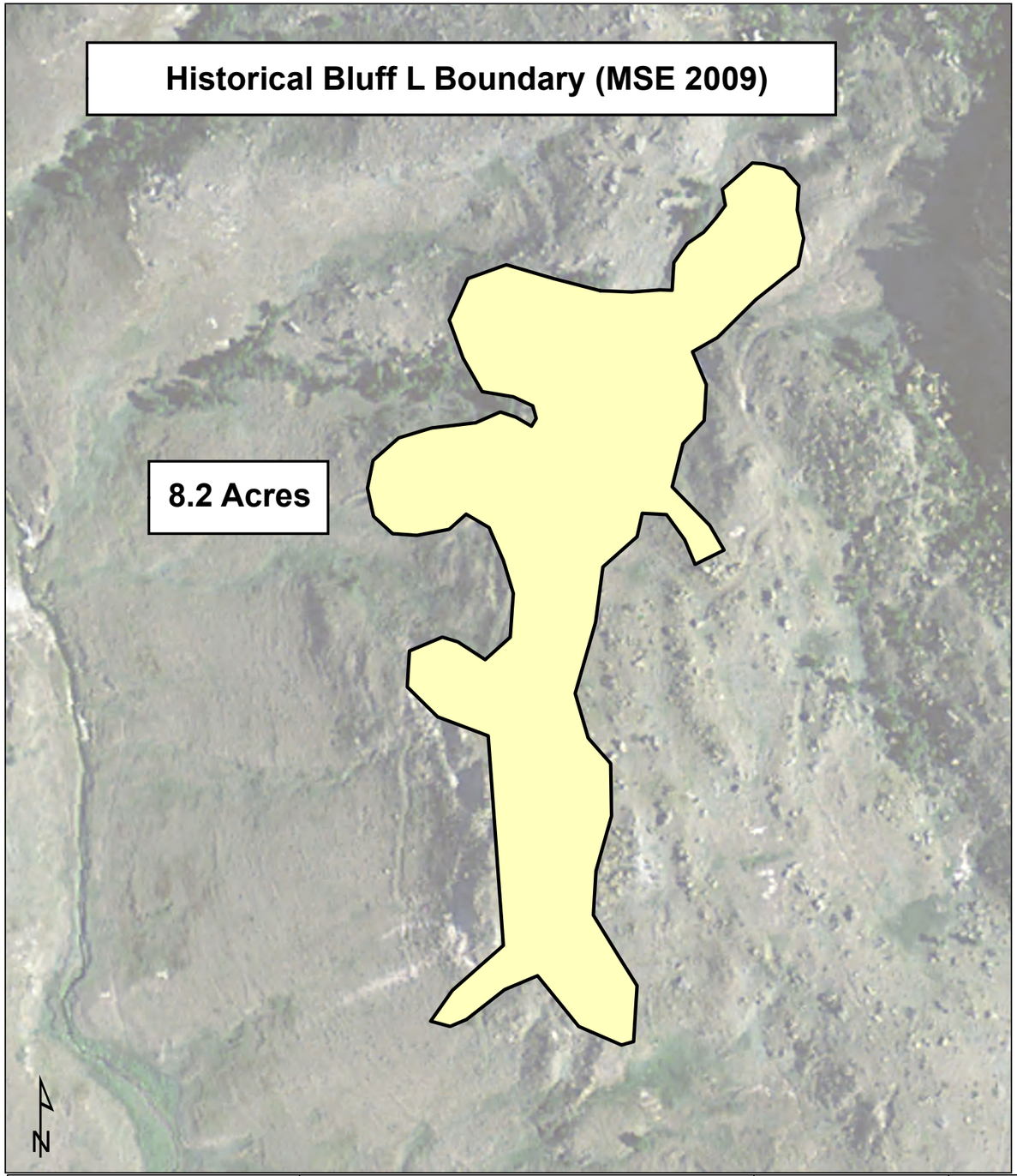


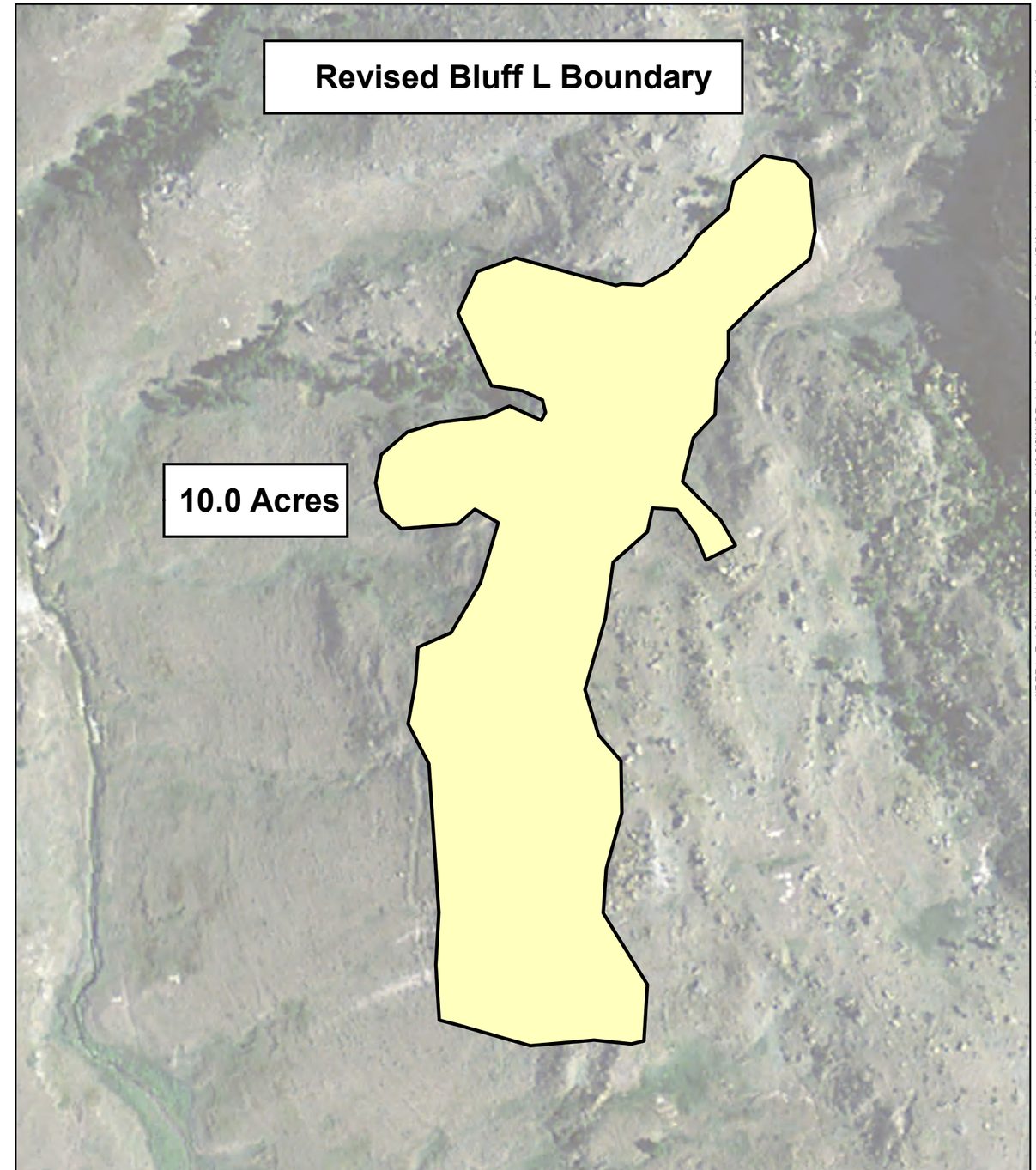


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**FIGURE D10**
**REVISED BLUFF L BOUNDARY**

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Project no.:
114-560486A

Date of Issue:
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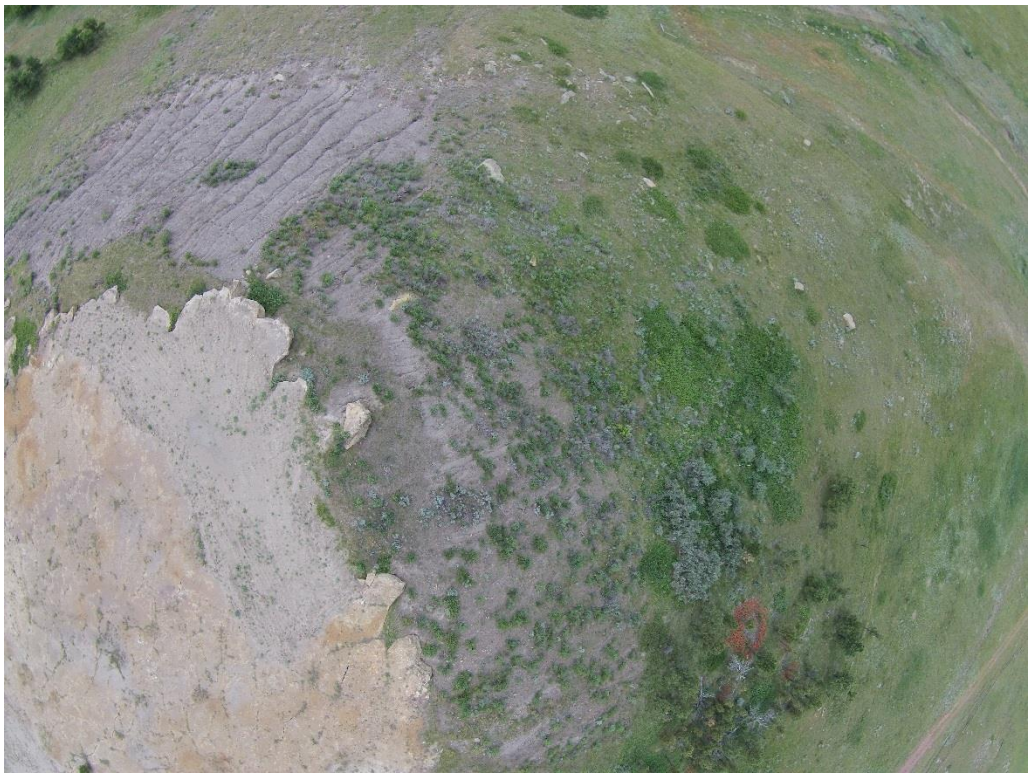
# APPENDIX E

# PHOTOGRAPHIC LOG

**1. Bluff B Drainage (Photo taken in July 2015)**

**2. Bluff F (Photo taken in July 2015)**



**3. Bluff G – North and West Side (Photo taken in July 2015)**

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**4. Bluff G (Photo taken in July 2015)**

**5. Bluff G (Photo taken in July 2015)**

**6. Bluff G – West Side (Photo taken in July 2015)**

**7. Bluff G (Photo taken in July 2015)**

**8. Reclaimed Western Portion of Bluff I (i.e. Bluff I2) (Photo taken in July 2015)**

**8. Reclaimed Western Portion of Bluff I [i.e. Bluff I2] (Photo taken in July 2015)**

**9. Repository at Bluff I (Photo taken in July 2015)**

**10. Repository at Bluff I (Photo taken in July 2015)**

**11. Repository at Bluff I (Photo taken in July 2015)**

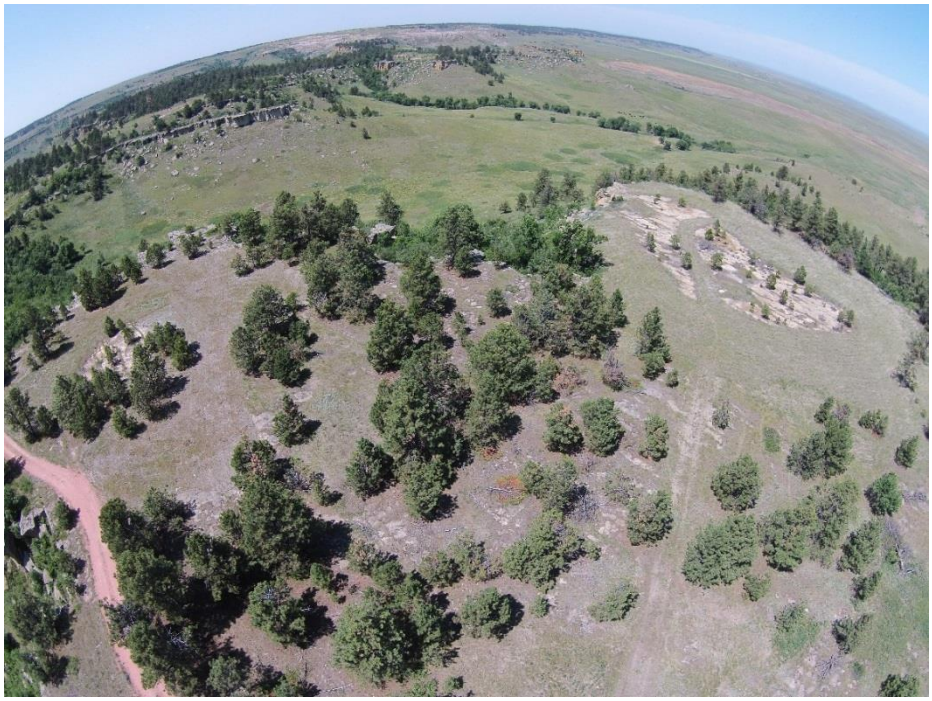
**12. Repository at Bluff I (Photo taken in July 2015)**

**12. Repository at Bluff I (Photo taken in July 2015)**

**13. Repository at Bluff I (Photo taken in July 2015)**

**15. Bluff F (Photo taken in July 2015)**

**17. View of Bluff I and Bluff G (Photo taken in July 2015)**



**19. Bluff F (Photo taken in July 2015)**

**20. Repository at Bluff I (Photo taken in July 2015)**

**21. Repository at Bluff I (Photo taken in July 2015)**

**23. Sediment Pond (SP2)**

# APPENDIX F

# DRAINAGE DELINEATION NETWORK FOR BLUFFS B, CDE, AND H

# Appendix F – Drainage Delineation Network on Bluffs B, CDE, and H

## 1.0 PURPOSE

The purpose of this appendix is to document the results of a hydrologic evaluation of the drainage delineation network at the Riley Pass study areas Bluff B, Bluff CDE, and Bluff H. Cleanup boundaries based on arsenic and radium-226 (Ra-226) were developed for study areas Bluff B, Bluff CDE, and Bluff H as shown in the waste evaluation report. Tetra Tech performed a hydrologic evaluation to delineate stream networks that could potentially flow through the contaminated areas identified with elevated heavy metals and radionuclides and transport these materials downstream.

## 2.0 METHODS

Elevation data was obtained from a Light Detection and Ranging (LiDAR) survey performed at the Riley Pass site. The survey was performed for the United States Geological Survey (USGS) by Aerometric and the results are summarized in Aerometric (2012). The study area encompassed 2.5 square miles of land area and consisted of four flight missions. The nominal point spacing (NPS) was 0.5 meters and the fundamental vertical accuracy (FVA) was 18.2 cm at a 92% confidence interval.

Stream networks were developed using a minimum watershed area of 1.6 acres using ArcGIS. The elevation data was provided in XML format. The following steps were followed to map the stream networks:

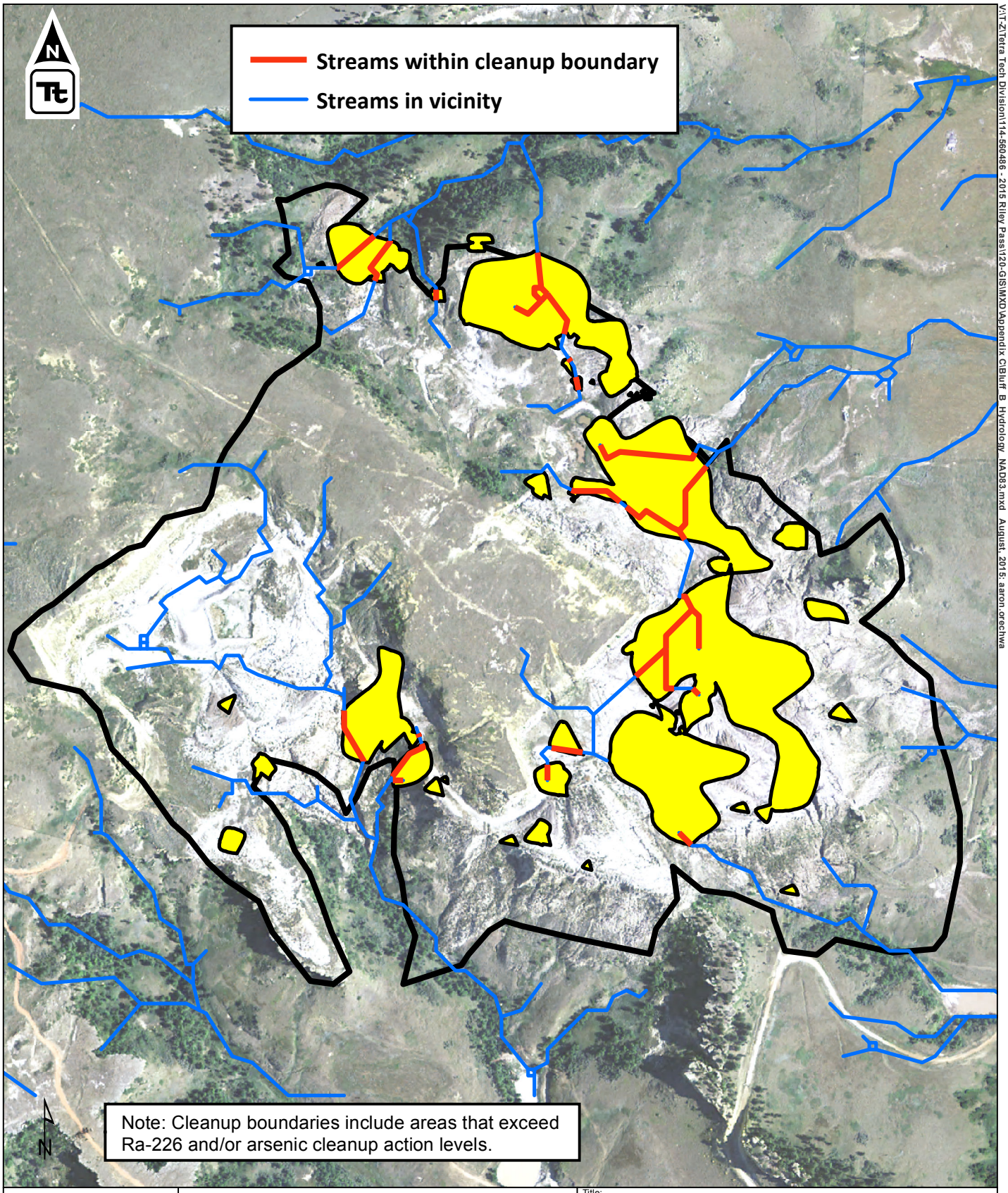
1. Import Digital Elevation Model of the study area of interest.
2. Check for sinks in the DEM.
3. Fill Sinks and Create Flow Direction Raster.
4. Create Source Raster for Watershed Delineation

# 3.0 RESULTS

Stream networks were determined using the methods described above. The clipping tool in ArcGIS was used to identify the stream sections (shown in red) that flow directly through the cleanup boundaries. Table D1 shows the stream lengths contained within each study area cleanup boundary and the total cleanup area for each study area. A total of 6,249 feet of streams flow through the cleanup boundaries. The density of streams per cleanup area for each study area was calculated and presented in Table F1. Bluff B had the highest density of streams within cleanup areas compared to all of the study areas. Figure F1 through Figure F3 show the stream networks that are contained within areas that exceed risk-based arsenic and Ra-226 cleanup criteria for Bluff B, Bluff CDE, and Bluff H, respectively.

**Table F1 Summary of Streams in Cleanup Areas**

| Study Area | Length (ft) | Cleanup Area (acres) | Density (ft/acre) |
|---|---|---|---|
| Bluff B | 3,913 | 25 | 154 |
| Bluff CDE | 1,643 | 33 | 49 |
| Bluff H | 693 | 10 | 67 |
| **Total** | **6,249** | **69** | **91** |

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NAD_1983_STATEPLANE
SOUTH_DAKOTA
NORTH_FIPS_4001_FEET

Bluff B Boundary
Cleanup Boundary

Title:

**BLUFF B EVALUATION OF EPHEMERAL DRAINAGES**

Prepared for:

Prepared by:

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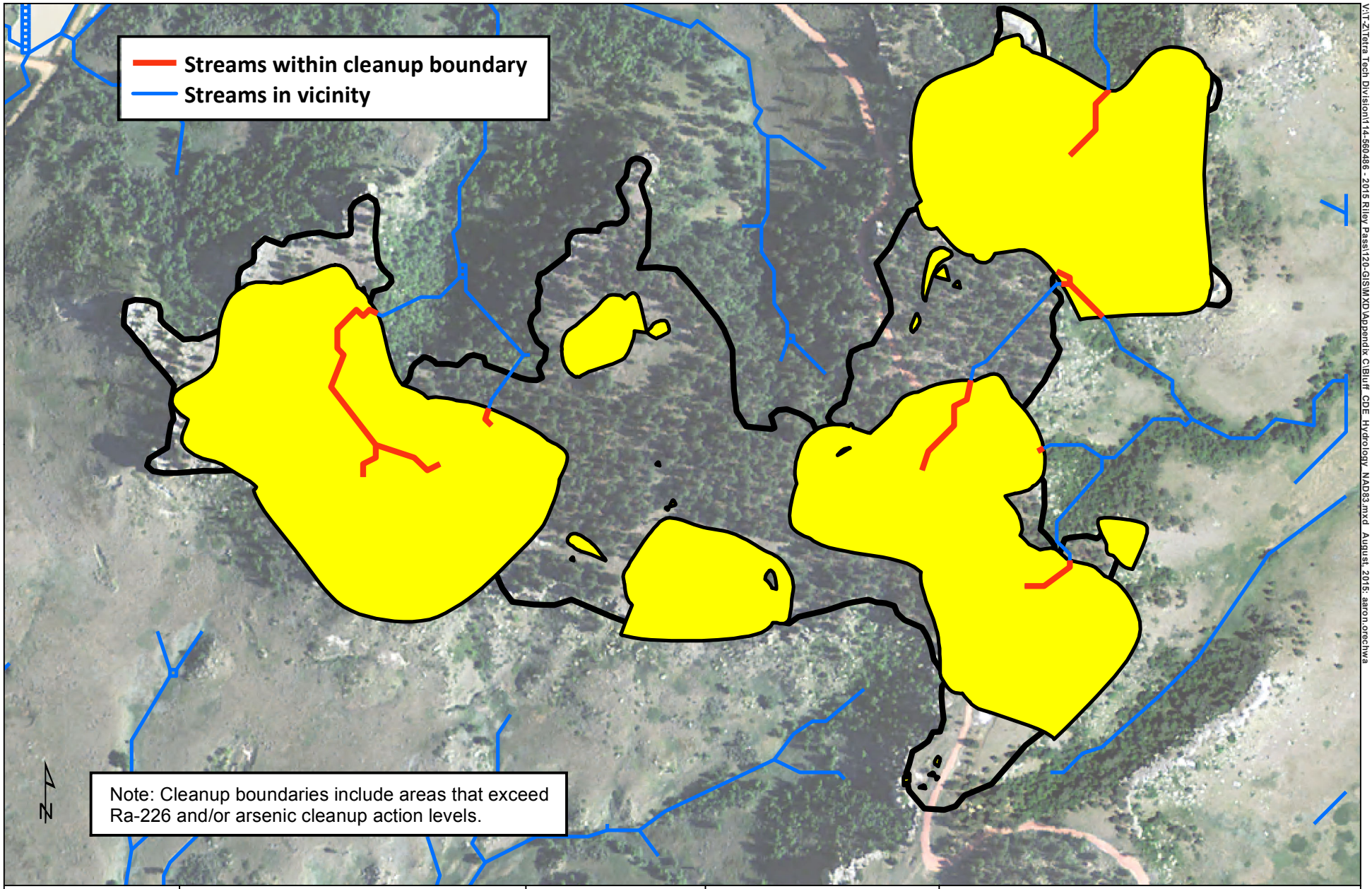
3801 Automation Way Suite 100
Fort Collins, Colorado 80525
(970)223-9600 (970)223-7171 fax

Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date: AUGUST 2015

Figure: **Figure F1**

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NAD_1983_STATEPLANE
SOUTH_DAKOTA
NORTH_FIPS_4001_FEET

Bluff CDE Boundary
Cleanup Boundary

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Prepared by:

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970-223-9600

Title: BLUFF CDE EVALUATION OF EPHEMERAL DRAINAGES

Location: HARDING COUNTY, SD

Project no.: 114-560486A

Date: AUGUST 2015

Figure: Figure F2

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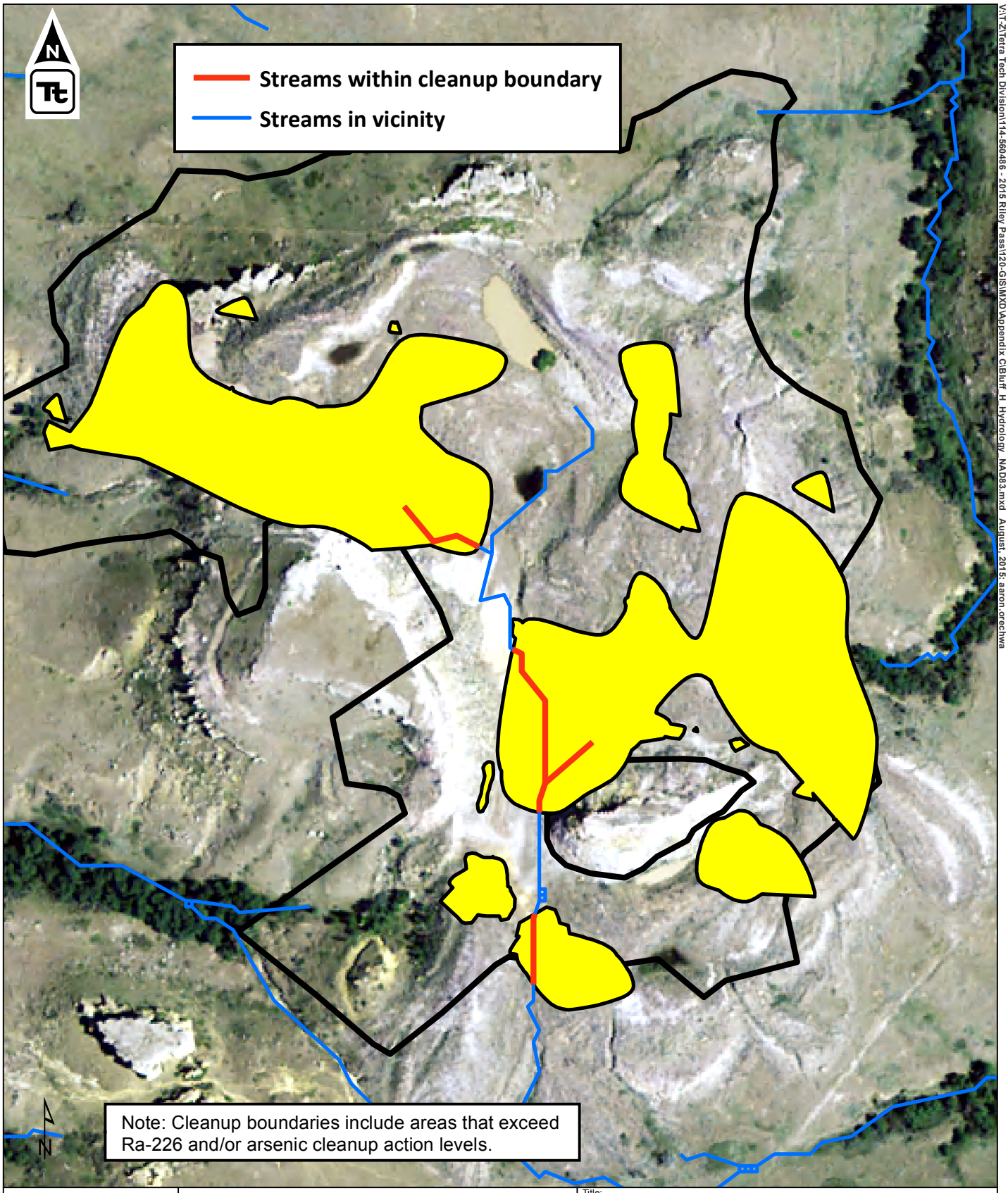


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Bluff H Boundary
Cleanup Boundary

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Title:
**BLUFF H EVALUATION OF EPHEMERAL DRAINAGES**

Location: HARDING COUNTY, SD

Project no.: 114-560486A

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Figure: **Figure F3**

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# 4.0 CONCLUSIONS

A hydrologic evaluation was performed at study areas Bluff B, Bluff CDE, and Bluff H. Drainage networks were identified based on a minimum 1.6 acre watershed size using ArcGIS. The results demonstrate approximately 6,249 feet of drainage paths flow directly through the arsenic/Ra-226 cleanup boundaries. This information can be used to identify areas to focus additional sampling and to prioritize removal actions.

# 5.0 REFERENCES

Aerometric. 2012. Airborne GPS Survey Report for the United States Geological Survey National Geospatial Technical Operations Center. *Mount Rushmore National Memorial and Riley Pass, Custer National Forest LiDAR.* Contract ID G10PC00025. Task Order G12PD01039. August.