Northern Agency Tronox Mines

FINAL
Removal Site Evaluation Report

Response, Assessment, and Evaluation Services (RAES)

Contract No. EP-S9-17-03

Task Order 0001

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Submitted to

U.S. Environmental Protection Agency

Submitted by

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TETRA TECH

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ACRONYMS AND ABBREVIATIONS

°F	Degrees Fahrenheit
µR/hr	Microroentgens per hour
ADWR	Arizona Department of Water Resources
AEC	Atomic Energy Commission
AML	Abandoned mine lands
amsl	Above mean sea level
ANSI/HPS	American National Standards Institute / Health Physics Society
ASPECT	Airborne Spectral Photometric Environmental Collection Technology
ASTM	ASTM International
ATSDR	Agency for Toxic Substances and Disease Registry
AUM	Abandoned uranium mine
Bi-214	Bismuth-214
bgs	Below ground surface
BSA	Background Study Area
BTV	Background threshold value
CAS	Chemical Abstracts Service
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
COPC	Contaminant of potential concern
cpm	Counts per minute
CSM	Conceptual site model
CWWA	Cove Wash Watershed Assessment
DOE	U.S. Department of Energy
DQO	Data quality objective
EDD	Electronic data deliverable
E&E	Ecology & Environment, Inc.
EE/CA	Engineering Evaluation/Cost Analysis
ERG	Environmental Restoration Group, Inc.
ERT	Emergency Response Team
FSP	Field Sampling Plan
GIS	Geographic information system
GPS	Global Positioning System
HDOP	Horizontal dilution of precision
HPIC	High-pressure ionization chamber
HRS	Hazard Ranking System
HUC	Hydrologic unit code

ACRONYMS AND ABBREVIATIONS (CONTINUED)

ICP-MS	Inductively coupled plasma-mass spectrometry
ICRP	International Council on Radiation Protection
ISO	International Organization for Standardization
Jc	Carmel Formation
Jmb	Brushy Basin Member
Jml	Lower Morrison Formation
Jmr	Recapture Member
Jms	Morrison Formation
Jmu	Upper Morrison Formation
Jmw	Westwater Canyon Member
Js	Summerville Formation
Jse	Undifferentiated Summerville and Entrada Formation
Jste	Undifferentiated Summerville, Todilto, and Entrada Formations
K-40	Potassium-40
Kerr-McGee	Kerr-McGee Oil Industries, Inc.
LCS	Laboratory control sample
LIDAR	Light detecting and ranging
m^2	Square meter
MARLAP	*Multi-Agency Radiological Laboratory Analytical Protocols Manual*
MARSSIM	*Multi-Agency Radiation Survey and Site Investigation Manual*
MCAP	Mine Category Assessment Protocol
mg/kg	Milligrams per kilogram
mph	Miles per hour
mrem	Millirem
MS/MSD	Matrix spike/matrix spike duplicate
mSv	Millisievert
n	Number of samples, analyses, or measurements
NA	Not applicable
NaI(TI)	Sodium iodide thallium-laced
NAMLRD	Navajo Nation Division of Natural Resources, Abandoned Mines Land Reclamation Department
NAMLRP	Navajo Nation Abandoned Mine Lands Reclamation Program
NAUM	Navajo-area abandoned uranium mine
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NCRP	National Council on Radiation Protection and Measurements
NECA	Navajo Engineering and Construction Authority
Neptune	Neptune and Company, Inc.
NNDFW	Navajo Nation Department of Fish and Wildlife
NNEPA	Navajo Nation Environmental Protection Agency
NOAA	National Oceanic and Atmospheric Administration

ACRONYMS AND ABBREVIATIONS (CONTINUED)

NORM	Naturally occurring radioactive material
NRC	U.S. Nuclear Regulatory Commission
NRCS	National Resources Conservation Service
NSP	Navajo Superfund Program
OSWER	Office of Solid Waste and Emergency Response
pCi/g	Picocuries per gram
pCi/L	Picocuries per liter
PCSM	Preliminary Conceptual Site Model
ppm	Parts per million
Qa	Quaternary Alluvium
QA	Quality assurance
QC	Quality control
QAPP	Quality Assurance Project Plan
R^2	Statistical measure of how close data come to a fitted regression line (also known as the coefficient of determination)
Ra-226	Radium-226
RAES	Response, Assessment, and Evaluation Services
Roux	Roux Associates
RPD	Relative percent difference
RPM	Remedial Project Manager
RPP	Radiation Protection Program
RSD	Relative standard deviation
RSE	Removal Site Evaluation
RSE Report	Northern Agency Tronox Removal Site Evaluation Report
SAP	Sampling and Analysis Plan
SDG	Sample delivery group
SERAS	Scientific Engineering Response & Analytical Services
SOP	Standard Operating Procedure
SPLP	Synthetic precipitation leaching procedure
SSRSE	Site-specific Removal Site Evaluation
T&E	Threatened and endangered
Tc	Chuska Sandstone
TCLP	Toxicity characteristic leaching procedure
TENORM	Technologically enhanced naturally occurring radioactive material
Tetra Tech	Tetra Tech, Inc.
Th-232	Thorium-232
TO	Task Order
Trc	Chinle Formation
Trw	Wingate Formation
TSG	TerraSpectra Geomatics

ACRONYMS AND ABBREVIATIONS (CONTINUED)

U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U. S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VCA	Vanadium Corporation of America
Weston	Weston Solutions, Inc.
XRF	X-ray fluorescence
yd^3	Cubic yards

EXECUTIVE SUMMARY

In the northern region of the Navajo Nation, on the Colorado Plateau, uranium ore mining began in the late 1940s as a response to the Atomic Energy Commission's (AEC) uranium procurement program. The uranium industry boomed, and numerous mine operators extracted ore in the Navajo Nation, including F.A Sitton, Navajo Uranium, Climax Uranium, Hopkins & Smith, Kerr-McGee Oil Industries, Inc. (Kerr-McGee), and, later, Vanadium Corporation of America (VCA). Many companies hired Navajo men to work in the mines, and many Navajo miners experienced health problems as a result of that work.

The Navajo Nation Environmental Protection Agency (NNEPA) was established in 1972 and is charged with protecting human health, welfare, and the environment of the Navajo Nation. The Navajo Nation Council established the Navajo Abandoned Mine Lands Reclamation Program (NAMLRP) in 1988 to address physical safety hazards posed by abandoned mines. The NAMLRP undertook a number of reclamation activities to address physical hazards at some abandoned uranium mine (AUM) sites in the late 1990s and early 2000s, and the NNEPA performed water sampling in the mid-2000s (Neptune and Company, Inc. [Neptune] and TerraSpectra Geomatics [TSG] 2018). However, many mines still contain unreclaimed waste piles and other mine features. Historical mining affected numerous communities, including Cove, Lukachukai, and Teec Nos Pos, and community members remain concerned about mining-related contamination.

In 2014, the United States District Court approved a historic legal settlement to provide nearly $1 billion to the U.S. Environmental Protection Agency (USEPA) to investigate and clean up approximately 50 AUM sites on or near the Navajo Nation that previously hosted operations of Kerr-McGee or its successor Tronox (referred to collectively as Tronox in this document). In 2017, USEPA awarded the Response, Assessment, and Evaluation Services (RAES) contract to Tetra Tech, Inc. (Tetra Tech) to provide engineering and technical consulting services for assessment and characterization of AUMs within the Navajo Nation.

This Northern Agency Tronox Removal Site Evaluation (RSE) Report (RSE Report) presents objectives, methods, results, and conclusions of Tetra Tech's field investigations in support of USEPA Region 9 between March and October 2018. Tetra Tech investigated 39 AUM sites, 37 Target sites, 22 miles of drainages, nearly 10 miles of access roads, and 32 background study areas (BSA) for this RSE. However, because one site (Tommy James Mine) was inaccessible, 38 AUM sites were sampled. Target sites included either (1) sites related to AUM sites ("AUM-related sites"), or (2) sites identified by USEPA as requiring additional characterization ("non-AUM Targets"). All AUM sites or AUM-related sites cited in this RSE Report were at one time operated by or associated with Tronox.

This RSE Report serves as a synopsis of the 13 appendices (Appendices A through M) that present the results and data of this RSE investigation. Purposes of the RSE investigations were to: (1) identify contaminants of potential concern (COPC), (2) delineate the lateral and vertical extent of mining-related contamination, and (3) determine volume of waste remaining in the areas investigated during the RSE. The field investigation included site mapping, X-ray fluorescence (XRF) field surveys, gamma radiation surveys, surface soil sampling, subsurface soil sampling, and radon monitoring.

Tetra Tech completed the following field activities:

- Recorded more than 2 million gamma radiation measurements across 32 BSAs, 38 AUM sites, and 37 Target sites; and evaluated 61 gamma-radium correlation plots to predict radium-226 (Ra-226) concentrations based on the gamma radiation measurements. These correlations may be used to convert the gamma radiation survey measurements into predicted Ra-226 concentations.

- Collected 292 surface soil samples within 0 to 6 inches below ground surface (bgs) and 502 XRF confirmatory soil samples within 0 to 3 inches bgs across 38 AUM sites and 37 Target sites. Results from these samples were used to identify COPCs and estimate the volume of mine waste present at each site.

- Collected more than 1,000 background soil samples at 32 BSAs. The site-specific BSAs were selected to represent unimpacted conditions of AUM and Target sites. Results were used to calculate background threshold values (BTV) for 29 analytes at each site-specific BSA and across four geologic regions. Analytical results from AUM and Target sites were compared to BTVs to identify COPCs.

- Recorded 9,540 in-situ XRF measurements across 38 AUM sites and 37 Target sites within the Northern Agency Tronox Mine area region; measurements occurred within a systematic 100-square-meter (m^2) survey unit grid system at each site. The XRF field survey extended across treacherous terrain within the Lukachukai Mountains and across the more forgiving lower-lying terrain at the base of the northwest Carrizo Mountains in the Tse Tah region of the Navajo Nation within Apache County in northeast Arizona. Moreover, as cited above, 502 confirmatory bulk soil samples were collected and evaluated via replicate ex situ XRF measurements. By application of correlation-supported correction factors to in situ XRF measurement data, the XRF technology evaluated during this study was used to quantitatively determine concentrations of nine target elements for future removal actions and/or final status surveys. Results of the XRF field survey were also used to identify COPCs and estimate the volume of waste present at each site.

- Analyzed 309 soil and sediment samples for uranium series isotopes to determine equilibrium conditions of uranium decay series radionuclides measured at AUM sites. A range of equilibrium conditions were observed, and results from the analysis support the conservative assumption of secular equilibrium between Ra-226 and its decay products.

- Installed 34 radon alpha track Etch detectors at AUM, BSA, and Target sites to monitor radon gas concentrations. Eight of these detectors were not recovered due to adverse weather conditions. Results ranged from below the detection limit to 4.5 picocuries per liter (pCi/L). Radon results from 23 out of the 24 recovered detectors were below the USEPA indoor radon gas action limit (4.0 pCi/L).

- Collected 100 soil samples at 38 AUM sites and five non-AUM Target sites for analysis of geochemical parameters. Paste pH and Acid Base Accounting results from these 100 samples indicated there is curenlty no generation of acid rock drainage at the AUM sites and non-AUM Target areas—and thus little chance of acid rock drainage occuring in the future.

- Investigated more than 22 miles of drainages, including 184,000 gamma radiation measurements, 305 sediment samples, and eight (including two duplicates) surface water samples. All sediment and surface water samples were analyzed for metals and radionuclides. Additional analyses occurred to document potential leachability of metals and radionuclides from sediment, and to evaluate general water quality parameters in surface water. Results indicated mining-related activities within the Cove Valley Region and Lukachukai Mountain Region have impacted drainages.

- Collected 66 soil samples from 34 AUM and Target sites for geotechnical laboratory testing. Subsurface soil samples at various depths were collected from 74 borings drilled at nine AUM and Target sites, and 10 geotechnical samples were obtained from these mechanically drilled borings. The remaining geotechnical samples were collected by use of hand tools. Sampling occurred at locations where relatively high radioactivity was detected or evidence of mining activities was observed. Results can be used to further delineate and calculate volumes of waste at sites where subsurface investigations via mechanical drilling allowed access to the bottoms of these wastes.

Quality assurance (QA) and quality control (QC) were priorities throughout all data acquisition and analysis tasks of the RSE investigations—implemented to evaluate and minimize potential sources of inaccuracy during sample collection and analysis. All analytical data were validated by a third party.

Conclusions from the RSE are as follows:

- To identify COPCs at each AUM, Tetra Tech conducted a background comparison analysis of measurement/sampling types individually and collectively (XRF field survey, XRF confirmation soil samples, surface soil samples, and subsurface soil samples). Many COPCs were identified at individual AUM or AUM-related sites, but arsenic, uranium, and Ra-226 were identified as COPCs at all AUM or AUM-related sites, and selenium, thallium, and vanadium were identified as COPCs at all but one of the sites.
- The RSE investigations identified or confirmed the presence of 60 unreclaimed waste piles across the 39 AUM sites and three AUM-related sites. Prior to the RSE investigations, 45 unreclaimed waste piles had been listed in the USEPA geodatabase.
- The RSE estimated the presence of 810,778 cubic yards (yd^3) of waste material exceeding background levels across all AUM sites and AUM-related sites (not including estimates of waste volumes at the Cove Transfer Station [T9/T37] or any of the non-AUM Target sites). The highest waste volume estimated (70,603 yd^3) was at Mesa I Mine 13 (M6). The second highest waste volume estimate (60,259 yd^3) was at Mesa V Mine – 103 (M17). The largest estimated volume of any single waste pile was at Mesa I Mine 13 (61,713 yd^3).
- Contaminants are migrating off site from multiple AUM sites via the surface water pathway in a majority of the drainages—commonly a result of erosion of waste piles off cliffs into drainages, passage of local drainages through on-site waste piles, or movement of local drainages along the bases of on-site waste piles.

Tetra Tech offers the following recommendations for future investigation and evaluation:

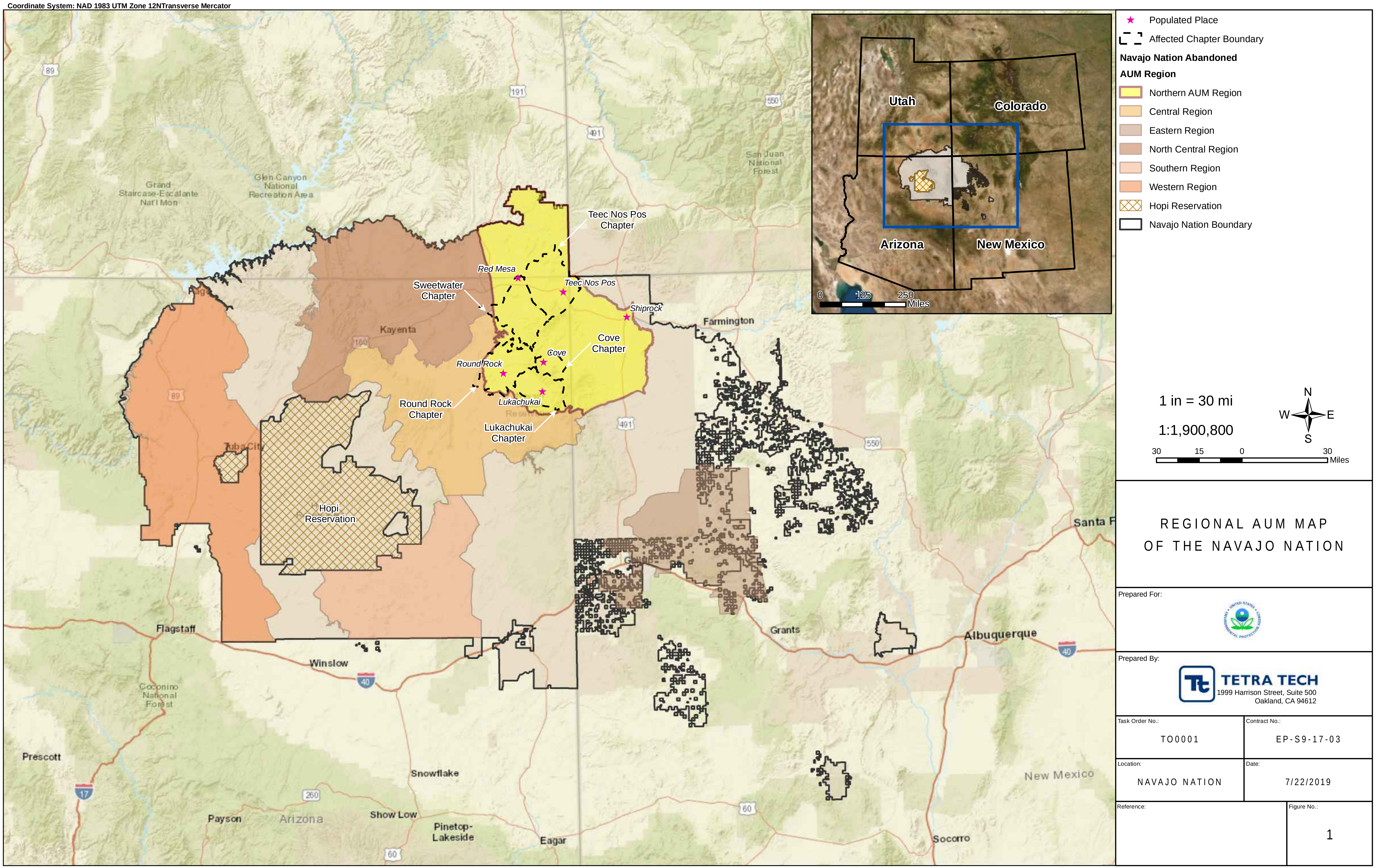
- ***Volume estimates:*** Data from a light detecting and ranging (LIDAR) study in June 2019 should be used with the information obtained from the risk assessment to refine waste volumes.
- ***Drainages:*** Off-site migration via the surface water pathway is occurring from multiple AUM sites in a majority of the drainages. The most likely sources of migration of contaminants into drainages are cliff-located waste piles eroding into the drainages and on-site waste piles through which or along bases of which local drainages pass. The overall amount of erodible material has not been estimated, and Tetra Tech recommends a geographic information system (GIS)-based contaminant transport model to estimate the erodible material quantities. Newly aquired LIDAR data and sediment sample analytical data would be inputs to the model. Use of a grid-based, revised, universal soil loss equation model paired with contaminant data would allow predictions of gross erosion and downstream sediment concentrations, and help determine with greater certainty contributions of contaminants from specific mine areas into the watershed below. This could also aid prioritization of mine cleanups.
- ***Physical properties of mine waste and borrow areas***: Additonal data will be required for repository design and determination of properties of waste placed in repositories. Geotechnical data needed for remedial design include in-situ moisture content and density, specific gravity, classification, moisture-density relationships, shear strength, and permeability of borrow materials.
- ***Evaluation of ratios of analytes***: Except for certain radionuclides, this RSE Report did not evaluate ratios of analytes or elements. Further evaluation of ratios of analytes during the engineering evaluation/cost assessment (EE/CA) may reveal that some analytes can serve as surrogates and represent a suite of analytes.
- ***Lateral extent of contamination***: The RSE investigations generally succeeded at delineating lateral and vertical extent of contamination at AUM and AUM-related sites. Tetra Tech recommends remote applications of sensing techniques and unmanned aerial vehicle technology to characterize areas that were inaccessible during the RSE investigations.

1.0 INTRODUCTION

Under Task Order (TO) 0001 of the Response, Assessment, and Evaluation Services (RAES) contract (EP-S9-17-03), the U.S. Environmental Protection Agency (USEPA) Region 9 tasked Tetra Tech, Inc. (Tetra Tech) to conduct removal site evaluation (RSE) investigations at 39 abandoned uranium mine (AUM) sites and 37 Target sites within the Northern Agency Region of the Navajo Nation. The term “Target sites” refers to either (1) sites related to AUM sites (referred to as “AUM-related sites” or “AUM-related sites”), or (2) sites identified as radiologically anomalous through airborne radiological detection requiring additional characterization (referred to as “non-AUM Targets”). All AUM sites or Target sites are believed to have previously hosted operations by Kerr-McGee Oil Industries, Inc., (Kerr-McGee) or its successor Tronox (both referred to solely as Tronox from this point forward). USEPA was the Lead Agency, and the Navajo Nation Environmental Protection Agency (NNEPA) was the Supporting Agency (together referred to as the “Agencies”). Between March and October 2018, Tetra Tech and team partners iiná bá, Inc., Navajo Engineering and Construction Authority (NECA), and Environmental Restoration Group, Inc. (ERG) conducted field work for this multi-mine RSE investigation of AUM sites and Target sites throughout the Northern AUM Region of the Navajo Nation in northeastern Arizona.

This Northern Agency Tronox Mine RSE Report presents the objectives, methodology, and results of RSE investigations at 39 AUM sites, three AUM-related sites, and 34 non-AUM Target sites identified by USEPA (collectively referred to as “sites”)—all within Apache County, Arizona. A map showing the Navajo Nation AUM regions is on Figure 1. Appendix H to this RSE Report provides the 42 Site-Specific Removal Site Evaluation (SSRSE) Reports developed for every AUM site (39) and AUM-related site (3). RSE investigations also occurred at the 34 USEPA-identified non-AUM Target sites, results from which are summarized in Appendix I. The primary purpose of this main RSE Report is to summarize results from RSE investigations at AUM and AUM-related sites. However, additional information is presented related to investigations and studies conducted to obtain sufficient information to support the RSE investigations. Data generated during the RSE investigations will be used to aid development and evaluations of cleanup options in the engineering evaluation/cost analysis (EE/CA).

Tetra Tech developed the Northern Agency Tronox Mines Removal Site Evaluation Work Plan (RSE Work Plan) submitted to the Agencies in May 2018 (Tetra Tech 2018), including the Sampling and Analysis Plan/Quality Assurance Project Plan (SAP/QAPP) as Appendix C. The RSE Work Plan and its appendices presented background information, data quality objectives (DQO), data gaps, sampling design rationale, quality assurance (QA) and quality control (QC) procedures, and requirements for sampling and analysis. Field work was conducted in accordance with the SAP/QAPP and the RSE Work Plan. The following section discusses the purposes and objectives of the RSE investigations.



Coordinate System: NAD 1983 UTM Zone 12NTransverse Mercator
Populated Place
Affected Chapter Boundary
Navajo Nation Abandoned AUM Region
Northern AUM Region
Central Region
Eastern Region
North Central Region
Southern Region
Western Region
Hopi Reservation
Navajo Nation Boundary
Utah
Colorado
Arizona
New Mexico
Teec Nos Pos Chapter
Sweetwater Chapter
Cove Chapter
Round Rock Chapter
Lukachukai Chapter
Red Mesa
Teec Nos Pos
Shiprock
Cove
Round Rock
Lukachukai
Kayenta
Farmington
Hopi Reservation
Flagstaff
Winslow
Grants
Albuquerque
Prescott
Snowflake
Payson
Show Low
Pinetop-Lakeside
Eagar
Socorro
1 in = 30 mi
1:1,900,800
Miles
REGIONAL AUM MAP OF THE NAVAJO NATION
Prepared For:
Prepared By:
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612
Task Order No.: TO0001
Contract No.: EP-S9-17-03
Location: NAVAJO NATION
Date: 7/22/2019
Reference:
Figure No.: 1

1.1 PURPOSE AND OBJECTIVES

RSE investigations at the Northern Agency Tronox Mines accorded with the RSE Work Plan and provisions of the Tronox Settlement, and complied with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP); Title 40 *Code of Federal Regulations* (CFR) §§300.410-300.415; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980; and guidance from the *Multi-Agency Radiation Site Survey Investigation Manual* (MARSSIM) (USEPA 2000). Deviations from the RSE Work Plan are summarized in Section 4.6 of this report. RSE investigations followed a multi-phase, multi-site, and multi-media sampling approach. More detail on site settings is in Section 1.2. The primary objective of the RSE investigations was to characterize and document locations of contamination remaining at the sites and related to historical Tronox mining operations. Secondary objectives were to acquire data that would support cleanup decisions via the EE/CA process. Objectives of the RSE investigations were as follows:

- During RSE investigations, delineate the lateral and vertical extent of mine waste via XRF field surveys, soil sampling, and gamma radiation surveys at 39 AUM sites and three AUM-related sites.
- Conduct a radiological and chemical background investigation.
- Perform detailed site assessments at non-AUM Target sites identified by USEPA.
- Conduct a drainage investigation including sediment sampling, surface water sampling, and gamma radiation surveys to evaluate impacts on the watershed from mining operations.
- Perform an access road investigation of all roads leading to and from the AUM sites.
- Conduct a radon monitoring program at background areas and AUM sites.
- Estimate the extent of naturally occurring radioactive material (NORM) and technologically enhanced naturally occurring radioactive material (TENORM) physical boundaries within the AUM sites and Target sites, following the USEPA-recommended process for determination of TENORM.
- Obtain data to support risk assessment and EE/CA development, and provide data to the U.S. Army Corps of Engineers (USACE) and USEPA to update the preliminary conceptual site model (CSM) for the Northern Agency Tronox Mines (Neptune and Company, Inc. [Neptune] and TerraSpectra Geomatics [TSG] 2018).

Tetra Tech and its subcontracted team partners followed the RSE Work Plan while conducting the work during the 2018 field season. Information and data resulting from the field work for every AUM site (39) and AUM-related site (3) have been documented through development of 42 SSRSE Reports included in Appendix H to this RSE Report; data for non-AUM Target sites are presented in Appendix I.

1.2 REPORT ORGANIZATION

This RSE Report describes RSE investigations at AUM sites and AUM-related sites, summarizing project objectives, methodology, and results, and guiding the reader to locations of pertinent reports and site-specific results within the appendices. This RSE Report is organized as follows:

- Section 1.0 provides an introduction and presents purposes and objectives of the project.
- Section 2.0 presents the site setting of the project, including information regarding the physical and environmental settings of the investigation areas, and conveys identifying information for the evaluated sites.
- Section 3.0 overviews the history of the sites, including mining and reclamation, and summarizes previous investigations.
- Section 4.0 presents the general approach, including investigation methodology, quality management, and other information necessary to understand the RSE investigations. Any deviations from the RSE Work Plan are also conveyed in this section.
- Section 5.0 summarizes pertinent results of RSE investigations (including the background investigation, gamma radiation survey, soil XRF measurements, soil sampling, radon monitoring, drainage investigation, and road investigation).
- Section 6.0 presents conclusions of the project including the identification of contaminants of potential concern (COPC), waste pile inventory, and summary of data gaps—and offers recommendations for a path forward.
- Section 7.0 lists sources cited in this RSE Report.

Additional information appears in individual reports and supporting information in 13 appendices to this RSE Report, organized as follows:

- Appendix A – Radiological and Chemical Background Investigation Report
- Appendix B – XRF Data Evaluation Report
- Appendix C – Gamma Correlation Report
- Appendix D – Uranium Equilibrium Report
- Appendix E – Geotechnical Evaluation Report
- Appendix F – Geochemical Evaluation Report
- Appendix G – Data Quality Assurance Summary Report
- Appendix H – Site-Specific Removal Site Evaluation Reports
- Appendix I – Non-AUM Target Sites Data Evaluation Report
- Appendix J – Drainage Investigation Report
- Appendix K – Access Road Investigation Report
- Appendix L – Laboratory Reports
- Appendix M – Data Validation Reports.

2.0 SITE SETTING

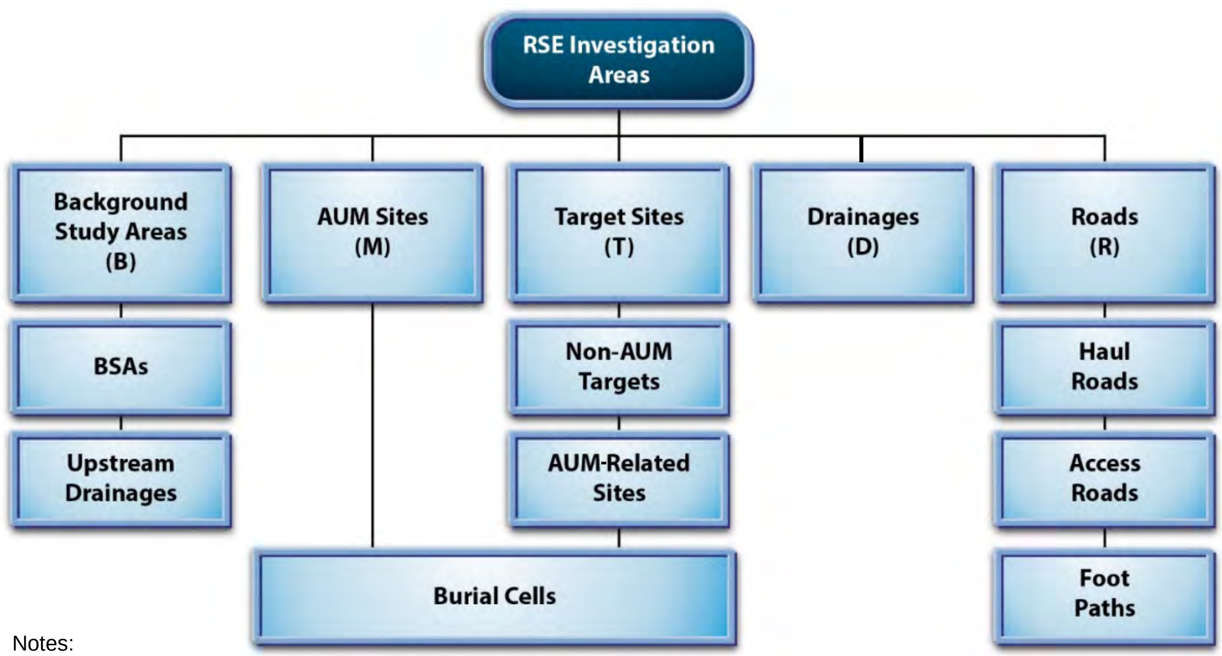
The following sections provide an overview of the site investigation areas and regional investigation areas, as well as regional climate and environmental settings, and the general and geological settings of Tse Tah, Cove Valley, and Lukachukai Mountain Regions.

2.1 OVERVIEW

The following sections provide an overview of the site investigation areas and regional investigation areas.

2.1.1 Site Investigation Areas

This Northern Agency Tronox RSE investigations involved detailed assessments and characterizations across a large number of sites of different types. Site-specific RSE investigations involved field sampling efforts at five types of sites: (1) AUM sites, (2) Target sites, (3) Background Study Areas (BSA), (4) Drainages, and (5) Roads. Figure 2 shows a breakdown of the types of investigation areas included as part of this RSE investigation.



Notes:
AUM Abandoned uranium mine
BSA Background study area
RSE Removal site evaluation

Figure 2. Summary of RSE Site Investigation Areas

This RSE investigation areas shown on Figure 2 were subdivided into the following categories:

- **AUM sites:** AUM sites include 39 former surface and/or underground AUMs previously operated by Tronox. Nineteen burial cells from previous reclamation efforts are within or adjacent to AUM site boundaries. Reclaimed and unreclaimed waste piles are also present at many AUM sites. Tetra Tech accessed digital versions of site boundaries from the USEPA geodatabase (Neptune and TSG 2018). Tetra Tech applied a site identification (Site ID) process to label AUM sites as M1 through M39. See Appendix H for the SSRSE reports.

- **Target sites:** Target sites include two categories: non-AUM Targets and AUM-related sites. Non-AUM Target sites were identified via analysis of the Airborne Spectral and Photometric Environmental Collection Technology (ASPECT) flyover gamma survey data set. AUM-related sites include areas where reclamation occurred or known mines were present but no mining had occurred. Weston Solutions, Inc. (Weston) identified 38 Target sites during the Mine Category Assessment Protocol (MCAP) project funded by USEPA (Weston 2016). Tetra Tech applied a Site ID process to label Target sites as T1 through T38. Evaluations of all non-AUM Target sites are in a standalone report (Non-AUM Target Sites Data Evaluation Report) in Appendix I to this RSE Report. Evaluations of AUM-related sites are in site-specific RSE reports in Appendix H to this RSE Report. Eight Target sites (seven non-AUM Target sites and one AUM-related site) are not addressed in this report for the following reasons: four non-AUM Target sites are partly or entirely within an AUM site boundary (T2, T16, T28, and T29); two non-AUM Target sites are located within a drainage (T35 and T36) and these Target sites are evaluated in a standalone report (Drainage Investigation Report) in Appendix J to this RSE Report; one non-AUM Target site was inaccessible because of extreme terrain and health and safety concerns (T34); and one AUM-related site is an interim action repository referred to as TS-2 (T38) located to the north of Cove Transfer Station which will evaluated during the EE/CA process. See Appendix I for results from non-AUM Target site investigations.
- **Drainages:** All AUM and Target sites are within the San Juan Watershed of Apache County, Arizona (Section 2.2.3). Drainages primarily consisting of ephemeral channels drain the former mines and potentially deposit mine-related contaminants into downstream areas. Previous investigations, particularly Weston's Cove Wash Watershed Assessment (Weston 2018) have revealed impairment of some of these drainages from a human health standpoint by historical mining operations. Tetra Tech evaluated more than 22 miles of drainage networks in and around the AUM sites to establish baseline conditions, as discussed in Section 5.5. See Appendix J for results of the drainage investigation.
- **Roads:** The RSE investigations evaluated an extensive network of historical and new roads within the mining region. Some roads may have been constructed by use of mine waste rock or other contaminated materials, and further evaluation of these is necessary. Tetra Tech investigated nearly 10 miles of mining region roads, as described in Section 5.6. See Appendix K for results of the access road investigation.
- **BSAs:** Tetra Tech performed a background investigation (Appendix A to this RSE Report) to establish site-specific and regional background threshold values (BTV) for 29 radiological and metal constituents, as well as for gamma radiation corresponding to each of the AUM sites, Target sites, drainages, and roads. Results from the sites were compared to respective applied BTVs, each of which was the lower of the site-specific and regional BTVs. See Appendix A for results of the background investigation.

Site investigation areas for this project described above are within four Navajo Nation chapters: (1) Sweetwater Chapter, (2) Teec Nos Pos Chapter, (3) Cove Chapter, and (4) Lukachukai Chapter. The following section indicates how these sites were subdivided across three different regional investigation areas.

2.1.2 Regional Investigation Areas

Because of the large number of AUM sites and Targets, and limited accessibility in some areas, Tetra Tech organized the investigation areas into three primary regional investigation areas and 10 subarea groups in the RSE Work Plan to enable completion of the field investigation cost-effectively and to simplify data management (Tetra Tech 2018). The 10 subarea groups were useful for logistical purposes and for categorizing non-AUM Target sites for data evaluation purposes. However, this RSE Report uses a different geographical organization.

For the purposes of this RSE Report, the Project Study Area was separated into three primary regional investigation areas, synonymous with the "regional background investigation areas" in the Background Investigation Report included as Appendix A to this report. These three regions are (1) Tse Tah Region, (2) Cove Valley Region, and (3) Lukachukai Mountain Region.

For mapping purposes, the Lukachukai Mountain Region can be subdivided into northern and southern portions. The three regional investigation areas are all shown within the Northern AUM Region of the Navajo Nation on Figure 3. As described in Section 2.1.1, site investigation areas are within four Chapters whose boundaries are shown on Figure 3. The Tse Tah Region includes sites within the Sweetwater Chapter and sites within the Teec Nos Pos Chapter. The Cove Valley Region includes only sites within the Cove Chapter. The Lukachukai Mountain Region includes sites within the Cove Chapter and sites within the Lukachukai Chapter. Table 1 summarizes the sites within each regional investigation area.

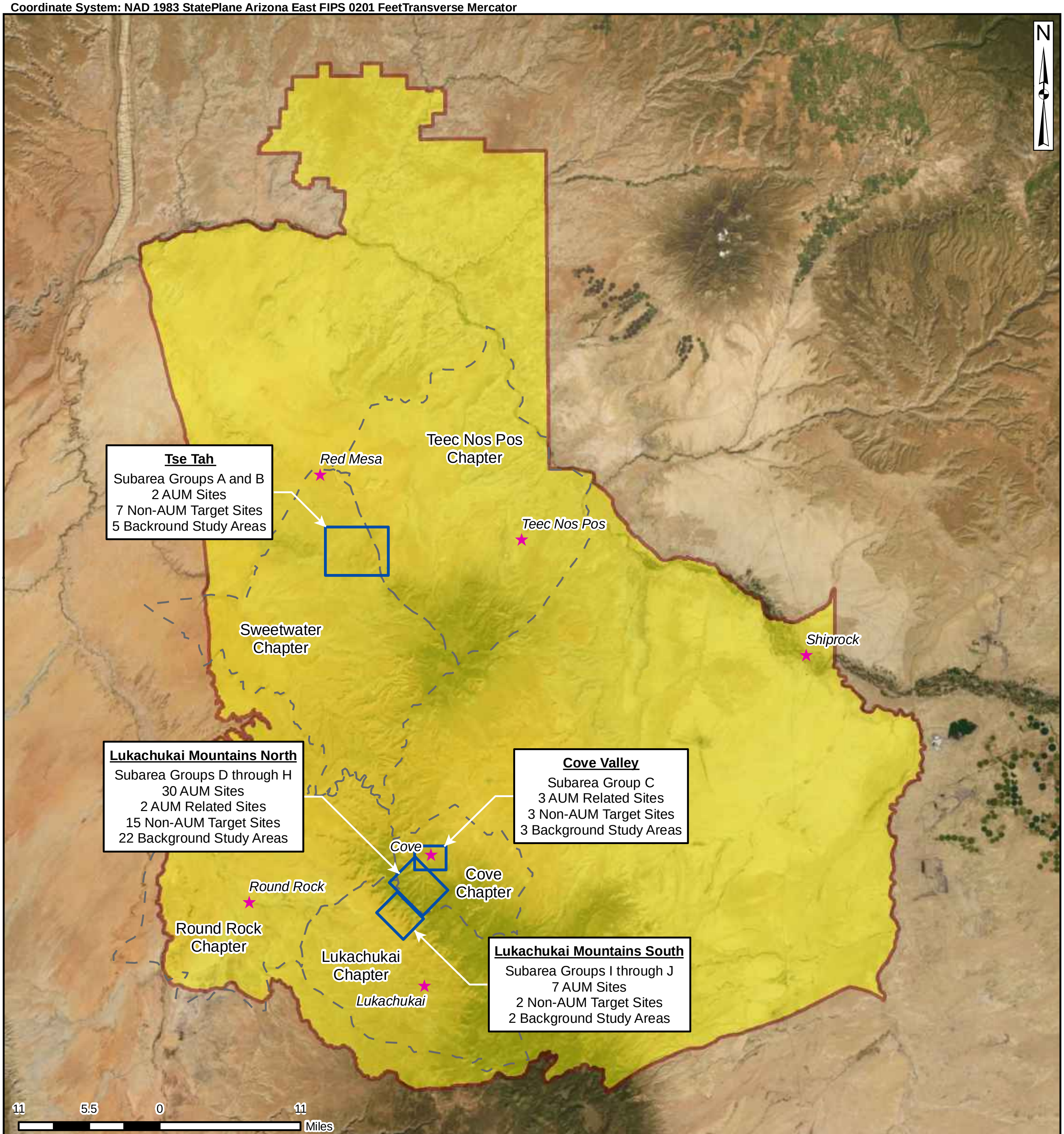
Table 1. Number of Sites within Each Regional Investigation Area

Regional Investigation Area	# of Background Study Areas (BSA)	# of Abandoned Uranium Mine (AUM) Sites	# of Target Sites
Tse Tah	5	2	8
Cove Valley	3	-	6
Lukachukai Mountains	24	37	24
Total	**32**	**39**	**38**

A detailed breakdown with more site information and identification of each region is in Section 2.3 through Section 2.5.

The following subsection presents regional overviews of climate and environmental settings. For more detailed information, see Appendix A of this report and Appendix B to the RSE Work Plan (Tetra Tech 2018).

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



★ Populated Place
Regional Background Investigation Area
Affected Chapter Boundary
Navajo Nation Northern Abandoned Uranium Mine Region

Prepared for: U.S. EPA Region 9

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

NORTHERN AGENCY TRONOX MINES
REGIONAL INVESTIGATION AREA MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	3
Location: NAVAJO NATION	Date: 7/22/2019	

2.2 REGIONAL ENVIRONMENTAL SETTINGS

The following sections describe regional environmental settings (geology, climate, surface hydrology, hydrogeology, and vegetation) of the site and regional investigation areas.

2.2.1 Regional Geology

As part of the Desktop Study presented as Appendix B to the RSE Work Plan (Tetra Tech 2018), a georeferenced image of the geology, structure, and uranium deposits of the Shiprock Quadrangle, New Mexico and Arizona (O'Sullivan and Beikman 1963) was downloaded from the U.S. Geological Survey (USGS) National Geologic Map Database by use of geoTiff, a public domain metadata standard that allows embedment of georeferencing information within a tagged-image file format. Formations from the geoTiff within the study area were manually digitized. Portions of the Cove mesa tops where member divisions of the Morrison Formation could not easily be distinguished were grouped together as Lower Morrison Formation (Jml), Recapture and Salt Wash Members undifferentiated. This was necessary only for the east side of the Cove mesa tops where the Morrison depositional layers and unit breaks are particularly intricate. A geospatial evaluation of geology and soil types of the region occurred, based on available information.

Further discussion on percent breakdown of each geological formation within the sites is in Appendix A to the RSE Report. Nine different geological formations found to underlie the sites were evaluated as part of this RSE investigation. Some other identified geological formations were not evaluated because each takes up a small area of a particular site. For example, the sandstone Wingate Formation (Trw) was identified within a small portion of the Frank Jr. Mine, Mesa IV mine complex, and at the Black No. 1 AUM site; however, the areas within the site boundaries were so small that a site-specific BSA was not selected within this geological formation. Descriptors of each mapped geologic unit are listed in Table 2 (modified from O'Sullivan and Beikman 1963, and Arizona Department of Water Resources [ADWR] 2009). Further discussions on localized geological formations within the regional investigation areas appear in Section 2.3 through Section 2.5.

In addition to the geological evaluation, soils data from the areas of interest were downloaded from the online Web Soil Survey system produced by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) (USDA 2018). NRCS provides soil maps of more than 95 percent of the nation's counties. Appendix A to this RSE Report describes the 14 unique soil types identified on the soil maps accessed from the NRCS online system. A detailed discussion of selection of BSAs based on these associations appears in Appendix A.

Table 2. Summary of Geological Formations in the RSE Investigation

Symbol	Formation	Description
Qa	Quaternary Alluvium	Unconsolidated surficial deposits of valley fill: mainly stream-deposited silt, sand, and gravel, but also includes some wind-blown sand and silt, colluvial material, and locally, low-level terrace gravels.
Tc	Chuska Sandstone	White to gray medium to fine-grained, moderately sorted sandstone.
Jml	Lower Morrison Formation	Recapture Member (Jmr): White and brown fine-to-medium grained sandstone, siltstone, and dark reddish-brown shale. Also includes Salt Wash Member (Jms): White and moderate orange very fine- to medium-grained sandstone, and grayish red shale.
Jms	Morrison Formation	White and moderate orange very fine- to medium-grained sandstone, and grayish red shale.
Js	Summerville Formation	Moderate reddish-brown, fine- to medium-grained sandstone and argillaceous siltstone.
Jse	Summerville and Entrada Formations Undifferentiated	Alternating thin beds of gray, green, and red siltstone; gray, greenish-gray, and reddish brown, fine grained sandstone; and red and greenish gray shale. Entrada is buff, white and pink medium-grained, massive cross-bedded sandstone.
Jste	Summerville, Todilto, and Entrada Formations Undifferentiated	Undifferentiated green and red siltstone; gray, greenish-gray, and reddish brown, fine-grained sandstone; and red and greenish gray shale. Buff, white, and pink medium-grained, massive cross-bedded sandstone. Red claystone interbedded with reddish orange sandstone.
Jc	Carmel Formation	Claystone, grayish red, shaly, silty, and sandy; interbeds of sandstone, moderate reddish orange, fine-grained.
Trc	Chinle Formation	Claystone, moderate red, calcareous, silty, interbedded with siltstone, moderate reddish orange, argillaceous; and with limestone, nodular, cherty; and with conglomerate, pale red, pebbles of limestone and chert. Some Sandstone, olive gray, course-grained, micaceous, friable.

2.2.2 Regional Climate

The climate of the broad valleys within the Cove and Tse Tah Regions is characterized as a Mid-Latitude Steppe dry semi-arid climate, whereas the surrounding mountainous regions are classified as Humid-Continental, Dry, Short Summer and Wet Winter (Neptune and TSG 2018).

In general, and typical of the Southwest, this region undergoes two distinct seasons of precipitation—monsoonal precipitation patterns during the summer (July to September) and variable snowfall from winter storms during the winter (December to March). Winter precipitation typically comes from frontal-type storms out of the Pacific bringing low-intensity precipitation distributed over large areas, whereas precipitation from summer convective storms is often intense and localized to small areas (Neptune and TSG 2018). Because this region receives precipitation from two distinct sources with various driving factors, it is subject to significant interannual climate variability.

Appendix B to the RSE Work Plan provides information on nearby weather stations that convey data used to characterize the climate. Annual average temperature at the Lukachukai weather station (elevation of 6,520 feet above mean sea level [amsl]) is 50.6 degrees Fahrenheit (ºF); at the Teec Nos Pos weather station (elevation 5,290 feet amsl), average annual temperature is 55.6 ºF (National Oceanic and Atmospheric Administration [NOAA] 2018). Monthly average maximum and minimum temperatures and precipitation at the Lukachukai and Teec Nos Pos weather stations are conveyed in Appendix B to the RSE Work Plan.

Annual average precipitation ranges between 7 and 19 inches, with monsoonal thunderstorms (generally occurring from early July through the middle of September) accounting for most of the rainfall. Because precipitation is usually relatively intense, some local runoff and flash flooding results (Cooley and others 1969). Mean snowfall ranges from 10 to 40 inches, with greatest amounts (exceeding 40 inches) occurring in the Lukachukai Mountains. Spring is generally the windy season, with frontal winds in the region that prevail from the southwest to westerly directions at speeds that may exceed 30 miles per hour (mph) for several hours and reach peak speeds of more than 50 mph. However, local wind conditions can vary substantially from this general pattern throughout the area due to local topographic effects. No weather station in Cove is known to measure wind speed, wind direction, temperature, or rainfall data (Neptune and TSG 2018). However, Cove Community residents have expressed concern regarding wind-blown contamination and dust. To gain understanding of dust resuspension and to conduct atmospheric modeling, USEPA plans to establish a meteorological station in Cove that should be considered within the area of AUM sites.

2.2.3 Regional Surface Hydrology

The Cove Chapter is within the San Juan River Basin of the Upper Colorado River Basin (USGS hydrologic unit code [HUC] Region 14). Most of the Navajo Nation is drained by two principal tributaries, the San Juan River and the Little Colorado River. The Colorado and San Juan Rivers are perennial streams, but all other streams in the region are either ephemeral or intermittent (Cooley and others 1969, Neptune and TSG 2018). The Tse Tah Region AUM sites and Target sites are within the Lower San Juan-Four Corners River Basin. Cove Chapter is within the upper reaches of the Middle San Juan River Basin that drains to the northeast from the Lukachukai Mountains.

Surface water runoff flows to the Cove Valley Region from the Lukachukai Mountains, south to north. Drainages in canyons and arroyos in the region are mostly dry during a large part of the year and radiate from the mountains, ultimately joining the San Juan River north of the area (Stokes 1951). Dams and channels divert water to holding ponds constructed of earthen berms in agricultural areas, and pipes carry water from the holding ponds to the fields for irrigation. Runoff is primarily ephemeral and intermittent, and is controlled by interception, transmission losses, and storm type and pattern. Unconsolidated surficial deposits intercept and absorb much of the precipitation, overland flow, and channel flow. Much of the water intercepted is retained near the surface, evaporated, or transpired. Ephemeral streams flow down undefined channels during and following heavy rainfall events that are mostly localized, short-duration, high-intensity thunderstorms.

Cove Wash is the only named waterbody within the Cove Wash watershed. Designated surface water uses are Secondary Human Contact, Aquatic and Wildlife Habitat, Fish Consumption, and Livestock Watering (Neptune and TSG 2018). Based on a document review, it is not clear if residents currently use local surface water and/or groundwater supplies for drinking water. Although the Cove Wash watershed is not a known drinking water source, residents may have used it for that purpose before provision of drinking water by a municipal source 20 years ago. The primary study of surface hydrology within the study area is the Cove Wash Watershed Assessment by Weston (2018), during which surface and groundwater samples were collected over four sampling events: a 2015 low flow sampling event, a 2016 spring snowmelt sampling event, a 2016 low flow sampling event, and a 2017 spring snowmelt sampling event. Groundwater wells, seeps, and springs were also sampled during the assessment to assess potential impacts of historical uranium mining.

Many AUM sites within the study area are along mesas separated by deeply incised canyons. Canyon drainages appear to be the primary environmental feature controlling migration of surficial mine wastes via contaminated water and sediments from the Lukachukai Mountains to the lower Cove Wash watershed, where the Cove Community lies. Tributary drainages generally flow from the headwaters to the northeast into the Cove Wash main stream that exits the northeastern portion of the watershed (Neptune and TSG 2018). Rock fractures and discharge to surface springs and seeps are the primary means for dissolved uranium to migrate from underground mines and regional groundwater to surface water.

2.2.4 Regional Hydrogeology

The project area is within the the Little Colorado River Plateau Groundwater Basin, composed of sedimentary and volcanic rocks (ADWR 2009). Regional groundwater movement is to the northwest within multiple aquifers that consist primarily of stacked sandstone and limestone units generally separated from one another by low-permeability shales and siltstones. Two of the three largest regional aquifers are the unconfined to semi-confined Dakota/Cow Springs (D-aquifer) and Navajo/Lukachukai (N-aquifer). The third of these largest regional aquifers is lower Coconino-De Chelly (C-aquifer), which occurs under confined conditions and can produce sizeable quantities of water when penetrated (drilled) at depth.

Beneath the Tse Tah Region, Cove Community, and the majority of Lukachukai Mountain AUM sites, first-encountered groundwater is primarily within permeable sandstones and paleochannels within the lower Morrison Formation. In addition, local aquifers composed of unconsolidated alluvial deposits may provide an important source of water where regional aquifers are too deep or have unsuitable water quality (ADWR 2009). Total depth of these deposits, as well as composition and extent of any other unsaturated deposits between the ground surface and top of the aquifer, are unknown (Weston 2018).

In addition to occurrence of groundwater in the lower Morrison Formation, the D-aquifer (also within the Morrison Formation) provides first-encountered groundwater beneath the lower stream reaches of the Cove Wash watershed, in the Lukachukai Mountains (Neptune and TSG 2018). Occurrence of groundwater is controlled principally by permeability of rocks, amount of fracturing, altitude of the water-bearing strata, presence or absence of surficial alluvial deposits, occurrence and extent of subsurface paleochannels, and duration, type, and amount of precipitation (ADWR 2009). The upper D- and N-aquifers are believed to have vertical hydrologic connection (or seepage) between hydrostratigraphic units.

The C-aquifer is hydraulically separated from the D- and N-aquifers by shaley siltstone of the Rock Point Member of the Wingate Sandstone and shaly siltstone, mudstones, and claystones of the Chinle Formation. In northeastern Arizona and the Monument Valley region, the C-aquifer is comprised of Shinarump Conglomerate of the Chinle Formation, permeable materials of the Moenkopi Formation, and the De Chelly Sandstone Member of the Cutler Formation. Desktop mapping comparisons of these C-aquifer groundwater level elevation contours to the valley mean ground surface contour elevation of 6,400 feet amsl within the Cove Valley regional investigation area are consistent with findings of previous investigations that estimated depth to groundwater beneath the Cove Region approximately between 500 and 1,000 feet below ground surface (bgs) (Weston 2018). Similarly, well “Cove PM-2” was reported to be completed in the C-aquifer at 806 feet bgs. Results of the desktop mapping study indicate that groundwater elevations in the shallower N-aquifer (Navajo-Lukachukai Aquifer) west of the Tse Tah Region range from 5,000 to 5,400 feet amsl, compared to land surface elevations of 5,500 feet amsl and 5,700 feet amsl, indicating that depths to groundwater are approximately 100 to 700 feet bgs. However, site-specific data are necessary to confirm these findings.

Hydraulic connectivity is noted to exist between the water-bearing alluvial materials, as well as hydrostratigraphic units adjoining the N- and D-aquifer systems (Cooley and others 1969, ADWR 2009). The stratified bedding of multiple, permeable, medium- to coarse-grained sandstone units interspersed with siltstones and clays of various thicknesses enables leakage between various water-bearing zones. If downward vertical groundwater movement is limited by low-permeability shales, siltstones, mudstones, and claystones, horizontal preferential groundwater pathways may develop in greater-permeability paleochannels or within perched aquifer zones. Localized permeable perched groundwater zones and paleochannels within alluvial deposits and sandstones of the lower Morrison Formation that outcrop along stratified bedrock layers are believed to discharge groundwater, which provides a local source of water for irrigation and livestock. For example, Weston (2018) noted occurrence of springs on tops of mesas above the Morrison Formation, and seeps throughout canyons between the mesas within the Cove Region. In addition, the Cove Wash tributary network was reported to have perennial surface flows from spring sources (USEPA 2015a). Springs historically have been developed for water supplies to support drilling and mining activities throughout the region, including between Mesa I and Mesa I 1/2 (Nestler and Chenoweth 1958).

Primary areas of groundwater recharge are in the Chuska Mountains along fractures and bedding planes. Aquifers are recharged seasonally from precipitation in the highlands, mainly in winter and spring. Percolation can be rapid, with water traveling more than 10 feet within 10-15 minutes downward along exposed fractures (Cooley and others 1969, Neptune and TSG 2018). Seasonal fracture flow predominates over porosity-based fracture flow.

2.2.5 Regional Vegetation

In the Lukachukai Mountains, vegetation varies from desert canyon scrub brush habitat to conifers and broad-leaved trees (Navajo Nation Division of Natural Resources, Abandoned Mines Land Reclamation Department [NAMLRD] 1991). Vegetation found in the study area included pinyon, juniper, ponderosa pine, fir, cottonwood, aspen, Gambel oak, cliffrose, sage, Mormon tea, both narrow and broadleaf yucca, rabbitbrush, snakeweed, prickly pear cactus, ricegrass, and various grasses and annuals (Navajo Nation Department of Fish and Wildlife [NNDFW] 1999). Figure 4 shows an aspen grove near Mesa I in the Lukachukai Mountains. Juniper and pinyon are abundant at elevations between 6,000 and 7,000 feet. Ponderosa pine and quaking aspen forests cover most of the northeastern mountain slopes above 7,000 feet amsl. Several species of the genus *Astragalus*, a selenium (and uranium) indicator plant, are locally abundant in mined areas (Chenoweth 1988). Vegetation in the lower elevations of the valleys is characterized by Semi-Desert Shrub Steppe and Big Sagebrush Shrublands with associated semidesert shrub-steppe, Greasewood flats, and salt desert scrub (Neptune and TSG 2018).

Figure 4. An Aspen Grove in the Lukachukai Mountains on Mesa I

2.3 TSE TAH REGION

The following sections provide an overview of site and geological settings of the Tse Tah Region.

2.3.1 Overview and Site Identification

In the northern portion of the study area, the Tse Tah Region is at the base of the Carrizo Mountains, approximately 20 miles northwest of Cove Chapter. The Tse Tah Region is one of the three regional investigation areas selected for the RSE investigations. This regional investigation area is synonymous with the Tse Tah regional background investigation area presented in Appendix A. Figure 3 shows the location of the Tse Tah Region with respect to the Northern AUM Region and to the two other regional investigation areas selected as part of this RSE investigation. As listed in Table 1, two AUM sites, seven Target sites (all non-AUM Target sites), and five BSAs are within the Tse Tah Region. The Tse Tah Region hosts three distinct geological formations as described in Section 2.3.2. Because so few sites are within the Tse Tah region and too few BSAs are spread across multiple geological formations, the regional background investigation presented in Appendix A did not include this area.

Figure 5 shows the Tse Tah regional investigation area with respect to AUM sites, Target sites, BSAs, drainages, and Chapter boundaries. Table 3 lists information related to the AUM sites within the Tse Tah Region. Brodie 1 Mine (M1) is within the Sweetwater Chapter and is associated with six Target sites, all non-AUM Targets (BR-01 through BR-06), which were included as part of this RSE investigations. Brodie 1 Mine yielded the lowest production of all mines evaluated for this project. Block K Mine (M2) is within the Teec Nos Pos Chapter, and is associated with two Target sites, both non-AUM Targets (BK-01 and BK-02). During its 1962-1964 period of operation, Block K produced a reported total volume of 2,016 tons of uranium (Chenoweth 2011). SSRSEs for the two AUM sites are in Appendix H to this RSE Report. Table 4 summarizes the Target sites within the Tse Tah Region. A full report of the data evaluation pertaining to these non-AUM Target sites is in Appendix I to this RSE Report. Table 5 summarizes BSAs within the Tse Tah region. A full report of the data evaluation pertaining to these BSAs is in Appendix A to this RSE Report.

Table 3. Summary of AUM Sites within the Tse Tah Region

AUM Site	Site ID	Site Boundary (acres)[1]	Survey Area (acres)[2]	Mining Production in Ore (tons)[3]
Brodie 1 Mine	M1	1.0	1.3	5
Block K Mine	M2	1.4	2.7	2,016
Total		**2.4**	**4.0**	**2,021**

Notes:

1 Site boundary acreage derived from the USEPA geodatabase (Neptune and TSG 2018).

2 Survey area boundary is the final survey area investigated by Tetra Tech with cultural site clearance.

3 Mining production refers to tons of uranium and vanadium ore for a given site obtained from Chenoweth (1988).

AUM Abandoned uranium mine

Table 4. Summary of Target Sites within the Tse Tah Region

Site Name	Site ID	Target Type	Survey Area (acres)
BR-01	T1	Non-AUM Target	4.0
BR-02	T2	Non-AUM Target	Not applicable[1]
BR-03	T3	Non-AUM Target	0.5
BR-04	T4	Non-AUM Target	2.6
BR-05	T5	Non-AUM Target	1.1
BR-06	T6	Non-AUM Target	1.4
BK-01	T7	Non-AUM Target	2.1
BK-02	T8	Non-AUM Target	2.1
Total			**13.8**

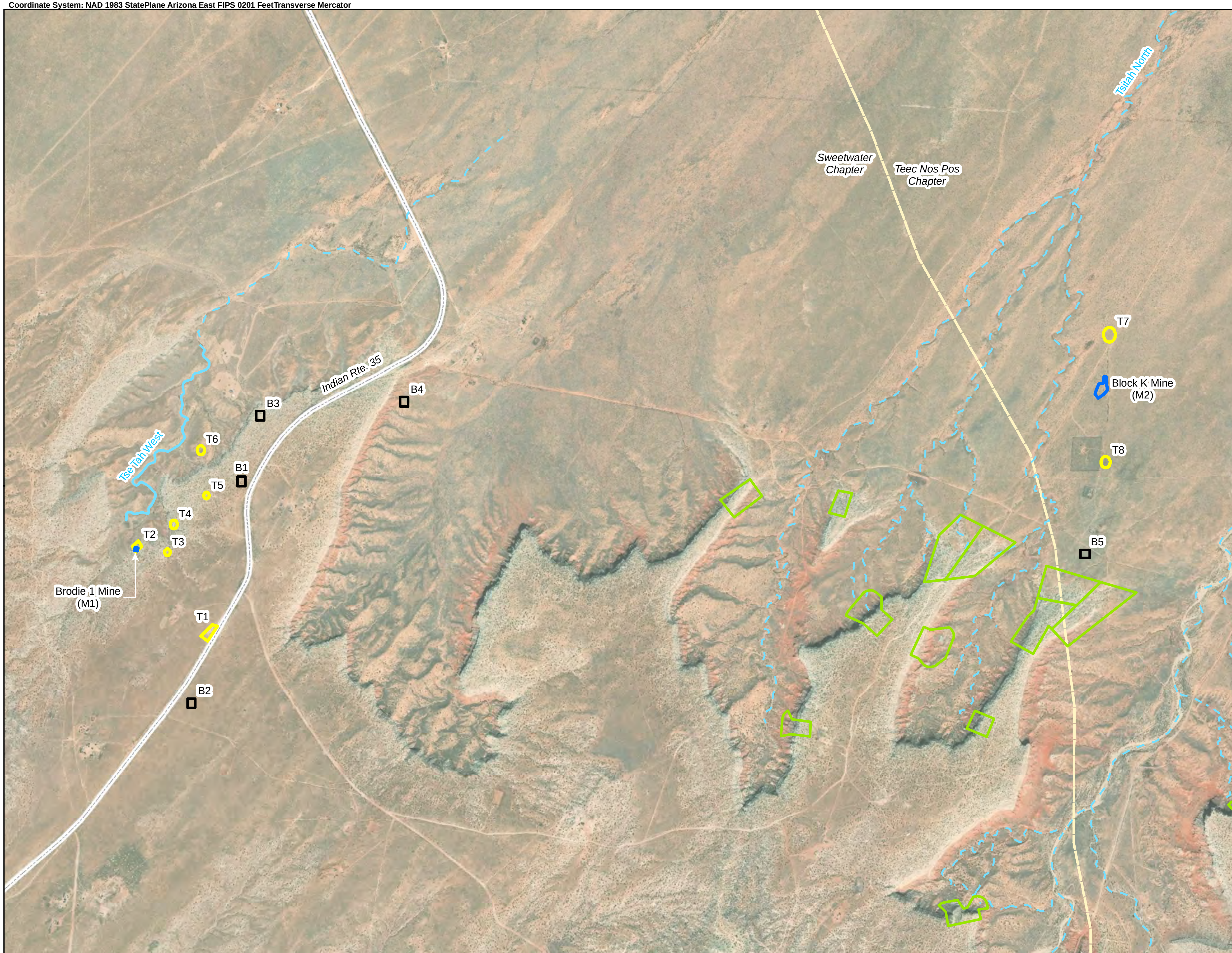
Note:
[1] This Target site was integrated into the Brodie 1 Mine RSE investigation and was not evaluated separately.
AUM Abandoned uranium mine

Table 5. Summary of Background Study Areas in the Tse Tah Region

Site Name	Surface Geology	Soil Type	Representative Sites[1]		
			Site 1	Site 2	Site 3
BSA-1	Jms	309	T3	T4	T5
BSA-2	Qa	313	T1		
BSA-3	Js	309	M1		
BSA-4	Js	314	M1	T6	
BSA-5	Qa	502	M2	T7	T8

Notes:
[1] Refers to which AUM or Target site(s) the BSA represents based on geology and soils. See Appendix A.
AUM Abandoned uranium mine
BSA Background study area
Jms Morrison Formation
Js Summerville Formation
Qa Quaternary Alluvium

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



AUM Site Boundary
Non-AUM Target Site Boundary
Background Study Area
Non-Tronox AUM Site
Navajo Nation Chapter Boundary
Community Road
Drainage*
Surveyed Drainage

1 in = 2,000 ft

1:24,000

0 1,000 2,000 4,000 Feet

N S E W

TSE TAH REGIONAL INVESTIGATION AREA
SITE LOCATION MAP

Prepared For:

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: NAVAJO NATION	Date: 7/12/2019

Reference:
*U.S Environmental Protection Agency, Region 9, Superfund Program, *Abandoned Uranium Mines and the Navjo Nation Part II Atlas With Geospatial Data.* NN_Drainage_HR_AUM.shp. July, 2007.

Figure No.: 5

2.3.2 Geological Setting

Surface geology within the Tse Tah Region includes three primary surface geological formations: Quaternary alluvium (Qa), Salt Wash Member of the Morrison Formation (Jms), and Summerville Formation (Js). Quaternary alluvium occurs primarily in surficial deposits of valley fill, and consists mainly of stream-deposited silt, sand, and gravel; aeolian (wind-blown) sand and silt; and colluvial material (O'Sullivan and Beikman 1963). Detailed maps showing the surface geology and surface soils within the Tse Tah region are in Appendix A to this RSE Report. Detailed maps of each surface geology and surface soils at AUM sites and AUM-related sites are in Appendix H to this RSE Report. Detailed maps of each surface geology and surface soils at non-AUM Target sites are in Appendix I to this RSE Report. Figure 6 shows a field team performing sampling in the Tse Tah Region.

Figure 6. The Field Crew Performing Sampling in the Tse Tah Region

2.4 COVE VALLEY REGION

The following sections provide an overview of site and geological settings of the Cove Valley Region.

2.4.1 Overview and Site Identification

The Cove Valley is at the base of the Lukachukai Mountains, and includes the population center of Cove, Arizona. The Cove Valley is one of the three regional investigation areas selected for this RSE background investigation. This regional investigation area is synonymous with the Cove Valley regional background investigation area presented in Appendix A. Figure 3 shows the location of the Cove Valley Region with respect to the Northern AUM Region and to the two other regional investigation areas selected as part of this RSE investigations. As listed in Table 1, no AUM sites, six Target sites (both non-AUM Target sites and AUM-related sites), and three BSAs are within the Cove Valley Region. The Cove Valley Region hosts one geological formation and multiple soil types as described in Section 2.4.2. Because multiple BSAs are in the same geological formation but have differing soil types, a regional background investigation in Appendix A did include this area.

Figure 7 shows the Cove Valley regional investigation area with respect to Target sites, BSAs, and drainages. The entire area shown on this figure is within the Cove Chapter. Table 6 summarizes Target sites within the Cove Valley region. Two AUM-related sites (T9 and T37) were combined into one RSE investigation as part of the Cove Transfer Station. Another AUM-related site is an interim action repository referred to as TS-2 (T38), which was not included as part of the RSE investigation and will be evaluated during the EE/CA process. This AUM-related site is not shown on Figure 7 or included in Table 6. A full report of the RSE investigation at Cove Transfer Station/Cove Transfer Station South (T9/T37) is in Appendix H40 to this RSE Report. Also, three non-AUM Target sites (CT-01 through CT-03) are within the Cove Valley Region. A full report on the data evaluation pertaining to these non-AUM Target sites is in Appendix I to this RSE Report. Table 7 summarizes the three BSAs (BSA-6 through BSA-8) within the Cove Valley region. A full report on the data evaluation pertaining to these BSAs is in Appendix A to this RSE Report.

Table 6. Summary of Target Sites within the Cove Valley Region

Site Name	Site ID	Target Type	Survey Area (acres)
T9	Cove Transfer Station[1]	AUM-related Site	7.5
T37	Cove Transfer Station South	AUM-related Site	4.4
T10	CT-01	Non-AUM Target	2.7
T11	CT-02	Non-AUM Target	1.5
T12	CT-03	Non-AUM Target	0.3
Total			**16.4**

Notes:

This table does not include the interim repository TS-2 (T38) that is north of Cove Transfer Station.

1 Cove Transfer Station (T9) was combined with Cove Transfer Station South (T37) for the RSE Investigation.

AUM Abandoned uranium mine RSE Removal site evaluation

Table 7. Summary of Background Study Areas in the Cove Valley Region

Site Name	Surface Geology	Soil Type	Representative Sites[1]		
			Site 1	Site 2	Site 3
BSA-6	Trc	410	T9	--	--
BSA-7	Trc	312	T9	T10	T11
BSA-8	Trc	404	T12	T37	--

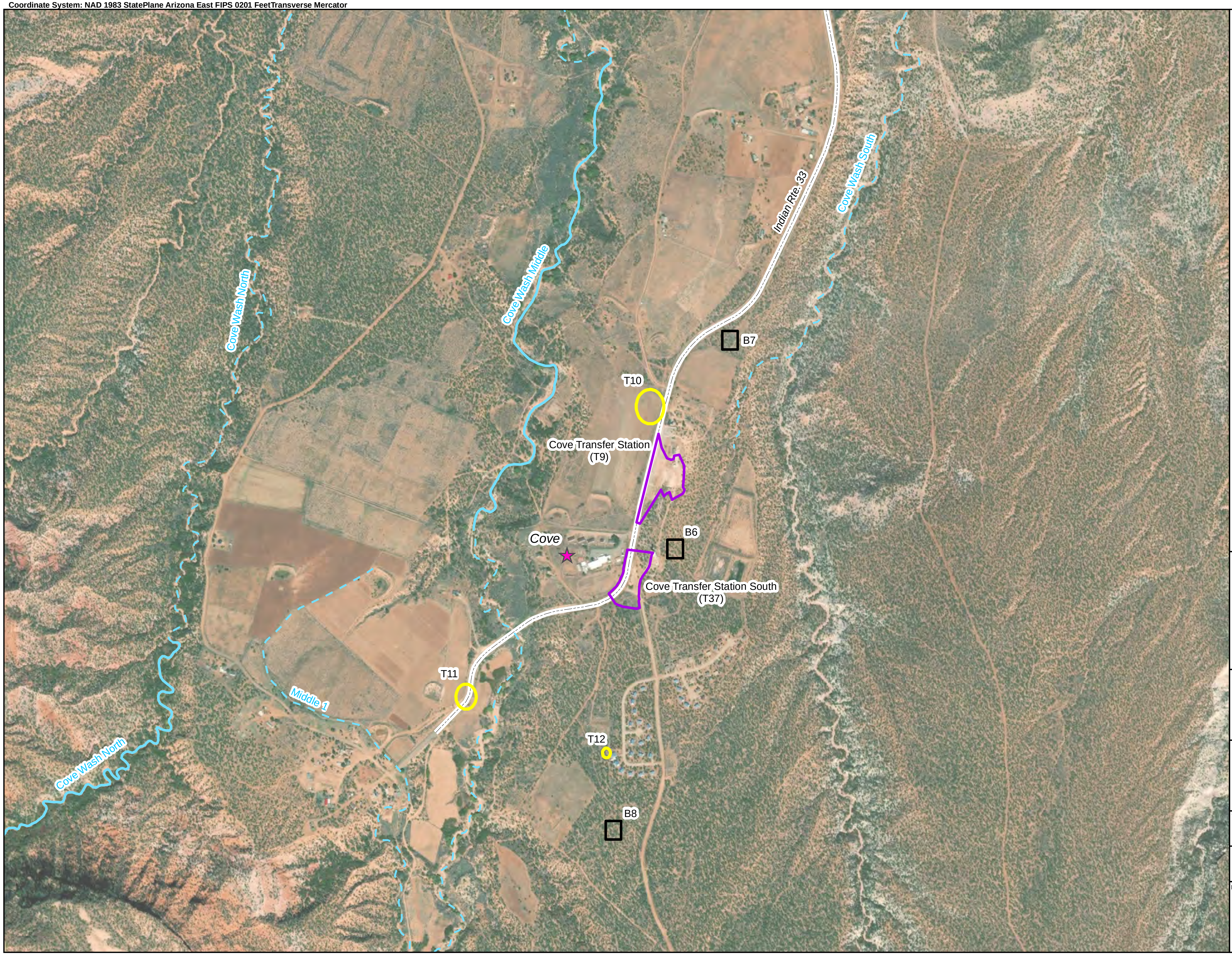
Notes:

1 Refers to which Target sites the BSA represents based on geology and soils. See Appendix A.

BSA Background study area

Trc Chinle Formation

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Community of Cove
AUM Related Site Boundary
Non-AUM Target Site Boundary
Background Study Area
Community Road
Drainage*
Surveyed Drainage

1 in = 1,000 ft

1:12,000

N W E S

0 500 1,000 2,000 Feet

COVE VALLEY
REGIONAL INVESTIGATION AREA
SITE LOCATION MAP

Prepared For:

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: NAVAJO NATION	Date: 7/12/2019
Reference: *U.S Environmental Protection Agency, Region 9, Superfund Program, *Abandoned Uranium Mines and the Navajo Nation Part II Atlas With Geospatial Data.* *NN_Drainage_HR_AUM.shp.* July, 2007.	Figure No.: 7

2.4.2 Geological Setting

Surface geology within the vicinity of the Cove Valley is marked by occurrence of the Chinle Formation (Trc), a fluvial and lacustrine formation exposed in the broad valleys around the mountains (Nestler and Chenoweth 1958). Uranium minerals have been found in bleached parts of the lower Chinle sandstones where carbon trash is present (Chenoweth 1967). Detailed maps showing the surface geology and surface soils of the Cove Valley region are in Appendix A to this RSE Report. Detailed maps of each surface geology and surface soils at AUM sites and AUM-related sites are in Appendix H to this RSE Report. Detailed maps of each surface geology and surface soils at non-AUM Target sites are in Appendix I to this RSE Report. Figure 8 is a photograph of the Cove Day School located within the Cove Valley Region.

Figure 8. The Cove Day School in the Cove Valley Region

2.5 LUKACHUKAI MOUNTAIN REGION

The following sections provide an overview of site and geological settings of the Lukachukai Mountain Region.

2.5.1 Overview and Site Identification

The Lukachukai Mountains are the northwestern spur of the Chuska Mountains, which span across the Cove Chapter and Lukachukai Chapter of the Navajo Nation. The Lukachukai Mountains Region is one of the three regional investigation areas selected for this RSE investigation, synonymous with the Lukachukai Mountain regional background investigation area presented in Appendix A; however, for the purposes of mapping for this RSE Report, the Lukachukai Mountain Region is subdivided into northern and southern regions. Figure 3 shows the location of the Lukachukai Mountain Region with respect to the Northern AUM Region and to the two other regional investigation areas selected as part of this RSE investigation. As listed in Table 1, 37 AUM sites, 24 Target sites, and 24 BSAs are within the Lukachukai Mountain Region. The Lukachukai Mountain Region hosts four distinct geological formations and six soil types as described in Section 2.5.2. Because the majority of BSAs and sites are here, estimation of regional BTVs within the geological formations in this region was important for the RSE investigations.

Figure 9 shows the northern portion of the Lukachukai Mountain regional investigation area with respect to AUM sites, Target sites, BSAs, drainages, and Chapter boundaries. Figure 10 shows the southern portion of the Lukachukai Mountain regional investigation area with respect to AUM sites, Target sites, BSAs, drainages, and Chapter boundaries. Table 8 lists information related to AUM sites within the Lukachukai Mountain Region. The 37 AUM sites encompass more than 183 acres of survey area. All sites within the northern portion (Figure 9) are in the Cove Chapter, and all sites within the southern portion are in the Lukachukai Chapter (Figure 10). SSRSEs for the 37 AUM sites are in Appendix H to this RSE Report. Table 9 summarizes Target sites within the Lukachukai Mountain Region. A full report of the data evaluation pertaining to these non-AUM Target sites is in Appendix I to this RSE Report. The two AUM-related sites within this region are Mesa I Camp and NA-0344B, where RSE investigations occurred; SSRSEs are in Appendix H to this RSE Report. Table 10 summarizes BSAs within the Lukachukai Mountain Region. A full report of the data evaluation pertaining to these BSAs is in Appendix A to this RSE Report.

Table 8. Summary of AUM Sites within the Lukachukai Mountain Region

AUM Site	Site ID	Site Boundary[1] (acres)	Survey Area[2] (acres)	Mining Production in Ore[3] (tons)
Mesa I Mine 10	M3	0.2	1.9	58,082
Mesa I Mine 11	M4	4.8	7.3	
Mesa I Mine 12	M5	6.7	12.7	
Mesa I Mine 13	M6	5.3	9.9	
Mesa I Mine 14	M7	4.9	7.9	
Mesa I Mine 15	M8	2.5	5.0	
Mesa I 1/4 Mine	M9	0.8	1.8	132
Mesa I 1/2 Mine	M10	1.2	2.6	7,555
Henry Phillips Mine	M11	0.7	2.3	16
Mesa I 1/2, West Mine	M12	0.4	1.7	Minor Production
Mesa VI Mine	M13	5.2	7.4	8,994
Frank Jr. Mine	M14	1.5	4.1	10,519
Mesa V Incline	M15	0.9	3.2	1,613
Mesa V Adit	M16	3.6	6.7	3,293
Mesa V Mine – 103	M17	1.0	3.5	55,599
Mesa V Mine – 508	M18	2.8	6.1	
Mesa IV 1/2 Mine and Simpson 181	M19	0.8	2.4	8,977
Mesa IV, Mine No. 1	M20	7.6	11.6	7,648
Mesa IV, Mine No. 2	M21	14.0	17.4	3,711
Mesa IV, Mine No. 3	M22	1.6	3.6	229
Mesa IV, West Mine	M23	2.6	4.5	3,365
Mesa II Pit	M24	2.1	4.6	822
Mesa I 3/4 Incline	M25	1.2	2.8	44,174
Mesa I 3/4, Mine No. 2, P150	M26	1.2	2.1	6,423
Mesa II, Mine No. 1 & 2, P-21	M27	5.9	8.8	274,128
Mesa II, Mine No. 1, P-150	M28	2.9	6.8	3,825
Mesa II, Mine 4	M29	0.9	2.6	36
Mesa II 1/2 Mine	M30	3.6	7.5	38,343
Mesa II 1/2, Mine 4	M31	0.2	1.7	114
Mesa III Mine	M32	1.1	4.7	50,907
Knife Edge Mesa Mine	M33	0.2	3.0	1,032
Black No. 1 Mine	M34	0.5	4.2	1,407
Black No. 2 Mine	M35	1.0	4.1	1,879
Black No. 2 Mine (West)	M36	0.2	1.3	Minor Production
Flag No. 1 Mine	M37	1.5	4.0	11,286
Step Mesa Mine	M38	0.6	1.1	8,841
Tommy James Mine	M39	0.4	*No Access*	853
Total		**92.6**	**183**	**613,803**

Notes:
1 Site boundary acreage derived from the USEPA geodatabase (Neptune and TSG 2018).
2 Survey area boundary is the final survey area investigated by Tetra Tech with cultural site clearance.
3 Mining production refers to tons of uranium and vanadium ore for a given site obtained from Chenoweth (1988).
AUM Abandoned uranium mine

Table 9. Summary of Target Sites within the Lukachukai Mountain Region

Site Name	Site ID	Target Site Type	Survey Area (acres)
M1-01	T13	Non-AUM Target	1.9
M1-02	T14	Non-AUM Target	1.1
M1-03	T15	Non-AUM Target	1.6
M1-04	T16	Non-AUM Target	Not applicable (NA)[1]
M1-05	T35	Non-AUM Target	NA[2]
M1-06	T36	Non-AUM Target	NA[2]
Mesa I Camp	T17	AUM-related Site	19.6
M5-01	T18	Non-AUM Target	1.2
M5-02	T19	Non-AUM Target	1.0
M5-03	T20	Non-AUM Target	0.6
M5-05	T21	Non-AUM Target	2.5
M5-06	T22	Non-AUM Target	3.3
NA-0344B	T23	AUM-related Site	2.4
M5-07	T24	Non-AUM Target	2.2
M5-08	T25	Non-AUM Target	0.6
M5-09	T26	Non-AUM Target	1.5
M4-02	T27	Non-AUM Target	0.6
M4-03	T28	Non-AUM Target	NA[3]
M4-04	T29	Non-AUM Target	NA[4]
M1-07	T30	Non-AUM Target	0.7
M1-08	T31	Non-AUM Target	1.1
M2-01	T32	Non-AUM Target	0.4
KE-01	T33	Non-AUM Target	1.4
KE-02	T34	Non-AUM Target	NA[5]
Total			**43.8**

Notes:
[1] M1-04 is within the survey area of Mesa I Mine 12.
[2] M1-05 and M1-06 is within the survey area of Mesa I Mine 12 and/or Mesa I Mine 14.
[3] M4-03 is within the survey areas of Mesa IV, Mine No. 3 and Mesa IV, Mine No. 1.
[4] M4-04 is within the survey area of Mesa IV, Mine No. 1.
[5] KE-02 is on a steep cliff and access was not safe.
AUM Abandoned uranium mine

Table 10. Summary of Background Study Areas in the Lukachukai Mountain Region

Site Name	Surface Geology	Soil Type	Representative Sites[1]							
			Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
BSA-9	Jml	413	M4	M5	M6	M7	M8	T15		
BSA-10	Jse	608	M26	M27						
BSA-11	Jse	610	T13							
BSA-12	Jml	610	T14	T17						
BSA-13	Jml	608	M6	M9						
BSA-14	Jml	608	M11	M12						
BSA-15	Jse	608	M10							
BSA-16	Tc	608	T26							
BSA-17	Jml	608	T25							
BSA-18	Jc	608	M14							
BSA-19	Jse	413	M17	M19	T18	T19				
BSA-20	Jml	413	M18							
BSA-21	Jml	413	M15	M16	T20					
BSA-22	Jml	414	M15	T21	T22	T23	T24			
BSA-23	Jc	413	M13							
BSA-24	Jse	413	M20	M21	M22	M24	M28	M29		
BSA-25	Jml	413	M20							
BSA-26	Jml	608	M23							
BSA-27	Jml	604	T27							
BSA-29	Jml	413	M28							
BSA-30	Jml	608	M25	M26	M27	M30	M31	T30	T31	T32
BSA-31	Jml	413	M32							
BSA-32	Jste	58	M33	M34	M37	M37	T33	T34		
BSA-33	Jml	58	M35	M38	M39					

Notes:

[1] Refers to which Target sites the BSA represents based on geology and soils. See Appendix A.

BSA Background study area

Jc Carmel Formation

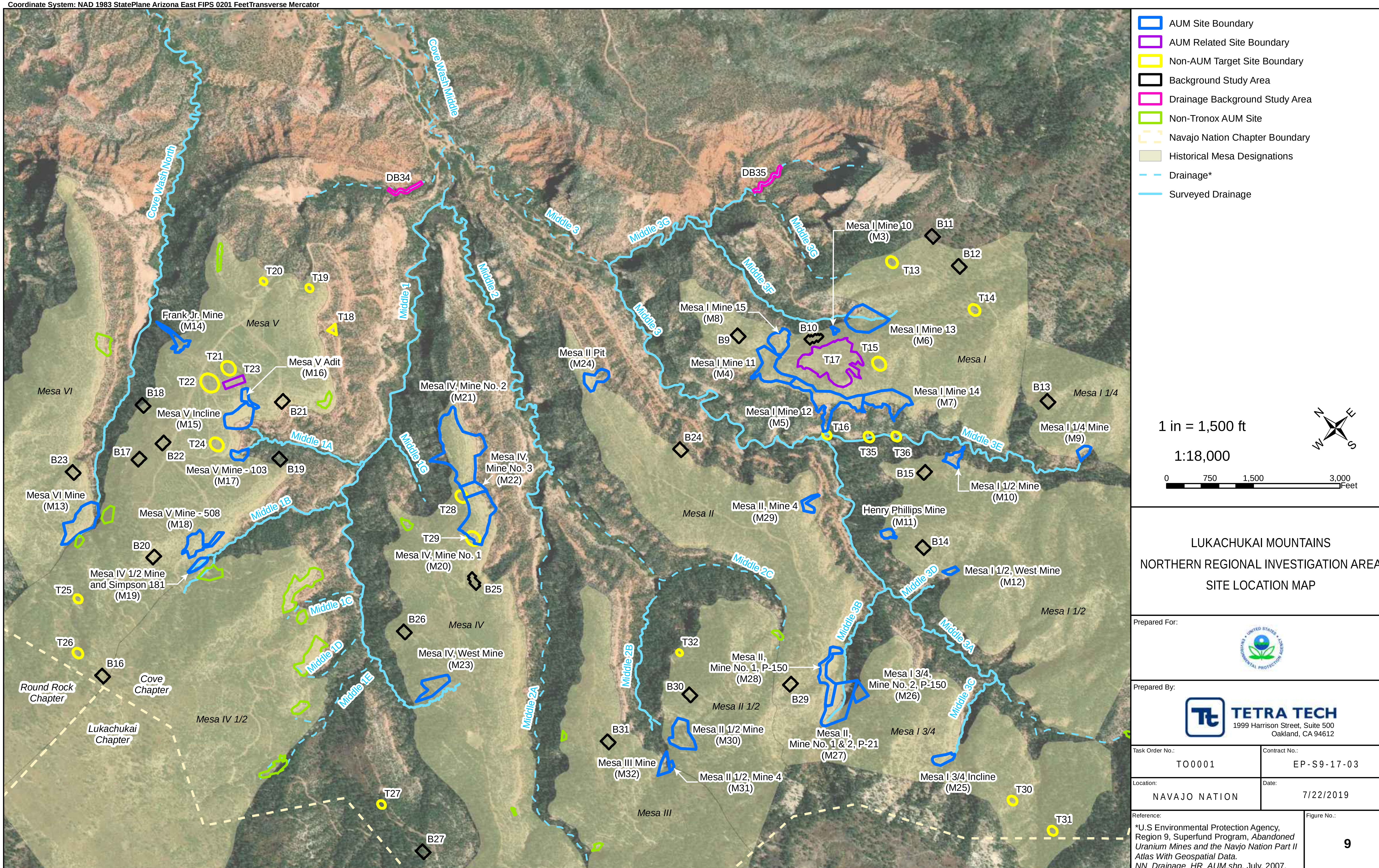
Jml Lower Morrison Formation

Jse Undifferentiated Summerville and Entrada Formation

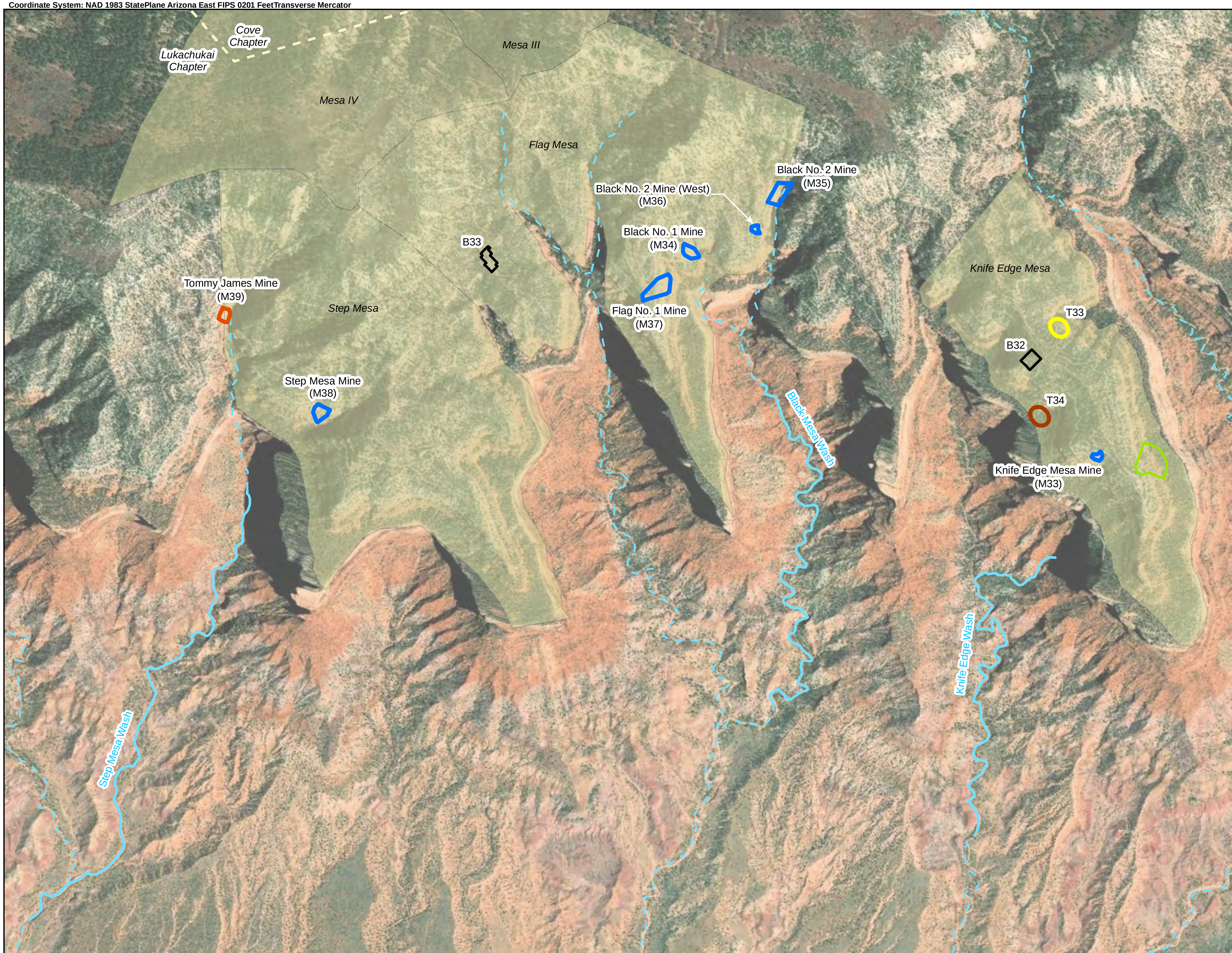
Jste Undifferentiated Summerville, Todilto, and Entrada Formations

Tc Chuska Sandstone

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



LUKACHUKAI MOUNTAINS
SOUTHERN REGIONAL INVESTIGATION AREA
SITE LOCATION MAP

Prepared For:

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: NAVAJO NATION	Date: 7/12/2019
Reference: *U.S Environmental Protection Agency, Region 9, Superfund Program, *Abandoned Uranium Mines and the Navjo Nation Part II Atlas With Geospatial Data. NN_Drainage_HR_AUM.shp.* July, 2007.	Figure No.: 10

2.5.2 Geological Setting

The Lukachukai Mountains are capped by the Tertiary Chuska Sandstone and rimmed by the cliff-forming, uranium ore-bearing Jms of the Jm. Dominant structural features of the Lukachukai Mountains include the Chuska syncline that trends northwest for nearly 45 miles oblique to the long axis of the Defiance uplift, the Lukachukai monocline, and the Toadlena anticline.

Primary surface geology within the region is characterized by undifferentiated deposits of the undifferentiated Summerville, Todilto, and Entrada Sandstone Formations (Jste); undifferentiated Summerville and Entrada Formation (Jse); as well as undifferentiated deposits of the Morrison Formation. A secondary component of the surface geology includes the Wingate Formation (Trw), characterized by aeolian sandstones and siltstones exposed around the foot of the mountains in steep slopes and vertical cliffs (Chenoweth 1988). The Jurassic Carmel Formation (Jc) consists of marginal marine siltstone and mudstones that thin southeastward and pinch out in the Lukachukai Mountains area as well.

Mesa tops, flanks, and drainages are characterized primarily by members of the Jm. O'Sullivan and Beikman (1963) extensively mapped the geology of the Four Corners Region. They subdivided the Morrison Formation into an upper and lower portion, which were further subdivided into two members each. The Upper Morrison Formation (Jmu) consists of the Brushy Basin Member (Jmb) and the Westwater Canyon Member (Jmw). The Lower Morrison Formation (Jml) is composed of the Recapture Member (Jmr) and the Salt Wash Member (Jms). Deposits of the Jml throughout the investigation area have been mapped extensively. The Jms and Jmr are regarded as two alluvial fans concurrently constructed by deposition from two separate stream systems that coalesced along a common margin across a wide swath through the Four Corners region. According to Nestler and Chenoweth (1958), structures and textures of the lower part of the Morrison formation indicate that both the Jms and Jmr were deposited in a dominantly fluvial environment and are composed of alternations of stream-deposited sediments and floodplain-deposited sediments. As a result, lower parts of the Jms intertongue and grade into the Jmr in northeastern Arizona, and an exact contact may be difficult to discern. Under these circumstances, for purposes of this RSE background investigation, these two units have been mapped together as Jml. Occurrence of Jml geology and predominance of the Jms of the Morrison Formation coincide with prevalence of sites in the Cove Region.

The 100- to 180-foot-thick, ore-bearing Jms has been eroded away at the southeastern end of the Lukachukai Mountains where they join the Chuska Mountains. The Jms of the Morrison Formation is made up of cross-stratified sandstones interbedded with siltstones and claystones, and commonly contains mud galls and claystone splits. Carbonized material of all sizes is abundant and widely distributed. Most uranium deposits are confined to a well-defined and nearly north-south trending belt across the southeastern end of the Lukachukai Mountains, which accounts for a reported 99.6 percent of production (Neptune and TSG 2018). The Summerville Formation (Js) consists of moderate reddish-brown, fine- to medium-grained sandstone and argillaceous siltstone. Figure 11 is an idealized stratigraphic profile of subsurface geology in the Lukachukai Mountains in Apache County, Arizona. Figure 12 is a photograph of the northern portion of the Lukachukai Mountains. Figure 13 is a photograph of the southern portion of the Lukachukai Mountains.

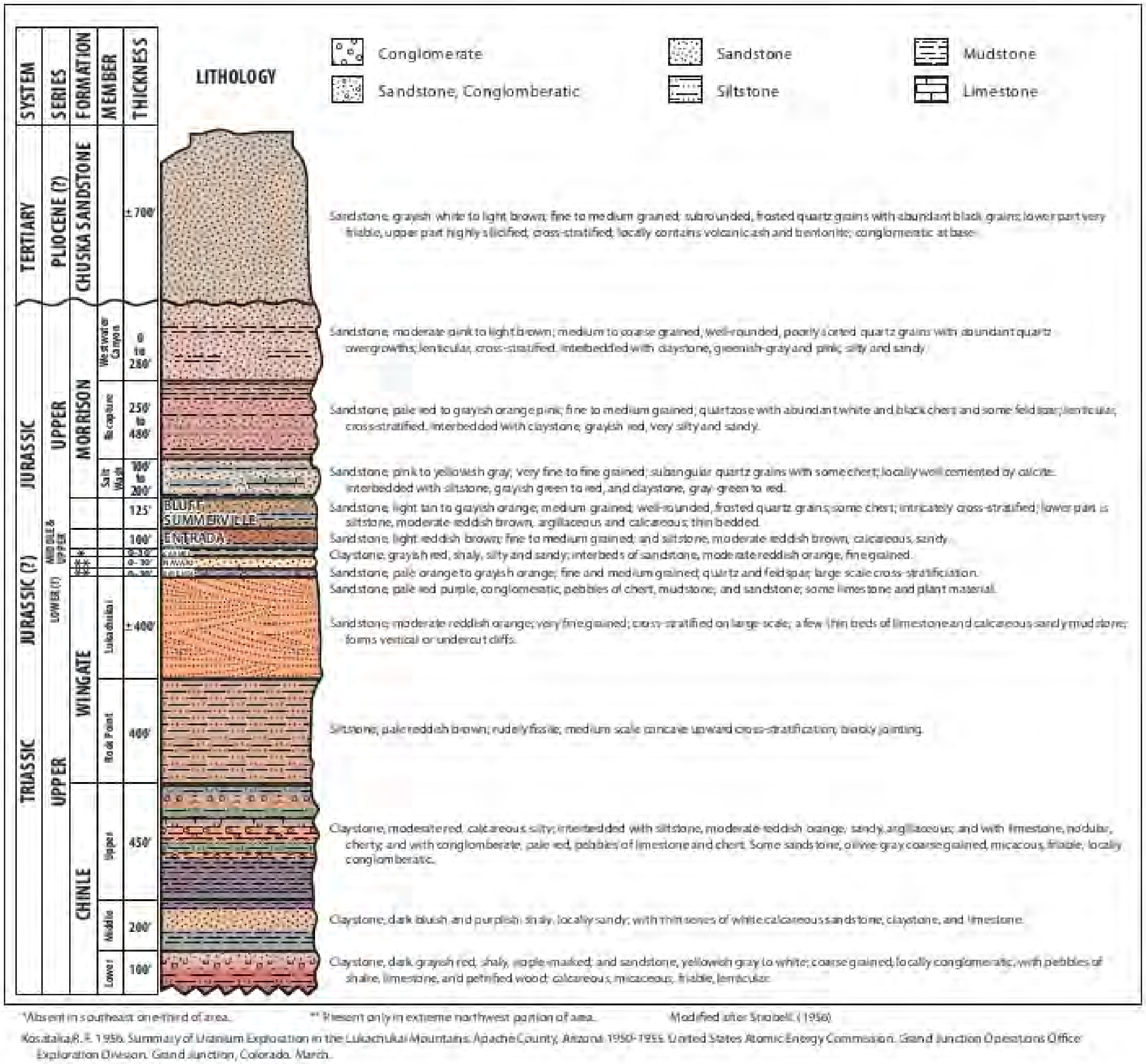


Figure 11. Idealized Stratigraphic Profile, Lukachukai Mountains

Figure 12. View of the Northern Portion of the Lukachukai Mountains

Figure 13. View of the Southern Portion of the Lukachukai Mountains

3.0 SITE HISTORY

Uranium mining began in the Colorado Plateau, on which the Navajo Nation is situated, in the early 20th century. Uranium ore was processed primarily for its vanadium (used to harden steel) and radium content. The Colorado Plateau became one of the world's most important sources of uranium ore. Similarly, radium was used extensively during the 20th century in military, industrial, and pharmaceutical products (Tyler and others 2013). Uranium mining on the Colorado Plateau declined significantly in the mid-1920s when rich uranium deposits were found in the Belgian Congo. Uranium mining increased during World War II, with the Colorado Plateau providing about 14 percent of the uranium oxide needs of the Manhattan Project (Atomic Heritage Foundation 2018).

Uranium ore mining began in the northern region of the Navajo Nation in the late 1940s as a response to the Atomic Energy Commission's (AEC) uranium procurement program. As the uranium industry boomed, numerous operators exploited ore in the Navajo Nation. Mining operators in the region included F.A Sitton, Navajo Uranium, Climax Uranium, Hopkins & Smith, Kerr-McGee, and, later, Vanadium Corporation of America (VCA). Many companies hired Navajo men to work in the mines, and many Cove miners experienced health problems as a result of working in the mines. When operations at most mines ceased in the mid-to-late 1960s, mining rights were returned to the Navajo Nation. The Navajo Nation Council established the Navajo Abandoned Mine Lands Reclamation Program (NAMLRP) in 1988 to address physical safety hazards of abandoned mines. NAMLRP conducted a limited number of reclamation activities at some AUM sites in the late 1990s and early 2000s (Neptune and TSG 2018).

3.1 MINING HISTORY

The uranium mining district of interest for this project is the Lukachukai Mountains and Carrizo Mountains Mining District as described by the U.S. Department of Energy (DOE) (2014). The Lukachukai Mountains are a high, rugged northwest spur of the Chuska Mountains in northeastern Arizona. The mountains terminate on the east and west sides as precipitous cliffs. On the west side, mountains drop off to 5,600 feet at the start of a desert-like expanse (Dare 1961). The Carrizo mountains are approximately 20 miles northwest of the Cove Chapter in the northern portion of the study area, the Tse Tah Region.

Carnotite (uranium-vanadium ore) was discovered around 1918 in the Carrizo Mountains, north of the Lukachukai Mountains, and many mining claims were filed within this region during the next few years, although little mining occurred until 1942, when wartime need for vanadium increased (Stokes 1951). By 1949, uranium-vanadium had been discovered and mined in the Lukachukai Mountains. Day Hayes, a prospector from Monticello, Utah, reportedly made the first uranium ore discovery in the Lukachukai Mountains. Hayes immediately had F.A. Sitton of Colorado examine the discovery, negotiate with the Navajo Tribal Council, and arrange for a mining release from the Bureau of Indian Affairs (Dare 1961).

All economic deposits within the Lukachukai Mountains are within a well-defined belt of the Salt Wash Member of the Jurassic Morrison Formation. The Salt Wash sandstone is the lowest member of the Morrison Formation and is the ore-bearing horizon in the Lukachukai Mountains (Stafford 1951). Tyuyamunite, the calcium uranium vanadate, is the most common ore mineral

(Chenoweth 1988). The ore-bearing Salt Wash member is approximately 100 to 180 feet thick, with most deposits confined to a nearly north-south trending belt across the southeastern end of the Lukachukai Mountains. Most of the ore bodies occur 30 to 80 feet above the base of the Salt Wash Member, and most ore deposits are within a north-south trending belt southeast of the Lukachukai Mountains (Chenoweth 1988). Approximately 666,850 tons of uranium ore was mined in the Cove Chapter. The uranium ore was transported to transfer stations in the Cove Wash valley on a series of unpaved mining roads (Neptune and TSG 2018).

The AEC conducted reconnaissance and drilling in the Lukachukai Mountains from September 1950 until August 1955 to identify minable ore reserves (Chenoweth 1988). Personnel of the AEC named the finger-like mesas in the Lukachukai Mountains when the AEC began its drilling program (Dare 1961, Chenoweth 1988). The prominent mesas on the northern side of the mountains are numbered Mesa I through Mesa VII toward the northwest terminus at Mexican City Mesa (Chenoweth 1988). The mesas on the southern side of the Lukachukai Mountains were given descriptive names, including Two Prong, Camp, Cisco, Three Point, Knife Edge, Bare Rock, Flag, Step, Fall Down, and Thirsty. Most mines were named for the mesas where they occurred, and hence assigned such minor divisions as Mesas I 1/2, Mesa I 3/4, Mesa II 1/2, and Mesa IV 1/2 (Chenoweth 1988).

Mining of uranium deposits in the Lukachukai Mountains commenced in spring 1950 and continued until early 1968. During this 19-year period, 53 individual mines produced 724,754 tons of ore that averaged 0.24 percent uranium oxide and 1.01 percent vanadium oxide, and contained 3,483,231 pounds of uranium oxide and 14,729,693 pounds of vanadium oxide (Chenoweth 1988). Kerr-McGee acquired properties in the Lukachukai Mountains in 1952, and was the leading producer until 1963, at which time its holdings were acquired by VCA (Chenoweth 1988). Climax Uranium Company, a subsidiary of American Metals Climax Inc., began prospecting in the Lukachukai Mountains about the same time (Dare 1961).

Uranium mining in the Tse Tah Region began at former vanadium mines in the Carrizo Mountains in 1948. Mining continued at approximately 60 mines in the region until 1966.

3.2 RECLAMATION HISTORY

The Navajo Nation Council established NAMLRP in 1988 to address physical safety hazards of abandoned mines. From 1992 through 2004, NAMLRP performed reclamation activities at AUM sites that posed physical safety hazards. These projects reclaimed 265 mine features and typically involved closure of mine portals, backfilling of rimstrips and pits, construction of erosion control features such as berms, and placement of mine waste in burial cells (Neptune and TSG 2018). Primary objectives of the NAMLRP reclamation were to eliminate physical safety hazards and contain mine waste. The NAMLRP projects included the closure of numerous portals primarily with polyurethane foam and with local non-radiological rocks. There are some portals that were collapsed and some portals that remain open or for which the reclamation is failing. Details on the portal closure for each site are contained within the SSRSEs found in Appendix H of this RSE Report. A number of previously reclaimed AUMs contain mine waste that could migrate off site.

NAMLRP required reclamation of sites such that residual gamma emission from reclaimed surfaces would not exceed 50 microroentgens per hour (μR/hr) (approximately 50,000 counts per minute [cpm]). In addition, NAMLRP specified that to consider a site reclaimed would require that residual radium-226 (Ra-226) concentration within the first 6 inches of reclaimed soil not exceed 25 picocuries per gram (pCi/g). Many of the individual mine sites are considered only partially reclaimed because some areas containing low-grade uranium ore and waste rock were not physically accessible. Appendix K to the Preliminary Conceptual Site Model (PCSM) describes each reclamation project (Neptune and TSG 2018). NAMLRP reclamation projects are summarized in Table 11.

In addition to the NAMLRP projects, USEPA Region 9 Emergency Response Section conducted a risk-based removal action at Cove Transfer Station and Cove Transfer Station South in 2012 (Ecology and Environment, Inc. [E&E] 2013). During the removal action, approximately 11,800 cubic yards (yd^3) of material with Ra-226 concentration exceeding 2 pCi/g was excavated and transported to a stockpile known as TS2 (E&E 2013), approximately 3 miles south of Cove Transfer Station on the northwest side of Indian Route 33. After the removal action in 2012, intense rain storms significantly eroded sections of Cove Transfer Station, causing formations of small channels and gullies throughout much of the site. In September 2017, USEPA completed work at the site to prevent surface erosion that included stabilizing slopes, constructing water diversion channels, restoring a roadside ditch with rock material, removing dead vegetation, revegetating the slope, and installing an on-site water tank to drip-irrigate plants (USEPA 2018).

Table 11. Summary of NAMLRP Projects for Northern Agency Tronox Mines

Site Name	Site ID	Site Type	NAMLRP Project	Burial Cell ID	Burial Cell Surface Area (Acres)	Mechanical Drilling Performed?
Brodie 1 Mine	M1	AUM Site	NA-0507	Burial Cell 41	0.03	No
Block K Mine	M2	AUM Site	NA-0929	Burial Cell 173	0.31	Yes
Mesa I Mine 10	M3	AUM Site	-	No burial cell	-	No
Mesa I Mine 11	M4	AUM Site	NA-0300; NA-0310C	Burial Cell 9	0.38	No
Mesa I Mine 12	M5	AUM Site	NA-0300; NA-0310D	No burial cell	-	No
Mesa I Mine 13	M6	AUM Site	NA-0300A; NA-0310AC	No burial cell	-	Yes
Mesa I Mine 14	M7	AUM Site	NA-0310D	No burial cell	-	No
Mesa I Mine 15	M8	AUM Site	NA-0300; NA-0310B; NA-0310AB	Burial Cell 6a	0.07	Yes
		AUM Site		Burial Cell 6b	0.02	No
		AUM Site		Burial Cell 7	0.02	Yes
Mesa I 1/4 Mine	M9	AUM Site	None	No burial cell	-	No
Mesa I 1/2 Mine	M10	AUM Site	None	No burial cell	-	No
Henry Phillips Mine	M11	AUM Site	NA-0321	No burial cell	-	No
Mesa I 1/2, West Mine	M12	AUM Site	NA-0322	No burial cell	-	No
Mesa VI Mine	M13	AUM Site	NA-0319	No burial cell	-	No
Frank Jr. Mine	M14	AUM Site	None	No burial cell	-	No
Mesa V Incline	M15	AUM Site	NA-0302 and NA-0318A	No burial cell	-	No
Mesa V Adit	M16	AUM Site	NA-0318A	Burial Cell 91	0.06	No
		AUM Site		Burial Cell 92	0.04	No
		AUM Site		Burial Cell 93		No
Mesa V Mine – 103	M17	AUM Site	NA-0302 and NA-0318A	No burial cell	-	No
Mesa V Mine – 508	M18	AUM Site	NA-0317	Burial Cell 87a	0.33	Yes
Mesa IV 1/2 Mine and Simpson 181	M19	AUM Site	NA-0318B	Burial Cell 86b	0.19	No
Mesa IV, Mine No. 1	M20	AUM Site	NA-0315	Burial Cell 56	0.37	No
Mesa IV, Mine No. 2	M21	AUM Site	NA-0315	Burial Cell 63	0.33	No
Mesa IV, Mine No. 3	M22	AUM Site	NA-0315	No burial cell	-	No
Mesa IV, West Mine	M23	AUM Site	NA-0314	Burial Cell 70b	0.05	No
Mesa II Pit	M24	AUM Site	NA-0324	Burial Cell 44	0.07	No
Mesa I 3/4 Incline	M25	AUM Site	NA-0311	Burial Cell 31a	0.03	No
		AUM Site		Burial Cell 31b	0.26	No
Mesa I 3/4 Mine No. 2, P-150	M26	AUM Site	NA-0312A	No burial cell	-	No
Mesa II, Mine No. 1 & 2, P-21	M27	AUM Site	NA-0312A	Burial Cell 39	1.73	No
Mesa II, Mine No. 1, P-150	M28	AUM Site	NA-0312A	No burial cell	-	No
Mesa II, Mine 4	M29	AUM Site	NA-0323	Burial Cell 43	0.10	No
Mesa II 1/2 Mine	M30	AUM Site	NA-0313	Burial Cell 48	0.23	No
Mesa II 1/2, Mine 4	M31	AUM Site	NA-0313	No burial cell	-	No
Mesa III Mine	M32	AUM Site	NA-0313	No burial cell	-	No
Knife Edge Mesa Mine	M33	AUM Site	None	No burial cell	-	No
Black No. 1 Mine	M34	AUM Site	NA-0329	No burial cell	-	No
Black No. 2 Mine	M35	AUM Site	NA-0327	No burial cell	-	No
Black No. 2 Mine (West)	M36	AUM Site	NA-0328	No burial cell	-	No
Flag No. 1 Mine	M37	AUM Site	NA-0329	No burial cell	-	No
Step Mesa Mine	M38	AUM Site	NA-0330	No burial cell	-	No
Mesa I Camp	T17	AUM-related Site	NA-0310AB	Burial Cell 310AB	0.79	Yes
NA-0344B	T23	AUM-related Site	NA-0344B	Burial Cell 344B-2	0.21	Yes

Notes:
Only statistics for detected data are listed in this table.
AUM Abandoned uranium mine
NAMLRP Navajo Nation Abandoned Mine Lands Reclamation Program

3.3 PREVIOUS INVESTIGATIONS

Several investigations have occurred to examine and characterize the nature and extent of AUM-related environmental contamination across the Navajo Nation and within the Project area. Part of the following timeline of key previous investigations derived from the PCSM (Neptune and TSG 2018):

1989-1992 NAMLRP conducted an inventory assessment at abandoned mine lands (AML) across the entire Navajo Nation. These assessments included descriptions of mine features still present at each site (for example, adits or rimstrips) and conditions of these features; assessments of accessibility and current site use (for example, whether mines were being used for livestock shelter); qualitative descriptions of mine drainage; general estimates of spoil and debris volume; and, in some cases, gamma measurements by use of field screening devices. Site visits were documented in field logbooks and sketches, and the documentation was later compiled into the MCAP database (Weston 2016).

1994-1999 DOE conducted aerial gamma radiation surveys of 41 AUM areas on the Navajo Nation for USEPA. The aerial survey data were used to characterize overall radioactivity and excess bismuth-214 (Bi-214) levels within the surveyed areas (Bechtel Nevada 2001). Bi-214 is an indicator of uranium ore deposits and uranium mines. Survey results were used to support design of field sampling plans for water and home surveys.

1999 USACE collected surface and groundwater samples at sources used for human consumption within the Cove Chapter area from March through December 1999. Field investigations identified elevated levels of uranium, arsenic, molybdenum, selenium, and vanadium in the Cove Wash watershed (Neptune and TSG 2018).

2001 NNEPA collected water samples at a single location (10COVEWASH09) during a single event at a Cove Wash tributary downgradient of the AUM sites (NNEPA 2014). Results of this sampling were consolidated with those from later sampling and discussed in a 2014 report.

2006-2007 TSG compiled a report documenting Navajo AUM project data acquisition and screening results from all known AUM sites on the Navajo Nation (TSG 2007). The report has two parts: the Navajo Nation AUM Screening Assessment Report and accompanying Atlas with geospatial data. The AUM Screening Assessment Report presented analytical results from a USEPA model based on Hazard Ranking System (HRS) criteria. Results of this broad-based screening process were organized to assist USEPA in recommending to the Navajo Nation follow-up investigations or cleanup responses that require attention. The Atlas portion of the report described the geospatial datasets used for the screening analysis.

2007-2010 Weston conducted preliminary assessments and site screenings in the vicinity of the AUM sites within the Northern Agency AUM Region. The site screening reports include aggregated information on historical mining and reclamation, descriptions of site settings and accessibilities, potential exposure factors, site photographs, and (for most sites) gamma measurements by use of field screening devices. Appendix H to the RSE Report includes maps that compare gamma radiation survey data from the 2018 RSE investigation to data from the Weston site screening gamma radiation surveys.

2011-2012	NNEPA collected water samples at the Cove Wash tributary in the watershed headwaters (10COVETRIB29) that flow intermittently downgradient of the AUM sites. Results from this sampling event were combined with those from 2001 in the NNEPA's Cove Wash Watershed – Surface Water Quality Assessment Report (NNEPA 2014).
2011-2012	E&E performed a removal assessment for USEPA at the Cove Transfer station non-AUM Target site (E&E 2012). This removal assessment formed the basis for a limited removal action at the transfer station in 2013.
2011	In 2011, as part of a federal bankruptcy case, Roux Associates (Roux) prepared an estimate of future costs to remediate environmental sites associated with activities of Kerr-McGee and its affiliates and predecessors (Roux 2011). This assessment of environmental liability addressed a wide range of sites nationally, including a section on mining sites in the Lukachukai and Tse Tah regions of the Navajo Nation. Preceding the estimate of remediation costs had been a desktop review and aggregation of historical mining and reclamation documentation.
2014-2015	USEPA's Airborne Spectral Photometric Environmental Collection Technology (ASPECT) aircraft flew over the Northern Agency AUM Region in December 2014 and May 2015 to obtain radiological signature data and aerial photographs (USEPA 2015b). The survey covered nearly 180 square miles and collected more than 70,000 data points. Surveyors also took approximately 600 high-resolution aerial photographs over the survey areas. Appendix H to the RSE Report includes maps that compare gamma radiation survey data from the 2018 RSE investigation to data from the ASPECT flyover.
2014	Weston conducted a Site Reassessment of Mesa I Mine 10 through Mesa I Mine 15 (Weston 2014).
2015	In January, the United States received funds from a historic legal settlement that made almost $1 billion available to USEPA to investigate and clean up uranium mines on or near the Navajo Nation that had been operated by Kerr-McGee and its successor, Tronox.
2015-2017	Weston conducted an investigation, the results of which appear in a Final Assessment Report regarding the Cove Wash Watershed Assessment (CWWA) Site (Weston 2018). The assessment included sampling of surface water and sediment samples to delineate sources contributing to contamination in drainages throughout the watershed.

2016-2017	Weston delineated wetlands within the Cove Wash watershed for USEPA (Weston 2017).
2016	In addition to assembling the database of historical documentation, Weston conducted limited site evaluation field work and prioritized mines for removal action as part of the MCAP (Weston 2016). Site evaluation field work included gamma measurements and documentation of mine features.
2016-2017	Under a USEPA Scientific Engineering Response & Analytical Services (SERAS) contract, Lockheed Martin performed a field and laboratory investigation within the Cove Wash watershed in historically farmed areas. Samples of soil, water, and plants were analyzed for a suite of metals. A limited number of samples were collected for Ra-226 and Ra-228 analyses (Lockheed Martin 2017a, b).

Weston's CWWA was the most comprehensive investigation of surface water and groundwater (Weston 2018). As part of the CWWA, surface water, groundwater, surface sediment, and subsurface sediment samples were collected within drainage areas in the Cove Wash to delineate sources contributing to drainage contamination from AUM sites throughout the watershed. Surface water and sediment samples were also collected from identified seeps and springs in the drainage, and a groundwater sample was collected from an area well presumably used to water livestock. The Cove Wash watershed was investigated for concentrations of total and dissolved metals, total and dissolved radionuclides, and gross alpha radioactivity during four separate sampling events beginning in 2015 and ending in 2017. Media investigated included surface water collected from stream channels, seeps, and springs; and groundwater collected from shallow wells near mined areas or in or above confluences of drainage channels downslope of AUM sites. Screening level surface gamma radiation surveys also occurred in Cove Wash watershed drainage areas during this CWWA. Biological assessments were completed during the watershed assessment, including a plant inventory and wetland and wildlife surveys. No tissue sampling and analysis occurred during this study. Findings confirmed the presence of one federally protected and Navajo-listed species, the Mexican spotted owl (*Strix occidentalis lucida*), within the canyon areas (Weston 2017).

4.0 RSE INVESTIGATION APPROACH

The following sections describe aspects of the approach to the RSE investigations including phased sampling, data quality objectives, pre-investigation site clearance, RSE field sampling methods, quality management, and deviations from the RSE Work Plan.

4.1 PHASED SAMPLING APPROACH

In the RSE Work Plan, Tetra Tech (2018) proposed to follow a phased sampling approach consisting of a Baseline Study and a Site Characterization Study. Both phases were completed during the 2018 field season (the Baseline Study from April through August 2018, and the Site Characterization Study from August through October 2018) (Attachment 1). The RSE investigations (described in SSRSEs in Appendix H to this RSE Report) acquired information sufficient to support the risk assessment and EE/CA, which will address mine-related contamination associated with historical mining operations.

4.1.1 Baseline Study

The Baseline Study was the first of the two major field investigation excursions. Because prior to initiation of field work, limited data were available on contamination levels within the different site investigation areas (described in Section 2.1.1), the Baseline Study was conducted to acquire data at each investigation area. Tetra Tech applied a systematic and probabilistic-based sampling strategy during the Baseline Study to maximize representativeness of the sampled population. The primary goals of the Baseline Study were to: (1) delineate lateral extent of elevated gamma radiation related to TENORM, (2) delineate lateral extent of elevated levels of metals concentrations, (3) acquire geospatial data on key site features to support the Site Characterization Study, and (4) gather sufficient information to support the risk assessment and EE/CA. Data acquired during the Baseline Study were then used to evaluate and refine then-current understanding of lateral extent of radionuclides and metals in surface soil and sediment, and to guide development of the sampling design for the follow-on Site Characterization Study.

To achieve these goals of the Baseline Study, a number of field sampling activities ensued. Tetra Tech followed a paired sampling approach to define contamination levels for both radionuclides and metals. This involved development of a high-resolution, low-cost dataset by application of less accurate field measurement techniques (considered the "fallible" dataset), and acquisition of a second, relatively low-resolution, high-cost dataset via more accurate laboratory analyses (considered the "definitive" dataset). Statistical analyses of these datasets yielded mathematical relationships between fallible and definitive datasets, allowing for correction of the fallible data set to improve its accuracy. The result of the paired sampling approach was a high-resolution dataset with broad coverage of investigation areas that could be considered "lab-like" following statistical correction procedures.

Data acquisition methods applied during the Baseline Study included gamma radiation surveys (Section 4.4.2), a gamma-radium correlation study (Section 4.4.4), X-ray fluorescence (XRF) field surveys (Section 4.4.5), drainage and access road sampling (Section 5.5 and Section 5.6, respectively), a background investigation (Section 5.1), and site mapping (Section 4.4.1). In addition to these activities, cultural and biological support occurred as necessary throughout the field investigation, as required by USEPA and as described in Section 4.3.

The following principal study questions were identified during the DQO process in the planning phases of the project for the Navajo Nation AUM sites to indicate the objectives of the Baseline Study:

Baseline Study Questions:

1. What are the background levels of gamma radiation and what are the background concentrations of radionuclides and metals in soils and sediment that are representative of conditions at each site?
2. What is the lateral extent of mine-related surficial contamination at each site?
3. Is there potential for contaminants to migrate off site via surface water pathway?
4. Is there potential for contaminants to migrate off site via the groundwater pathway?
5. What are the spatial extent, locations, and types of NORM and TENORM at each site?
6. Have the Tronox Navajo-area abandoned uranium mine (NAUM) risk prioritization factors been evaluated adequately (such as site accessibility, reclamation status, land use, and waste material characteristics)?

Section 4.2 includes further discussion of how these questions were addressed and indicates locations of the associated documentation.

4.1.2 Site Characterization Study

The Site Characterization Study was the second portion of the phased sampling strategy. Purposes and benefits of the Site Characterization Study to the phased sampling approach were threefold:

1. Comprehensive areal data acquired during the Baseline Study led to delineation of relatively well-defined lateral boundaries of contamination. These lateral boundaries were used to identify key areas where additional data should be acquired during the Site Characterization Study in support of eventual planning for remediation via EE/CAs. Specifically, during preparation of an EE/CA, it is important to understand volumes and waste characteristics of material that may be remediated. The Site Characterization Study provided opportunities to delineate vertical extent of contamination so that volume determinations could occur, and to analyze contaminated material for waste characteristics so that the EE/CA could plan for proper disposal of the material (including geochemical and geotechnical analyses of soil samples collected from waste piles).
2. Comprehensive areal data acquired during the Baseline Study were examined to identify key data gaps, such as areas where contaminant levels were close to BTVs. The Site Characterization Study provided an opportunity to revisit those areas that fell into the statistical "gray zone," and allowed the team to collect samples that could yield definitive data in order to fine-tune delineation of lateral extent of contamination.

3. Site mapping data acquired during the Baseline Study allowed identification of areas and media that could be sampled to supplement data for the streamlined risk assessment that would be part of the EE/CA process. Known contamination levels in features such as on-site buildings, seeps, springs, and wells, and in media such as surface water and sediment, can be key data for risk assessments.

Based on these three primary goals, Tetra Tech implemented a methodology for data acquisition during the Site Characterization Study that focused first on fine-tuning delineations of lateral extent of contamination in any areas with lingering data gaps, second on acquiring data for future remediation and engineering planning, and third on acquiring data to support future streamlined risk assessments.

Because most sampling planned for the Site Characterization Study was targeted based on an analysis of the Baseline Study datasets, a judgmental sampling approach was followed (USEPA 2002a). The methodology for Site Characterization Study sampling was broadly described in the SAP/QAPP of the RSE Work Plan, but was subject to change for each site based on results of the Baseline Study.

The following principal study questions were identified during the DQO process in the planning phases of the project, and appear in the RSE Work Plan for the Navajo Nation AUM sites to indicate the objectives of the Site Characterization Study:

Site Characterization Study Questions:

1. Did the Baseline Study adequately identify the lateral extent of surficial contamination at the site, downwind areas, and drainages?
2. Has the lateral extent of mine-related radionuclides and metals in surface soil, waste, or sediment been adequately delineated?
3. What is the lateral and vertical extent of mine-related subsurface radionuclides and metals in soils and waste at each site?
4. Are mine-related radionuclides and metals in surface soils, waste, and drainage sediments potentially leaching to surface water or groundwater?
5. Has groundwater been impacted by historical mining activities?
6. What is the distribution of concentrations of radon gas present at accessible mine openings, waste piles, and drainages, and being emitted from buried waste cells?
7. Have the physical characteristics of mine waste been adequately evaluated to support modeling, remedy evaluation, and evaluation of the Tronox NAUM risk prioritization factors?
8. Has the distribution of gamma radiation dose rates in surface soils and drainage sediment at the site been determined?

Regarding Study Question 8, Tetra Tech calculated gamma exposure rates which can be used to approximate dose rates. The gamma exposure rates were calculated using a linear regression developed between gross gamma count rate (measured with portable gamma survey instrumentation) and gamma exposure rate (measured with a high-pressure ionization chamber).

The development of the correlation between gross gamma count rate and gamma exposure rate is discussed in detail in Appendix C of the RSE report. Attachment 2 to this report includes figures displaying gross gamma count rate measurements converted to gamma exposure rate in µR/hr. The intervals displayed on the figures in Attachment 2 are related to a variety of gamma exposure rates found at various locations or other sources of radiation dose.

4.2 DATA QUALITY OBJECTIVES

The RSE investigation was developed by application of the DQO process, a systematic planning approach to data acquisition. The overall DQO process, USEPA orders, and federal regulations that mandate a Quality System are described in USEPA's guidance document *Guidance for the Data Quality Objectives Process* (USEPA 2006a). The document addresses all environmental data operations, from initial characterization to final cleanup and release. The latest version of this document segregates the type of project by the final objective: *decision or estimation.* Other guidance for applying the DQO process specifically to sites contaminated with radioactive materials is in Chapter 2 of MARSSIM and in American National Standards Institute (ANSI)/Health Physics Society (HPS) N13.59-2008 (R2014). A chart depicting the seven steps of the DQO process is on Figure 14.

A primary objective of the RSE investigation was to address the DQOs established for both the Baseline Study and Site Characterization Study. Principal study questions for the Baseline Study are in Section 4.1.1. Principal study questions for the Site Characterization Study are in Section 4.1.2. DQOs for the project are detailed in Tables C-7 and C-8 of Appendix C to the RSE Work Plan, and site-specific DQOs appear in the site-specific field sampling plans (FSP) in Appendix F to the RSE Work Plan.

Table 12 and Table 13 indicate how Baseline Study DQOs and Site Characterization Study DQOs, respectively, are addressed in this RSE Report. Baseline Study Question No. 4 regarding groundwater impacts was not addressed as part of the project-wide RSE investigation per technical direction from the USEPA RPM. No groundwater samples were collected because no seeps or springs were identified during the 2018 field sampling season. Therefore, depth to groundwater and groundwater quality remain data gaps.

The only other DQOs not achieved for this project were (1) delineations of lateral extent of contamination at certain sites where accessibility was precluded because of a health and safety concern, and (2) resolution of issues pertaining to groundwater. Both of these remain data gaps.

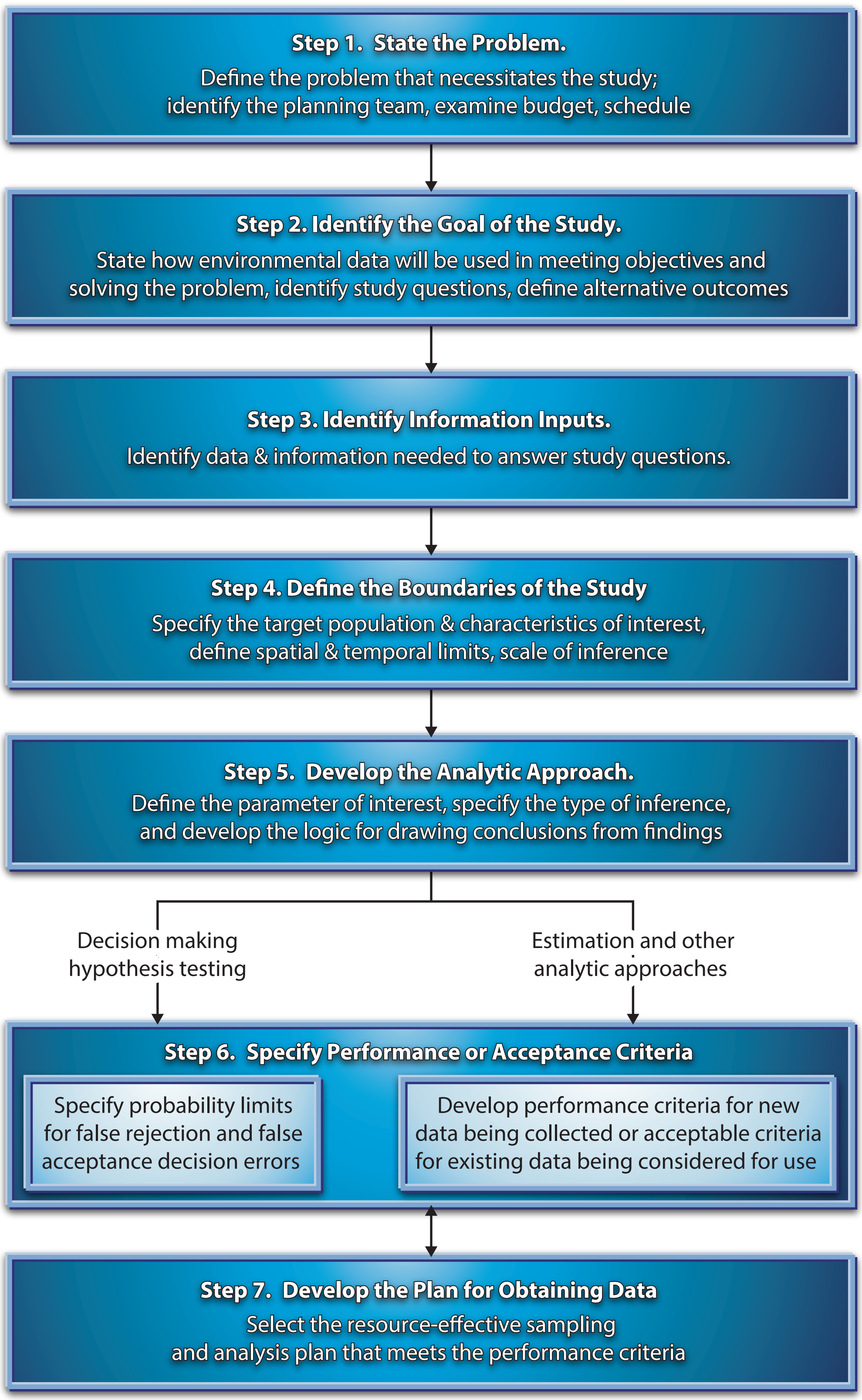


Figure 14. Data Quality Objectives Process Flow Chart (USEPA 2006a)

Table 12. Baseline Study Data Quality Objective Roadmap

Phase of the RSE	Question No.	Principal Study Question	Activity Performed to Address DQO	Section of RSE Report
Baseline Study	1	What are the background levels of gamma radiation and background concentrations of radionuclides and metals in soils and sediment are representative of conditions at each site?	Background Investigation and Drainage Background Sampling	Appendix A and Appendix J
	2	What is the lateral extent of mine-related surficial contamination at each site?	Site Mapping; Gamma Radiation Surveys; Soil Samples	Appendix H Appendix I Appendix J
	3	Is there potential for contaminants to migrate off site via surface water pathways at each site?	Sediment and Surface Water Sampling	Appendix J
	4	Is there potential for contaminants to migrate off site via the groundwater pathway?[1]	None	NA
	5	What is the spatial extent, locations, and types of NORM and TENORM at the site?	Site Mapping	Appendix H
	6	Have the Tronox NAUM risk prioritization factors been evaluated adequately (such as site accessibility, reclamation status, land use, and waste material characteristics)?[2]	Site Mapping	Appendix H

Notes:

1 Baseline Study Question No. 4 regarding groundwater impacts was not addressed as part of this SSRSE or the project-wide RSE investigation per technical direction from USEPA; this is discussed in the main RSE Report in more detail.

2 Tronox NAUM risk prioritization factors are under development by stakeholders to prioritize cleanup at Northern Agency Tronox Mines.

- No activities were performed to address DQO

DQO Data quality objective

NAUM Navajo Area Uranium Mines

NORM Naturally occurring radioactive material

RSE Removal Site Evaluation

SSRSE Site-specific Removal Site Evaluation

TENORM Technologically enhanced naturally occurring radioactive material

USEPA U.S. Environmental Protection Agency

Table 13. Site Characterization Study Data Quality Objective Roadmap

Phase of the RSE	Question No.	Principal Study Question	Activity Performed to Address DQO	Section of RSE Report
Site Characterization Study	1	Did the Baseline Study adequately delineate lateral extent of surficial contamination at the site, downwind areas, and drainages?	Site Mapping; Gamma Radiation Survey; Soil Samples; XRF Field Surveys	Appendix I and Appendix H
	2	Has the lateral extent of mine-related radionuclides and metals in surface soil, waste, or sediment been adequately defined?	Soil Samples	Appendix I and Appendix H
	3	What is the lateral and vertical extent of mine-related subsurface radionuclides and metals in soils and waste at each site?	Subsurface Sampling Program	Appendix H
	4	Are mine-related radionuclides and metals in surface soils, waste, and drainage sediments potentially leaching to surface water or groundwater?	Geochemical Sampling; Sediment Sampling; Surface Water Sampling	Appendix H and Appendix J
	5	Has groundwater been impacted by historical mining activities? [1]	None	NA
	6	What is the distribution of concentrations of radon gas present at accessible mine openings, waste piles, and drainages, and is radon gas being emitted from buried waste cells?	Ambient Radon Monitoring	Appendix H and Section 5.4
	7	Have the physical characteristics of mine waste been adequately evaluated to support modeling, remedy evaluation, and evaluation of the Tronox NAUM risk prioritization factors? [2]	Site Mapping; Geochemical Sampling; Geotechnical Sampling	Appendix H
	8	Has the distribution of gamma radiation dose rates in surface soils and drainage sediment at the site been determined? [2]	Use of high-pressure ionization chambers (HPIC) at various sites to measure gamma exposure rates. These exposure rates were correlated to gamma counts obtained by use of sodium iodide (NaI) detection systems collocated with the HPICs.	Appendix C and Attachment 2

Notes:

[1] Site Characterization Question No. 5 regarding groundwater impacts was not addressed as part of this SSRSE or the project-wide RSE investigation per technical direction from the U.S. Environmental Protection Agency.

[2] Tronox NAUM risk prioritization factors are under development by stakeholders to prioritize cleanup at Northern Agency Tronox Mines.

[3] Site Characterization Question No. 8 regarding dose rates is not included in the site-specific removal site evaluations presented in Appendix H because dose rates are not presented in those reports.

- Not applicable
DQO Data quality objective
NAUM Navajo Area Uranium Mines
RSE Removal Site Evaluation
SSRSE Site-specific Removal Site Evaluation
XRF X-ray fluorescence

4.3 PRE-INVESTIGATION SITE CLEARANCE

Before any site was accessed, the Agencies determined whether Navajo individuals had any interest in the area, possibly because they: (1) had homesite leases, (2) had interest in land in the vicinity of an AUM site, (3) were allotted lands proximate to an AUM site, or (4) had a grazing permit for land within an AUM site. Tetra Tech provided maps of potential RSE study areas to USEPA to allow sufficient time for the Agencies to request access from the appropriate parties. All such persons were notified of the nature of the work anticipated and informed of what access would be necessary to perform the work.

USEPA requested from the Cove Chapter access to roads leading to Mesa V in order to improve those roads, and access to mine sites for RSEs. The Cove Chapter approved these requests for access at a chapter meeting on March 12, 2017, and provided a written resolution to USEPA (Cove Chapter 2017). The resolution from March 12, 2017, stated the following:

> Access is approved to allow USEPA Region 9 to grade Mesa V to improve access roads to several mine sites for road clearing; this access will also include all mountain access roads and to conduct removal site evaluations.

USEPA also requested, from grazing committees, access to mine areas within the following grazing areas:

- Cove Chapter Grazing Areas
- Round Rock Chapter District #11 Grazing Areas
- Teec Nos Pos Chapter Grazing Areas.

Grazing permit holders in the Cove Chapter consented to access in January 2017 by providing written consent to NNEPA and USEPA (NNEPA and USEPA 2017a). The District #11 Grazing Committee indicated absence of existing and active grazing permittees in the areas mapped for abandoned mine cleanup in a letter submitted to the Superfund Division Community Involvement section of USEPA Region 9. The letter was signed by the District #11 Grazing Committee Chair (Navajo Nation District #11 2018). Grazing permit holders in the Teec Nos Pos Chapter consented to access in November 2017 by providing written consent to NNEPA and USEPA (NNEPA and USEPA 2017b).

Representatives from the above-listed grazing areas granted access to USEPA for the following purposes:

- Conducting radiological surveys
- Collecting samples of soil, water, sediment, air, and/or plants, and/or conducting other potentially hazardous waste surveys
- Improving roads
- Performing other response actions as deemed necessary by USEPA or NNEPA to address release or threatened release of a hazardous substance at or around the grazing areas.

To address potential issues with AUM site access arising during field activities, Tetra Tech ensured presence of at least one Navajo-speaking individual on each AUM site during all field activities.

4.3.1 Cultural Surveys

Dinetahdoo Cultural Resources Management LLC conducted cultural resource surveys under a separate contract with USEPA. Survey areas included all survey boundaries of AUM sites, Target sites, drainages, and roads. Cultural survey personnel performed monitoring during ground disturbing activities of the project and were present during the gamma radiation surveys, XRF field surveys, and soil sampling. Some survey units were identified as culturally sensitive during the course of the project. Tetra Tech provided cultural survey assistance to USEPA as needed to support initial consultations with the Navajo Nation Heritage and Historic Preservation Department. On February 13, 2018, Tetra Tech provided USEPA a summary of anticipated RSE field activities and sampling locations to support cultural survey work.

4.3.2 Biological Surveys

Tetra Tech completed a desktop review of biological surveys of AUM sites within the Cove Chapter (Clifford 2015; USEPA 2015a, 2017; Adkins Consulting, Inc. 2017). Previous biological assessment reports received by both the U.S. Fish and Wildlife Service (USFWS) and NNDFW listed possible sensitive species in the Cove Wash area based on information from the Environmental Conservation Online System and Arizona Game and Fish Department (USEPA 2017). The following federally or Navajo Nation threatened and endangered (T&E) species were considered for potential adverse effects related to RSE field work:

- Zuni fleabane (*Erigeron rhizomatus*)
- Navajo sedge (*Carex specuicola*)
- Mexican spotted owl (*Strix occidentalis lucida*)
- American dipper (*Cinclus mexicanus*).

During biological surveys in 2015 and 2017, the Mexican spotted owl was observed within the Cove Chapter, inducing establishment of buffers around the location of the sighting known as Protected Activity Centers. These visual observation buffers extend to the two AUM sites Mesa II Mine 4 and Frank Jr. Mine.

Tentative observations of the American dipper in the Cove Chapter occurred in 2015 and 2016 (USEPA 2017). No other T&E species listed were observed in project areas (USEPA 2017). Botanist Arnold Clifford surveyed potential habitat for Navajo sedge and Zuni fleabane within Cove Wash beginning in June 2015. During botanical surveys and wetlands delineations in 2015, 2016, and 2017, neither Navajo sedge nor Zuni fleabane was observed (Clifford 2015, USEPA 2017).

Based on results of previous biological surveys, the following effects on T&E species were anticipated during RSE field work:

- Zuni fleabane – No effect

- Navajo sedge – No effect
- Mexican spotted owl – Possible but not likely adverse effect
- American dipper – No effect.

Most RSE activities occurred at AUM sites, Target sites, and other previously disturbed areas on mesa tops and ridges, at least 500 feet away from canyon bottoms. Project areas typically ranged from 500 to more than 1,000 feet above canyon bottoms. RSE activities did not disturb mixed conifer stands or riparian areas. Standard best management practices ensured no release of debris or earthen material to the drainages where those materials could impair surface water quality, vegetation, and/or potential habitat.

The following is a summary of habitat conditions and biological surveys at the RSE regions:

- **Cove Transfer Station:** The Cove Transfer Station is on a residential property previously disturbed by removal activities, and currently consists of bare ground, rocks, and grasses, with sparse individual juniper and pinyon trees. In a letter to USFWS, USEPA indicated that this area does not provide any habitat for species of concern and does not affect any species of concern.
- **Lukachukai Mountain Region:** Before engaging in any intrusive activities beyond foot surveys and gamma scanning, USEPA conducted habitat surveys within these project areas. USEPA requested advice from USFWS and NNDFW regarding appropriate times of the year and potential target species habitat for these surveys.
- **Tse Tah Northwest Carrizo Mountain Region:** Before engaging in any intrusive activities beyond foot surveys and gamma scanning, USEPA conducted habitat surveys within these project areas. USEPA requested advice from USFWS and NNDFW regarding appropriate times of the year and potential target species habitat for these surveys.
- **Mesa V Gate Construction:** USEPA performed habitat and species surveys at the Mesa V subarea. Mexican-spotted owls had been observed within the Mesa V subarea adjacent to the Frank Jr. mine. The area was inspected for owls before construction began.

Tetra Tech conducted multiple Mexican spotted owl surveys during the course of the 2018 nesting season according to USFWS survey protocol. Figure 15 shows a Mexican spotted owl observed in a drainage within the Lukachukai Mountains.

Figure 15. Mexican Spotted Owl Observed during the 2018 Biological Survey

4.3.3 Public Participation

USEPA engaged in formal public participation during certain stages of the project. Upon request, Tetra Tech supported USEPA with community involvement by participating in and providing content for meetings as needed. Tetra Tech activities generally accorded with the following USEPA guidance documents:

- *Community Relations in Superfund: A Handbook* (USEPA 1992a)
- *Superfund Removal Procedures Public Participation Guidance for On-Scene Coordinators: Community Relations and the Administrative Record* (USEPA 1992b)
- *Superfund Community Involvement Handbook* (USEPA 2016)

In accordance with USEPA direction, Tetra Tech provided technical support for development, planning, and implementation of community relations and public support-oriented documents, brochures, communication packets, and public meetings, as appropriate. Over the course of the project, four public meetings occurred with USEPA and Tetra Tech at Cove Chapter, Lukachukai Chapter, and Sweetwater Chapter (Figure 16). As needed throughout the course of the project, Tetra Tech also provided culturally skilled and experienced public communications and outreach staff fluent in both English and Navajo, and capable of interacting with the public and local residents.

Figure 16. Tetra Tech Project Manager Meeting with the Lukachukai Chapter President

4.4 RSE FIELD SAMPLING METHODS

All Tetra Tech field sampling activities conformed to the SAP/QAPP (Appendix C to the RSE Work Plan). Development of the SAP/QAPP had accorded with *Sampling and Analysis Plan Guidance and Template from USEPA Region 9 for Documenting Procedural and Analytical Requirements* (R9QA/009.1) (USEPA 2014), and *Guidance on Choosing a Sampling Design for Environmental Data Collection for Use in Developing a Quality Assurance Project Plan* (EPA QA-G5) (USEPA 2002b). Tetra Tech developed DQOs as part of the SAP/QAPP based on USEPA's seven-step DQO development process as described in Section 4.2.

Two primary field sampling phases of the RSE investigation occurred at most AUM sites and AUM-related sites. At a few locations, the Baseline Study met DQOs, and no further investigation was warranted during the Site Characterization Study. Most of the Baseline Study occurred between March and August 2018, and typically involved the following field activities:

- Background investigation
- XRF field surveys, including in situ XRF measurements and collection of XRF confirmation soil samples for laboratory analysis
- Gamma radiation surveys
- Gamma-exposure rate correlation
- Gamma-radium correlation

Data acquired from the Baseline Study were evaluated and used to update the sampling design for the Site Characterization Study. The field team then returned to the site for the Site Characterization Study, most of which occurred during August and September 2018, and typically involved the following field activities:

- Site mapping
- Goback XRF field surveys
- Goback gamma radiation surveys
- Surface soil characterization via gamma measurements, XRF measurements, and sampling for laboratory analysis; and subsurface characterization via investigation of the shallow subsurface and collection of soil samples for laboratory analysis
- Drainage investigation
- Roads investigation
- Radon monitoring

Following completion of the Baseline Study and Site Characterization Study, data from each site were evaluated against objectives of the RSE investigations. The following data evaluation activities occurred:

- Third-party data validation of all analytical data—approximately 90 percent of the data underwent Stage 2B validation in accordance with USEPA *Guidance for Labeling Externally*

Validated Laboratory Analytical Data for Superfund Use (USEPA 2009), while the remaining 10 percent underwent Stage 4 validation

- Correlation of in situ XRF measurements to laboratory-reported concentrations (see Appendix B to the RSE Report)
- Statistical evaluation of all data, including calculations of summary statistics
- Development of contaminant mapping of primary analytes (defined in Section 7.1 of Appendix H SSRSEs)
- Classification of each AUM site or AUM-related site by use of a MARSSIM (USEPA 2000) approach based on gamma radiation levels and historical knowledge of mining features
- Comparisons of all acquired data to BTVs
- Estimations of lateral and vertical extent of contamination ("contamination" here defined as an exceedance of background concentration by a primary analyte concentration)
- Estimation of mine waste volumes within areas of the site where contaminant concentration(s) exceeded background

The following subsections discuss field sampling methods cited above for the RSE investigations and other investigations during this project.

4.4.1 Site Mapping

Site mapping occurred at every AUM site and AUM-related site, typically during the Site Characterization Study and conducted by a multidisciplinary team of environmental engineers, geologists, and radiation health physicists. Some site mapping occurred during multiple trips to a site and during both phases of sampling.

The overall goal of site mapping was to gain better understanding of site conditions in accordance with the methodology presented in the FSP and the SAP/QAPP in Appendix F and Appendix C, respectively, to the RSE Work Plan (Tetra Tech 2018). Objectives of site mapping at the Northern Agency Tronox Mines included the following:

- Identifying any immediate physical hazards remaining at the site
- Locating access routes, including foot pathways and roads
- Differentiating NORM from TENORM via geological assessment and visual observation
- Mapping all drainages and potential surface water pathways at the site
- Identifying any remaining exploration borings or roads
- Confirming existing mine site features and identifying additional site features relevant to the RSE investigation process
- Verifying soil types and geological formations at the site
- Identifying evidence of surface water erosion and off-site migration
- Conducting physical measurements and visual estimates of mine waste volumes of waste materials at the site

The process for identifying TENORM involved site mapping and inventory of mining- or reclamation-related impacts across the site, including waste piles, burial cells, exploration cuts or rimstrips, historical mining roads, ore or protore, portals, and other types of features that would indicate presence of TENORM. The process for identifying NORM involved use of gamma radiation survey data and geological information to identify potential natural outcrops or ore deposits that had not been physically disturbed or mined previously. At a large number of sites in the Lukachukai Mountains, wastes within most of the site boundary were considered TENORM because of presence of roads and areas of disturbance from phases of mining and reclamation.

Site mapping consisted of recording geospatial locations of key site features by use of handheld Trimble Geo 7XH Global Positioning System (GPS) units with subfoot accuracy after post-processing. Additionally, gamma radiation survey Mesa tablets were also capable of recording geospatial locations during the gamma radiation surveys, and were used by field staff to geospatially locate obstacles, hazards, and site features discovered during field work. Results of site mapping are shown in each SSRSE report in Appendix H to this RSE Report. The field crew documented all site mapping activities using GPS units or tablets, and entered acquired data into the project geodatabase daily following field work. Scanned copies of site mapping field forms are in attachments to the SSRSE reports in Appendix H. Table 14 summarizes site mapping activity.

In addition to maps of specific features as described above, the GPS-based gamma survey provided a detailed geospatial dataset covering each recorded measurement of gamma radiation. This dataset clearly documented boundaries of gamma survey activities at each site, and provided an exact geospatial measurement for each gamma measurement taken. These data were then used in site-specific models of gamma radiation distribution. Correlation studies helped distinguish radioactive materials as NORM or TENORM, and increased understanding of spatial distribution of gamma exposure rates across each site.

Table 14. Site Mapping Activity Summary

Site Feature	Purpose
NORM/TENORM Boundaries	Provide information on geospatial locations of NORM and TENORM. The distinction is crucial because future remedial actions will focus solely on TENORM.
Location of nearest surface water body	Provide information to assess likelihood of contaminated material migrating to surface water. Distance to nearest surface water body is a factor in the Tronox NAUM Risk Prioritization metric. Locations of nearby surface water bodies guided planning for surface water and sediment sampling during the Site Characterization Study.
Location of visible mine workings/features	Provide information on potential physical risks at the mine, as well as likelihood that runoff can enter the mine body and provide a direct path to groundwater. Impact on groundwater is a factor in the Tronox NAUM Risk Prioritization metric. Locations of open pathways to groundwater guided planning for sampling during the Site Characterization Study.
Boundaries of mine reclamation features	Provide information on locations and areas of reclamation features such as burial pits. Statuses and sizes of reclamation features are factors in the Tronox NAUM Risk Prioritization metric. Visual boundaries of reclamation features were refined during Site Characterization Study sampling efforts.
Location of nearest access road/path	Provide information to assess the ease with which the general public can access the site. Ease and likelihood of public access are factors in the Tronox NAUM Mines Risk Prioritization metric.
Changes to anticipated locations of data acquisition	Exact locations of each (1) XRF measurement, (2) surface soil sample for metals analysis, and (3) surface soil sample for radionuclide analysis were predetermined and documented in site-specific FSPs in Appendix F to the RSE Work Plan. Any changes to anticipated locations of data acquisition (necessitated by field conditions) from those specified in site-specific FSPs were documented. This geospatial information contributed to development of maps of contaminant distributions across each site.

Notes:

FSP Field Sampling Plan
NAUM Navajo-area abandoned uranium mines
NORM Naturally occurring radioactive material
RSE Removal Site Evaluation
TENORM Technologically enhanced naturally occurring radioactive material
XRF X-ray fluorescence

4.4.2 Gamma Radiation Survey

Tetra Tech initially performed GPS-based gamma radiation surveys of AUM sites, Target sites, BSAs, drainages, and roads as part of the Baseline Study. Additional Goback gamma radiation surveys or drainage transects occurred during the Site Characterization Study to enhance coverage of areas and delineate the lateral extent of contamination.

Objectives of the GPS-based gamma surveys were to: (1) delineate areal extent of TENORM at a site, (2) help establish a basis for investigation of the subsurface, (3) establish a basis for predicting Ra-226 concentrations across a site, and (4) establish a basis for predicting radiation exposure rates across a site.

A gamma radiation survey occurred at every site following the methods outlined in Appendix C to the RSE Work Plan (Tetra Tech 2018). Field staff used mobile scanning systems with Ludlum Model 44-10 (2- by 2-inch) sodium iodide (NaI) gamma scintillation detectors coupled to Ludlum Model 2221 ratemeters/scalers set in ratemeter mode. The detectors were coupled to ERG Model 105 GPS units. The ERG Model 105 GPS unit consists of a Juniper Mesa 2 field computer and geode GPS receiver. Typically, as within the survey area of Mesa II, Mine No. 1, P-150, the gamma radiation survey occurred at maximum spacing of 2-meter transect widths. Detector height was 1 meter above ground surface as prescribed in the RSE Work Plan. The "field of view" of the NaI detector in this configuration (2-meter transects and 1-meter height) provides 100-percent coverage of land areas. Gamma count rate measurements and associated geospatial coordinates were recorded every 1 second. Project-wide results of the gamma radiation survey are presented in Section 5.2. Within each SSRSE report in Appendix H is a summary of detection systems used and when they were used during the gamma radiation survey of each site.

All Ludlum Model 44-10/2221 instrument systems used in the gamma surveys were calibrated in accordance with the *American National Standard Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments* (American National Standards Institute [ANSI] 1997) and Standard Operating Procedure (SOP) 002: Calibration of a Radiological Survey Meter and SOP 001: Calibration of a Radiological Survey Detector in Appendix D to the RSE Work Plan (Tetra Tech 2018). Calibration of a detection system is required (1) prior to initial use, (2) at least annually, and (3) after any scheduled or unscheduled maintenance or repair that may affect its operation. General maintenance of detection systems, such as cleaning, painting, and changing buttons, does not include recalibration. The instruments were function-checked twice daily— before and at the end of each work day—in accordance with SOP 009: Operational Checkout of Single Detector with Meter in Appendix D to the RSE Work Plan. Table 15 summarizes information regarding the detection equipment and calibration.

Gamma survey data were acquired by use of the ERG 105 GPS and logged to a binary file in a manner precluding modifications to those data. That is, the user had no interaction with gamma measurements, and no translation errors could occur in transmittal of those measurements. The integrity of that file allowed retention of and reference to the original field data, if necessary, to track changes or revert to the original version. The ERG RadSync and RadScene applications were used to transfer all gamma survey field data to the management computer. Only one computer was used to accept incoming field data, thus preventing duplication of data files. Files were not copied manually between the data logger and the project computer. Moreover, raw data files were not renamed from their original file names.

Table 15. Summary of Detection Equipment and Calibration Information

Equipment	Use/Calibration Summary	Relevant RPP SOP No.[1]
Ludlum 2221/ Ludlum 44-10 (or equivalent)	**Use:** Ludlum 2221 ratemeter/scaler instruments were paired with Ludlum 44-10 NaI detectors to measure surface gamma radiation. This detection system was combined with a GPS unit and data logger to record gamma survey and spatial location results in real time. **Calibration:** Each system (Ludlum 2221/44-10 pair) was calibrated at least annually. Calibration also occurred following any maintenance or repair that could affect functionality. **Functional Checks:** Checks of each system occurred twice during each day of use—one check prior to use and one check after completion of all measurement activities for the day. Checks utilized a standardized source, and net results (source less background counts) had to be within ±20% of results established as part of ongoing control charting.	SOP 001 SOP 002 SOP 009
ERG Model 105 GPS	**Use:** The ERG Model 105 GPS system pairs radiation instruments with GPS units to simultaneously record gamma measurements and associated geospatial locations. The system includes a handheld tablet computer that acquires and displays survey results in real time and protects the data from manipulation. **Calibration:** NA **Functional Checks:** NA	NA

Notes:

[1] SOPs are in Appendix D to the RSE Work Plan (Tetra Tech 2018).

ERG	Environmental Restoration Group, Inc.	RPP	Radiation Protection Program
GPS	Global positioning system	RSE	Removal Site Evaluation
NA	Not applicable	SOP	Standard Operating Procedure
NaI	Sodium iodide	Tetra Tech	Tetra Tech, Inc.

The following steps were taken to validate and verify gamma survey data in accordance with SOP 006: Validation and Verification of Gamma Survey Data (in Appendix C [SAP/QAPP] to the RSE Work Plan [Tetra Tech 2018]):

- Gamma measurements were reviewed in their shapefiles for minimum values to verify that they were within an appropriate range for the Ludlum Model 44-10 and survey area. If low counts were detected, the cause of this was assessed. Invalid measurements could have resulted, for example, if a GPS unit was left on unintentionally during travel in a vehicle.
- Horizontal dilution of precision (HDOP) measurements from the GPS unit in the GPS-based gamma radiation survey were reviewed to verify that the values did not exceed 3.0. HDOP values exceeding this threshold may have a high positional error and would then be used cautiously during post-processing tasks, such as identifying locations of correlation samples and anomalies.
- Symbology was applied to the gamma measurements, which were then inspected visually for patterns that might indicate detector or cable problems.
- Invalid data of the types described above were removed from the shapefile in accordance with SOP 006.

Steps taken to analyze the gamma survey data were as follows:

- Measurements within each survey unit (100 m^2) and areas extending outward were averaged. Survey unit averages across the site were analyzed statistically by use of ArcGIS software. These results were then compared to results from the background studies (Section 5.1 of each SSRSE report in Appendix H).
- Gamma survey measurements were retained as cpm and converted to predicted exposure rates based on the regression analysis in Section 4.5.2 of each SSRSE report and in Section 5.2.3 of this RSE Report. The data were interpreted only in terms of cpm. However, exposure rate maps are provided in the main RSE Report.
- Gamma survey measurements were analyzed by use of statistical software (ProUCL, JMP, and Microsoft Excel), and applicable statistical parameters were generated. Parameters included the number of measurements, arithmetic or geometric mean, median, percentiles, and standard deviation.
- Symbology was applied to the gamma survey measurements according to intervals established as multiples of the applicable BTVs.

All QA/QC results and calibration documentation for all radiation detection equipment used in the Northern Agency Tronox Mine RSE investigations are included in the QA/QC Summary Report (Appendix G). That report presents daily calibration checks for the gamma radiation surveys at every site.

4.4.3 Gamma-Exposure Rate Correlation Study

The purpose of the gamma-exposure rate correlation study and predicted energy-independent exposure rates was to translate the relatively high-density gamma measurements to more meaningful energy-independent measures of direct human exposure—thus allowing evaluation of human exposure across the entire area surveyed. To accomplish this translation, Tetra Tech employed high-pressure ionization chambers (HPIC) at various sites to measure gamma exposure rates. These exposure rates were correlated to gamma counts obtained by use of NaI detection systems collocated with the HPICs.

The HPIC measures ionization effects of incoming radiation by applying an electric field to collect charges created by ionization within the detector gas induced directly by that incoming radiation. The HPIC measures ionization effects of gamma radiation, X-rays, and cosmic radiation without discrimination of these.

Specific numbers and locations of HPIC measurements and gamma counts were selected in the field by a certified health physicist; the final analysis and results of the gamma exposure rate correlation are in Appendix C to the RSE Report. HPIC measurements and gamma counts were strategically acquired to span a large range of gamma survey results and thus allow a robust correlation. Tetra Tech took HPIC measurements and obtained gamma counts at all types of sites, including AUM sites, Target sites, roads, drainages, and BSAs.

For the exposure-rate correlation, an HPIC (GE Reuter-Stokes RSDetection, RS-S131-200) was used to take energy-independent measurements of exposure rates in accordance with SOP 003: Marking Exposure Rate Measurements Using a HPIC in Appendix C to the RSE Work Plan (Tetra Tech 2018). A summary of instrument-specific calibration and functional checks is in

Table 16. At each measurement location, gamma exposure rate measurements occurred at 1-minute integrated intervals over a duration of at least 10 minutes. The HPIC gamma exposure rate representing a grid is the average of the 1-minute integrated measurements, excluding the first minute of data acquisition during which the HPIC exhibits a startup pulse. The HPIC was centered within the correlation plot area at 1 meter above ground surface. Figure 17 is a photograph of an HPIC taking measurements at a site. Correspondingly, a 1-minute static gamma count occurred at the same location by use of an NaI detection system. Height of the NaI detector was maintained at 1 meter above ground surface. A linear regression occurred on data pairs of exposure rate and gamma count rate. A single, project-wide correlation was determined. Methods for performance of the correlation study are conveyed in Section 4.4.4.

Table 16. High-Pressure Ionization Chamber Equipment Usage Summary

Equipment	Use/Calibration Summary	Relevant SOP No.
GE-Energy Model RSS-131 HPIC or similar	**Use:** HPIC instrumentation was used to take energy-independent measurements of gamma exposure rates. At each measurement location, gamma exposure rate measurements were taken at 5-second intervals over a duration of 10 minutes. **Calibration:** The HPIC used had been calibrated within the previous year. Calibration also occurred after any maintenance or repair that could affect functionality. **Functional Checks:** NA	SOP 003

Notes:

HPIC High-pressure ionization chamber
NA Not applicable
SOP Standard Operating Procedure

Figure 17. A High-Pressure Ionization Chamber

4.4.4 Gamma Correlation Study

Tetra Tech performed GPS-based gamma radiation surveys and collected nine-point composite samples of surface soils in a large number of correlation plots across different types of sites within various geologies and subarea groups. The sample plot locations were distributed across many different AUM sites and background sites to obtain a representative distribution of the correlation between detected Ra-226 and gamma measurements. These areas were selected according to criteria established in the RSE Work Plan. No DQO was established for homogeneity of the correlation plots—homogeneity of the correlation plots was evaluated qualitatively. Results of the gamma-radium correlation appear in more detail in Appendix C.

The 2- by 2-inch NaI detectors used in this investigation are sensitive to surface Ra-226 decay products and other gamma emitting radionuclides. The purpose of the gamma correlation was to estimate Ra-226 concentrations in the upper 6 inches of soil. Tetra Tech and ERG field personnel selected correlation plots based on the range of gamma radiation levels detected. If surface soil concentrations of gamma emitting radionuclides varied among correlation locations, that variability would be included in the regression model. Soil correlation areas were selected according to criteria established in the RSE Work Plan. Activities occurred contemporaneously by area and on the same day such that variations in gamma count rate measurements could be limited largely to variability of soils and rocks at the locations. The soil samples were analyzed by ALS Environmental in Fort Collins, Colorado, for Ra-226, thorium-232 (Th-232), and potassium-40 (K-40) via USEPA Method 901.1.

4.4.5 XRF Field Survey

Tetra Tech took 9,540 in-situ XRF measurements across 38 AUMs and 37 Target sites within the Northern Agency Tronox Mine area region; measurements occurred within a systematic 100-m^2 survey unit grid system at each site. The XRF field survey proceeded across treacherous terrain within the Lukachukai Mountains and across the more forgiving lower lying terrain at the base of the northwest Carrizo Mountains in the Tse Tah region of the Navajo Nation within Apache County in northeast Arizona. In addition to in situ XRF measurements, 502 confirmatory bulk soil samples were collected and evaluated via replicate ex situ XRF measurements. The XRF technology evaluated during this study proved useful for determinations of concentrations of nine target elements, with application of correction factors to the XRF data. These corrected XRF datasets can be used to aid design of future removal actions and/or final status surveys.

Appendix B, the XRF Data Evaluation Report, summarizes a data evaluation study of performance of field-portable (hand-held) XRF analyzers (Niton XL5) for detection and quantification of trace element concentrations in surface soils at AUM sites and Target sites within the Northern Agency region of the Navajo Nation.

4.4.6 Soil Sampling

Tetra Tech conducted three types of soil sampling during the RSE investigations: (1) XRF confirmation soil sampling, (2) surface soil sampling, and (3) subsurface soil sampling. This section describes the methods applied to collect and analyze each type of sample.

All soil samples were submitted for laboratory analysis for metals as listed in Table 17; however, not all samples were analyzed for mercury, as discussed in Section 4.6. All samples were tested for K-40, Ra-226, and Ra-228, as listed in Table 18. Select radionuclides were also analytes for evaluation of secular equilibrium in the uranium decay series. In total, 502 XRF confirmation soil samples (0 to 3 inches bgs), 292 surface soil samples (0 to 6 inches bgs), and 444 subsurface soil samples (deeper than 6 inches bgs) were collected as part of the RSE investigations.

Laboratory geochemical analyses and geotechnical analyses of soil samples also occurred. Table 19 lists methods of laboratory geochemical analysis for metals in soil samples, and Table 20 lists methods of laboratory geochemical analysis for radionuclides in soil samples. Table 21 lists methods of geotechnical analysis of soil samples.

4.4.6.1 Surface Soil Sampling/Measurement

As described above, the project involved three primary aspects of surface soil sampling/measurement: (1) in situ XRF measurements, (2) laboratory analyses of XRF confirmation soil samples, and (3) laboratory analyses of surface soil samples. Descriptions of geospatial locations and laboratory sample delivery group identifications of the XRF confirmation soil samples and the surface soil samples are in attachments to every SSRSE report. All final in situ XRF measurements and laboratory results from XRF confirmation soil samples and surface soil samples are in attachments to the SSRSE reports in Appendix H.

The XRF field survey occurred on a systematic grid system within the center of 100-m^2 survey units following the methods outlined in Section 4.4.5. The in situ XRF measurements were corrected to represent predicted laboratory soil concentrations of nine analytes (by application of the methodology presented in the XRF Data Evaluation Report in Appendix B). The in situ XRF measurements at each site are presented in an attachment to each of the SSRSE reports in Appendix H, and include final corrected measurements of the nine analytes.

Surface soil samples collected within 0 to 6 inches bgs during the Site Characterization Study were collocated with subsurface boring locations cited in Section 4.4.6.2.

Surface soil sample results were compared to background levels for each analyte to identify COPCs. Combined surface soil sample results for select analytes in the form of contaminant maps are in SSRSE reports in Appendix H.

Table 17. Methods of Laboratory Analysis for Metals in Soil Samples

Analyte	CAS Number	Analytical Method
Aluminum	7429-90-5	USEPA SW-846 6020B
Antimony	7440-36-0	USEPA SW-846 6020B
Arsenic	7440-38-2	USEPA SW-846 6020B
Barium	7440-39-3	USEPA SW-846 6020B
Beryllium	7440-41-7	USEPA SW-846 6020B
Cadmium	7440-43-9	USEPA SW-846 6020B
Calcium	7440-70-2	USEPA SW-846 6020B
Chromium	7440-47-3	USEPA SW-846 6020B
Cobalt	7440-48-4	USEPA SW-846 6020B
Copper	7440-50-8	USEPA SW-846 6020B
Iron	7439-89-6	USEPA SW-846 6020B
Lead	7439-92-1	USEPA SW-846 6020B
Lithium	7439-93-2	USEPA SW-846 6020B
Magnesium	7439-95-4	USEPA SW-846 6020B
Manganese	7439-96-5	USEPA SW-846 6020B
Mercury	7439-97-6	USEPA SW-846 7471A
Molybdenum	7439-98-7	USEPA SW-846 6020B
Nickel	7440-02-0	USEPA SW-846 6020B
Selenium	7782-49-2	USEPA SW-846 6020B
Silver	7440-22-4	USEPA SW-846 6020B
Sodium	7440-23-5	USEPA SW-846 6020B
Thallium	7440-28-0	USEPA SW-846 6020B
Thorium	-	USEPA SW-846 6020B
Uranium	-	USEPA SW-846 6020B
Vanadium	7440-62-2	USEPA SW-846 6020B
Zinc	7440-66-6	USEPA SW-846 6020B

Notes:
- Not applicable
CAS Chemical Abstracts Service
USEPA U.S. Environmental Protection Agency

Table 18. Methods of Laboratory Analysis for Select Radionuclides in Soil Samples

Decay Series	Analyte	CAS Number	Analytical Method[1]
Uranium	**Uranium-238[2]**	7440-61-1	ASTM D3972 Modified
	Uranium-234	13966-29-5	ASTM D3972 Modified
	Thorium-230	14269-63-7	ASTM D3972 Modified
	Radium-226	13982-63-3	USEPA 901.1
	Lead-210	14255-04-0	Eichrom method
Actinide	**Uranium-235**	15117-96-1	ASTM D3972 Modified
Thorium	**Thorium-232[2]**	7440-29-1	ASTM D3972 Modified
	Radium-228	15262-20-1	USEPA 901.1
	Thorium-228	14274-82-9	ASTM D3972 Modified
Potassium	**Potassium-40**	13966-00-2	USEPA 901.1

Notes:

1 Applied to surface soil samples (0 to 6 inches bgs) and XRF confirmation soil samples (0 to 3 inches bgs).

2 Measured via alpha and gamma spectroscopy. Only results from alpha spectroscopy are presented in the report because detection limits of gamma spectroscopy were high.

ASTM ASTM International
bgs Below ground surface
CAS Chemical Abstracts Service
USEPA U.S. Environmental Protection Agency

Table 19. Methods of Laboratory Geochemical Analysis for Metals in Soil Samples

Analyte	Geochemical Parameter	CAS Number	Analytical Method
Aluminum	SPLP	7429-90-5	USEPA SW-846 6020B
Antimony	SPLP	7440-36-0	USEPA SW-846 6020B
Arsenic	SPLP, TCLP	7440-38-2	USEPA SW-846 6020B
Barium	SPLP, TCLP	7440-39-3	USEPA SW-846 6020B
Beryllium	SPLP	7440-41-7	USEPA SW-846 6020B
Cadmium	SPLP, TCLP	7440-43-9	USEPA SW-846 6020B
Calcium	SPLP	7440-70-2	USEPA SW-846 6020B
Chromium	SPLP, TCLP	7440-47-3	USEPA SW-846 6020B
Cobalt	SPLP	7440-48-4	USEPA SW-846 6020B
Copper	SPLP	7440-50-8	USEPA SW-846 6020B
Iron	SPLP	7439-89-6	USEPA SW-846 6020B
Lead	SPLP, TCLP	7439-92-1	USEPA SW-846 6020B
Lithium	SPLP	7439-93-2	USEPA SW-846 6020B
Magnesium	SPLP	7439-95-4	USEPA SW-846 6020B
Manganese	SPLP	7439-96-5	USEPA SW-846 6020B
Mercury	SPLP	7439-97-6	USEPA SW-846 7471A
Molybdenum	SPLP	7439-98-7	USEPA SW-846 6020B
Nickel	SPLP	7440-02-0	USEPA SW-846 6020B
Selenium	SPLP, TCLP	7782-49-2	USEPA SW-846 6020B
Silver	SPLP, TCLP	7440-22-4	USEPA SW-846 6020B
Sodium	SPLP	7440-23-5	USEPA SW-846 6020B
Thallium	SPLP	7440-28-0	USEPA SW-846 6020B
Vanadium	SPLP	7440-62-2	USEPA SW-846 6020B
Zinc	SPLP	7440-66-6	USEPA SW-846 6020B
Thorium	SPLP	-	USEPA SW-846 6020B
Uranium	SPLP	-	USEPA SW-846 6020B
paste pH	pH	-	USDA60
Acid-Base Accounting	Total Sulfur, Acid Potential, Neutralization Potential	-	Modified Sobek Method

Notes:

-	Not applicable
CAS	Chemical Abstracts Service
SPLP	Synthetic precipitation leaching procedure
TCLP	Toxicity characteristic leaching procedure
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency

Table 20. Methods of Laboratory Geochemical Analysis for Radionuclides in Soil Samples

Decay Series	Analyte	CAS Number	Analytical Method
Uranium	**Uranium-238[a]**	7440-61-1	ASTM D3972 Modified
	Uranium-234	13966-29-5	ASTM D3972 Modified
	Thorium-230	14269-63-7	ASTM D3972 Modified
	Radium-226	13982-63-3	USEPA 901.1
	Lead-210	14255-04-0	Eichrom method
	Polonium-210	15117-96-1	ASTM D3972 Modified
Actinide	**Uranium-235**	7440-29-1	ASTM D3972 Modified
Thorium	**Thorium-232[1]**	15262-20-1	ASTM D3972 Modified
	Radium-228	14274-82-9	ASTM D3972 Modified
	Thorium-228	13966-00-2	USEPA 901.1

Notes:
All analyses involved application of synthetic precipitation leaching procedure (SPLP).
[1] Measured via alpha spectroscopy.
ASTM ASTM International
CAS Chemical Abstracts Service
USEPA U.S. Environmental Protection Agency

Table 21. Methods of Geotechnical Analysis of Soil Samples

Analyte	Analytical Method
Wet Sieve[1]	ASTM D6913
Atterberg limits	ASTM D4318
Proctor	ASTM D698

Notes:
[1] Sieve stack including #200, #100, #80, #40, #10, #4, and 3/8 inches.
ASTM ASTM International

4.4.6.2 Subsurface Soil Sampling

Subsurface sampling occurred at each AUM site or AUM-related site, manually by hand or via mechanical drilling depending on accessibility and terrain. A surface soil sample (0 to 6 inches bgs) was collected by use of a hand trowel at every location where a boring to subsurface occurred.

During subsurface drilling by hand, a shovel was used to collect each subsurface soil sample by creation of a small test pit, and depth was measured. If soil conditions allowed, discrete soil samples were collected at 6-inch intervals. Samples were placed into dedicated plastic bags and designated for either metals or radionuclide laboratory analysis. Given the shallowness of subsurface sampling downhole, gamma readings were not taken. Test pits were backfilled with surrounding soil.

Mechanical subsurface drilling proceeded by use of a Central Mining Equipment (CME)-75 truck-mounted drilling rig (shown on Figure 18) or a track-mounted drill rig (shown on Figure 19). Both methods involved continuous collection of soil samples by use of 4.5-inch hollow-stem augers and a pneumatic split-spoon sampling apparatus. A surface soil sample (0 to 6 inches bgs) was collected by use of a hand trowel. Continuous split-spoon cores were collected from 6 inches bgs to 15 feet bgs or when encounter with native conditions occurred. Discrete soil samples were collected based on soil conditions and gamma readings per judgement of field personnel. Samples were placed into dedicated plastic bags and designated for either metals or radionuclide laboratory analysis. Following boring termination, continuous gamma readings were obtained by lowering a detector down the open borehole. Borings were backfilled with dehydrated bentonite clay chips.

A mechanical subsurface drilling program occurred at seven sites. Results of the subsurface drilling program are summarized in individual SSRSE reports in Appendix H.

Figure 18. The Larger CME-75 Truck-Mounted Drill Rig

Figure 19. The Track-Mounted Drill Rig

4.4.7 Radon Monitoring

A study goal identified in the DQO process for the Site Characterization Study (Table C-8 of Appendix B to the RSE Work Plan [Tetra Tech 2018]) was to determine concentrations of radon gas at mine openings, buried waste cells, and drainages, and emanating from waste rock piles. Tetra Tech performed radon monitoring at AUM sites and Target sites using alpha track Etch detectors. Retrieved detectors were analyzed by Radonova Laboratories AB on December 28, 2018. Radonova performs internal QA/QC on its measurement procedures according to International Organization for Standardization (ISO)17025 standards. The lab report was provided electronically. Data were not validated because these were not planned for use in site characterization or risk assessment.

Deviations from the work plan occurred as follows:

- Only one duplicate sample was deployed with 34 radon detectors, less than the 10 percent of total samples specified in the work plan.
- Of the 34 detectors deployed, 26 were retrieved. The remaining eight detectors, including one field duplicate, could not be retrieved because of weather and accessibility issues. Because no resulting data came from duplicate detectors, a precision check and control charting of the data, as discussed in Section 4.4.1.3 of the RSE Work Plan (Tetra Tech 2018), were not possible.

Detector housings were mounted at the approximate height of the breathing zone of an adult on fence posts or trees, depending on terrain. The sampling period began with removal of the protective bag in which the detector was packaged. At the end of the measurement period (1 quarter year), the detector was retrieved and resealed. Time and date of removal were entered on the data form for the detector. After retrieval, each detector was returned to the analytical laboratory for processing. Project-wide results of the radon monitoring are conveyed in Section 5.4.

4.5 QUALITY MANAGEMENT

QA and QC were priorities throughout all data acquisition and analysis tasks completed in support of the RSE investigations. Specific QA/QC procedures were implemented to both minimize and evaluate potential sources of inaccuracy during sample collection and analysis. QA/QC procedures were designed to conform to relevant guidance from USEPA, as well as MARSSIM and the *Multi-Agency Radiological Laboratory Analytical Protocols Manual* (MARLAP) (USEPA 2004), and are described in detail in Appendix G to this RSE Report.

4.5.1 Quality Assurance/Quality Control

QA/QC procedures were implemented throughout data acquisition and analysis tasks completed under Task Order 0001.

All project QA/QC data are included in appendices to the RSE Report as described in Section 1.2. XRF field survey QA/QC results are in Appendix B, gamma radiation survey QA/QC results are in Appendix C, and soil, sediment, and water sampling QA/QC results are in Appendix G. All documentation of factory calibrations of field equipment is in the relevant appendices. All laboratory reports are in Appendix L, and data validation reports are in Appendix M (a data validation report includes explanations for sample results that were qualified during the data validation process, and summary data sheets indicating which results were qualified). All laboratory analytical reports underwent complete third-party data validation. USEPA's Remedial Project Manager (RPM) subjected Tetra Tech to numerous random field audits. All QA/QC results, both field and laboratory, met performance criteria specified in the SAP/QAPP of the RSE Work Plan (Tetra Tech 2018).

4.5.2 Data Validation

All samples to be analyzed for inorganic chemicals and all samples to undergo radiological analysis were sent to ALS Environmental Laboratories, Inc., in Fort Collins, Colorado. Exceptions to this were samples submitted for acid-base accounting, which were sent to ALS Environmental in Tucson, Arizona, and samples for methyl mercury and total Kjeldahl nitrogen analyses, which were sent to ALS Environmental in Kelso, Washington. All results were validated by third-party contractor Validata Chemical Services, Inc., in Duluth, Georgia; Tetra Tech chemists reviewed the third-party data validation reports. Data validation results are presented within 127 data validation reports that validate laboratory results from 126 paired inorganic and radiological laboratory reports, as well as one laboratory report that conveys both inorganic and radiological results (sample delivery group [SDG] 1811450). One additional laboratory report (SDG 1903120) that conveyed results of re-analyses of five samples for individual analytes was not validated, and the data were not used for site characterization. Data validation reports are organized by paired SDGs. Laboratory reports are in Appendix L to the RSE Report.

Ninety percent of all samples were validated according to Stage 2B validation methodology, and 10 percent of all samples were validated according to Stage 4 validation methodology, which builds on the Stage 2B methodology. Descriptions of these validation methodologies are in Appendix G to the RSE Report.

4.5.3 Data Management

Tetra Tech customized a Scribe database for this project. Scribe is a software tool developed by USEPA to assist management of environmental data. All field samples and associated information (such as sample date, time, sample type, analytical analysis) were loaded into the project database daily. The Scribe database, published under USEPA Region 9 to Scribe.net, provides a method for storing and sharing Scribe projects. During the project, the database was published at least once per day when any additions or modifications to the data occurred.

In addition to field data, laboratory analytical results were loaded into the database in project-specific electronic data deliverable (EDD) format. Validated data were entered into validation-specific fields to ensure that original laboratory data remained intact. Compiled XRF field data also were loaded into the project database as a custom table. Geospatial data were input into the geodatabase for use in the geographic information system (GIS).

An extensive set of Scribe.NET Auditor rules was developed to ensure data integrity and completeness in the Scribe project. This custom rule set checked for valid values, blanks and nulls, missing records, and other project-specific criteria. The set of Scribe.NET Auditor rules was run prior to publication to Scribe.NET. If any Auditor issues were identified, these were addressed prior to publication or as soon as practicable.

4.5.4 Data Quality Assessment

This section presents the parameters used to assess data quality. Precision, accuracy, representativeness, completeness, and comparability parameters were reviewed to validate all analytical data. This section discusses overall quality of the analytical data, including precision, accuracy, representativeness, completeness, and comparability parameters, as established by the data validation. A complete evaluation of data quality, including quality of gamma radiation data, is in Appendix G.

Precision is a measure of reproducibility of an experimental value without regard to the true or reference value. The primary indicators of site data precision are relative percent differences (RPD) between results from pairs of field and field duplicate samples, and laboratory and laboratory duplicate samples. For this investigation, one or more sample results in 72 of 127 SDGs were qualified for at least one precision-related QC issue. Within each SDG, only a subset of results was qualified. The majority of precision-related QC issues involved RPD exceedances in results for a minority of metals analytes (typically one, but as many as five, of the 28 metals analytes). RPDs outside the guidance for duplicate pairs were noted in the data validation reports. No data were rejected because of laboratory or field precision violations. The data underwent the documented data validation process, and overall, precisions of results were found acceptable.

Accuracy assesses the proximity of an experimental value to the true or reference value. The primary accuracy indicators are matrix spike/matrix spike duplicate (MS/MSD) and laboratory control sample (LCS) spike percent recoveries, as well as ion chromatography (IC) results for metals analyses and tracer/chemical yield for radiological analyses. Among all analytical data from this investigation, one or more sample results from 122 of 127 SDGs were qualified as estimated. Within each SDG, only a subset of results was qualified. The majority of these qualifications were MS/MSD exceedances that may have affected only the sample spiked for the MS/MSD. No data were rejected because of accuracy violations.

A subset of accuracy is bias, which assesses the direction (high or low) an experimental value may deviate from the true reference value. In addition to MS/MSD, LCS, and tracer/chemical yield percent recoveries, primary indicators of bias are method/preparation and field blanks, IC results for metals analyses, and sample density for radiological analyses. Among all analytical data from this investigation, one or more sample results from all SDGs were qualified as estimated. The majority of these were blank contamination qualifiers and affected only a subset of the samples submitted within each SDG. No data were rejected because of bias violations. The data underwent the documented data validation process, and overall, accuracy of the results was found acceptable.

Representativeness refers to how closely sample data reflect true environmental conditions. Determinants of representativeness include sampling locations, frequency, collection procedures, and possible compromises to sample integrity (such as cross-contamination) that can occur during collection, transport, and analysis. Selection of representative sampling sites is important to obtain samples that accurately reflect site conditions. Correct sample collection, transport, and analytical procedures are important to ensure that samples closely resemble the medium sampled, and to minimize contamination.

Sampling locations, frequencies, and collection protocols for the RAES TO 0001 RSE investigations were described in the SAP (Appendix C to the RSE Work Plan [Tetra Tech 2018]). These protocols followed standard accepted methods of site characterization, and were approved by USEPA and the Navajo Superfund Program (NSP). The RAES investigations followed the sampling program outlined in the SAP except for the deviations discussed in Section 4.6. Thus, the sampling program for this investigation met all relevant requirements for data representativeness with respect to accepted site characterization approaches, existing guidance, and regulatory compliance.

Completeness is defined as the percentage corresponding to the ratio of the number of valid results to the total number of results obtained. Valid data are those identified as acceptable or qualified as estimated during the data validation process. Data qualified as rejected are considered unusable and not valid. (Data that would have resulted from analyses of samples planned but not ultimately analyzed are also considered incomplete—any samples planned but not collected or analyzed are discussed in the deviations section of the main text of the RSE Report.) The assessment of completeness involved comparison of the number results acceptable and qualified as estimated to the total number of results.

Comparability is a qualitative assessment of how well one data set compares with another. The important determinants of comparability include uniformity of sampling activities, analytical procedures, data reporting, and data validation. A high degree of analytical comparability results from appropriate applications of USEPA protocol, establishment and application of appropriate and well-documented analytical protocols and methods, use of approved laboratories, and implementation of the standardized process of data review and validation.

Although some qualifiers were added to the data, a final review of the data set against the USEPA data quality parameters indicated that the data are of high overall quality. Excluding the XRF soil cup pilot study data, the data meet all precision, accuracy, representativeness, completeness, and comparability requirements specified in USEPA guidance for QA project plans (USEPA 2002b), and are useable for risk assessment. The overall assessment of the sampling program, QA/QC data, data review, and data validation results indicates that the data are of acceptable precision, accuracy, representativeness, completeness, and comparability. Supporting data validation reports are provided in Appendix M. Chain-of-custody forms were used to track possession of samples from field collection to the analytical laboratory. Completed chain-of-custody forms are in Attachment G3 to Appendix G.

4.6 DEVIATIONS FROM THE WORK PLAN

Deviations from the RSE Work Plan are as follows:

- The RSE Work Plan called for an XRF field survey at BSAs. However, only surface soil samples were collected at BSAs and submitted for laboratory analysis. The USEPA RPM concurred with this decision prior to field work.
- SOPs for subsurface sampling by hand and mechanical drilling were not included in the SAP/QAPP of the RSE Work Plan prior to field work. However, field procedures were documented and approved by USEPA.
- The RSE Work Plan specified analysis for mercury in all samples. Because mercury is not generally associated with AUM waste and because of additional holding time and temperature requirements for mercury anlaysis, many soil samples were not anlayzed for mercury. Following the baseline study, mercury was eliminated from the sample suite, a decision made in consultation with USEPA.
- The SAP/QAPP specified in situ water quality measurements when water samples were collected, and analysis for orthophosphate. USEPA was consulted prior to collection of the water samples, and concurred with decisions to collect the samples without measurements of water quality parameters and to eliminate orthophosphate from the analytical suite. Thus, two water samples were collected on September 30, 2018, but no water quality parameters were measured in the field, and the samples were not analyzed for orthophosphate.
- The RSE Work Plan did not specify sampling at Cove Transfer Station South (Tetra Tech ID T37). However, this area was evaluated along with Cove Transfer Station (Tetra Tech ID T9) at the request of the USEPA RPM.
- The RSE Work Plan did not specify entry to the Haul Shaft at Mesa V Mine – 103 (Tetra Tech ID M17). USEPA asked Tetra Tech to investigate inside the haul shaft, and Tetra Tech prepared a confined space entry plan to complete the sampling, with oversight by the USEPA Environmental Response Team (ERT).
- The RSE Work Plan identified a background drainage in the Tse Tah region and specified sampling of that drainage. However, further investigation revealed presence of a non-Tronox AUM in that drainage. The on-site USEPA RPM concurred in a decision to eliminate sampling a background drainage in the Tse Tah region and instead sample a background drainage in the Lukuchuaki Region.
- An RSE investigation did not occur at Tommy James mine on the southern side of the Lukachukai Mountains because of extreme terrain. Further investigation would be required to identify access routes to this AUM site or to develop innovative strategies for aquiring radiometric data at the site.

- Only one duplicate sample was deployed among the 34 radon detectors, a rate less than the 10 percent of total samples, as specified in the RSE Work Plan.
- Of the 34 radon detectors deployed, 26 were retrieved. The remaining eight detectors, including one field duplicate, could not be retrieved because of weather and accessibility issues. Because resulting data included no data from duplicate detectors, a precision check and control charting of the data (as discussed in Section 4.4.1.3 of the RSE Work Plan [Tetra Tech 2018]) was not possible.

5.0 RSE INVESTIGATION RESULTS

This section presents some results of the RSE investigations at nearly all sites identified in the RSE Work Plan. RSE investigation results from Cove Transfer Station are not included because the site has already been reclaimed. Tommy James AUM site was not accessible, precluding a field investigation.

Results of the gamma radiation surveys at all AUM sites and AUM-related sites are in Section 5.2. Section 5.3 presents results of surface soil sampling across all the sites. Additional investigations occurred to supplement the main RSE investigation, including evaluations of background, radon, drainages, and roads. Results of the Background Investigation are in Section 5.1. Results of radon monitoring are in Section 5.4. Results of the Drainage Investigation are in Section 5.5. Results of the Roads Investigation are in Section 5.6. Information pertaining to the geotechnical and geochemical analyses appears in Appendix E and Appendix F, respectively.

5.1 BACKGROUND INVESTIGATION RESULTS

The Background Investigation Report is Appendix A to this report. The objective of the background investigation was to determine site-specific and regional background radionuclide concentrations, metals concentrations, and gamma radiation levels within surface soils overlying geologic formations and soil types within the Tse Tah region, Cove Valley, and Lukachukai Mountains regional background investigation areas. In this document, the term "background" refers generally to the range of natural concentrations of radionuclides and metals naturally occurring in soils and rock. To simplify comparisons of background data sets to data sets from potentially impacted sites, BTVs were calculated—single numbers representing respective higher ranges of naturally occurring background data sets.

Site-specific BSAs were carefully selected following a Desktop Study (as part of the RSE Work Plan) evaluating regional geology, soils, geomorphology, drainage, climate, and other factors related to development of a robust background investigation. Thirty-two site-specific BSAs were selected to represent previous conditions unimpacted by anthropogenic disturbances or mining/milling at 39 AUM sites and 37 Target sites believed to have hosted operations of Kerr-McGee (Tronox) during the Cold War mining boom.

Background study areas were selected primarily based on geology and soil type, among other factors (e.g., upgradient of mines, upwind, close proximity). RSE background investigation field sampling efforts at BSAs involved surface soil sampling, subsurface soil sampling, gamma radiation surveys, cultural resource surveys, and site mapping. Field QC methods were followed during the sampling and surveys, and third-party data validation of all laboratory data was conducted. Tetra Tech field personnel and subcontractors conducted field sampling between April and September 2018. More than 1,000 surface and subsurface soil samples were collected and submitted for laboratory analyses for 29 analytes. More than 120,000 individual gamma measurements were recorded across the BSAs.

Estimates of site-specific and regional BTVs were based on analytical and gamma radiation data from BSAs throughout the regions of interest. Those data from the BSAs have been validated as a background data set by:

- Application of comprehensive research and field verification methods to ensure correct association of each selected BSA with the appropriate geologic formation, and verification that these sites had been unimpacted by anthropogenic activities
- Comparisons of surface data sets with subsurface data sets to identify trends with depth or statistical differences between depths
- Evaluation and screening of all field data by use of USEPA statistical software ProUCL 5.1.002.

During this RSE background investigation, concentrations of 29 analytes (metals and radionuclides) and cpm gamma radiation were determined within the 32 site-specific BSAs, thus resulting in 960 estimated BTVs. Results of the site-specific background investigation and BTVs are in Appendix A to this RSE Report.

For Tse Tah Region sites, data from potentially impacted areas were compared to site-specific BTVs identified during the site-specific background investigation. Regarding sites within Cove Valley and Lukachukai Mountains, data from potentially impacted areas were compared to *both* site-specific and regional BTVs. These site-to-background data comparisons led to identification of COPCs and delineations of lateral and vertical extent of elevated contaminant concentrations with respect to background levels—crucial bases of human health and ecological risk assessments to occur during the EE/CA phase of the project that will guide USEPA in decision-making pertaining to cleanup of the sites.

A regional background geological investigation occurred within the Cove Valley and Lukachukai Mountains regional background investigation areas, which host 90 percent of the sites. As part of the regional background investigation, BTVs were selected for 29 analytes and for gamma radiation within the four primary geologies. Results of the regional background investigation are in Appendix A to this RSE Report along with BTVs across overlying soils of the four geologic formations. Notably, Ra-226 concentrations roughly correlate to gamma cpm within three of the four geologies. However, the Lower Morrison Formation/Salt Wash Member's Ra-226 BTV is low, given the high gamma cpm BTV there, perhaps because of presence of K-40 and Ra-228 there (both gamma emitters).

For every AUM site or AUM-related a site, an applied BTV was selected for 29 analytes and for gamma radiation to represent unimpacted radiological and chemical conditions. The "applied BTV" for each analyte is the lower of the site-specific BTV and the regional BTV. Table 22 summarizes applied BTVs for primary analytes (see Section 5.3) for AUM sites and AUM-related sites of the Northern Agency Tronox Mines.

Table 22. Summary of Applied BTVs for AUM Sites and AUM-related Sites (Primary Analytes)

Site Name	Site ID	Applied BTV								
		Gamma Radiation (cpm)	Arsenic (mg/kg)	Lead (mg/kg)	Molybdenum (mg/kg)	Radium-226 (pCi/g)	Selenium (mg/kg)	Thorium (mg/kg)	Uranium (mg/g)	Vanadium (mg/kg)
Brodie 1	M1	8,673	1.4	4.0	0.30	0.94	0.46	1.7	0.59	8.2
Block K	M2	11,010	3.9	5.0	0.34	2.38	0.47	1.9	1.5	11
Mesa I Mine 10	M3	12,232	2.0	11	0.25	2.23	0.93	4.7	0.91	13
Mesa I Mine 11	M4	14,566	2.5	7.0	0.16	2.23	0.77	4.7	1.5	15
Mesa I Mine 12	M5	14,566	2.5	7.0	0.16	2.23	0.77	4.7	1.5	15
Mesa I Mine 13	M6	12,232	2.0	7.0	0.16	2.23	0.77	4.7	0.91	13
Mesa I Mine 14	M7	14,566	2.5	7.0	0.16	2.23	0.77	4.7	1.5	15
Mesa I Mine 15	M8	14,566	2.5	7.0	0.16	2.23	0.77	4.7	1.5	15
Mesa I 1/4 Mine	M9	12,232	2.0	11	0.25	2.23	0.93	4.7	0.91	13
Mesa I 1/2 Mine	M10	11,132	2.5	12	0.32	1.56	0.85	3.6	1.7	13
Henry Phillips Mine	M11	9,854	2.9	11	0.29	0.69	0.77	4.7	0.67	12
Mesa I 1/2, West Mine	M12	9,854	2.9	11	0.29	0.69	0.77	4.7	0.67	12
Mesa VI Mine	M13	12,700	3.5	11	0.29	2.23	0.99	4.7	1.5	20
Frank Jr. Mine	M14	11,920	3.6	9.5	0.52	1.98	0.90	3.2	1.7	22
Mesa V Incline	M15	11,907	2.2	9.7	0.29	1.54	0.93	3.6	1.3	15
Mesa V Adit	M16	14,566	3.5	10	0.29	2.23	0.99	4.5	1.5	24
Mesa V Mine – 103	M17	11,319	2.4	9.3	0.20	1.57	0.84	2.4	1.3	22
Mesa V Mine – 508	M18	11,330	1.6	5.8	0.07	0.95	0.78	4.3	0.53	13
Mesa IV 1/2 Mine and Simpson 181	M19	11,319	2.4	9.3	0.20	1.57	0.84	2.4	1.3	22
Mesa IV, Mine No. 1	M20	9,703	3.5	10	0.29	2.23	0.94	3.6	1.5	24
Mesa IV, Mine No. 2	M21	9,703	4.7	10	0.32	2.78	0.94	3.6	2.7	31
Mesa IV, Mine No. 3	M22	9,703	3.5	10	0.29	2.23	0.94	3.6	1.5	24
Mesa IV, West Mine	M23	12,602	3.5	11	0.29	2.23	0.99	4.7	1.5	24
Mesa II Pit	M24	9,703	4.7	10	0.32	2.78	0.94	3.6	2.7	31
Mesa I 3/4 Incline	M25	11,378	2.2	9.9	0.29	0.87	1.0	4.7	0.64	22
Mesa I 3/4, Mine No. 2, P150	M26	11,378	2.2	9.9	0.29	0.87	1.0	3.8	0.64	22
Mesa II, Mine No. 1 & 2, P-21	M27	11,378	2.2	9.9	0.29	0.87	0.98	3.6	0.64	22
Mesa II, Mine No. 1, P-150	M28	9,703	2.0	10	0.26	0.85	0.92	3.6	1.1	12
Mesa II, Mine 4	M29	9,703	4.7	10	0.32	2.78	0.94	3.6	2.7	31
Mesa II 1/2 Mine	M30	11,378	2.2	9.9	0.29	0.87	1.0	4.7	0.64	22
Mesa II 1/2, Mine 4	M31	11,378	2.2	9.9	0.29	0.87	1.0	4.7	0.64	22
Mesa III Mine	M32	10,433	2.5	11	0.29	1.62	0.99	4.7	1.1	14
Knife Edge Mesa Mine	M33	20,165	68	14	1.1	20.2	2.1	5.9	21	42
Black No. 1 Mine	M34	15,781	4.8	12	0.34	4.15	0.98	3.6	3.4	31
Black No. 2 Mine	M35	12,611	1.7	7.8	0.29	2.23	0.82	4.7	1.5	24
Black No. 2 Mine (West)	M36	15,781	4.8	12	0.34	4.15	0.98	3.6	3.4	31
Flag No. 1 Mine	M37	15,781	4.8	12	0.34	4.15	0.98	3.6	3.4	31
Step Mesa Mine	M38	12,611	1.7	7.8	0.29	2.23	0.82	4.7	1.5	24
Mesa I Camp	T17	14,566	3.5	11	0.23	2.23	0.99	4.7	1.5	24
NA-0344B	T23	11,907	2.2	9.7	0.29	1.54	0.93	3.6	1.3	15

Notes:

Only statistics for detected data and primary analytes are listed in this table.

AUM Abandoned uranium mine
BTV Background threshold value
cpm Counts per minute
mg/kg Milligrams per kilogram
pCi/g Picocuries per gram

5.2 GAMMA RADIATION SURVEY

The following sections discuss the intent and procedure of the gamma radiation survey, and resulting gamma-exposure rates and gamma-radiation correlations.

5.2.1 Features and Overall Results of the Gamma Radiation Survey

A gamma radiation survey (or scanning) occurred at every AUM site, Target site, and BSA. Scanning was also performed in more than 22 miles of drainages throughout the region and on 9.8 miles of roads. Results of the gamma radiation survey within the drainages are in Appendix J to this RSE Report and discussed in Section 5.5. Results of the gamma radiation survey at the roads are in Appendix K to this RSE Report and discussed in Section 5.6. Gamma radiation survey methodology, outlined in Section 4.4.2, followed the methodology outlined in the SAP/QAPP in Appendix C to the RSE Work Plan (Tetra Tech 2018).

Gamma radiation surveys were critical to the RSE investigations because they allowed rapid acquisition of high-quality data across large land areas. These surveys provided gross gamma count rates in cpm, and all gamma radiation survey maps in the reports in the appendices indicate these data in cpm; however, ensuing figures display gamma count rate data converted to gamma exposure rates by use of the equation presented in Section 5.2.2. Summary statistics of gamma count rate measurements taken at each site are listed in Table 23.

Table 23. Summary of Raw Gamma Radiation Survey Results for Northern Agency Tronox Mines

Mine Name	Mine ID	Applied BTV[1] (cpm)	Accessible Survey Units[2]	Points per Survey Unit[3]	n	Minimum (cpm)[4]	Maximum (cpm)[5]	Average (cpm)[6]	Median (cpm)[7]	Standard Deviation (cpm)[8]	90th Percentile (cpm)	95th Percentile (cpm)	99th percentile (cpm)	Relative Standard Deviation
Brodie 1 Mine	M1	8,673	52	134	6,970	5,436	53,775	11,715	10,299	4,697	16,605	21,905	30,611	40%
Block K Mine	M2	11,010	108	85	9,201	5,335	19,884	8,429	8,073	1,583	10,177	11,536	14,922	19%
Mesa I Mine 10	M3	12,232	75	269	20,165	8,139	300,241	26,853	20,112	19,700	50,249	71,155	102,358	73%
Mesa I Mine 11	M4	14,566	272	115	31,291	5,987	278,255	23,644	14,571	23,940	45,866	72,814	128,341	101%
Mesa I Mine 12	M5	14,566	432	99	42,706	6,119	614,370	40,875	18,152	50,903	112,207	157,588	231,252	125%
Mesa I Mine 13	M6	12,232	362	111	40,252	7,973	302,107	27,913	18,216	25,334	52,513	73,133	137,331	91%
Mesa I Mine 14	M7	14,566	289	84	24,296	7,361	999,960	49,359	29,815	59,991	111,296	163,498	278,243	122%
Mesa I Mine 15	M8	14,566	196	121	23,735	6,413	247,115	30,074	17,565	32,115	70,392	102,140	169,188	107%
Mesa I 1/4 Mine	M9	12,232	55	134	7,379	8,770	199,610	23,960	18,919	17,783	38,422	52,419	116,886	74%
Mesa I 1/2 Mine	M10	11,132	80	94	7,530	9,213	146,342	27,249	18,630	19,229	55,361	68,673	95,448	71%
Henry Phillips Mine	M11	9,854	81	98	7,971	6,107	114,220	15,080	12,269	8,364	23,855	31,095	51,504	55%
Mesa I 1/2, West Mine	M12	9,854	46	110	5,050	6,603	61,446	13,130	11,496	6,665	16,594	24,248	45,057	51%
Mesa VI Mine	M13	12,700	226	115	25,902	7,033	479,108	18,381	13,376	23,326	26,041	42,997	106,647	127%
Frank Jr. Mine	M14	11,920	154	166	25,568	7,218	429,225	41,891	25,362	37,413	98,894	118,458	149,684	89%
Mesa V Incline	M15	11,907	131	145	18,953	8,893	427,523	21,313	17,611	14,251	33,247	40,419	69,334	67%
Mesa V Adit	M16	14,566	251	136	34,028	9,793	335,225	30,198	23,341	17,568	54,742	64,525	87,888	58%
Mesa V Mine – 103	M17	11,319	134	155	20,835	9,747	299,750	56,170	25,937	56,330	151,398	183,271	215,991	100%
Mesa V Mine – 508	M18	11,330	227	140	31,800	6,072	395,198	14,911	12,066	14,648	19,547	25,752	78,942	98%
Mesa IV 1/2 Mine and Simpson 181	M19	11,319	96	165	15,843	10,050	304,800	27,229	18,083	27,298	43,743	81,732	166,741	100%
Mesa IV, Mine No. 1	M20	9,703	443	152	67,395	5,568	445,968	25,414	15,261	29,397	50,592	81,457	165,995	116%
Mesa IV, Mine No. 2	M21	9,703	597	118	70,738	6,253	412,708	22,046	15,570	25,231	32,898	51,892	161,075	114%
Mesa IV, Mine No. 3	M22	9,703	139	148	20,581	8,480	123,298	18,610	16,505	8,517	25,007	30,549	55,914	46%
Mesa IV, West Mine	M23	12,602	180	106	19,000	5,637	124,315	15,036	11,352	10,189	28,538	38,232	55,836	68%
Mesa II Pit	M24	9,703	183	174	31,911	5,066	701,536	13,359	11,227	23,176	15,950	18,625	46,182	173%
Mesa I 3/4 Incline	M25	11,378	86	75	6,473	7,332	75,371	16,561	13,878	8,043	26,978	34,655	47,858	49%
Mesa I 3/4 Mine No. 2, P-150	M26	11,378	62	82	5,089	8,818	42,106	15,083	14,271	3,683	19,330	21,845	28,550	24%
Mesa II, Mine No. 1 & 2, P-21	M27	11,378	332	103	34,076	9,426	108,898	19,705	18,080	7,854	29,435	33,697	48,538	40%
Mesa II, Mine No. 1, P-150	M28	9,703	225	119	26,696	7,269	219,903	26,719	18,910	26,728	47,797	93,581	142,998	100%
Mesa II, Mine 4	M29	9,703	100	193	19,268	5,168	88,566	13,313	10,448	8,265	21,678	28,904	48,971	62%
Mesa II 1/2 Mine	M30	11,378	290	113	32,694	7,104	267,632	26,817	14,995	29,083	62,600	93,212	151,207	108%
Mesa II 1/2, Mine 4	M31	11,378	64	140	8,950	9,130	268,180	26,390	17,377	22,402	46,717	65,644	134,529	85%
Mesa III Mine	M32	10,433	189	161	30,444	8,446	602,776	32,362	17,345	34,704	69,811	98,794	159,599	107%
Knife Edge Mesa Mine	M33	20,165	117	88	10,301	6,109	127,916	16,449	15,151	8,911	22,926	27,615	57,787	54%
Black No. 1 Mine	M34	15,781	121	88	10,690	9,599	578,627	28,778	19,407	40,648	34,074	72,453	254,701	141%
Black No. 2 Mine	M35	12,611	113	90	10,202	9,515	245,659	19,894	17,159	11,864	26,899	35,230	73,588	60%
Black No. 2 Mine (West)	M36	15,781	44	121	5,326	12,650	335,116	27,300	20,085	24,829	42,048	83,588	132,147	91%
Flag No. 1 Mine	M37	15,781	102	59	6,023	7,784	633,603	33,435	16,790	49,377	69,252	145,848	224,353	148%
Step Mesa Mine	M38	12,611	17	290	4,937	8,076	155,575	27,337	22,950	16,312	46,330	57,991	96,605	60%
Mesa I Camp	T17	14,566	795	80	63,470	6,892	245,495	14,633	12,682	11,923	18,269	20,464	51,440	81%
NA-0344B	T23	11,907	97	121	11,779	8,834	25,498	13,511	13,135	2,126	15,987	17,403	21,489	16%

Table 23. Summary of Raw Gamma Radiation Survey Results for Northern Agency Tronox Mines (Continued)

Notes:

Gamma radiation survey data were acquired at 1 meter above ground surface by use of GPS-based mobile scan systems with Ludlum Model 44-10 NaI[Tl] scintillators coupled to Ludlum Model 2221 datalogger.

1 The applied BTV is the lowest of the BTV from the site-specific BSA(s) and the BTV from the regional background investigation that applies to a given site; further details of this are in Appendix A.

2 accessible survey unit is defined as a survey unit that underwent a minimum of one gamma radiation measurement. Any survey units that did not undergo a minimum of one gamma radiation measurement were considered inaccessible to the gamma survey team.

3 The points per survey unit refers to the number of gamma radiation measurements geospatially located within the physical boundary of a given survey unit.

4 Minimum refers to the minimum gamma radiation measurement within the survey area of a given site.

5 Maximum refers to the maximum gamma radiation measurement within the survey area of a given site.

6 Average refers to the average of all gamma radiation measurements within the survey area of a given site.

7 Median refers to the median of all gamma radiation measurements within the survey area of a given site.

8 Standard Deviation refers to the standard deviation of all gamma radiation measurements within the survey area of a given site.

BSA Background Study Area
BTV Background threshold value
cpm Counts per minute
GPS Global positioning system
n Number of gamma radiation measurements
NaI[Tl] Sodium iodide thallium-doped

5.2.2 Gamma-Exposure Rate Results

Tetra Tech field personnel collocated measurements of static gamma count rates and gamma exposure rates at 33 locations project-wide in June and August 2018. Sample plot locations were distributed across different AUM sites, Target sites, and BSAs project-wide to achieve a representative distribution of measured exposure rates and gamma count rates. A total of 29 of the 33 locations were within soil correlation plots. Four measurements were taken at locations that did not undergo corresponding soil correlation measurements. Exposure rate correlation plot locations and gamma scan data are in Appendix C along with serial numbers of detectors and meters, with their dates of use.

The regression resulted in a statistical measure of how close the data came to the fitted regression line, also known as the coefficient of determination (R^2), of 0.99, which exceeded the applicable project DQO ($R^2 > 0.8$). Regression results are shown on Figure 20. The equation below converts a gamma count rate to an equivalent gamma exposure rate:

$$Y\left(\frac{\mu R}{hour}\right) = 8.476 + 0.000545 * (X\,[cpm])$$

Where: Y is the gamma exposure rate
X is the gamma count rate
μR is microroentgens
cpm is counts per minute

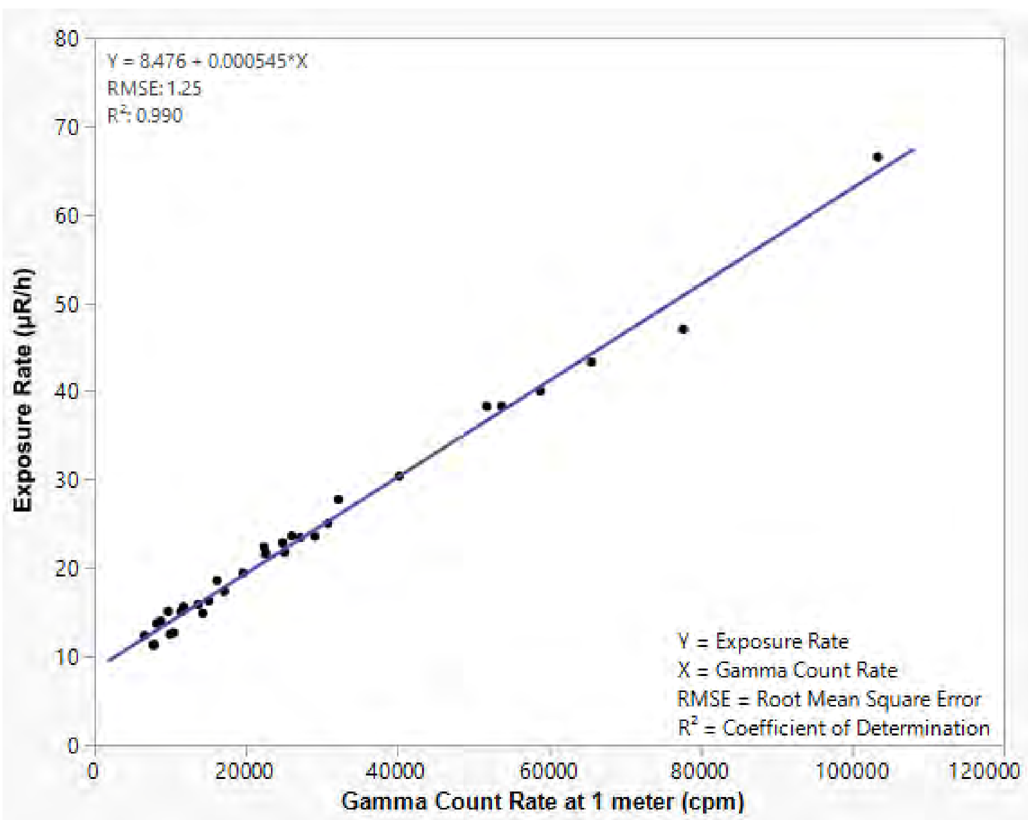


Figure 20. Gamma Count Rate (Counts per Minute) versus Exposure Rate (Microroentgens per Hour)

Attachment 2 includes figures displaying gross gamma count rate measurements converted to gamma exposure rate in μR/hr. The intervals displayed are related to a variety of gamma exposure rates found at various locations or other sources of radiation dose. In comparisons of effective tissue doses from, for example, medical x-ray procedures, the gamma exposure unit of roentgen is assumed equal to 1 centigray (unit of absorbed radiation dose) (Cember and Johnson 2009); moreover, because the radiation weighting factor for photons is 1 (International Council on Radiation Protection [ICRP] 2007), assumption for these comparative purposes is that 1 roentgen equals 1 centisievert or 1,000 millirems (mrem). Table 24 lists gamma exposure rates at a variety of sources commonly seen in our daily lives for comparison purposes.

Table 24. Gamma Exposure Rate Display Intervals and Comparisons

Gamma Exposure Rate (μR/hr)	Description	Source
<12	Gamma exposure rates measured in a parking lot in Farmington, New Mexico	Tetra Tech field personnel
12-16	Gamma exposure rates measured in the Fort Collins Tetra Tech Office	Tetra Tech field personnel
16-20	Gamma exposure rates in Rocky Mountains above ~8,000 feet (Leadville, Colorado)	Mauro and Briggs 2005
20-22	Effective dose from a head CT scan spread out over a year	HPS 2019
22-30	Typical gamma exposure rate measured at elevation of 30,000 feet in an aircraft by use of a Ludlum Model 19	Tetra Tech field personnel
30-71	Average ionizing radiation exposure to a member of the U.S. public (620 mrem, all sources) spread out over a year	NCRP 2009
71-127	Effective dose from a chest and head CT scan spread out over a year	HPS 2019
127-350	The current ICRP-recommended annual occupational dose limit (20 mSv) would be reached by a person remaining at a location measuring approximately 230 μR/hr for one year.	ICRP 2007

Notes:

μR/hr Microroentgens per hour
ANSI American National Standards Institute
HPS Health Physics Society
ICRP International Council on Radiation Protection
mrem Millirem
mSv Millisievert
NCRP National Council on Radiation Protection and Measurements

5.2.3 Gamma-Radium Correlation Results

Mean relationships between gamma count rates and concentrations of Ra-226 in surface soils (0 to 6 inches bgs) were determined within multiple major geologies and regions as described in Section 4.4.4 and in Appendix C to this RSE Report. These relationships are described by linear regression models. Coefficients of determination (R^2) of correlations of gamma count rates to Ra-226 soil concentrations ranged from 0.769 to 0.977. A correlation between gamma count rate and Ra-226 concentration was applied to gross gamma count rate data at each site. For each site and applied regression model, predicted Ra-226 soil concentrations were compared to surface soil Ra-226 concentrations determined by laboratory analysis, and this comparison is included in each corresponding SSRSE. In some cases, multiple correlations were applicable to a site based on the geologic makeup and location, so the correlation evaluation occurred to determine which correlation to apply.

Resulting gamma-radium equations from the correlation studies are as follows:

- The correlation pertaining to the Lower Morrison Formation (Jml) region had an R^2 of 0.946. The relationship between gamma count rates and Ra-226 soil concentrations was determined by application of a linear regression model:

$$\left({}^{226}Ra\left[picocuries\ per\ gram\ \left(\frac{pCi}{g}\right)\right]\right) = 0.000596 * (gamma\ count\ rate\ [counts\ per\ minte\ (cpm)]) - 6.0685$$

- Correlations pertaining to the Summerville Entrada Formation (Jse) and Undifferentiated Summerville, Todilto, and Entrada Formations (Jste) geologies were combined and analyzed to represent both of these geologies as one region. The correlation pertaining to this combined region had an R^2 of 0.769. The relationship between gamma count rates and Ra-226 soil concentrations was determined by application of a linear regression model:

$$\left({}^{226}Ra\left[\frac{pCi}{g}\right]\right) = 0.000869 * (gamma\ count\ rate\ [cpm]) - 10.904$$

- The correlation pertaining to the Tse Tah region had an R^2 of 0.966. The relationship between gamma count rates and Ra-226 soil concentrations was determined by application of a linear regression model:

$$\left({}^{226}Ra\left[\frac{pCi}{g}\right]\right) = 0.001307 * (gamma\ count\ rate\ [cpm]) - 10.618$$

  Further analysis of the Tse Tah regression indicated a bias because of a single high measurement separated from a cluster of low measurements. Removal of the high measurement resulted in a linear regression model with an R^2 of 0.219. The bias analysis on the regression occurred only for informational purposes and was not used for any subsequent data processing.

- The correlation pertaining to the Group D region had an R^2 of 0.957. The relationship between gamma count rates and Ra-226 soil concentrations was determined by application of a linear regression model:

$$\left({}^{226}Ra\left[\frac{pCi}{g}\right]\right) = 0.000413 * (gamma\ count\ rate\ [cpm]) - 2.776$$

- The correlation pertaining to the Group F region had an R^2 of 0.977. The relationship between gamma count rates and Ra-226 soil concentrations was determined by application of a linear regression model:

$$\left({}^{226}Ra\left[\frac{pCi}{g}\right]\right) = 0.000596 * (gamma\ count\ rate\ [cpm]) - 4.99$$

- The correlation pertaining to the Group G region had an R^2 of 0.956. The relationship between gamma count rates and Ra-226 soil concentrations was determined by application of a linear regression model:

$$\left({}^{226}Ra\left[\frac{pCi}{g}\right]\right) = 0.000737 * (\ gamma\ count\ rate\ [cpm]) - 6.704$$

- The correlation pertaining to the Group H region had an R^2 of 0.804. The relationship between gamma count rates and Ra-226 soil concentrations was determined by application of a linear regression model:

$$\left({}^{226}Ra\left[\frac{pCi}{g}\right]\right) = 0.00080 * (gamma\ count\ rate\ [cpm]) - 13.196$$

- Correlations pertaining to Group I and Group J were combined and analyzed to represent both of these as one region. The region had an R^2 of 0.852. The relationship between gamma count rates and Ra-226 soil concentrations was determined by application of a linear regression model:

$$\left({}^{226}Ra\left[\frac{pCi}{g}\right]\right) = 0.000815 * (gamma\ count\ rate\ [cpm]) - 8.463$$

- A project-wide relationship between gamma count rate and exposure rate was also determined and described by application of a linear regression model:

$$Exposure\ rate\ \left(microroentgens\ per\ hour\ \left[\frac{\mu R}{hr}\right]\right) = 8.476 + 0.000545 * (gamma\ count\ rate\ [cpm])$$

  R^2 of the correlation of exposure rate to gamma count rate was 0.99.

5.3 SOIL SAMPLING AND SOIL XRF MEASUREMENTS

In subsequent sections, AUM sites and the AUM-related sites are referred to as "sites." Because of the large number of analytes in this study, and at concentrations above background, the analytes were categorized as either primary or secondary. Primary analytes are those typically associated with uranium-vanadium mining activities, and generally more hazardous to the environment and human health than secondary analytes. Thus, differentiation between primary and secondary analytes facilitated contaminant mapping presented in Appendix H and estimations of mine waste volumes. Primary analytes are as follows:

- Arsenic
- Lead
- Molybdenum
- Ra-226
- Selenium
- Thorium
- Uranium
- Vanadium

The 21 analytes not listed above are considered secondary analytes.

This section presents summary results, tables, and graphs of primary analytes in surface soils at all AUM sites that were sampled and at the AUM-related sites of Mesa I Camp (T17) and NA-0344B (T23). The AUM-related site of Cove Transfer Station (T9/T37) is not included in the summary tables and graphs because a removal action was completed at this site in 2012 (E&E 2013) and Tetra Tech did not estimate a removal volume. All results from the RSE investigation at Cove Transfer Station are provided in Appendix H40. Therefore, there are a total of 40 sites in each of the summary tables and graphs.

As previously noted, the project involved three primary types of surface soil sampling/measurement: (1) in situ XRF measurements, (2) laboratory analyses of XRF confirmation soil samples, and (3) laboratory analyses of surface soil samples. In situ XRF measurements were not applicable to selenium and Ra-226. Mercury is not considered a primary analyte but is included in this report, and is discussed in Section 5.3.4.

5.3.1 Arsenic

Arsenic concentrations in surface soil were evaluated across all AUM sites and within two AUM-related sites (Mesa I Camp and NA-0344B). The two AUM-related sites were included because an RSE investigation also occurred there, and mine waste materials were known to be present. A primary analyte of interest in the RSE investigations, arsenic was identified as a COPC and found at concentrations above background at numerous sites. The atomic number of arsenic is 33, and the crustal abundance of arsenic is approximately 1.5 to 2.0 mg/kg (USGS 2017). Concentrations of naturally occurring arsenic in surface soils can range from 1 to 50 mg/kg (USEPA 2006b). Analysis for arsenic proceeds successfully via inductively coupled plasma-mass spectrometry (ICP-MS) and field-portable XRF technology (as described in Appendix B to this RSE Report). The average ratio of lead to arsenic found during this project was 3.0; therefore, spectral interferences from lead were not an issue for determinations of arsenic concentrations via XRF technology.

Arsenic surface soil concentrations were evaluated across the sites as discussed in Section 5.2.2. Table 25 summarizes statistics of detected arsenic concentrations in surface soils via the three different sampling/measurement types, including in situ XRF results corrected to laboratory predicted values. Figure 21 shows an individual value plot of arsenic concentrations in surface soils at respective sites. At only two sites did average arsenic concentration exceed 10 mg/kg (Mesa V Adit [11 mg/kg] and Mesa II Pit [10 mg/kg]). Average arsenic concentration at the sites ranged between 1.7 mg/kg (Block K Mine) and 11 mg/kg (Mesa V Adit). Maximum arsenic concentrations detected in surface soils across all sites ranged between 2.3 mg/kg (Block K Mine) and 190 mg/kg (Mesa VI Mine). The average arsenic concentration in surface soils exceeded the applied BTV at 38 of the 40 sites, as listed in Table 25. The average arsenic concentration in surface soils was about twice the applied BTV at a given site. Figure 22 shows an interval plot of arsenic in surface soils across all sites, indicating the means of surficial arsenic concentrations across all the respective sites with a 95 percent confidence interval banding each calculated mean.

Arsenic levels within the Lukachukai Mountains are, on average, higher than the crustal abundance of arsenic reported in USGS (2017) but within the range presented by USEPA (2006b). At certain geographical areas of the mountains, elevated arsenic concentrations were detected in the natural environment—for example, at BSA-32 natural arsenic levels were found at 68 mg/kg (at that site, other analytes such as calcium, uranium, and Ra-226 were also detected at elevated concentrations). At some sites, arsenic concentrations were found higher in areas where mine waste materials were present, while at other mines, arsenic concentrations were not found elevated. Thus, elevated arsenic concentration is not necessarily a good indicator of presence of mine waste at the Tronox mines within the Northern AUM Region. Moreover, at most sites, average levels of arsenic were detected at only twice background levels. Individual maps of surface and subsurface arsenic concentrations, along with more detailed statistical analysis for every AUM site and AUM-related site, are in the SSRSEs in Appendix H.

Arsenic was identified as a COPC, found at concentrations above background levels at all 40 sites evaluated. Further discussion of COPCs across all sites is in Section 6.0. Arsenic results from non-AUM Target sites are in Appendix I.

Table 25. Summary Statistics of Arsenic Concentration in Surface Soils

Site Name	Site ID	Applied BTV (mg/kg)	n	Minimum (mg/kg)	Maximum (mg/kg)	Standard Deviation (mg/kg)	Average (mg/kg)	Median (mg/kg)	RSD
Brodie 1 Mine	M1	1.4	23	1.1	9.0	1.7	2.8	2.4	61%
Block K Mine	M2	3.9	21	1.1	2.3	0.4	1.7	1.6	22%
Mesa I Mine 10	M3	2.0	49	1.4	35	5.9	4.5	2.7	132%
Mesa I Mine 11	M4	2.5	113	0.8	7.1	1.2	2.9	2.5	42%
Mesa I Mine 12	M5	2.5	185	0.7	28	2.9	3.5	2.7	83%
Mesa I Mine 13	M6	2.0	238	0.8	51	5.1	4.4	2.9	117%
Mesa I Mine 14	M7	2.5	166	1.4	49	5.8	4.7	2.8	124%
Mesa I Mine 15	M8	2.5	103	0.9	19	2.9	3.6	2.6	79%
Mesa I 1/4 Mine	M9	2.0	10	0.9	15	4.2	3.2	2.0	130%
Mesa I 1/2 Mine	M10	2.5	47	1.2	7.0	1.0	2.8	2.8	38%
Henry Phillips Mine	M11	2.9	54	1.0	7.7	1.6	3.2	2.6	50%
Mesa I 1/2, West Mine	M12	2.9	26	0.5	32	5.9	4.0	2.7	145%
Mesa VI Mine	M13	3.5	108	1.6	190	19	8.7	5.4	214%
Frank Jr. Mine	M14	3.6	135	1.3	19	4.2	5.5	4.0	76%
Mesa V Incline	M15	2.2	144	2.2	69	10	9.5	6.0	104%
Mesa V Adit	M16	3.5	231	1.2	56	8.5	11	8.3	79%
Mesa V Mine – 103	M17	2.4	125	1.6	41	6.4	6.8	4.5	94%
Mesa V Mine – 508	M18	1.6	137	1.3	26	3.8	5.0	3.7	77%
Mesa IV 1/2 Mine and Simpson 181	M19	2.4	58	1.7	176	23	5.8	2.6	394%
Mesa IV, Mine No. 1	M20	3.5	345	1.4	44	4.9	6.0	4.3	82%
Mesa IV, Mine No. 2	M21	4.7	567	1.0	55	6.9	8.3	6.3	84%
Mesa IV, Mine No. 3	M22	3.5	108	1.9	24	4.2	5.9	4.8	71%
Mesa IV, West Mine	M23	3.5	99	1.4	9.7	2.1	3.8	2.9	55%
Mesa II Pit	M24	4.7	156	1.8	91	11	10	6.4	108%
Mesa I 3/4 Incline	M25	2.2	53	0.5	14	3.1	4.6	4.1	67%
Mesa I 3/4 Mine No. 2, P-150	M26	2.2	23	1.4	30	6.3	4.7	2.6	134%
Mesa II, Mine No. 1 & 2, P-21	M27	2.2	262	1.3	58	6.8	5.4	3.8	127%
Mesa II, Mine No. 1, P-150	M28	2.0	173	1.0	104	11	7.4	4.3	150%
Mesa II, Mine 4	M29	4.7	38	0.9	75	12	6.9	3.8	177%
Mesa II 1/2 Mine	M30	2.2	174	0.7	58	5.4	4.9	3.5	111%
Mesa II 1/2, Mine 4	M31	2.2	46	0.8	14	3.1	4.8	4.2	65%
Mesa III Mine	M32	2.5	145	1.8	39	4.2	4.7	3.4	88%
Knife Edge Mesa Mine	M33	68	89	1.5	85	13	9.5	5.1	136%
Black No. 1 Mine	M34	4.8	85	1.0	34	5.2	5.4	4.0	96%
Black No. 2 Mine	M35	1.7	69	1.7	28	5.3	5.5	3.6	95%
Black No. 2 Mine (West)	M36	4.8	39	0.8	15	3.6	4.8	3.8	75%
Flag No. 1 Mine	M37	4.8	94	0.6	35	6.2	6.8	4.7	92%
Step Mesa Mine	M38	1.7	13	2.2	13	2.7	5.7	5.3	47%
Mesa I Camp	T17	3.5	402	1.0	29	3.2	3.3	2.5	96%
NA-0344B	T23	2.2	102	1.9	13	1.8	3.8	3.4	47%

Notes:
Only statistics for detected data are listed in this table.
BTV Background threshold value
mg/kg Milligrams per kilogram
n Number of analytical results including corrected XRF measurements
RSD Relative standard deviation

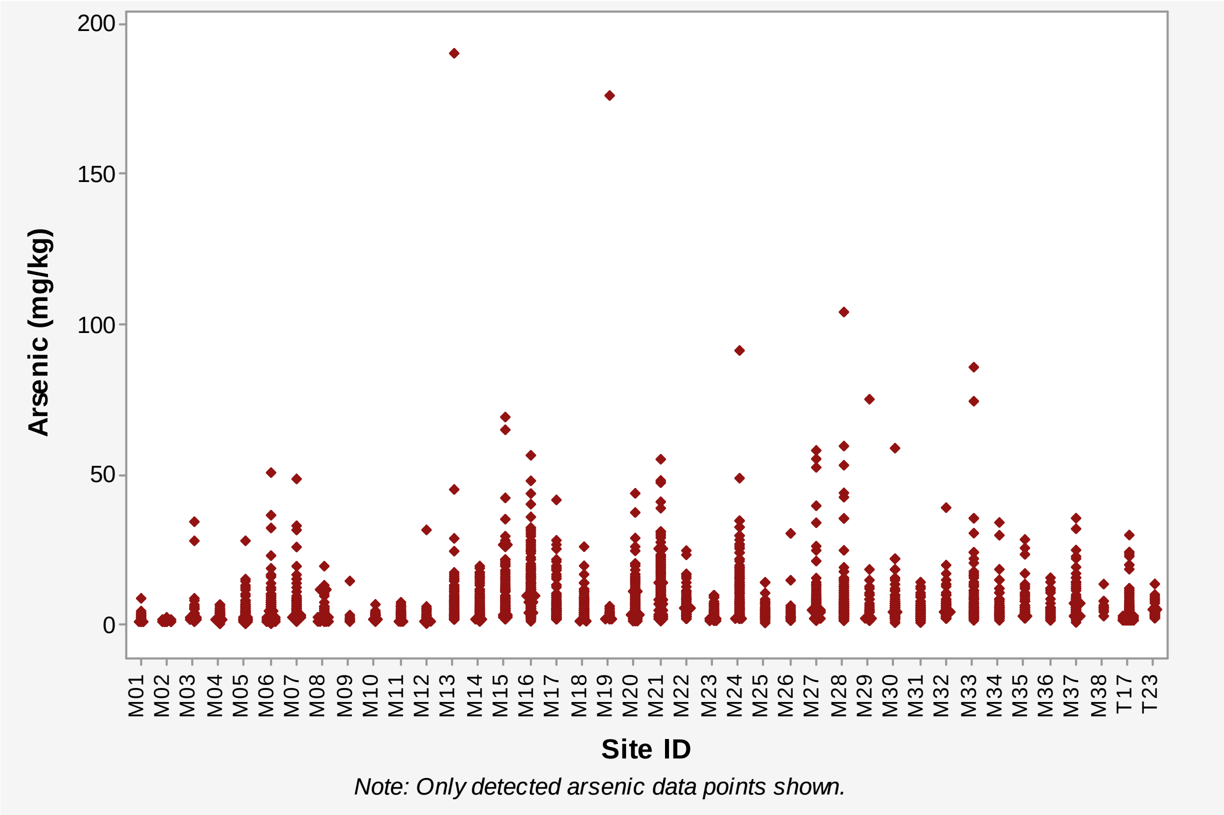


Figure 21. Individual Value Plot of Arsenic Concentrations in Surface Soils

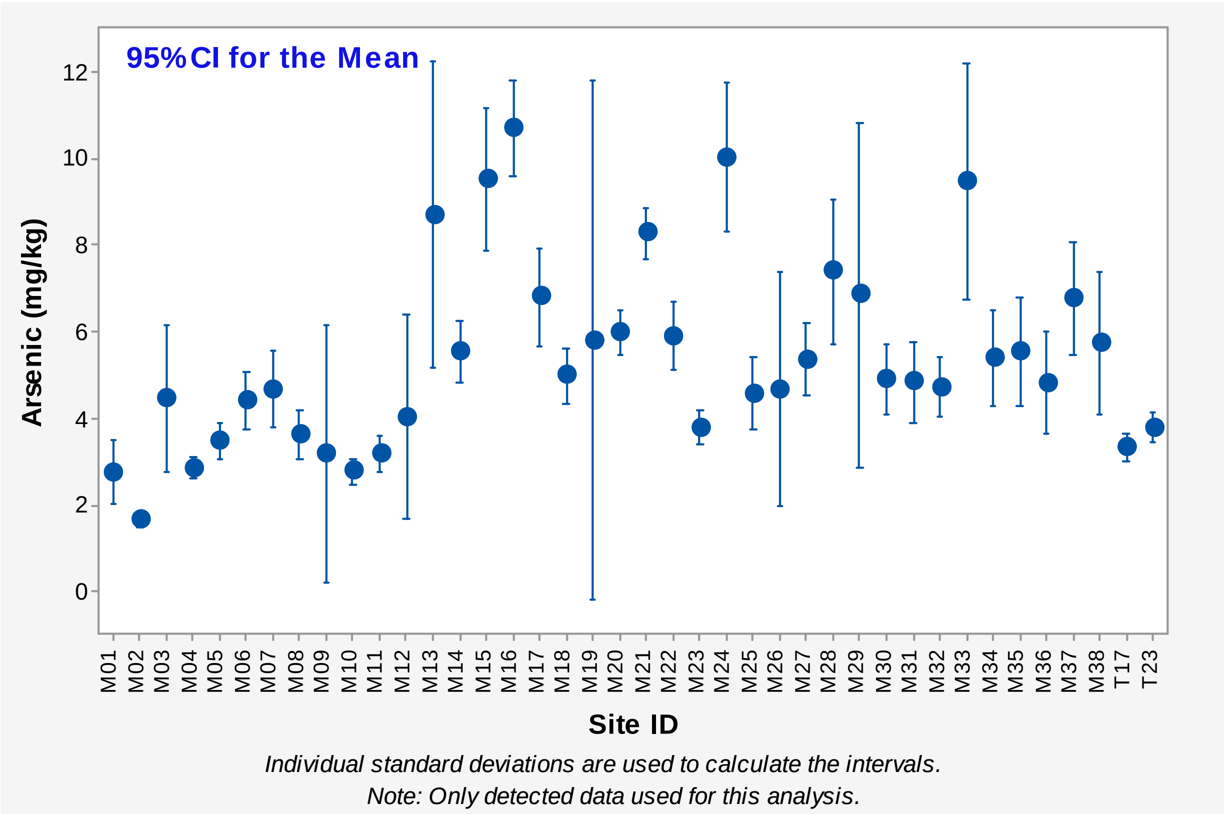


Figure 22. Interval Plot of Arsenic Concentrations in Surface Soils

5.3.2 Lead

Lead was a primary analyte of interest in the RSE investigations. The atomic number of lead is 82, and the average crustal abundance is approximately 20 mg/kg (USEPA 1995). Concentrations of naturally occurring lead in surface soils typically range from 2 to 200 mg/kg (USEPA 2006b). Both ICP-MS and field-portable XRF technology were used during this project for determination of trace elemental lead concentrations in soils at the sites.

Evaluations of lead surface soil concentrations occurred across the sites as discussed in Section 4.4. Table 26 summarizes statistics of detected results of lead concentrations in surface soils via the three different sampling/measurement types, including in situ XRF results corrected to laboratory predicted values. Average detected lead concentration in surface soils ranged between 3.4 and 8.6 mg/kg across all sites. Figure 23 shows an individual value plot of lead concentrations in surface soils at the respective sites. The average lead concentration at all sites was below 9 mg/kg. Maximum lead concentration detected in surface soils across all sites ranged between 6.5 mg/kg (Block K Mine) and 195 mg/kg (Mesa V Incline). The average lead concentration in surface soils exceeded the applied BTV at only two of the 40 sites (Brodie 1 Mine and Mesa V Mine – 508), as listed in Table 26. The average lead concentration in surface soils was about 1.2 times the applied BTV for a given site. Figure 24 shows an interval plot of lead concentrations in surface soils across all sites, indicating the means of surficial lead concentrations across all the respective sites with a 95 percent confidence interval banding each calculated mean. One outlier was removed—at Mesa II 1/2, Mine 4 (M31)—and this outlier was confirmed erroneous by the laboratory upon reanalysis.

Lead levels within the Lukachukai Mountains are, on average, much lower than the crustal abundance of lead reported in USEPA (1997) but within the range presented by USEPA (2006b). The highest lead concentration detected in BSAs was 19 mg/kg. Lead concentration was not a good indicator of presence of mine waste at the Tronox mines within the Northern AUM Region. Individual maps of surface and subsurface lead concentrations, along with more detailed statistical analysis for every AUM site and AUM-related site, are in SSRSEs in Appendix H.

Generally, lead concentrations did not prove to be a good indicator of spatial extent of mine waste at the majority of sites, and on average, lead concentrations at the sites were below background. Mesa I Camp (T17) had the highest spread of lead concentrations in surface soils above background levels. Lead was found to be a COPC, detected above background levels at 36 of the 40 sites for which background comparison analyses occurred. Further discussion on COPCs across all sites is in Section 6.0. Lead results from non-AUM Target sites are in Appendix I.

Table 26. Summary Statistics of Lead Concentration in Surface Soils

Site Name	Site ID	Applied BTV for Lead (mg/kg)	n	Minimum (mg/kg)	Maximum (mg/kg)	Standard Deviation (mg/kg)	Average (mg/kg)	Median (mg/kg)	RSD
Brodie 1 Mine	M1	4.0	56	1.2	12.0	1.9	4.1	4.0	47%
Block K Mine	M2	5.0	126	1.0	6.5	1.1	3.4	3.3	32%
Mesa I Mine 10	M3	11	85	2.5	10	1.8	5.8	5.3	32%
Mesa I Mine 11	M4	7.0	287	0.5	30.3	2.9	5.1	4.7	56%
Mesa I Mine 12	M5	7.0	398	0.5	50	3.2	5.2	4.9	62%
Mesa I Mine 13	M6	7.0	401	0.9	20	2.3	5.9	5.7	39%
Mesa I Mine 14	M7	7.0	281	0.5	23	2.9	6.0	5.5	48%
Mesa I Mine 15	M8	7.0	224	0.3	29	3.7	6.8	6.6	54%
Mesa I 1/4 Mine	M9	11	40	2.6	84	12.6	8.2	5.8	153%
Mesa I 1/2 Mine	M10	12	92	0.7	18.3	2.4	5.1	5.1	47%
Henry Phillips Mine	M11	11	113	1.1	19.0	3.0	5.9	5.7	51%
Mesa I 1/2, West Mine	M12	11	72	0.5	12	2.9	5.2	5.4	56%
Mesa VI Mine	M13	11	167	1.5	20	2	6.6	6.3	37%
Frank Jr. Mine	M14	9.5	182	1.6	16	2.5	6.9	6.5	37%
Mesa V Incline	M15	9.7	149	2.7	195	16	8.4	6.9	185%
Mesa V Adit	M16	10	262	1.2	15	2.0	5.7	5.4	36%
Mesa V Mine – 103	M17	9.3	155	1.5	11	2.1	5.8	5.5	36%
Mesa V Mine – 508	M18	5.8	230	1.9	23	2.5	6.8	6.6	37%
Mesa IV 1/2 Mine and Simpson 181	M19	9.3	105	2.7	24	3	8.2	7.6	35%
Mesa IV, Mine No. 1	M20	10	459	0.7	20	2.8	7.4	7.2	37%
Mesa IV, Mine No. 2	M21	10	663	0.8	183	7.6	7.7	7.0	99%
Mesa IV, Mine No. 3	M22	10	137	0.7	17	2.9	7.2	6.3	41%
Mesa IV, West Mine	M23	11	195	1.5	18.3	2.7	7.3	7.0	37%
Mesa II Pit	M24	10	210	2.0	20	3	5.7	5.4	44%
Mesa I 3/4 Incline	M25	9.9	118	2.3	17	2.3	5.5	5.0	41%
Mesa I 3/4 Mine No. 2, P-150	M26	9.9	56	0.3	12	1.9	5.0	4.8	38%
Mesa II, Mine No. 1 & 2, P-21	M27	9.9	347	0.7	10	1.7	5.4	5.4	30%
Mesa II, Mine No. 1, P-150	M28	10	227	1.2	22	2	6.0	5.9	39%
Mesa II, Mine 4	M29	10	111	0.4	27	3	5.3	4.3	65%
Mesa II 1/2 Mine	M30	9.9	313	1.4	20	2.4	6.0	5.8	39%
Mesa II 1/2, Mine 4	M31	9.9	77	2.1	21	2.6	6.2	5.9	42%
Mesa III Mine	M32	11	198	0.7	19	2.6	6.7	6.4	39%
Knife Edge Mesa Mine	M33	14	141	0.6	17	2	5.6	5.4	43%
Black No. 1 Mine	M34	12	135	1.1	18	2.4	6.5	6.1	37%
Black No. 2 Mine	M35	7.8	109	0.7	15	2.6	5.6	5.5	46%
Black No. 2 Mine (West)	M36	12	52	2.2	12	2.0	5.5	5.6	37%
Flag No. 1 Mine	M37	12	120	2.0	17	2.6	6.8	6.2	39%
Step Mesa Mine	M38	7.8	16	2.5	11	2.4	6.8	5.9	35%
Mesa I Camp	T17	11	846	1.7	160	8.2	8.2	7.2	100%
NA-0344B	T23	9.7	111	4.1	17	2.1	8.6	8.3	24%

Notes:

Only statistics for detected data are listed in this table.

BTV Background threshold value

mg/kg Milligrams per kilogram

n Number of analytical results including corrected XRF measurements

RSD Relative standard deviation

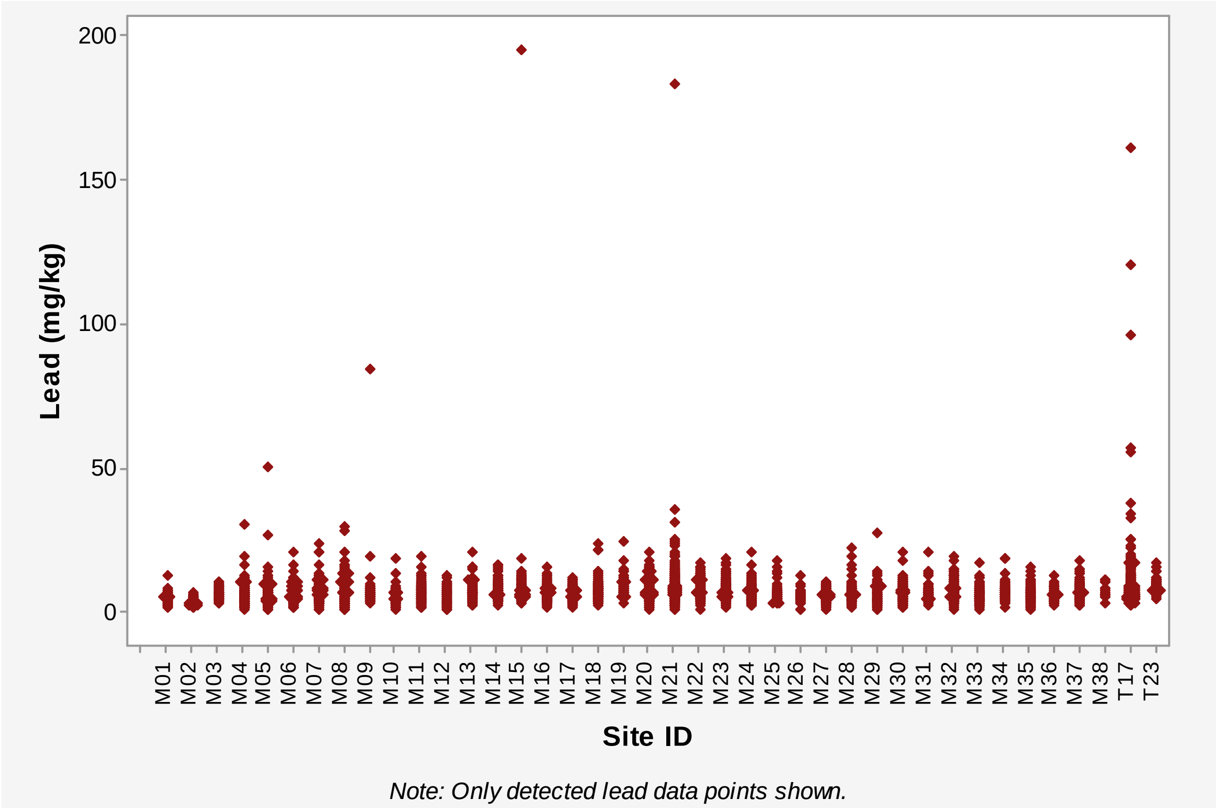


Figure 23. Individual Value Plot of Lead Concentrations in Surface Soils

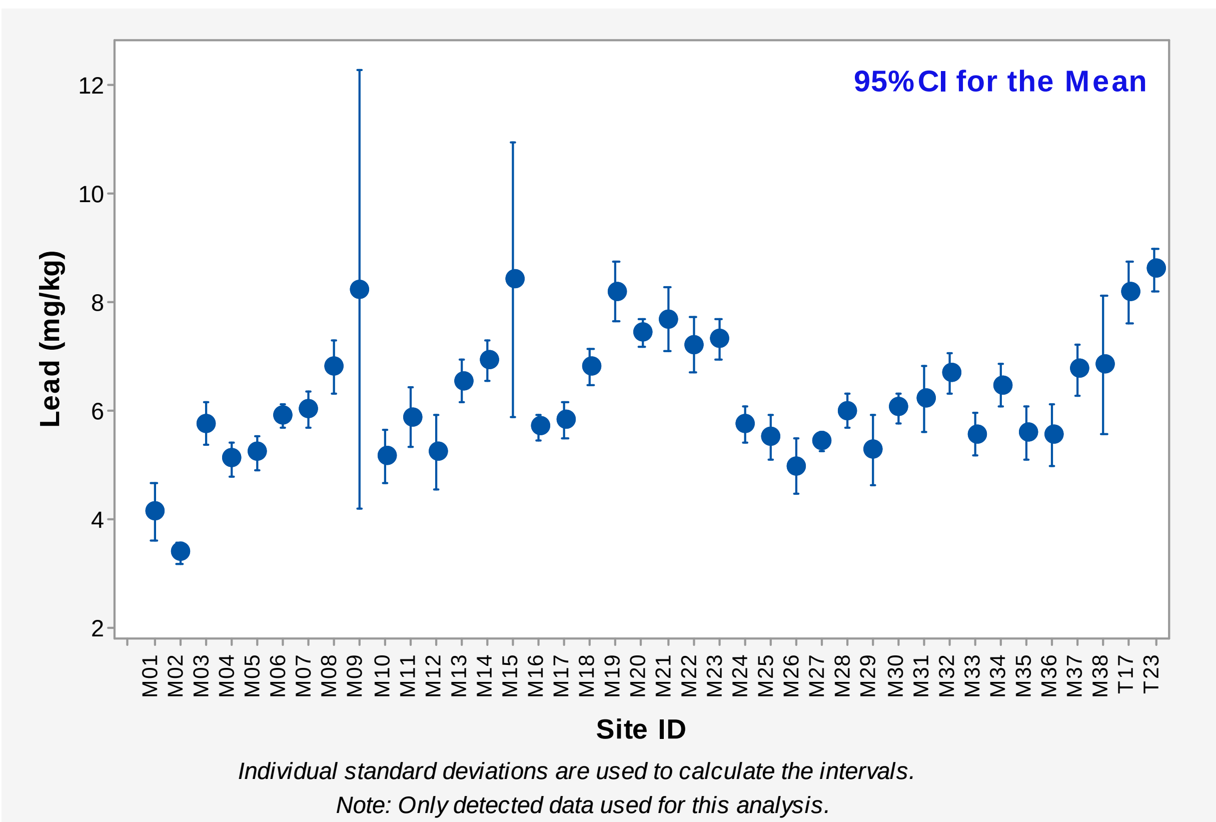


Figure 24. Interval Plot of Lead Concentrations in Surface Soils

5.3.3 Molybdenum

Molybdenum was a primary analyte of interest in the RSE investigations. The atomic number of molybdenum is 42, and the average crustal abundance is approximately 1.5 mg/kg (USGS 2017). Concentration of naturally occurring molybdenum in surface soils ranges from less than 1 to 115 mg/kg in uranium roll-front deposits (Bullock and Parnell 2017). Successful analysis for molybdenum occurs via ICP-MS and use of field-portable XRF technology (as described in Appendix B). The XRF spectrometer is effective in determining higher concentrations of molybdenum associated with uranium deposits, and for comparing soil concentrations to risk-based screening levels. Risk-based soil screening levels for molybdenum typically exceed 1 mg/kg (UESPA 2019). Because background soil concentrations of molybdenum reported in this study were often below or close to the detection limit, the XRF spectrometer was not as useful for evaluating low concentrations of molybdenum as it was for determinations of low concentrations of other target elements.

Evaluations of molybdenum surface soil concentrations occurred across the sites as discussed in Section 5.2.2. Table 27 summarizes statistics of detected molybdenum concentrations in surface soils via the three different sampling/measurement types, including in situ XRF results corrected to laboratory predicted values. Average detected molybdenum concentration in surface soils ranged between 0.34 and 8.4 mg/kg. Figure 25 shows an individual value plot of molybdenum concentrations in surface soils at the respective sites. The average molybdenum concentration in surface soils exceeded the applied BTV at every site, with the highest reported average at Mesa I Mine 14. The average molybdenum concentration in surface soils was about six times higher than the applied BTV for a given site. The highest reported molybdenum concentration in surface soils was 60 mg/kg at Mesa II, Mine No. 1 P-150. Figure 26 shows an interval plot of molybdenum concentrations in surface soils across all sites, indicating the means of surficial molybdenum concentrations across all the respective sites with a 95 percent confidence interval banding each calculated mean.

The average molybdenum concentration across all 3,165 measurements at all mined areas of the Lukachukai Mountains was 2.0 mg/kg, slightly higher than the crustal abundance of molybdenum reported in USGS (2017) but within the range presented by Bullock and Parnell (2017). This value was also 10 times higher than the average molybdenum concentration across all BSAs of 0.20 mg/kg. The maximum reported molybdenum concentration found in all background surface soil samples was 4.9 mg/kg. At some sites, elevated molybdenum concentrations were indicative of presence of mine waste materials, although molybdenum level did not always prove to be a good indicator of mine waste at the Tronox mines within the Northern AUM Region. Individual maps of surface and subsurface molybdenum concentrations, along with more detailed statistical analyses for every AUM site and AUM-related site, are in SSRSEs in Appendix H.

At most sites, average levels of molybdenum were found at six times background levels. Molybdenum was found to be a COPC, identified above background levels at all 40 sites evaluated. Further discussion of COPCs across all sites is in Section 6.0. Molybdenum results from non-AUM Target sites are in Appendix I.

Table 27. Summary Statistics of Molybdenum Concentration in Surface Soils

Site Name	Site ID	Applied BTV for Molybdenum (mg/kg)	n	Minimum (mg/kg)	Maximum (mg/kg)	Standard Deviation (mg/kg)	Average (mg/kg)	Median (mg/kg)	RSD
Brodie 1 Mine	M1	0.30	11	0.08	1.34	0.41	0.35	0.14	118%
Block K Mine	M2	0.34	42	0.09	3.13	0.68	0.51	0.19	134%
Mesa I Mine 10	M3	0.25	26	0.10	4.49	1.21	1.08	0.48	112%
Mesa I Mine 11	M4	0.16	106	0.04	4.30	0.71	0.62	0.38	114%
Mesa I Mine 12	M5	0.16	107	0.04	8.18	1.53	1.14	0.59	134%
Mesa I Mine 13	M6	0.16	119	0.05	5.81	1.06	0.95	0.58	111%
Mesa I Mine 14	M7	0.16	147	0.07	24.73	6.91	8.38	12.19	82%
Mesa I Mine 15	M8	0.16	69	0.04	5.71	0.98	0.63	0.20	154%
Mesa I 1/4 Mine	M9	0.25	11	0.04	0.89	0.35	0.34	0.21	104%
Mesa I 1/2 Mine	M10	0.32	31	0.05	5.64	1.14	0.97	0.38	118%
Henry Phillips Mine	M11	0.29	47	0.07	3.75	0.87	0.86	0.76	101%
Mesa I 1/2, West Mine	M12	0.29	17	0.04	2.03	0.54	0.44	0.26	123%
Mesa VI Mine	M13	0.29	49	0.04	3.64	0.86	0.91	0.67	94%
Frank Jr. Mine	M14	0.52	103	0.05	10.11	1.96	2.06	1.21	95%
Mesa V Incline	M15	0.29	88	0.05	43.06	5.05	1.92	0.90	263%
Mesa V Adit	M16	0.29	213	0.06	18.75	2.75	2.94	2.00	93%
Mesa V Mine – 103	M17	0.20	88	0.07	7.63	1.66	2.17	1.80	76%
Mesa V Mine – 508	M18	0.07	62	0.06	2.67	0.68	0.76	0.54	90%
Mesa IV 1/2 Mine and Simpson 181	M19	0.20	61	0.07	16.22	2.80	2.16	1.06	130%
Mesa IV, Mine No. 1	M20	0.29	232	0.05	18.45	2.38	1.79	1.13	133%
Mesa IV, Mine No. 2	M21	0.32	253	0.04	45.65	3.59	2.23	1.26	161%
Mesa IV, Mine No. 3	M22	0.29	64	0.05	5.19	1.38	1.64	1.33	84%
Mesa IV, West Mine	M23	0.29	76	0.05	8.10	1.29	1.05	0.53	123%
Mesa II Pit	M24	0.32	92	0.06	20.81	2.95	2.08	1.08	142%
Mesa I 3/4 Incline	M25	0.29	23	0.05	20.88	5.68	2.62	0.46	217%
Mesa I 3/4 Mine No. 2, P-150	M26	0.29	18	0.04	1.89	0.55	0.66	0.51	84%
Mesa II, Mine No. 1 & 2, P-21	M27	0.29	109	0.05	51.56	7.02	2.33	0.79	301%
Mesa II, Mine No. 1, P-150	M28	0.26	96	0.04	60.00	8.79	3.73	1.22	236%
Mesa II, Mine 4	M29	0.32	17	0.04	1.81	0.53	0.42	0.17	126%
Mesa II 1/2 Mine	M30	0.29	136	0.05	18.00	2.80	2.00	1.26	140%
Mesa II 1/2, Mine 4	M31	0.29	40	0.09	23.86	3.80	2.16	1.08	176%
Mesa III Mine	M32	0.29	110	0.05	25.17	4.55	3.06	1.83	149%
Knife Edge Mesa Mine	M33	1.1	39	0.07	2.44	0.61	0.74	0.54	82%
Black No. 1 Mine	M34	0.34	46	0.04	6.46	1.42	1.10	0.60	130%
Black No. 2 Mine	M35	0.29	14	0.09	4.27	1.25	1.03	0.55	121%
Black No. 2 Mine (West)	M36	0.34	15	0.04	4.47	1.39	1.12	0.67	124%
Flag No. 1 Mine	M37	0.34	55	0.11	37.25	6.06	2.61	1.25	232%
Step Mesa Mine	M38	0.29	7	0.07	1.86	0.57	0.61	0.42	93%
Mesa I Camp	T17	0.23	272	0.04	7.13	1.00	0.88	0.52	114%
NA-0344B	T23	0.29	54	0.07	6.98	1.56	1.54	1.11	101%

Notes:

Only statistics for detected data are listed in this table.

BTV Background threshold value
mg/kg Milligrams per kilogram
n Number of analytical results including corrected XRF measurements
RSD Relative standard deviation

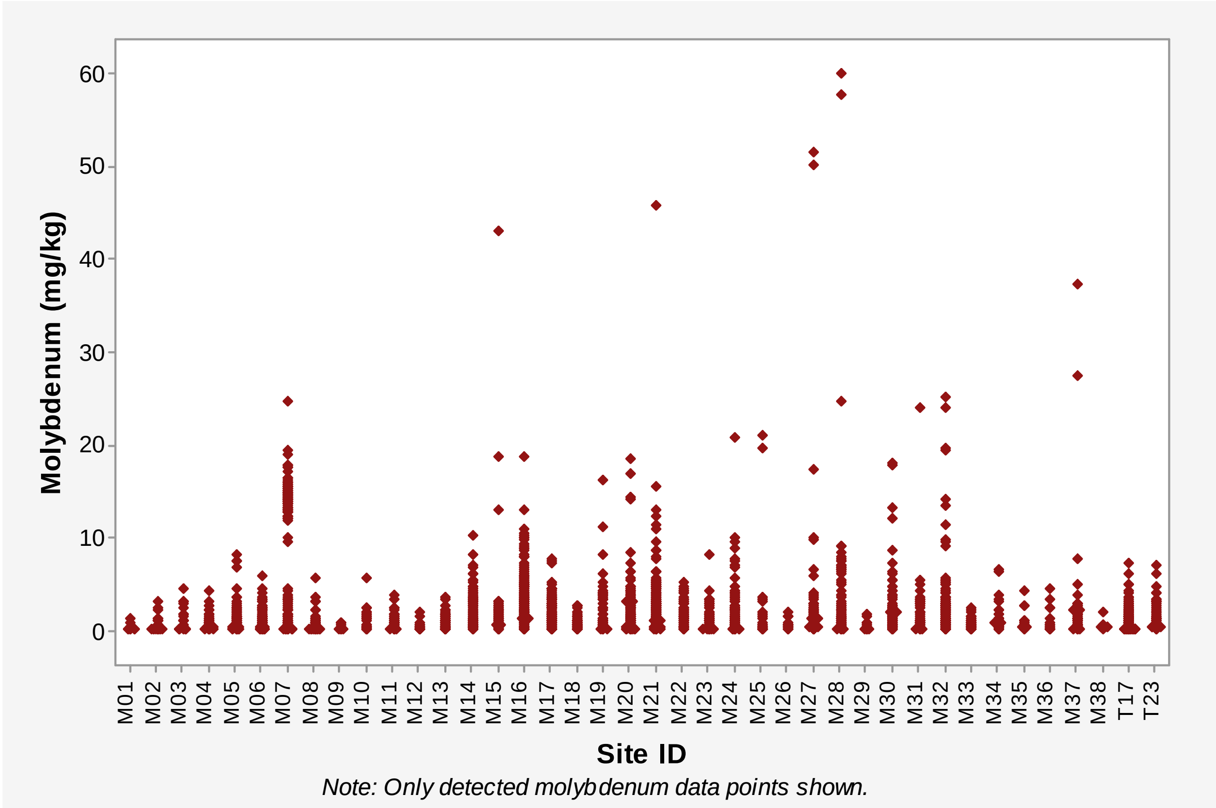


Figure 25. Individual Value Plot of Molybdenum Concentrations in Surface Soils

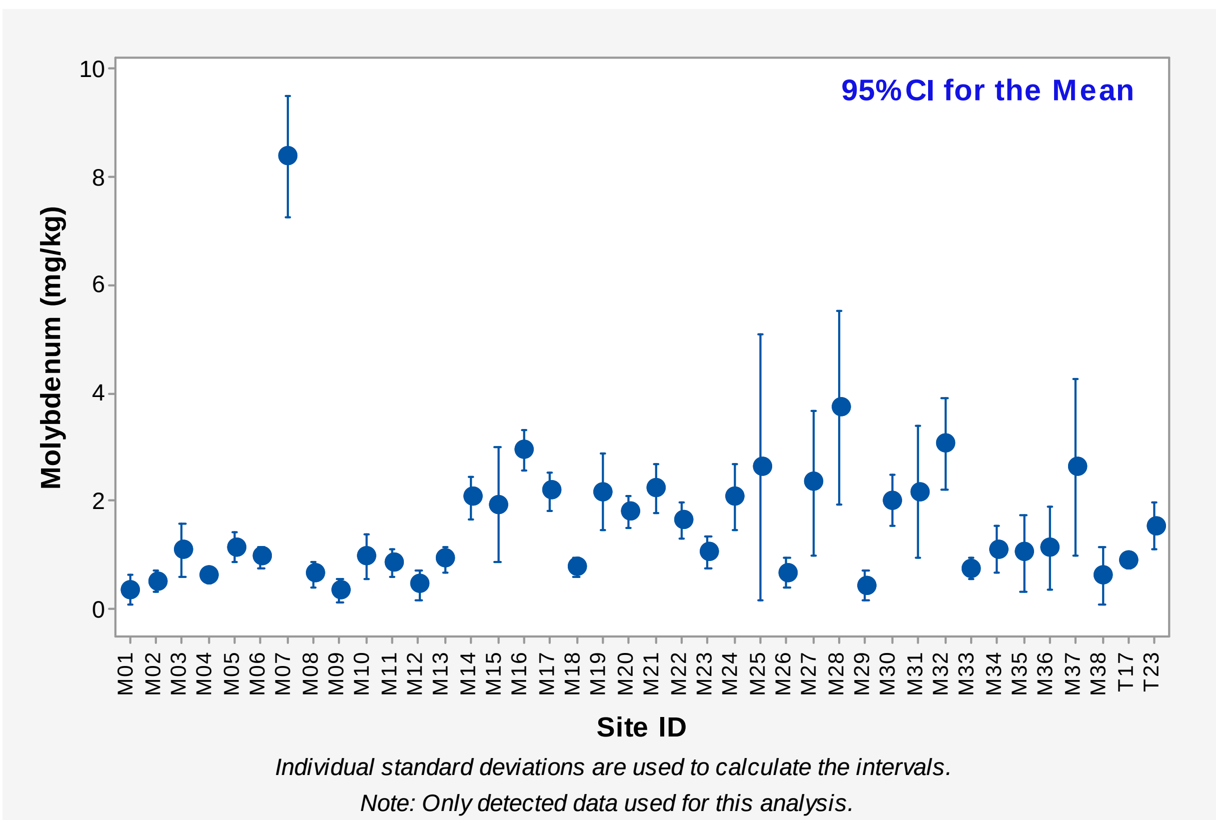


Figure 26. Interval Plot of Molybdenum Concentrations in Surface Soils

5.3.4 Mercury

Mercury is considered a secondary analyte of interest in the RSE investigations. Mercury was an analyte for surface soil samples collected at 980 locations during the background investigation. Detected mercury concentrations in background surface soils ranged between 0.000067 and 0.068 mg/kg, with an average and a standard deviation of 0.0109 and 0.0075, respectively. Mercury was an analyte for only select samples collected at AUM sites and Target sites during the RSE investigations because it was determined that mercury was not typically associated with mine waste. Thirty-seven soil samples (including two duplicate samples) collected across 25 sites (19 AUM sites and six Target sites) were analyzed for mercury during the Baseline Study. These samples were collected from unreclaimed waste piles, burial cells, and near portals in the Tse Tah Region, Cove Valley Region, and Lukachukai Region. Eight of the 37 samples yielded nondetect values for mercury. Out of the remaining 29 samples, the average concentration was 0.0093 mg/kg and maximum concentration was 0.0720 mg/kg. After discussing these results with the USEPA RPM, it was agreed to discontinue mercury sampling at any of the sites during the Site Characterization Study. Table 28 summarizes mercury concentrations at the sites where samples were collected and analyzed for mercury.

Table 28. Summary of Mercury Results at Northern Agency Tronox Mines

Site ID	Sample ID	Result (mg/kg)	Q	Applied BTV (mg/kg)
T1	T1-XSG5A-01-081918	<0.0330	U	0.0075
	T1-XSG49A-01-081918	<0.0330	U	0.0075
T4	T4-XS15A-01-081918	<0.0310	U	0.0168
	T4-XSG50A-01-081918	<0.0330	U	0.0168
T9	T9-XS217-01-042518	0.0130	J-	0.0197
T10	T10-XS20-01-042518	0.0065	J-	0.0260
M3	M3-XS34-01-043018	0.0071	J-	0.0378
	M3-XS36-01-043018	0.0084	J-	0.0378
M4	M4-XS238-01-051018	0.0120	J-	0.0378
M6	M6-XS269-01-042618	0.0080	J-	0.0378
M7	M7-XS162A-01-081518	<0.0310	U	0.0378
	M7-XS181-01-051018	0.0018	J-	0.0378
	M7-XS181-02-051018	0.0016	J-	0.0378
M8	M8-XS102-01-050918	0.0013	J-	0.0378
T14	T14-XS27-01-050818	0.0081	J-	0.0378
T17	T17-XS143-01-042618	0.0070	J-	0.0378
	T17-XS377-01-042818	0.0150	J-	0.0378
M9	M9-XS19A-01-081718	<0.0320	U	0.0378
	M9-XS28A-01-081718	<0.0300	U	0.0378
M11	M11-XS11-01-071118	0.0720	J-	0.0206
M15	M15-XS3-01-052118	0.0057	J-	0.0261
M16	M16-XS30-01-052118	0.0043	J-	0.0378
	M16-XS177-01-052618	0.0035	J-	0.0378
M20	M20-XS365-01-060618	0.0160	J-	0.0298
M21	M21-XS46-01-060818	0.0150	J-	0.0298
	M21-XS302-02-060918	0.0054	J-	0.0298
M22	M22-XS87-01-060418	0.0110	J-	0.0298
M25	M25-XS88-01-071718	0.0086	J-	0.0160
M26	M26-XS25-01-061818	0.0037	J-	0.0160
M27	M27-XS38-01-061918	0.0037	J-	0.0160
	M27-XS275-01-061918	0.0039	J-	0.0160
	M27-XS283-01-061818	0.0045	J-	0.0160
M28	M28-XS148-01-062018	0.0065	J-	0.0111
M30	M30-XS170-01-071618	<0.0380	R	0.0160
M34	M34-XS110-01-081218	0.0014	J-	0.0298
M37	M37-XS44-01-081318	<0.0320	U	0.0298
	M37-XS124A-01-081318	0.0076	J-	0.0298

Notes:

BTV	Background threshold value
J-	Estimated value, may be biased low.
J+	Estimated value, may be biased high.
mg/kg	Milligrams per kilogram
pCi/g	Picocuries per gram
Q	Qualifier
U	Not detected. The associated value is the reporting limit.
UJ	Not considered detected. The associated value is the reported concentration, which is estimated.
R	Rejected due to temperature requirement not being met.

5.3.5 Thorium

Thorium was a primary analyte of interest in the RSE investigations, and is a naturally occurring, radioactive metal. The principal sources of external exposure to terrestrial radiation are the penetrating gamma radiations emitted by K-40 and the series originating from U-238 and Th-232. The atomic number of thorium is 90, and the average crustal abundance is approximately 4.5 mg/kg (Lambert and Heir 1968). Thorium exists primarily as Th-232 (99.98 percent by mass) with a small amount of Th-230 (0.02 percent). Th-232 decays slowly via alpha decay with a half-life on the order of the age of the universe (14 billion years). Thorium occurs naturally in soils at average concentrations of 2 to 12 mg/kg (Agency for Toxic Substances and Disease Registry [ATSDR] 1990). Thorium was measured in analytical soil samples via alpha spectroscopy (ASTM 3972) in a laboratory, and was also measured by use of field-portable XRF technology as described in Appendix B to this report.

Evaluations of thorium surface soil concentrations occurred across all AUM sites and within two AUM-related sites (Mesa I Camp and NA-0344B). The two AUM-related sites were included because an RSE investigation also occurred there, and those sites were known to include mine waste materials. Table 29 summarizes statistics of detected thorium concentrations in surface soils via the three different sampling/measurement types, including in situ XRF results corrected to laboratory predicted values. The average detected thorium concentration in surface soils ranged between 1.5 and 3.5 mg/kg across all of the sites. Figure 27 shows an individual value plot of thorium concentrations in surface soils at the respective sites, which indicates thorium concentrations generally within the natural levels for U.S. soils presented in ASTDR (1990); however, outliers of thorium concentration were found at a few sites. Generally, the relative standard deviation (RSD) was less than 50 percent, except at sites where outliers were detected. Notable sites where extreme outliers were detected include Mesa V Incline and Mesa IV, Mine No. 2 (maximum levels of 90 and 87 mg/kg, respectively); at both of these sites, average thorium concentrations were still within the range of averages for the project. Figure 28 shows an interval plot of thorium concentrations in surface soils across all of the site, indicating the means of surficial thorium concentrations across all of the respective sites with an 95 percent confidence interval banding each calculated mean.

Thorium levels within the Lukachukai Mountains are consistent with national levels. At certain geographical areas of the mountains, elevated thorium concentrations were detected in the natural environment—for example, at BSA-12 where significant levels of thorium contributed to elevated gamma radiation levels (at that site, other analytes such as nickel and potassium also were detected at elevated concentrations). At most AUM sites, thorium concentration is not generally higher in areas with mine waste materials; that is, thorium concentration is not necessarily a good indicator of presence of mine waste at the Tronox mines within the Northern AUM Region. Individual maps of surface and subsurface thorium concentrations, along with more detailed statistical analyses for every AUM site and AUM-related site, are in SSRSEs in Appendix H to this RSE Report.

The average thorium concentration in surface soils exceeded the applied BTV at only one of the sites (Mesa IV 1/2 Mine and Simpson 181). Generally, thorium concentration is not a good indicator of presence of mine waste, and average levels of thorium are relatively low; however, thorium was found to be a COPC, identified above background levels at 30 of 41 sites evaluated. Further discussion of COPCs across all of the sites is in Section 6.0. Thorium results from non-AUM Target sites are conveyed in Appendix I.

Table 29. Summary Statistics of Surface Soil Concentrations of Thorium

Mine Name	Site ID	Applied BTV for Thorium (mg/kg)	n	Minimum (mg/kg)	Maximum	Standard Deviation (mg/kg)	Average (mg/kg)	Median	RSD
Brodie 1 Mine	M1	1.7	48	1.0	3.7	0.6	1.7	1.5	36%
Block K Mine	M2	1.9	114	0.9	2.6	0.4	1.5	1.5	24%
Mesa I Mine 10	M3	4.7	83	1.1	4.6	0.6	2.3	2.2	27%
Mesa I Mine 11	M4	4.7	279	1.1	10	1.1	2.3	2.0	47%
Mesa I Mine 12	M5	4.7	379	0.8	7.4	0.8	2.1	1.9	37%
Mesa I Mine 13	M6	4.7	388	1.0	7.6	0.9	2.4	2.3	35%
Mesa I Mine 14	M7	4.7	271	1.0	11	1.8	3.5	2.8	52%
Mesa I Mine 15	M8	4.7	203	1.0	38	3.9	3.0	2.4	127%
Mesa I 1/4 Mine	M9	4.7	33	1.0	2.9	0.5	1.6	1.5	30%
Mesa I 1/2 Mine	M10	3.6	87	1.1	3.9	0.5	2.1	2.0	26%
Henry Phillips Mine	M11	4.7	100	0.8	5.1	0.9	2.2	2.1	40%
Mesa I 1/2, West Mine	M12	4.7	55	0.8	4.9	1.0	2.3	2.3	44%
Mesa VI Mine	M13	4.7	164	1.0	11.9	1.3	2.7	2.4	48%
Frank Jr. Mine	M14	3.2	174	1.0	5.0	0.8	2.3	2.2	34%
Mesa V Incline	M15	3.6	145	1.0	90	7.4	3.3	2.4	223%
Mesa V Adit	M16	4.5	259	0.8	7.7	0.9	2.5	2.4	35%
Mesa V Mine – 103	M17	2.4	153	1.1	5.2	0.6	2.2	2.2	29%
Mesa V Mine – 508	M18	4.3	229	0.8	5.8	0.8	2.4	2.3	33%
Mesa IV 1/2 Mine and Simpson 181	M19	2.4	103	1.1	5.6	0.7	2.5	2.5	27%
Mesa IV, Mine No. 1	M20	3.6	446	1.0	9.7	1.0	2.6	2.5	40%
Mesa IV, Mine No. 2	M21	3.6	622	1.0	87	3.6	2.7	2.3	131%
Mesa IV, Mine No. 3	M22	3.6	134	1.0	14	1.4	2.8	2.7	49%
Mesa IV, West Mine	M23	4.7	179	1.0	4.8	0.8	2.3	2.2	34%
Mesa II Pit	M24	3.6	196	1.0	8.6	1.3	2.6	2.2	50%
Mesa I 3/4 Incline	M25	4.7	110	1.1	7.4	0.8	2.1	1.9	38%
Mesa I 3/4 Mine No. 2, P-150	M26	3.8	44	1.0	5.3	0.9	2.1	1.8	44%
Mesa II, Mine No. 1 & 2, P-21	M27	3.6	338	1.0	7.3	0.8	2.4	2.3	34%
Mesa II, Mine No. 1, P-150	M28	3.6	239	1.0	11	1.3	2.6	2.4	49%
Mesa II, Mine 4	M29	3.6	91	0.8	5.4	1.0	2.0	1.7	50%
Mesa II 1/2 Mine	M30	4.7	304	1.0	9.3	1.0	2.5	2.2	40%
Mesa II 1/2, Mine 4	M31	4.7	77	1.2	5.0	0.8	2.5	2.4	31%
Mesa III Mine	M32	4.7	189	1.0	8.2	1.1	2.5	2.3	43%
Knife Edge Mesa Mine	M33	5.9	109	1.0	6.4	1.0	2.5	2.3	43%
Black No. 1 Mine	M34	3.6	120	1.2	8.6	1.1	2.5	2.3	43%
Black No. 2 Mine	M35	4.7	81	1.0	9.5	1.6	2.6	2.2	60%
Black No. 2 Mine (West)	M36	3.6	48	1.1	9.8	1.5	2.4	2.0	60%
Flag No. 1 Mine	M37	3.6	118	1.0	7.3	1.1	3.0	2.9	39%
Step Mesa Mine	M38	4.7	16	1.2	5.0	1.0	2.8	2.7	37%
Mesa I Camp	T17	4.7	840	1.0	21	0.9	2.4	2.4	35%
NA-0344B	T23	3.6	111	1.6	4.6	0.6	2.9	2.8	21%

Notes:
Only statistics for detected data are listed in this table.
BTV Background threshold value
mg/kg Milligrams per kilogram
n Number of analytical results including corrected XRF measurements
RSD Relative standard deviation

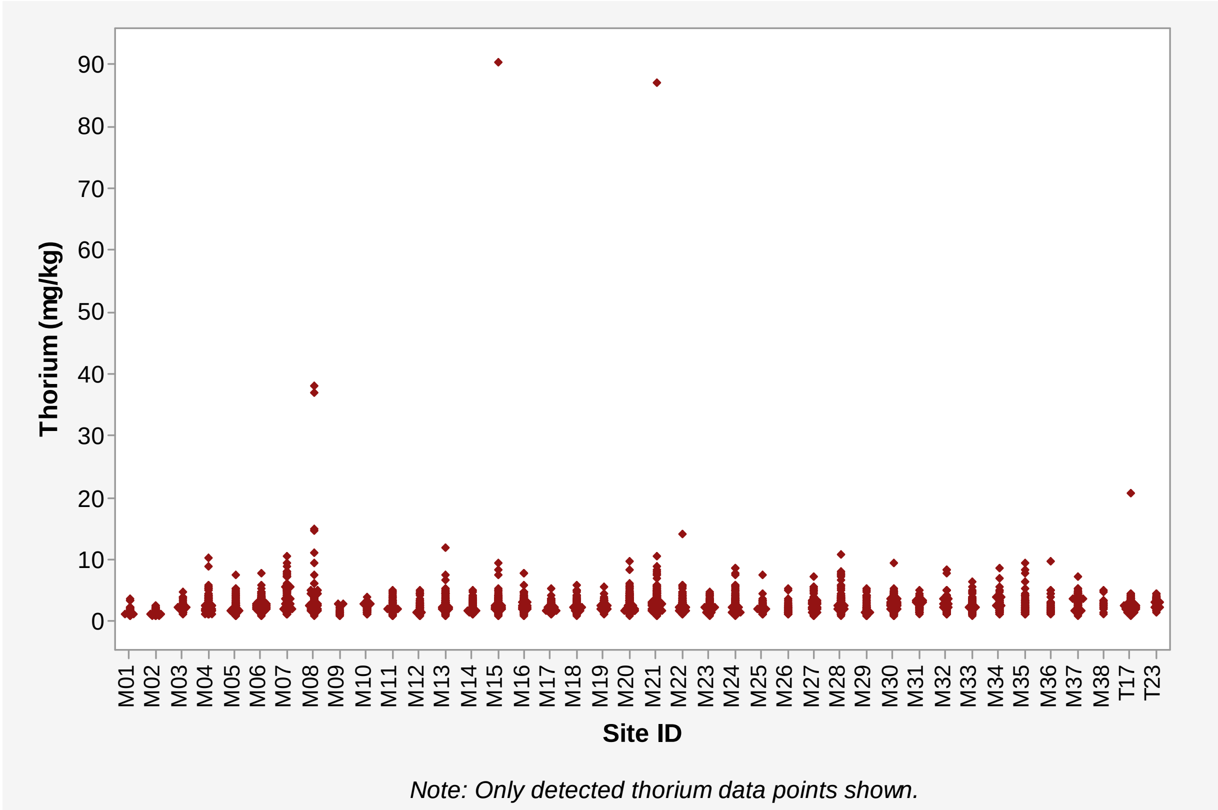


Figure 27. Individual Value Plot of Thorium Concentrations in Surface Soils

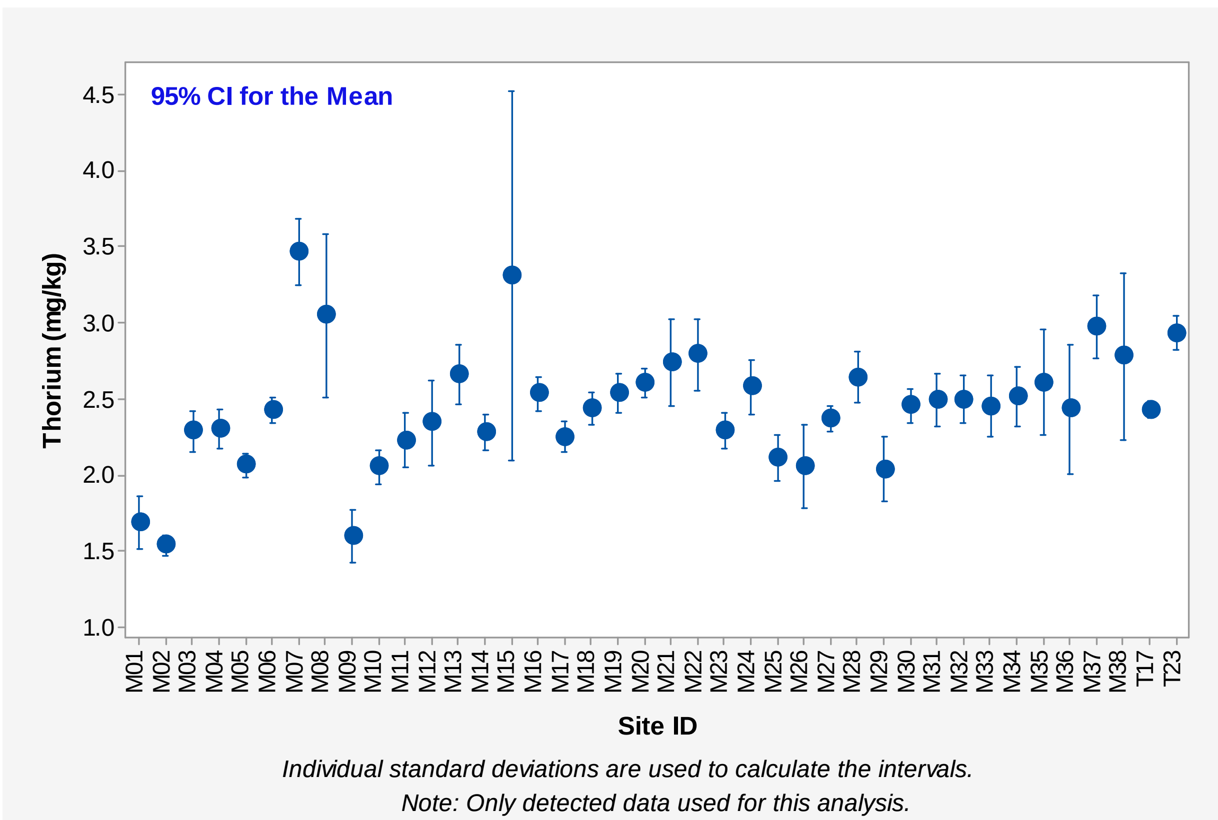


Figure 28. Interval Plot of Thorium Concentrations at AUM Sites

5.3.6 Radium-226

Ra-226 was a primary analyte of interest in the RSE investigations because it is mining related. Elevated gamma radiation is likely in areas around overburden, low-grade ore, or waste rock piles or soils where increased levels of Ra-226 may be present, and Ra-226 is expected to drive risk at most AUM sites. Ra-226 was identified as a COPC, found at concentrations above background at every site evaluated during the RSE investigations. Ra-226 decays via alpha emission, so its concentration can be measured via alpha spectroscopy. Ra-226 also emits gamma radiation of specific energy in about 3 percent of its decays, but because U-235 (commonly associated with radium) emits gamma radiation of similar energy, measured intensity (µR/hr or cpm) of Ra-226 gamma radiation (indication of Ra-226 concentration) can be difficult to discriminate from the intensity of the similar-energy U-235 gamma radiation. Because of its long half-life, Ra-226 concentration can also be determined indirectly by measurements of gamma radiation intensity from its daughters—Rn-222 and associated progeny such as Bi-214. Although Ra-226 is not a major gamma emitter, its short-lived daughters are, and can often be directly correlated to gamma exposure rate.

Evaluations of Ra-226 surface soil concentrations occurred across the sites as discussed in Section 5.2.2. Table 30 summarizes statistics of detected Ra-226 concentrations in surface soils via two different sampling/measurement types, including laboratory analyses of XRF confirmation soil samples and surface soil samples. The field-portable XRF spectroscope was not used for estimation of Ra-226 in surface soils. A gamma-radium correlation also occurred, and is discussed in individual SSRSE reports. In some cases, use of a gamma-radium correlation can generate an accurate and much larger data set; however, in other cases, applying the correlations with use of the gamma survey data may underpredict or overpredict actual Ra-226 soil concentrations, and caution is necessary. Thus, this approach must be evaluated case by case, with reference to data from confirmatory sampling to determine its efficacy. For purposes of this analysis, Ra-226 results provided are only from laboratory analyses of soil samples collected at each site. Figure 29 shows an individual value plot of Ra-226 concentrations in surface soils at respective sites. Average Ra-226 concentrations at the sites ranged between 1.2 pCi/g (Block K Mine) and 48.3 pCi/g (Mesa VI Mine). The highest detected Ra-226 concentration in surface soils was 367 pCi/g at Mesa VI Mine (M13). This site also had the highest average Ra-226 concentration in surface soils. Average Ra-226 concentrations in surface soils exceeded the applied BTV at all the sites evaluated except for Block K Mine, as listed in Table 30. The average Ra-226 concentration in surface soils was about 12 times the applied BTV for a given site, similar to uranium. Figure 30 shows an interval plot of Ra-226 concentrations in surface soils across all sites, indicating the means of surficial Ra-226 concentrations across all the respective sites with a 95 percent confidence interval banding each calculated mean.

Ra-226 levels at AUM sites in the Lukachukai Mountains are, on average, higher than the background levels. At some geographical areas, elevated Ra-226 concentrations are present in the natural environment, particularly in the southern Lukachukai Mountains. For example, at BSA-32, Ra-226 levels were found to exceed 20 pCi/g. At all sites, Ra-226 concentrations were found higher in the areas where mine waste materials are present. Higher Ra-226 concentration is an excellent indicator of presence of mine waste at the Tronox mines within the Northern AUM Region. Individual maps of surface and subsurface Ra-226 concentrations, along with more detailed statistical analyses for every AUM site and AUM-related site, are in SSRSEs in Appendix H. Ra-226 was found to be a COPC, detected above background levels at all sites evaluated. Further discussion of COPCs across all the sites is in Section 6.0. Ra-226 results from non-AUM Target sites are conveyed in Appendix I.

Table 30. Summary Statistics of Radium-226 Concentrations in Surface Soils

Site Name	Site ID	Applied BTV for Ra-226 (pCi/g)	n	Minimum (pCi/g)	Maximum (pCi/g)	Standard Deviation (pCi/g)	Average (pCi/g)	Median (pCi/g)	RSD
Brodie 1 Mine	M1	0.94	7	1.13	19.6	6.70	6.37	3.80	105%
Block K Mine	M2	2.38	16	0.62	4.79	1.31	1.24	0.73	106%
Mesa I Mine 10	M3	2.23	11	1.15	65.0	22.0	16.1	5.34	137%
Mesa I Mine 11	M4	2.23	18	0.63	102	33.3	25.1	10.7	133%
Mesa I Mine 12	M5	2.23	22	0.61	152	34.5	21.6	7.70	159%
Mesa I Mine 13	M6	2.23	34	0.43	128	23.7	14.0	7.44	169%
Mesa I Mine 14	M7	2.23	21	0.70	195	52.1	37.3	17.6	140%
Mesa I Mine 15	M8	2.23	32	0.58	139	30.6	17.4	5.24	176%
Mesa I 1/4 Mine	M9	2.23	5	1.80	110	47.5	25.1	4.00	189%
Mesa I 1/2 Mine	M10	1.56	10	1.20	52.1	17.5	13.4	4.33	131%
Henry Phillips Mine	M11	0.69	12	1.10	191	53.9	23.3	4.50	231%
Mesa I 1/2, West Mine	M12	0.69	6	0.95	5.2	1.95	2.6	1.91	74%
Mesa VI Mine	M13	2.23	10	0.70	367	114	48.3	3.10	236%
Frank Jr. Mine	M14	1.98	15	0.66	92.0	31.0	24.8	5.27	125%
Mesa V Incline	M15	1.54	18	0.73	150	36.8	23.4	7.87	158%
Mesa V Adit	M16	2.23	18	1.79	76.7	22.7	29.1	29.3	78%
Mesa V Mine – 103	M17	1.57	11	1.10	149	55.9	44.3	9.90	126%
Mesa V Mine – 508	M18	0.95	15	0.60	292	82.4	32.8	2.10	251%
Mesa IV 1/2 Mine and Simpson 181	M19	1.57	12	1.80	157	60.2	42.8	5.10	141%
Mesa IV, Mine No. 1	M20	2.23	32	0.81	278	55.2	29.4	6.50	188%
Mesa IV, Mine No. 2	M21	2.78	43	0.79	307	56.0	28.1	9.70	199%
Mesa IV, Mine No. 3	M22	2.23	13	1.55	39.3	10.1	9.93	7.30	102%
Mesa IV, West Mine	M23	2.23	16	0.68	76.2	19.4	8.34	1.12	233%
Mesa II Pit	M24	2.78	14	0.59	40.5	10.5	5.75	2.01	183%
Mesa I 3/4 Incline	M25	0.87	10	0.56	31.6	10.0	8.32	4.60	120%
Mesa I 3/4 Mine No. 2, P-150	M26	0.87	5	0.81	38.5	16.3	11.2	1.28	146%
Mesa II, Mine No. 1 & 2, P-21	M27	0.87	23	0.84	55.5	18.2	14.0	6.64	130%
Mesa II, Mine No. 1, P-150	M28	0.85	19	0.80	136	45.3	27.3	5.00	166%
Mesa II, Mine 4	M29	2.78	12	0.56	21.6	7.39	5.48	1.00	135%
Mesa II 1/2 Mine	M30	0.87	17	0.39	115	30.3	20.9	8.90	145%
Mesa II 1/2, Mine 4	M31	0.87	11	1.59	103	29.7	13.7	4.85	217%
Mesa III Mine	M32	1.62	12	1.10	141	41.2	24.6	5.20	167%
Knife Edge Mesa Mine	M33	20.2	9	1.30	152	52.0	35.2	10.4	148%
Black No. 1 Mine	M34	4.15	12	3.60	122	36.1	30.3	14.4	119%
Black No. 2 Mine	M35	2.23	11	0.98	95.0	27.5	13.9	4.29	198%
Black No. 2 Mine (West)	M36	4.15	9	1.90	107	33.9	17.8	5.50	190%
Flag No. 1 Mine	M37	4.15	15	1.40	145	41.2	29.2	5.40	141%
Step Mesa Mine	M38	2.23	4	5.94	36.7	14.7	14.7	8.06	100%
Mesa I Camp	T17	2.23	53	0.67	166	23.2	7.56	2.09	307%
NA-0344B	T23	1.54	14	1.43	8.80	2.87	4.41	3.05	65%

Notes:

Only statistics for detected data are listed in this table.

BTV Background threshold value

n Number of analytical results

pCi/g Picocuries per gram

RSD Relative standard deviation

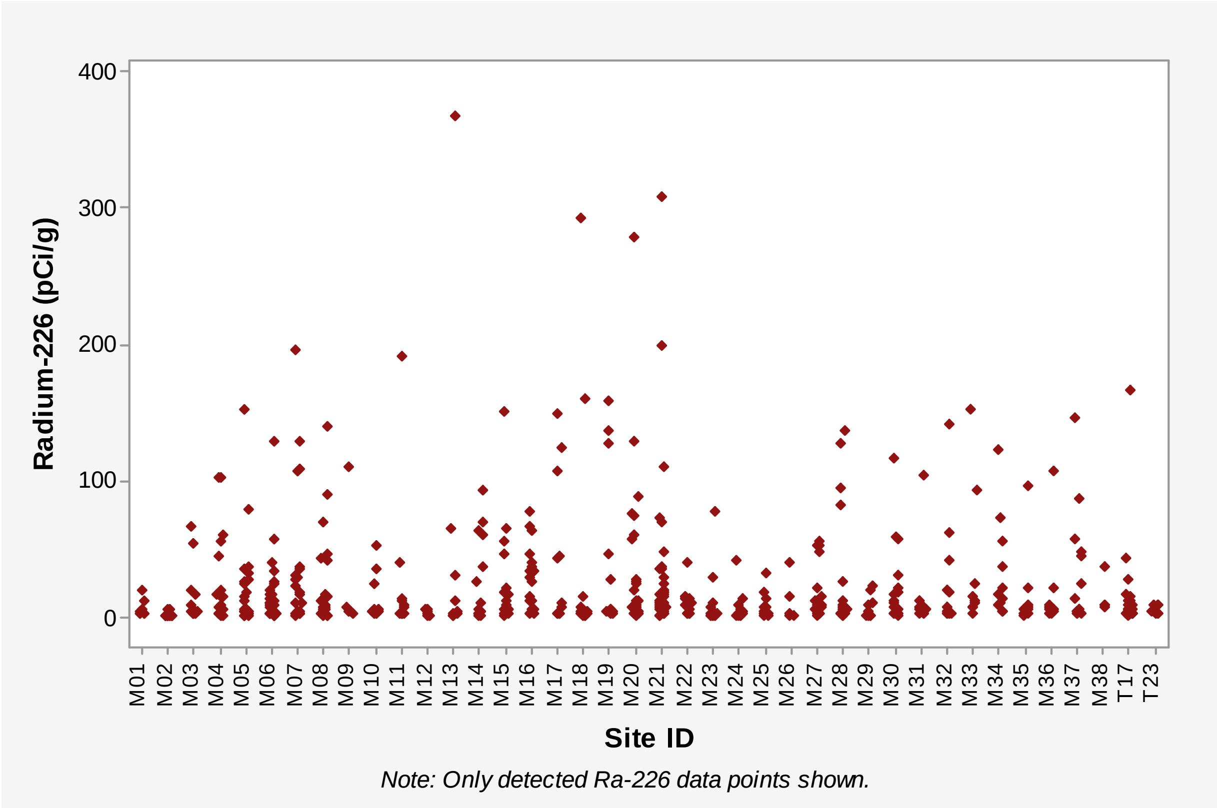


Figure 29. Individual Value Plot of Radium-226 Concentrations in Surface Soils

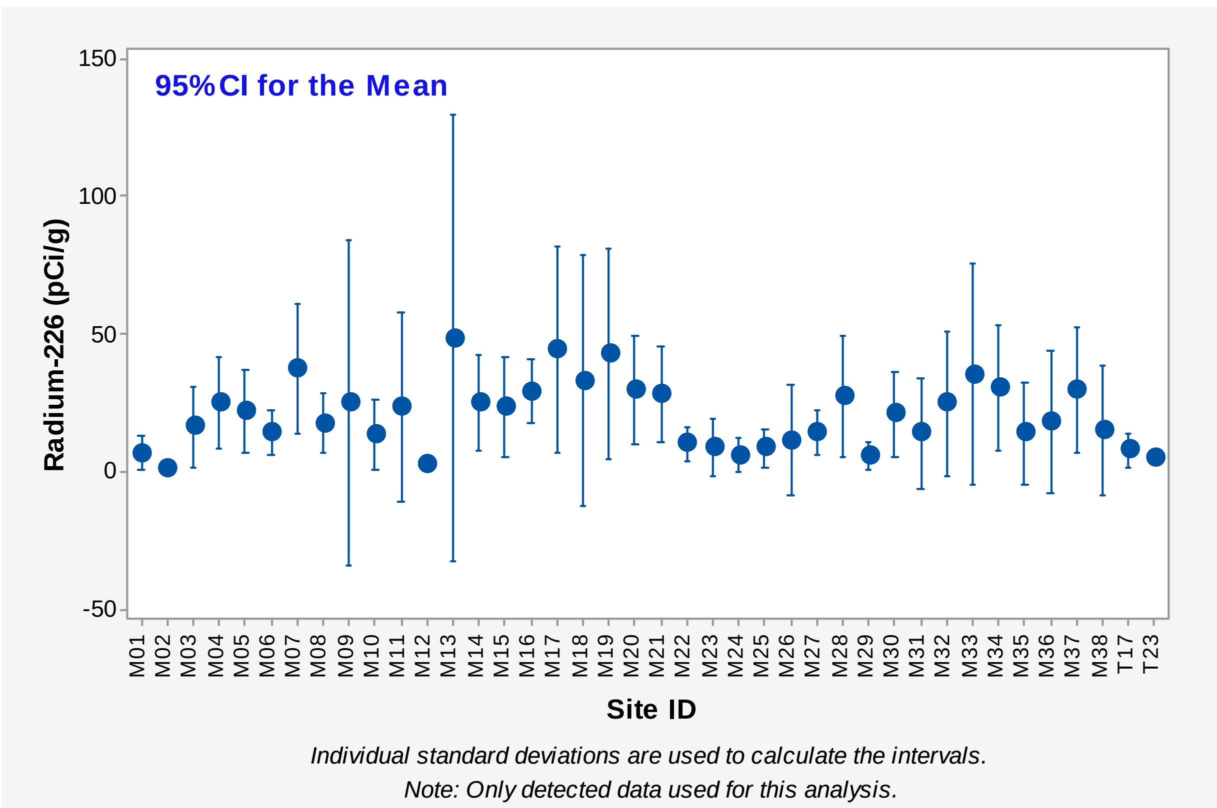


Figure 30. Interval Plot of Radium-226 Concentrations in Surface Soils

5.3.7 Selenium

Selenium was a primary analyte of interest in the RSE investigations. Selenium has an atomic number of 34 and an average crustal abundance of 0.05 mg/kg. It is associated with uranium roll-front deposits where its concentrations can reach 168 parts per million (ppm) (Bullock and Parnell 2017). Selenium is an essential micronutrient for animals.

Evaluations of selenium surface soil concentrations occurred across the sites as discussed in Section 5.2.2. Table 31 summarizes statistics of detected selenium concentrations in surface soils via two different sampling/measurement types, including laboratory analyses of XRF confirmation soil samples and surface soil samples. The field-portable XRF spectrometer was not used for estimation of selenium in surface soils. Figure 31 shows an individual value plot of selenium concentrations in surface soils at respective sites. The average detected selenium concentration in surface soils exceeded the applied BTV at 33 of the 40 sites listed in Table 31. Average selenium concentrations at the sites ranged between 0.38 mg/kg (Block K Mine) and 7.4 mg/kg (Mesa IV 1/2 Mine and Simpson 181). The maximum selenium concentration detected in surface soils across all sites ranged between 0.46 mg/kg at Block K Mine (M2) and 24 mg/kg at Mesa V Incline (M15). The average selenium concentration in surface soils exceeded the applied BTV at 38 of the 40 sites as listed in Table 31. The average selenium concentration in surface soils was about twice the applied BTV for a given site. Figure 32 shows an interval plot of selenium concentrations in surface soils across all sites, indicating the means of surficial selenium concentrations across all the respective sites with a 95 percent confidence interval banding each calculated mean.

Selenium levels within the Lukachukai Mountains are, on average, higher than the crustal abundance, and high selenium concentrations can typically be associated with mining waste. Selenium concentrations measured at AUM sites, on average, were twice the background level, but the average at one site was as high as eight times background level. Maximum selenium concentration detected in surface soils at potentially impacted sites was 24 mg/kg compared to a maximum detected selenium concentration in background soil samples of 3.1 mg/kg. Higher selenium concentration is a potential indicator of presence of mine waste at the Tronox mines within the Northern AUM Region. Selenium was found to be a COPC, detected at concentrations above background levels at 39 of the 40 sites for which a background comparison analysis occurred. Further discussion of COPCs across all the sites is in Section 6.0. Selenium results from non-AUM Target sites are in Appendix I. Individual maps of surface and subsurface selenium concentrations, along with more detailed statistical analyses for every AUM site and AUM-related site, are in SSRSEs in Appendix H.

Table 31. Summary Statistics of Selenium Concentration in Surface Soils

Site Name	Site ID	Applied BTV for Selenium (mg/kg)	n	Minimum (mg/kg)	Maximum (mg/kg)	Standard Deviation (mg/kg)	Average (mg/kg)	Median (mg/kg)	RSD
Brodie 1 Mine	M1	0.46	7	0.36	0.77	0.16	0.49	0.44	31%
Block K Mine	M2	0.47	15	0.32	0.46	0.05	0.38	0.37	13%
Mesa I Mine 10	M3	0.93	11	0.44	1.4	0.34	0.90	0.88	37%
Mesa I Mine 11	M4	0.77	17	0.34	5.0	1.48	1.62	0.95	91%
Mesa I Mine 12	M5	0.77	22	0.39	6.2	1.71	1.63	0.91	105%
Mesa I Mine 13	M6	0.77	34	0.34	2.7	0.58	1.07	0.90	54%
Mesa I Mine 14	M7	0.77	21	0.49	7.4	1.45	1.34	1.10	108%
Mesa I Mine 15	M8	0.77	29	0.39	7.0	1.42	1.33	0.83	107%
Mesa I 1/4 Mine	M9	0.93	5	0.29	1.3	0.42	0.77	0.90	55%
Mesa I 1/2 Mine	M10	0.85	10	0.43	1.9	0.56	0.86	0.54	65%
Henry Phillips Mine	M11	0.77	12	0.36	3.0	0.83	1.04	0.61	80%
Mesa I 1/2, West Mine	M12	0.77	5	0.30	0.47	0.07	0.40	0.43	17%
Mesa VI Mine	M13	0.99	11	0.44	18.0	5.13	2.70	1.00	190%
Frank Jr. Mine	M14	0.90	15	0.49	2.2	0.42	1.06	0.95	39%
Mesa V Incline	M15	0.93	18	0.81	24	6.94	4.53	1.65	153%
Mesa V Adit	M16	0.99	19	0.42	7.3	1.80	2.22	1.60	81%
Mesa V Mine – 103	M17	0.84	11	0.49	12	4.04	3.57	1.00	113%
Mesa V Mine – 508	M18	0.78	14	0.36	2.9	0.70	0.94	0.65	74%
Mesa IV 1/2 Mine and Simpson 181	M19	0.84	12	1.10	22	8.52	7.43	1.35	115%
Mesa IV, Mine No. 1	M20	0.94	34	0.37	7.0	1.47	1.65	1.10	89%
Mesa IV, Mine No. 2	M21	0.94	43	0.42	7.6	1.26	1.49	1.10	85%
Mesa IV, Mine No. 3	M22	0.94	13	0.73	3.1	0.71	1.36	1.20	52%
Mesa IV, West Mine	M23	0.99	16	0.37	2.4	0.58	0.97	0.81	60%
Mesa II Pit	M24	0.94	14	0.46	5.4	1.27	1.20	0.81	106%
Mesa I 3/4 Incline	M25	1.0	8	0.38	2.4	0.66	1.01	0.90	65%
Mesa I 3/4 Mine No. 2, P-150	M26	1.0	5	0.75	3.9	1.38	1.75	0.87	79%
Mesa II, Mine No. 1 & 2, P-21	M27	0.98	23	0.42	2.5	0.64	1.29	1.00	50%
Mesa II, Mine No. 1, P-150	M28	0.92	20	0.31	7.5	2.03	1.63	0.94	124%
Mesa II, Mine 4	M29	0.94	12	0.39	2.5	0.76	1.13	0.83	68%
Mesa II 1/2 Mine	M30	1.0	16	0.31	8.4	2.59	2.29	1.05	113%
Mesa II 1/2, Mine 4	M31	1.0	10	0.34	3.5	1.03	1.18	0.72	87%
Mesa III Mine	M32	0.99	12	0.62	12	3.20	2.31	0.91	139%
Knife Edge Mesa Mine	M33	2.1	9	0.45	2.7	0.83	1.40	1.10	60%
Black No. 1 Mine	M34	0.98	12	0.47	3.3	0.89	1.46	1.20	61%
Black No. 2 Mine	M35	0.82	11	0.39	2.3	0.60	1.26	1.40	48%
Black No. 2 Mine (West)	M36	0.98	9	0.38	2.1	0.55	0.84	0.73	65%
Flag No. 1 Mine	M37	0.98	15	0.38	2.9	0.92	1.32	0.85	70%
Step Mesa Mine	M38	0.82	4	1.00	3.1	1.03	2.13	2.20	49%
Mesa I Camp	T17	0.99	52	0.35	2.4	0.34	0.68	0.57	50%
NA-0344B	T23	0.93	14	0.77	2.7	0.74	1.67	1.45	44%

Notes:
Only statistics for detected data are listed in this table.

BTV Background threshold value
mg/kg Milligrams per kilogram
n Number of analytical results
RSD Relative standard deviation

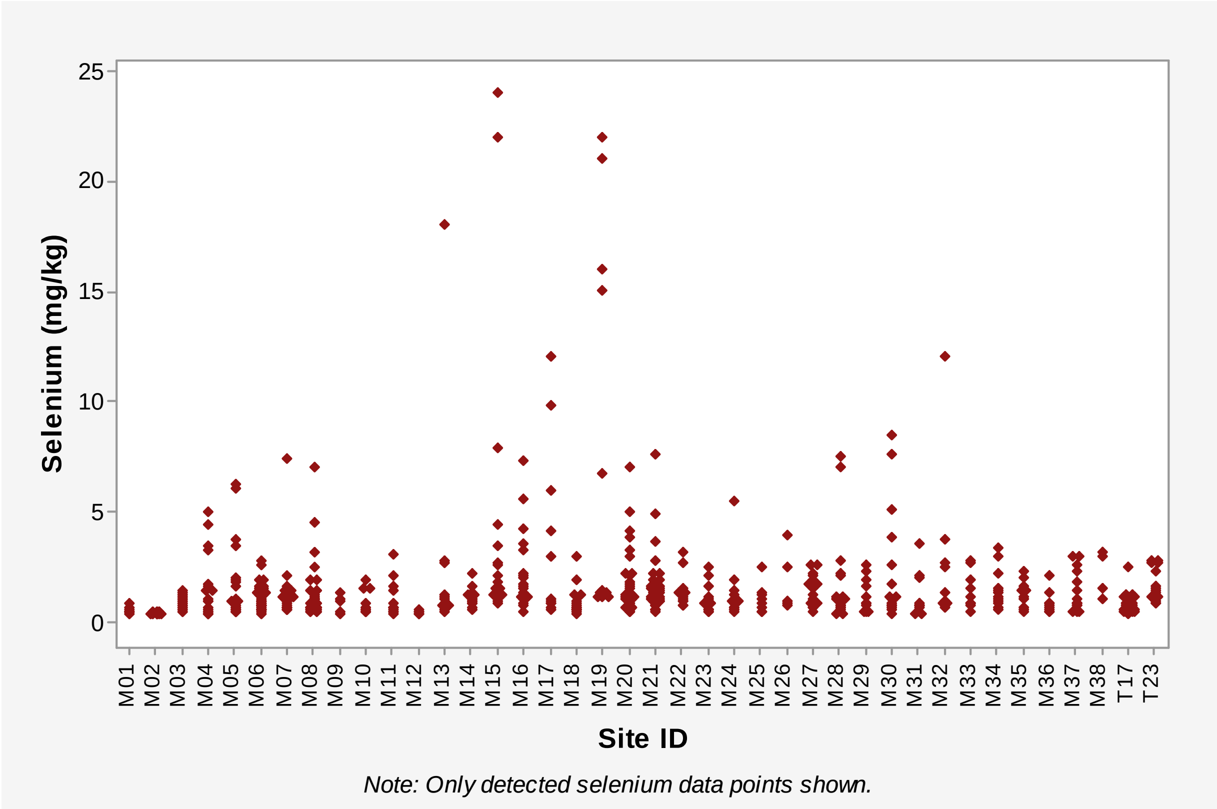


Figure 31. Individual Value Plot of Selenium Concentrations in Surface Soils

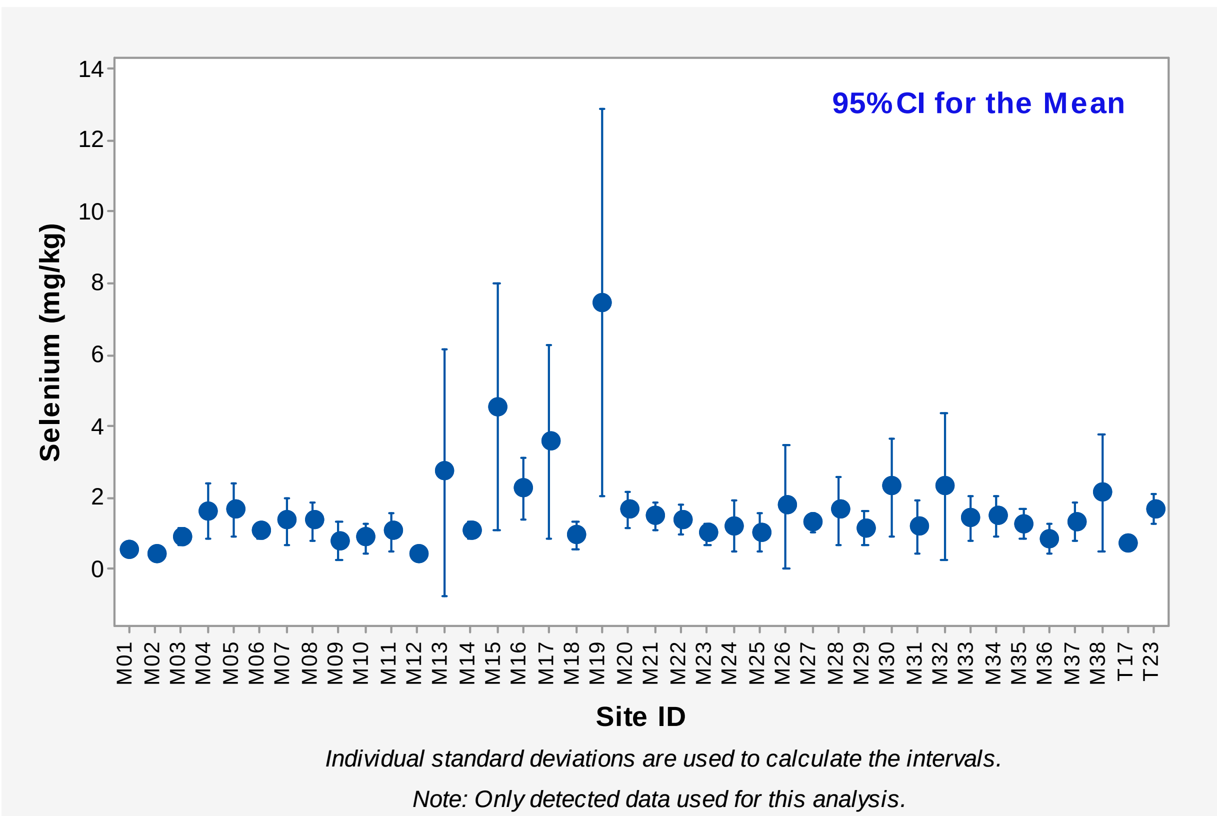


Figure 32. Interval Plot of Selenium Concentrations in Surface Soils

5.3.8 Uranium

Uranium was a primary analyte of interest in the RSE investigations, and is a naturally occurring radioactive metal. The atomic number of uranium is 92, and the average crustal abundance is 2 to 4 mg/kg (ASTDR 2013). In nature, uranium is found as U-238, U-235, and U-234. Almost all uranium found in nature is U-238 (>99.27 percent by mass), with small amounts of U-235 (0.7 percent) and U-234 (0.006 percent). Both ICP-MS and field-portable XRF technology were used during this project for measurements of trace elemental uranium concentrations in soils at the sites. Uranium concentrations among the BSAs presented in Appendix A ranged from 0.09 to 22 mg/kg, with an average of 1.1 mg/kg. Risk-based soil screening levels for uranium typically exceed 1 mg/kg. Because most background soil concentrations of uranium reported in this study were close to the detection limit, the XRF spectrometer was not as useful for determining low concentrations of uranium as it was for determining low concentrations of other target elements. However, the XRF spectrometer was effective in determining higher concentrations of uranium associated with AUM sites, and will be useful for comparing soil concentrations to risk-based screening levels.

Evaluations of uranium surface soil concentrations occurred across the sites as discussed in Section 5.2.2. Table 32 summarizes statistics of detected uranium concentrations in surface soils via the three sampling/measurement types, including in situ XRF analysis corrected to laboratory predicted values. Figure 33 shows an individual value plot of uranium concentrations in surface soils at respective sites. At 24 of the 40 sites listed in Table 32, average uranium concentration in surface soils exceeded 10 mg/kg. The average uranium concentration detected in surface soil ranged between 1.2 mg/kg (Block K Mine) and 48 mg/kg (Mesa V Mine – 103) across all sites. The maximum uranium concentration detected in surface soils across all sites ranged between 6.9 mg/kg (Mesa I 1/2, West Mine) and 1,264 mg/kg (Mesa III Mine). Average uranium concentration in surface soils exceeded the applied BTV at 39 of the 40 sites as listed in Table 32. Average uranium concentration in surface soils was about 12 times the applied BTV for a given site. Figure 34 shows an interval plot of uranium concentrations in surface soils across all sites, indicating the means of surficial uranium concentrations across all the respective sites with a 95 percent confidence interval banding each calculated mean.

Uranium levels within the Lukachukai Mountains are, on average, higher than the crustal abundance of uranium reported in ASTDR (2013). At certain geographical areas of the mountains, elevated concentrations of uranium were detected in the natural environment, particularly in the southern Lukachukai Mountains. For example, at BSA-32, natural uranium levels were found to exceed 20 mg/kg. At that same site, as expected, elevated concentrations of Ra-226 were detected. At all sites, uranium concentrations were found higher in areas where mine waste materials are present. Higher uranium concentration is an excellent indicator of presence of mine waste at the Tronox mines within the Northern AUM Region. Individual maps of surface and subsurface uranium concentrations, along with more detailed statistical analyses for every AUM site and AUM-related site, are in SSRSEs in Appendix H. Higher uranium concentration is a good indicator of presence of mine waste at all sites, and average levels of uranium at most AUM sites are 10 times greater than background levels. Uranium was found to be a COPC, identified at concentrations above background levels at all sites evaluated. Further discussion of COPCs across all the sites is in Section 6.0. Uranium results from non-AUM Target sites are conveyed in Appendix I.

Table 32. Summary Statistics of Surface Soil Concentrations of Uranium

Site Name	Site ID	Applied BTV for Uranium (mg/kg)	n	Minimum (mg/kg)	Maximum (mg/kg)	Standard Deviation (mg/kg)	Average (mg/kg)	Median (mg/kg)	RSD
Brodie 1 Mine	M1	0.59	51	0.17	38	6.5	5.0	2.8	131%
Block K Mine	M2	1.5	34	0.09	8.2	1.6	1.2	0.6	136%
Mesa I Mine 10	M3	0.91	80	0.16	86	13	8.7	5.0	147%
Mesa I Mine 11	M4	1.5	241	0.09	320	29	11	3.7	257%
Mesa I Mine 12	M5	1.5	362	0.15	366	41	28	9.3	149%
Mesa I Mine 13	M6	0.91	344	0.10	210	21	9.5	3.7	220%
Mesa I Mine 14	M7	1.5	271	0.19	349	35	20	13	175%
Mesa I Mine 15	M8	1.5	191	0.08	180	24	12	3.6	194%
Mesa I 1/4 Mine	M9	0.91	40	0.30	842	134	32	5.7	412%
Mesa I 1/2 Mine	M10	1.7	85	0.29	170	31	18	5.0	174%
Henry Phillips Mine	M11	0.67	93	0.13	230	25	8.5	2.9	299%
Mesa I 1/2, West Mine	M12	0.67	58	0.10	6.9	1.5	2.2	1.7	69%
Mesa VI Mine	M13	1.5	147	0.10	710	60	10	2.4	594%
Frank Jr. Mine	M14	1.7	173	0.10	277	33	16	4.9	203%
Mesa V Incline	M15	1.3	147	0.45	237	28	15	6.6	186%
Mesa V Adit	M16	1.5	255	0.26	152	28	22	12	127%
Mesa V Mine – 103	M17	1.3	152	0.08	404	86	48	7.9	179%
Mesa V Mine – 508	M18	0.53	184	0.14	300	33	8.2	2.7	403%
Mesa IV 1/2 Mine and Simpson 181	M19	1.3	104	0.10	845	104	36	6.9	288%
Mesa IV, Mine No. 1	M20	1.5	448	0.08	370	47	21	5.4	230%
Mesa IV, Mine No. 2	M21	2.7	656	0.12	660	57	19	6.8	307%
Mesa IV, Mine No. 3	M22	1.5	137	0.99	71	9.1	8.2	6.0	110%
Mesa IV, West Mine	M23	1.5	177	0.17	86	9.6	4.9	1.9	196%
Mesa II Pit	M24	2.7	175	0.11	34	5.6	5.9	4.0	96%
Mesa I 3/4 Incline	M25	0.64	95	0.19	74	13	7.6	3.2	176%
Mesa I 3/4 Mine No. 2, P-150	M26	0.64	47	0.13	73	15	8.2	2.2	182%
Mesa II, Mine No. 1 & 2, P-21	M27	0.64	338	0.25	320	20	8.6	5.5	230%
Mesa II, Mine No. 1, P-150	M28	1.1	231	0.19	660	77	28	5.8	274%
Mesa II, Mine 4	M29	2.7	81	0.13	37	6.8	5.2	2.0	131%
Mesa II 1/2 Mine	M30	0.64	290	0.16	360	38	14	3.9	273%
Mesa II 1/2, Mine 4	M31	0.64	77	0.21	278	39	13	4.1	290%
Mesa III Mine	M32	1.1	193	0.32	1,264	100	22	4.4	446%
Knife Edge Mesa Mine	M33	21	127	0.15	230	26	12	6.8	211%
Black No. 1 Mine	M34	3.4	134	0.62	544	54	22	9.3	244%
Black No. 2 Mine	M35	1.5	107	0.10	90	15	10	5.4	150%
Black No. 2 Mine (West)	M36	3.4	50	0.24	224	34	16	7.3	221%
Flag No. 1 Mine	M37	3.4	119	0.55	489	75	36	7.3	206%
Step Mesa Mine	M38	1.5	16	3.3	45	12	15	10	79%
Mesa I Camp	T17	1.5	771	0.09	410	16	5.4	2.8	291%
NA-0344B	T23	1.3	110	0.11	29	6.0	6.8	4.8	87%

Notes:
Only statistics for detected data are listed in this table.

BTV Background threshold value
mg/kg Milligrams per kilogram
n Number of analytical results/corrected XRF measurements
RSD Relative standard deviation

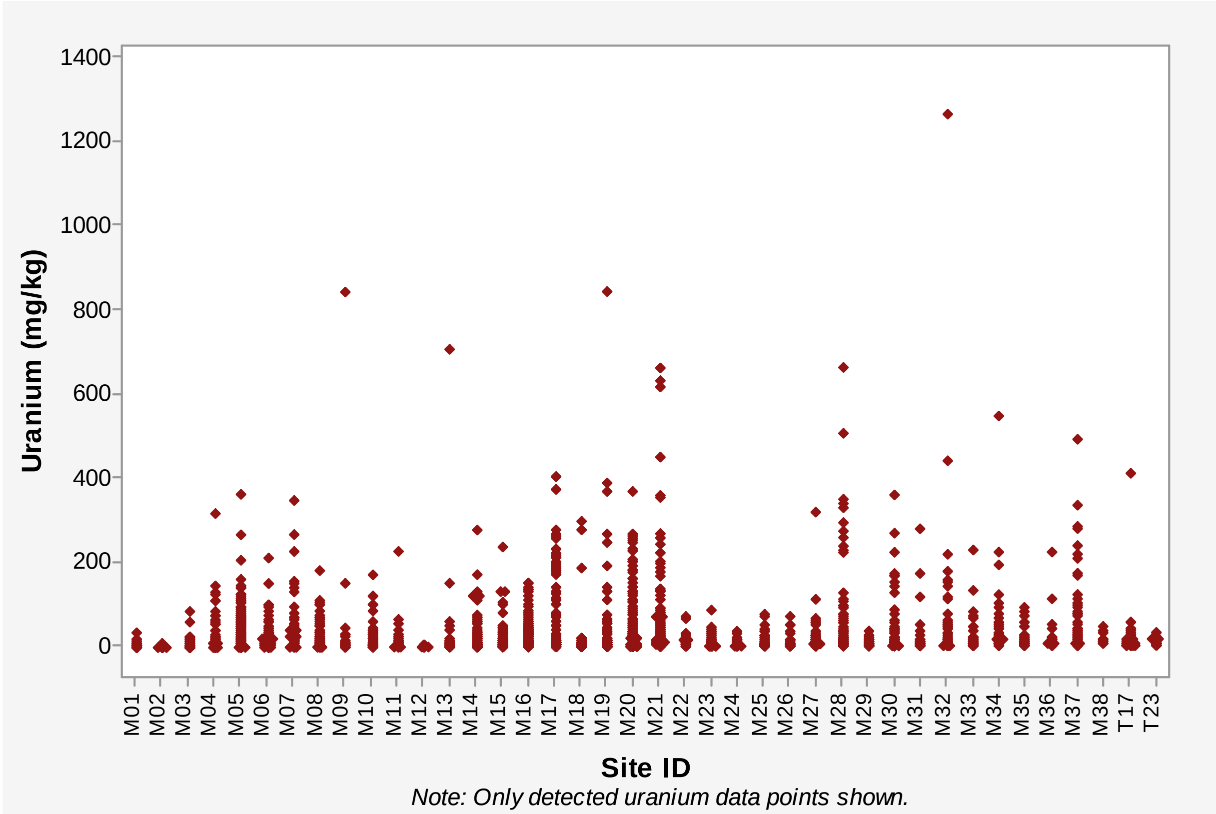


Figure 33. Individual Value Plot of Uranium Concentrations in Surface Soils

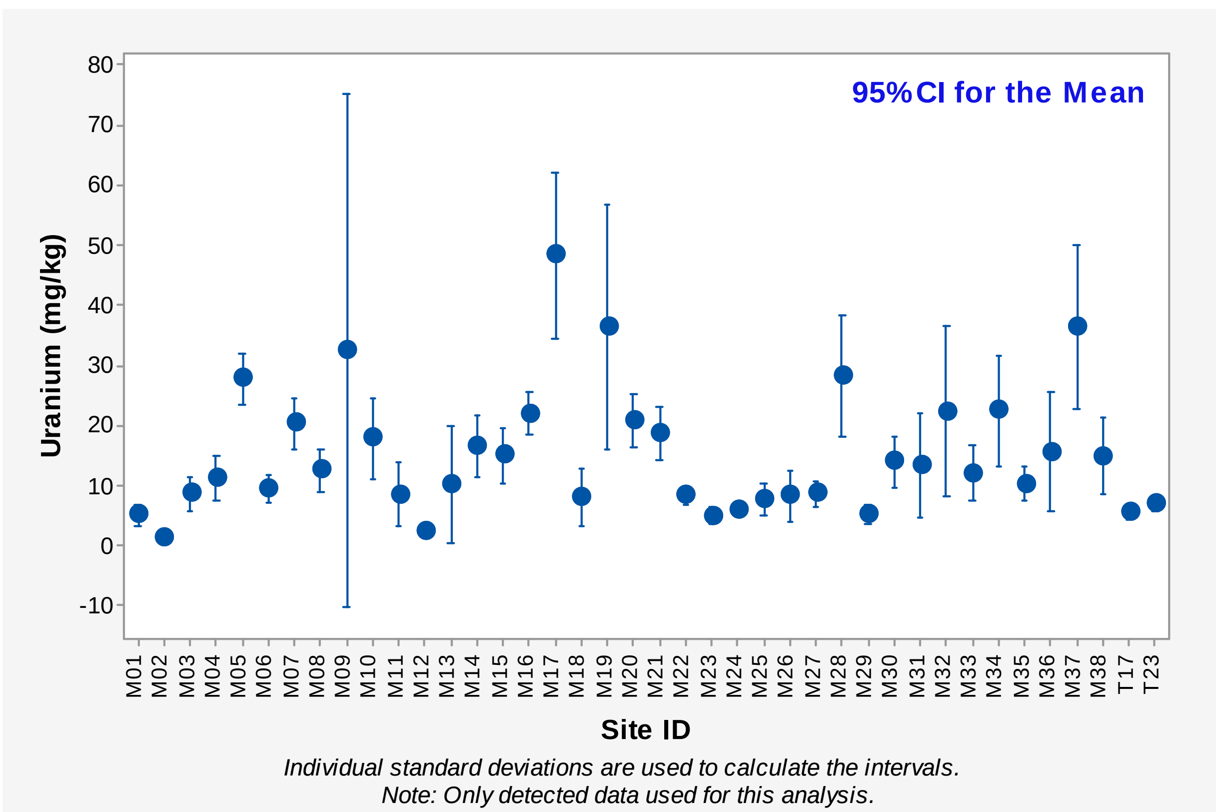


Figure 34. Interval Plot of Uranium Concentrations in Surface Soils

5.3.9 Vanadium

Vanadium was a primary analyte of interest in the RSE investigations. The atomic number of vanadium is 23, and the average crustal abundance is approximately 100 mg/kg. Concentrations of naturally occurring vanadium in surface soils typically range from 20 to 500 mg/kg (USEPA 2006a). Both ICP-MS and field-portable XRF technology were used during this project for determination of trace elemental vanadium concentrations in soils at the sites. Vanadium concentrations among the BSAs presented in Appendix A ranged from 3.2 to 330 mg/kg, with an average of 13 mg/kg. Risk-based soil screening levels for vanadium typically exceed 50 mg/kg (UESPA 2019). Because the vanadium detection limit is 3 mg/kg by use of the XRF analyzer, this was found to be a useful tool to evaluate soil concentrations with reference to background concentrations and risk-based soil screening levels. ICP-MS and XRF analytical methods both provide dependable measures of vanadium concentration.

Evaluation of vanadium surface soil concentrations occurred across the sites as discussed in Section 5.2.2. Table 33 summarizes statistics of detected vanadium concentrations in surface soils via the three sampling/measurement types, including in situ XRF analysis corrected to laboratory predicted values. Figure 35 shows an individual value plot of vanadium concentrations in surface soils at each site. Across all sites, vanadium levels were, on average, four times the applied BTV for vanadium. At nine sites, vanadium concentrations exceeded 100 mg/kg. Average vanadium concentrations at the sites ranged between 22 mg/kg (Block K Mine) and 180 mg/kg (Frank Jr. Mine). The maximum vanadium concentration detected in surface soils across all sites ranged between 74 mg/kg (NA-0344B) and 3,387 mg/kg (Mesa I 1/4 Mine). Average vanadium concentration in surface soils exceeded the applied BTV at all the sites, as listed in Table 33. The average vanadium concentration in surface soils was about five times the applied BTV for a given site, and the average value exceeded the applied BTV for vanadium at every site as well. Figure 36 shows an interval plot of vanadium concentrations in surface soils across all sites, indicating the means of surficial vanadium concentrations across all the respective sites with a 95 percent confidence interval banding each calculated mean.

Vanadium levels within the Lukachukai Mountains are, on average, within the range of the typical crustal abundance of vanadium. At certain geographical areas of the mountains, elevated vanadium concentrations were detected in the natural environment. Maximum detected vanadium concentration in surface soils at potentially impacted sites was 3,387 mg/kg—10 times higher than the maximum measured vanadium concentration in surface soils at background sites (330 mg/kg). Higher vanadium concentration is an excellent indicator of presence of mine waste at the Tronox mines within the Northern AUM Region. Individual maps of surface and subsurface vanadium concentrations, along with more detailed statistical analyses for every AUM site and AUM-related site, are in SSRSEs in Appendix H. Higher vanadium concentration is a good indicator of presence of mine waste at all sites. Vanadium was found to be a COPC, detected at concentrations exceeding background levels at 39 of the 40 sites evaluated. Further discussion of COPCs across all the sites is in Section 6.0. Vanadium results from non-AUM Target sites are conveyed in Appendix I.

Table 33. Summary Statistics of Vanadium Concentration in Surface Soils

Site Name	Site ID	Applied BTV for Vanadium (mg/kg)	n	Minimum (mg/kg)	Maximum (mg/kg)	Standard Deviation (mg/kg)	Average (mg/kg)	Median (mg/kg)	RSD
Brodie 1 Mine	M1	8.2	32	8.2	170	50	57	41	88%
Block K Mine	M2	11	24	6.2	166	33	22	8.6	148%
Mesa I Mine 10	M3	13	81	17	290	52	74	59	70%
Mesa I Mine 11	M4	15	270	12	1,900	152	97	51	157%
Mesa I Mine 12	M5	15	344	6.6	1,574	155	124	64	125%
Mesa I Mine 13	M6	13	291	5.9	820	82	62	36	132%
Mesa I Mine 14	M7	15	161	8.2	977	131	93	49	141%
Mesa I Mine 15	M8	15	199	13	1,100	139	88	49	158%
Mesa I 1/4 Mine	M9	13	40	13	3,387	533	152	49	350%
Mesa I 1/2 Mine	M10	13	60	11	250	66	75	48	88%
Henry Phillips Mine	M11	12	104	9.3	2,700	338	166	59	203%
Mesa I 1/2, West Mine	M12	12	53	11	127	27	42	34	64%
Mesa VI Mine	M13	20	82	8.6	1,800	288	90	27	320%
Frank Jr. Mine	M14	22	152	10	1,027	222	180	71	124%
Mesa V Incline	M15	15	133	8.7	881	115	91	42	127%
Mesa V Adit	M16	24	230	4.6	1,124	139	130	76	107%
Mesa V Mine – 103	M17	22	141	10	813	186	161	68	116%
Mesa V Mine – 508	M18	13	92	7.9	1,245	182	62	25	295%
Mesa IV 1/2 Mine and Simpson 181	M19	22	78	16	1,113	230	141	45	163%
Mesa IV, Mine No. 1	M20	24	355	8.1	1,200	201	140	79	144%
Mesa IV, Mine No. 2	M21	31	605	14	1,434	142	91	50	156%
Mesa IV, Mine No. 3	M22	24	131	16	319	68	99	84	69%
Mesa IV, West Mine	M23	24	108	8.2	420	71	56	26	127%
Mesa II Pit	M24	31	132	6.4	320	47	45	31	104%
Mesa I 3/4 Incline	M25	22	34	5.1	196	47	46	29	102%
Mesa I 3/4 Mine No. 2, P-150	M26	22	35	6.8	284	55	41	26	135%
Mesa II, Mine No. 1 & 2, P-21	M27	22	200	7.9	422	43	42	31	104%
Mesa II, Mine No. 1, P-150	M28	12	137	5.1	1,000	144	74	31	195%
Mesa II, Mine 4	M29	31	79	9.9	860	116	70	33	166%
Mesa II 1/2 Mine	M30	22	200	5.3	660	92	65	32	142%
Mesa II 1/2, Mine 4	M31	22	49	6.9	860	150	69	31	217%
Mesa III Mine	M32	14	166	11	954	133	70	34	189%
Knife Edge Mesa Mine	M33	42	89	9.7	535	95	57	28	165%
Black No. 1 Mine	M34	31	127	12	586	87	76	46	114%
Black No. 2 Mine	M35	24	72	9.2	290	44	35	26	125%
Black No. 2 Mine (West)	M36	31	40	13	400	83	57	32	145%
Flag No. 1 Mine	M37	31	96	8.1	2,472	356	174	39	205%
Step Mesa Mine	M38	24	16	23	170	35	50	40	70%
Mesa I Camp	T17	24	466	7.5	680	35	31	24	112%
NA-0344B	T23	15	80	14	74	15	32	26	48%

Notes:

Only statistics for detected data are listed in this table.

BTV Background threshold value
mg/kg Milligrams per kilogram
n Number of analytical results/corrected XRF measurements
RSD Relative standard deviation

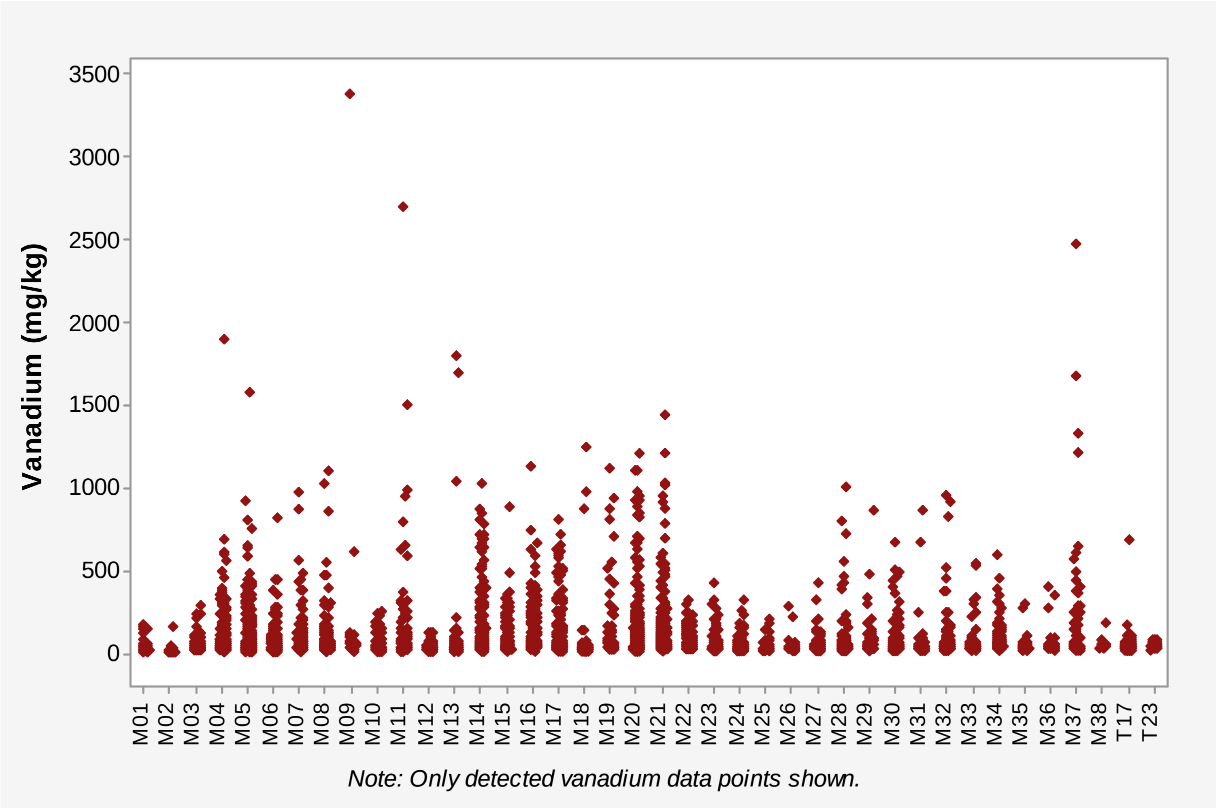


Figure 35. Individual Value Plot of Vanadium Concentrations in Surface Soils

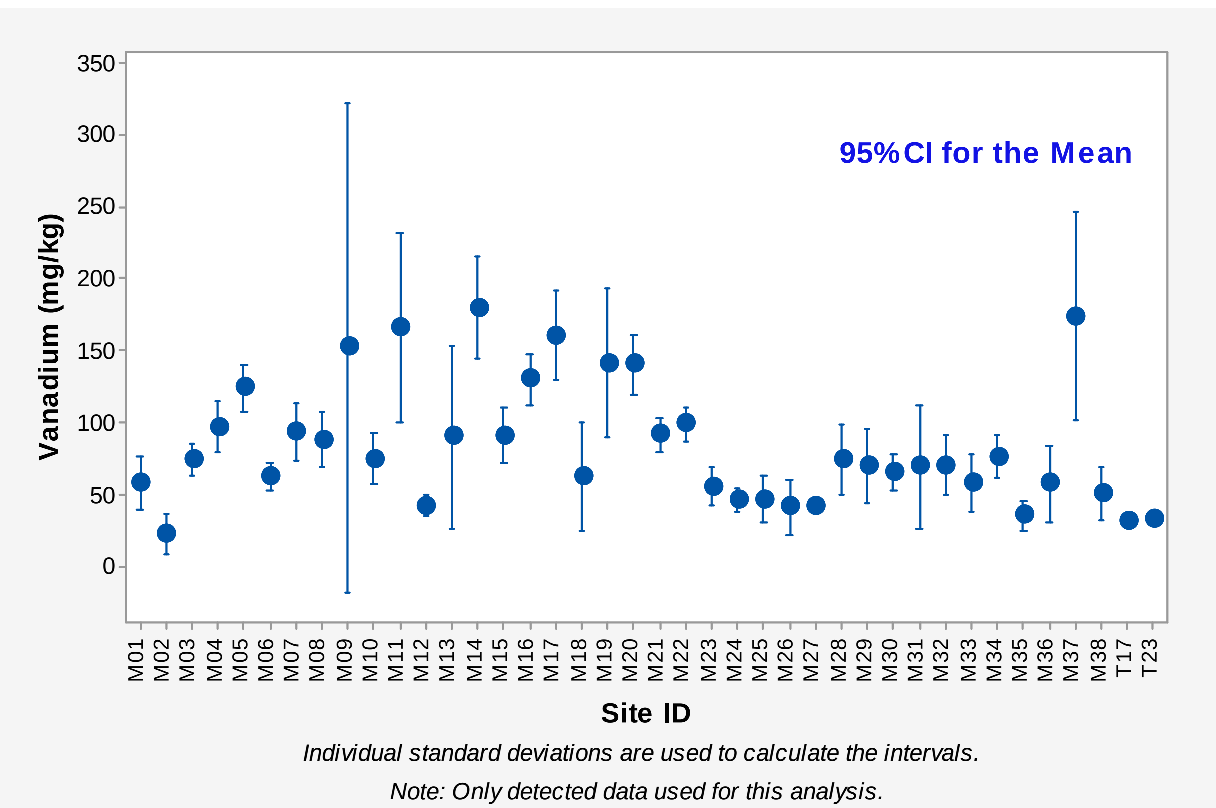


Figure 36. Interval Plot of Vanadium Concentrations in Surface Soils

5.4 RADON MONITORING

Tetra Tech performed radon monitoring at BSAs, AUM sites, and Target sites using alpha track Etch detectors. Concentrations of radon gas at each site are listed in Table 34. A total of 34 detectors were installed at 33 unique locations, but 8 detectors were not recovered because of adverse weather conditions. Results ranged from below the detection limit to 4.5 picocuries per liter (pCi/L). Radon results from 25 out of the 26 recovered detectors were below the USEPA indoor radon gas action limit (4.0 pCi/L).

Table 34. Summary of Radon Gas Results

Site ID	Survey Unit ID	Date	Latitude	Longitude	Duplicate	Serial Number	Sample ID	Result (pCi/L)
B10	13	9/15/18	36.52424931	-109.2203999	No	706774-7	B10-RN01-01-091518	0.30 ± 0.14
B16	26	9/15/18	36.53679601	-109.2642703	No	370719-7	B16-RN01-01-091518	< 0.22
B18	19	9/15/18	36.54467318	-109.2509872	No	286973-3	B18-RN01-01-091518	0.22 ± 0.14
B2	13	9/16/18	36.89701571	-109.348763	No	775546-5	B2-RN01-01-091618	0.27 ± 0.14
B26	13	9/14/18	36.52830646	-109.24974	No	152433-9	B26-RN01-01-091418	Not Recovered
B3	18	9/16/18	36.91343352	-109.3436832	No	789039-5	B3-RN01-01-091618	< 0.24
B7	1	9/15/18	36.56528566	-109.2144004	No	388489-7	B7-RN01-01-091518	< 0.22
M1	32	9/16/18	36.90586172	-109.3526015	No	437597-8	M1-RN01-01-091618	0.27 ± 0.14
M14	81	9/14/18	36.54530549	-109.2469803	No	103247-3	M14-RN01-01-091418	0.38 ± 0.14
M14	72	9/14/18	36.54547661	-109.2470027	No	153685-3	M14-RN02-01-091418	0.49 ± 0.14
M15	22	9/14/18	36.5417104	-109.2464835	No	355699-0	M15-RN01-01-091418	0.51 ± 0.14
M16	70	9/14/18	36.54126153	-109.247157	No	467482-6	M16-RN01-01-091418	0.38 ± 0.14
M16	108	9/14/18	36.54109907	-109.2469274	No	468378-5	M16-RN02-01-091418	0.92 ± 0.19
M17	24	9/13/18	36.54000709	-109.249479	No	338837-8	M17-RN02-01-091318	1.3 ± 0.22
M17	64	9/13/18	36.53972974	-109.2491308	No	414781-5	M17-RN01-01-091318	1.8 ± 0.25
M18	114	9/14/18	36.53805293	-109.2548372	No	491484-2	M18-RN01-01-091418	0.27 ± 0.14
M18	41	9/14/18	36.53850796	-109.2547783	No	566323-2	M18-RN02-01-091418	0.30 ± 0.14
M2	56	9/16/18	36.91447606	-109.2834634	No	467962-7	M2-RN01-01-091615	0.81 ± 0.17
M20	397	9/14/18	36.52874215	-109.2425366	No	179329-8	M20-RN01-01-091418	Not Recovered
M21	357	9/12/18	36.53235705	-109.2392801	No	120560-8	M21-RN01-01-092118	Not Recovered
M27	59	9/14/18	36.51146449	-109.2348127	No	395702-4	M27-RN01-01-091418	1.3 ± 0.22
M3	51	9/15/18	36.52366791	-109.2193777	No	239505-1	M3-RN01-01-091518	0.46 ± 0.14
M33	74	9/18/18	36.48524206	-109.2463397	No	337815-5	M33-RN01-01-091818	Not Recovered
M35	11	8/13/18	36.49977448	-109.2484386	No	141033-1	M35-RN01-01-081318	Not Recovered
M35	11	8/13/18	36.49977448	-109.2484386	Yes	222354-3	M35-RN01-02-081318	Not Recovered
M36	24	8/13/18	36.49917104	-109.2497989	No	420393-1	M36-RN01-01-081318	Not Recovered
M37	72	8/13/18	36.50007062	-109.2545057	No	407488-6	M37-RN01-01-081318	Not Recovered

Table 34. Summary of Radon Gas Results (Continued)

Site ID	Survey Unit ID	Date	Latitude	Longitude	Duplicate	Serial Number	Sample ID	Result (pCi/L)
M4	106	9/15/18	36.52487137	-109.2233717	No	942634-7	M4-RN01-01-091518	0.62 ± 0.11
M5	127	9/15/18	36.52188676	-109.2222651	No	533782-9	M5-RN01-01-091518	4.5 ± 0.57
M6	269	9/15/18	36.52292481	-109.2176287	No	979066-8	M6-RN01-01-091518	3.8 ± 0.49
M7	121	9/15/18	36.51960797	-109.2197541	No	166229-5	M7-RN01-01-091518	1.2 ± 0.19
M8	115	9/15/18	36.52496603	-109.2223286	No	198835-1	M8-RN01-01-091518	0.68 ± 0.14
T38	No ID[1]	9/30/18	36.58519008	-109.2000546	No	360888-2	T38-RN01-01-093018	< 0.27
T9	145	9/14/18	36.5608474	-109.2166673	No	158106-5	T9-RN01-01-091418	< 0.22

Notes:

[1] T38-RN01-01-093018 was placed inside interim action repository (TS-2; T38) containment fence.

pCi/L Picocuries per liter

5.5 DRAINAGE INVESTIGATION RESULTS

The Drainage Investigation Report (Appendix J) documents DQOs, sampling and analytical methodology, and results of the drainage investigation that was part of the RSE investigations. More than 22 miles of drainage was assessed along 21 drainages to: (1) determine whether transport of contaminants from AUMs via surface water pathways was occurring, (2) evaluate drainages possibly impacted by historical mining operations, and (3) determine whether COPC concentrations in sediment and surface water samples exceeded background levels for local drainages.

Between June and September 2018 as part of the Baseline Study and Site Characterization Study, Tetra Tech conducted GPS-based gamma radiation surveys of drainages with potential to receive surface water runoff from the Northern Agency Tronox Mines—primarily to identify current locations of radiological contaminants and delineate extent of those contaminants in the drainages. These surveys accorded with the methods outlined in Section 4.4.2. During the gamma radiation surveys, a two-person team traversed drainages in both upstream and downstream directions, and typically maintained a maximum spacing of 2 meters between transects. At locations where the drainage warranted a different approach, surveyors followed serpentine paths to achieve the required scan density.

Collection of sediment samples for laboratory analysis involved sampling the upper 6 inches of sediment within the drainage channels. Sediment sampling followed methods outlined in Section 4.4.6 and accorded with Appendix C to the RSE Work Plan. An XRF field survey did not occur within the drainages because of moist sediment conditions. Samples were collected within drainages every 100 meters along a drainage reach. Sampling at the location farthest downstream occurred first to prevent cross-contamination between sample locations. Some additional judgmental samples were collected between systematic sampling locations in areas where additional characterization was warranted (e.g., in areas of relatively high gamma measurements, at a waste pile in the drainage, or where the gamma survey equipment did not function properly due to poor GPS signal). In addition, a subset of sediment samples was collected opportunistically in AUM survey areas where a waste pile was directly spilling into a drainage (such as at Mesa II Mine 1, P-150). These sediment samples were collected within the site boundary in a drainage, and were evaluated along with the other sediment samples from the closest drainage.

The drainage investigation involved 183,809 gamma radiation measurements, 305 sediment samples collected within drainages, and eight (including two duplicates) surface water samples in the vicinity of the Tronox mines. Gamma radiation measurements were recorded in June 2018, and sediment samples were collected in June, August, and September 2018. Surface water samples were collected from drainages containing surface water in September 2018. All sediment and surface water samples were analyzed for metals and radionuclides. Additional analyses also occurred to document potential leachability of metals and radionuclides from sediment, and to evaluate general surface water quality parameters.

An evaluation of gamma survey and sediment sampling results indicated that the majority of AUMs appear to contribute to elevated concentrations of mine-related contaminants. For each drainage, gamma measurements and concentrations of primary analytes relative to applied BTVs were considered, as well as concentrations of analytes at each sampling location relative to results from upgradient and downgradient sampling locations. Table 35 lists drainages with primary analytes and/or gamma radiation exceeding two times the applied BTV, which may indicate presence of mining-related contamination requiring removal action or source control at individual AUMs. Table 35 also identifies mines where waste piles are within, adjacent to, or directly eroding into the drainage. Figure 37 and Figure 38 show, in the Tse Tah Region and Lukachukai Mountain Region, respectively, levels of impact in each drainage reach based on comparisons of maximum sediment concentrations of Ra-226 and uranium to BTVs. Figure 37 indicates that except for the Tse Tah West drainage, Step Mesa Wash, and Knife Edge Wash, all other sampled drainages host at least one Ra-226 sediment concentration exceeding twice the applied BTV for sediment in regional drainages. Similarly, except for the Tse Tah West drainage, Knife Edge Wash, and Middle 3G drainage, all drainages host at least one uranium sediment concentration exceeding twice the applied BTV for sediment in regional drainages. Comparing maximum concentrations to BTVs is a conservative metric but indicates here that mine-related contaminants impact the majority of the drainages at least in some portions of their respective drainage reaches.

Ra-226 sediment concentrations in Middle 1, Middle 1A, Middle 1B, Middle 2B, Middle 3, Middle 3E, and Middle 3G exceeded the BTV by more than an order of magnitude (10 times). Moreover, Ra-226 concentrations in opportunistic sediment samples collected within or immediately downgradient of AUM waste piles within field-mapped drainages (from Mesa II Mine No. 1, P-150, Mesa I Mine 12, Mesa I Mine 13, Mesa I Mine 14, Mesa IV Mine No. 2, Mesa I 1/2 Mine, and Mesa III Mine) also exceeded the BTV by more than 10 times. The highest sediment concentration of Ra-226 was detected within a drainage passing through a waste pile at Mesa III Mine that flows into Middle 2B. The second highest concentration was in a sample collected along a drainage within Waste Pile M17 associated with Mesa V Mine – 103 that flows into Middle 1A drainage.

Uranium sediment concentrations exceeded the BTV by more than 10 times in 12 of the 21 drainages; the exceptions were Tse Tah West, Cove Wash North, Middle 1G, Middle 3C, Middle 3D, Middle 3G, Knife Edge, and Step Mesa drainages. The two highest concentrations were detected at the same locations as the two highest radium-226 concentrations: in a sample collected along a drainage within Waste Pile M17 associated with Mesa V Mine – 103 that extends into Middle 1A drainage, and in a sample collected within a drainage passing through a waste pile at Mesa III Mine that extends into Middle 2B. The sample collected below Mesa I Mine 12 waste pile upgradient of Middle 3E drainage contained the same elevated levels of uranium as the sample associated with Mesa III Mine.

Conclusions from the drainage investigation are as follows:

- Drainages have been impacted by mining-related activities within the Cove Valley Region and Lukachukai Mountain Region.
- The Tse Tah West drainage and Knife Edge drainage appear to be minimally impacted by mining-related activities in the drainage reaches where surveys and sampling occurred.
- Off-site migration via the surface water pathway from multiple AUM sites is occurring in a majority of the drainages. The most likely sources from which contamination is migrating into drainages are waste piles that are eroding off cliffs into drainages, or on-site waste piles where local drainages pass through or along the bases of the piles.
- The linear extent of radiological contamination within the drainages were well documented via gamma radiation surveys. The longitudinal extent of areas where contaminant

concentrations exceeded applied BTVs was delineated in all surveyed areas except those where GPS signal was poor or accessibility was precluded due to presence of waterfalls or other hazardous terrain.

- Sediment concentrations of all primary analytes exceeded background in at least one drainage. Concentrations of arsenic, lead, and thorium infrequently exceeded BTVs within the drainages.
- Ra-226, uranium, and vanadium—all strong indicators of mine waste—were found at elevated levels in sediment within the majority of the drainages.
- Levels of molybdenum and Ra-226 in surface water in the Middle 3 and Middle 3E drainages exceeded maximum background concentrations (at one of six sample locations) (Weston 2018), but levels of other primary analytes did not exceed background concentrations. Sufficient flow was not observed in other drainages in September 2018.
- With few exceptions, mine-related analyte concentrations detected during Tetra Tech 2018 low-flow surface water sampling are similar to the concentrations of those analytes measured during the Weston Cove Wash watershed study (Weston 2018) in 2015, 2016, and 2017 during both low and high flow regimes.

The drainage investigation achieved most of the DQOs; a few data gaps pertaining to the drainages remain. Data gaps are discussed in Section 6.4.

Table 35. Summary of Sediment Sampling and Gamma Survey Results Indicating Potential Impacts from Mine Waste within and Adjacent to Drainages

Drainage ID[1]	Drainage Name	Mines with Mine Waste Within and Adjacent to Drainage[2]	Soil Sampling Results Indicate Potential Impacts?	Gamma Survey Results Indicate Potential Impacts?
DM1	Tse Tah West	Brodie 1 (M1)	No (<2x BTV)	No (median <BTV)
DCWN	Cove Wash North	Mesa VI Mine (M13) Frank Jr. Mine (M14)	Yes (>2x BTV)	Yes, downgradient of Frank Jr. Mine (median <BTV, maximum value >2x BTV)
DC1	Middle 1	Mesa IV West Mine (M23)	Yes (>2x BTV)	Yes, in multiple areas downgradient of Middle 1D confluence (maximum value >2x BTV)
DC1A	Middle 1A	Mesa V Adit (M16) Mesa V-103 (M17)	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC1B	Middle 1B	Mesa V – 508 Mine (M18) Mesa IV 1/2 Mine and Simpson 181 (M19)	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC1G	Middle 1G	None	Yes (>2x BTV)	No (maximum value >2x BTV, median <BTV)
DT9	Cove Wash Middle	None	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC2, M21	Middle 2	None	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC2A	Middle 2A	None	Yes (>2x BTV)	No (median <BTV)
DC2B, M32	Middle 2B	Mesa II 1/2 Mine (M30) Mesa II 1/2 Mine 4 (M31) Mesa III Mine (M32)	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC3	Middle 3	None	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC3A	Middle 3A	None	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC3B, M28	Middle 3B	Mesa II Mine No. 1 and No. 2 and P-21 (M27) Mesa II Mine No. 1, P-150 (M28)	Yes (>2x BTV)	Yes (maximum value >2x BTV)

Table 35. Summary of Sediment Sampling and Gamma Survey Results Indicating Potential Impacts from Mine Waste within and Adjacent to Drainages (Continued)

Drainage ID[1]	Drainage Name	Mines with Mine Waste Within and Adjacent to Drainage[2]	Soil Sampling Results Indicate Potential Impacts?	Gamma Survey Results Indicate Potential Impacts?
DC3C, M25	Middle 3C	Mesa I 3/4 incline (M25)	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC3D	Middle 3D	Mesa I 1/2, West Mine (M12)	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC3E, M5, M7, M10	Middle 3E	Mesa I Mine 12 (M5) Target T16 (M1-04) Target T36 (M1-06) Mesa I 1/2 Mine (M10)	Yes (>2x BTV)	No (median <BTV)
DC3F, M6	Middle 3F	Mesa I Mine 10 (M3) Mesa I Mine 13 (M6) Mesa I Mine 15 (M8)	Yes (>2x BTV)	Yes (maximum value >2x BTV)
DC3G	Middle 3G	None	No (<2x BTV)	Yes (maximum value >2x BTV)
DM33	Knife Edge	None	Yes (>2x BTV)	No (maximum value <BTV)
DM35	Black Mesa	Black No.1 Mine (M34) Black No.2 Mine (M35)	Yes (>2x BTV)	No (maximum value <BTV)
DM39	Tommy James	None	Yes (>2x BTV)	No (maximum value <BTV)

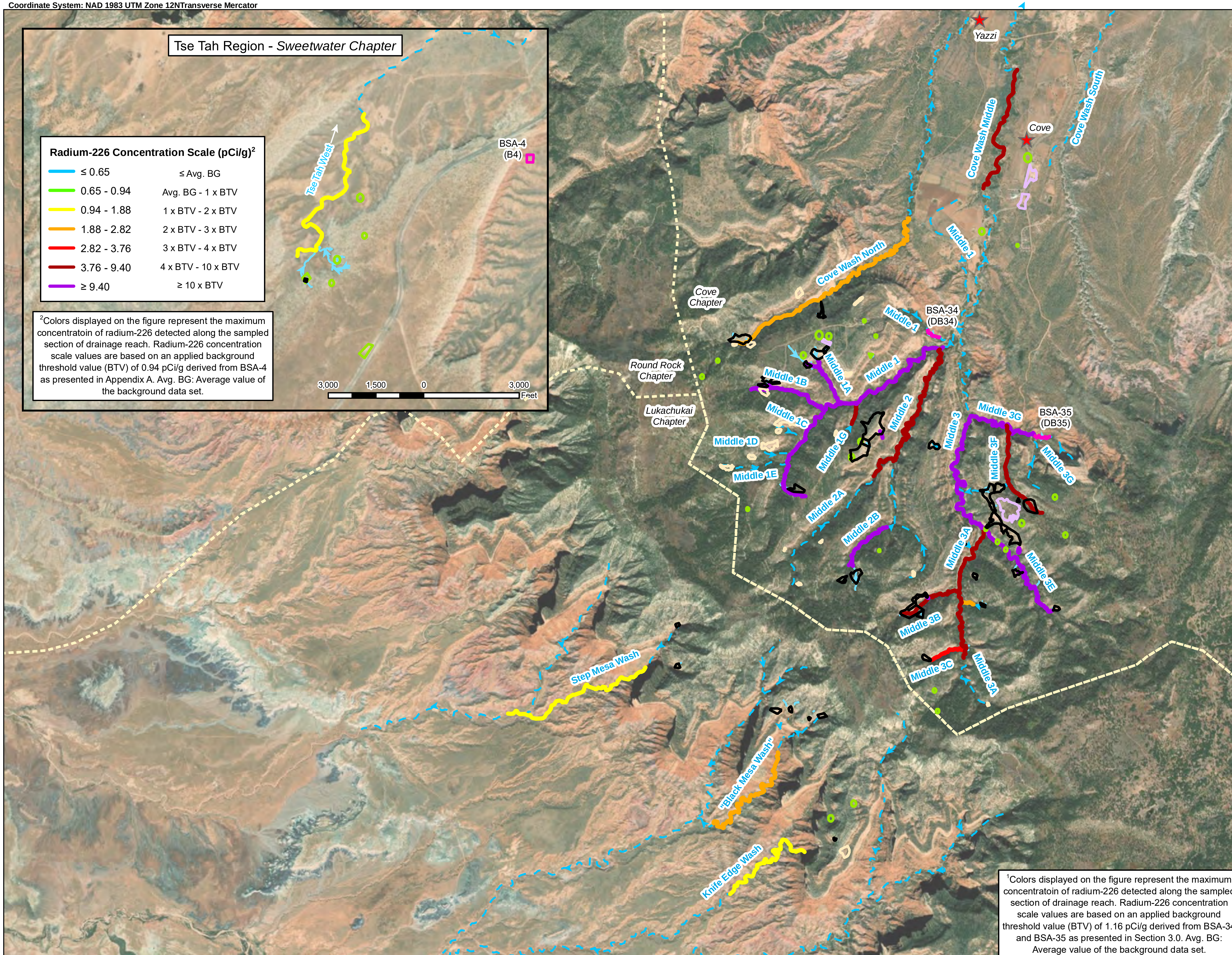
Notes:

1 Drainage IDs beginning with "M" indicate that an opportunistic sediment sample was collected downgradient of a waste pile associated with the mine with that Tetra Tech ID.

2 Mines with unreclaimed waste piles within 500 feet of field-mapped drainage, with primary analyte concentrations or gamma activity found to be higher in downgradient samples or measurements.

BTV Background threshold value

Coordinate System: NAD 1983 UTM Zone 12NTransverse Mercator



[1]Colors displayed on the figure represent the maximum concentratoin of radium-226 detected along the sampled section of drainage reach. Radium-226 concentration scale values are based on an applied background threshold value (BTV) of 1.16 pCi/g derived from BSA-34 and BSA-35 as presented in Section 3.0. Avg. BG: Average value of the background data set.

Populated Place

Radium-226 Concentration Scale (pCi/g)[1]

≤ 0.68	≤ Avg. BG
0.68 - 1.16	Avg. BG - 1 x BTV
1.16 - 2.32	1 x BTV - 2 x BTV
2.32 - 3.48	2 x BTV - 3 x BTV
3.48 - 4.64	3 x BTV - 4 x BTV
4.64 - 11.6	4 x BTV - 10 x BTV
≥ 11.6	≥ 10 x BTV

AUM Site Boundary
Drainage Background Location
AUM Related Site Boundary
Non-AUM Target Site Boundary
Non-Tronox AUM Site
Affected Chapter Boundary
Drainage[3]
Drainage - Field Mapped

1 in = 4,000 ft
1:48,000
N W E S
4,000 2,000 0 4,000 Feet

MAXIMUM RADIUM-226 SEDIMENT CONCENTRATIONS IN DRAINAGES FOR THE NORTHERN AGENCY TRONOX MINES

Prepared For:

Prepared By:
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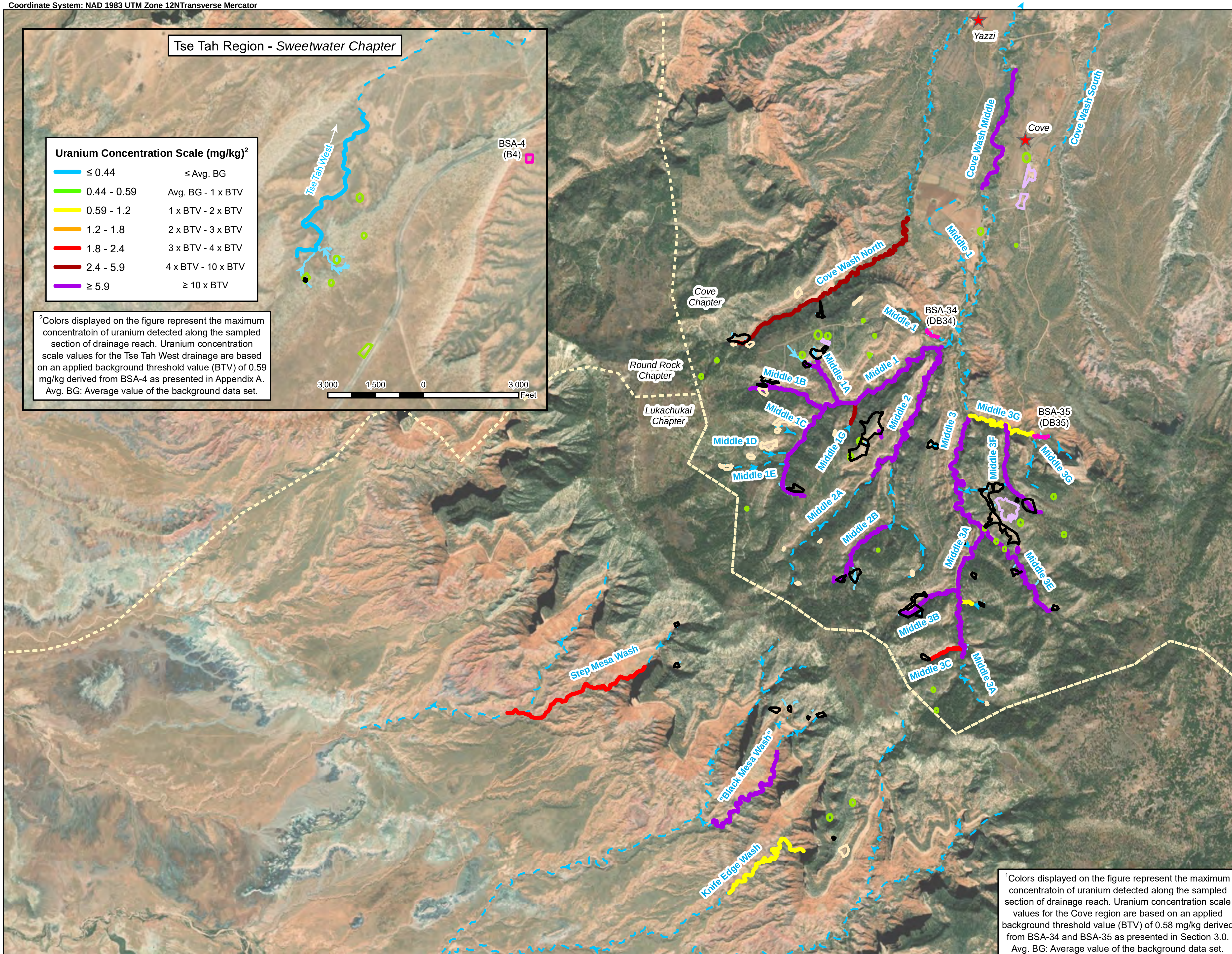
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: NAVAJO NATION	Date: 7/12/2019

Notes:
[3]U.S Environmental Protection Agency, Region 9, Superfund Program, *Abandoned Uranium Mines and the Navjo Nation Part II Atlas With Geospatial Data. NN_Drainage_HR_AUM.shp.* July, 2007.

Figure No.: 37

Coordinate System: NAD 1983 UTM Zone 12NTransverse Mercator



MAXIMUM URANIUM SEDIMENT CONCENTRATIONS IN DRAINAGES FOR THE NORTHERN AGENCY TRONOX MINES

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Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location:	Date:
NAVAJO NATION	7/12/2019

Notes:
[3]U.S Environmental Protection Agency, Region 9, Superfund Program, *Abandoned Uranium Mines and the Navjo Nation Part II Atlas With Geospatial Data. NN_Drainage_HR_AUM.shp.* July, 2007.

Figure No.: 38

5.6 ROAD INVESTIGATION RESULTS

The Access Road Investigation Report, Appendix K to this RSE Report, documents DQOs, sampling and analytical methodology, and results of the access road investigation by Tetra Tech between March and October 2018 that was part of the RSE investigations. The roads investigation involved characterization of 9.8 miles of access roads and footpaths via measurements of gamma radiation and XRF, and confirmatory XRF soil sampling. Objectives were to: (1) determine whether transport of contaminants from AUMs via vehicular or foot traffic was occurring, (2) evaluate access roads and footpaths that may have been impacted by historical mining operations, and (3) determine whether COPC concentrations exceed background levels for road clusters. Because of the wide extent of access roads and footpaths in the project area, this report has been organized to group access roads into clusters associated with one or more AUM sites, as listed in Table 36. Figure 39 shows the access road cluster indices, and locations of XRF measurements and confirmatory XRF soil sampling.

Table 36. Access Road Cluster and Associated AUM Sites

Cluster No.	Road Cluster Name	Associated Mines
1	Block K Road	Block K Mine
2	Mesa V Mine Complex Roads	Mesa IV 1/2 Mine and Simpson 181; Mesa V Mine 103; Mesa V Adit; Mesa V Incline; and Frank Jr. Mine
3	Mesa V Mine – 103 Haul Shaft Road	Mesa V Mine – 103
4	Mesa IV Mine Complex Roads	Mesa IV, Mine No. 1; Mesa IV, Mine No. 3; and Mesa IV, Mine No. 2
5	Mesa IV, West Mine Road	Mesa IV, West Mine
6	Mesa II 1/2 Mine and Mesa III Mine Roads	Mesa II 1/2 Mine and Mesa III Mine
7	Mesa I 3/4 and Mesa II Mine Roads	Mesa I 3/4 Mine No. 2 P150; Mesa II, Mine No. 1 & 2, P-21; and Mesa II, Mine No. 1, P-150
8	Mesa II, Mine 4 Road	Mesa II, Mine 4
9	Mesa I Mine Complex Roads	Mesa I Mine 10; Mesa I Mine 11; Mesa I Mine 12; Mesa I Mine 13; Mesa I Mine 14; and Mesa I Mine 15
10	Mesa II Pit Road	Mesa II Pit
11	Mesa I 1/2 Roads	Mesa I 1/2 Mine, Mesa 1 1/2 West Mine, Mesa I 1/4 Mine, and Henry Phillips Mine
12	Mesa I 3/4 Incline Road	Mesa I 3/4 Incline Mine

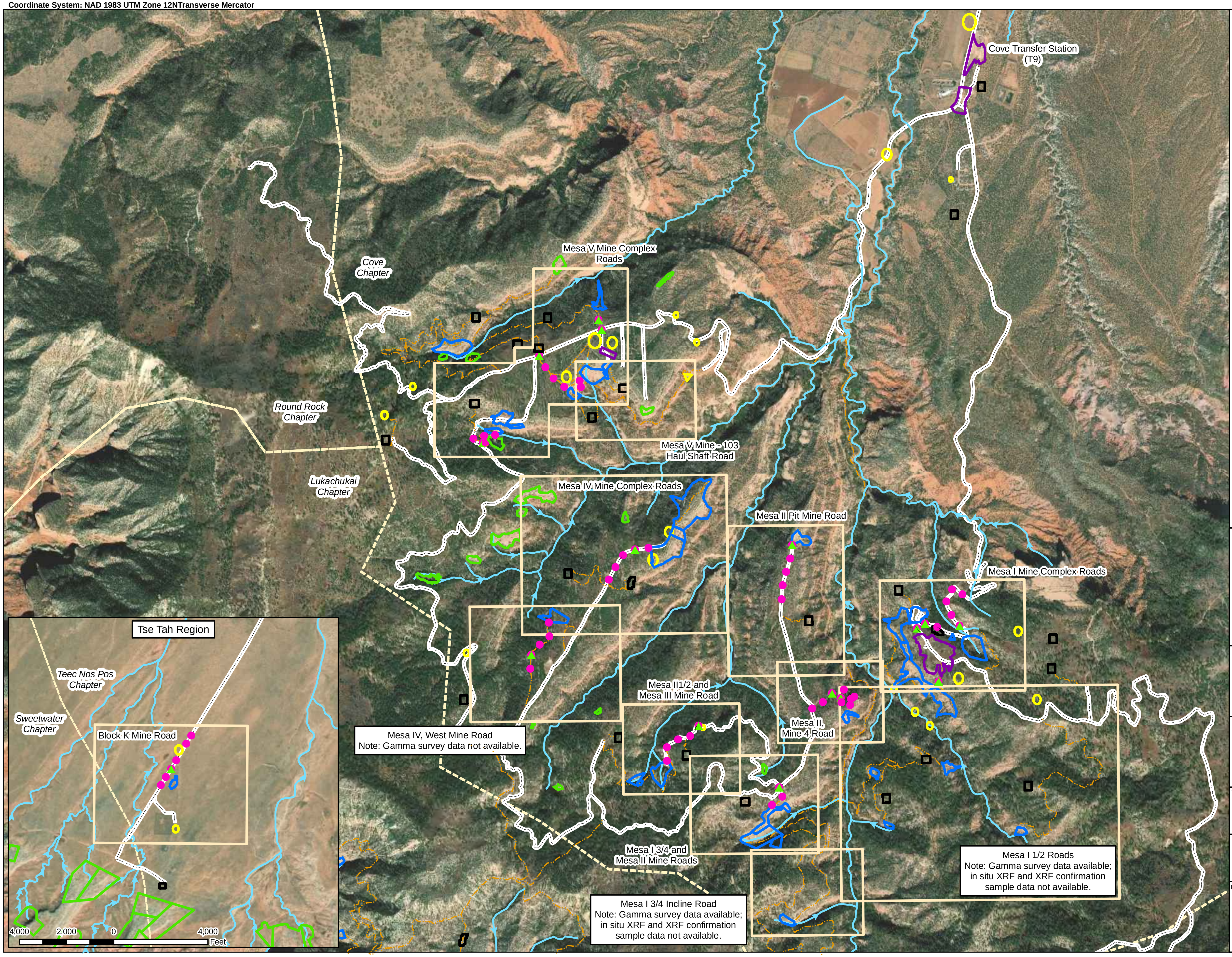
A two-person team conducted the gamma radiation surveys, traversing access roads and footpaths in both directions. The team typically achieved a maximum spacing of 2 meters between transects, resulting in 100 percent coverage. Detector height was 1 meter above ground surface as prescribed in Section 4.4.2 of this RSE Report and in Appendix C to the RSE Work Plan. Additionally, on September 30, 2018, Tetra Tech performed an XRF field survey along the access roads and footpaths that involved in situ XRF measurements approximately every 100 feet and collection of XRF confirmation soil samples at minimum frequency of 5 percent; at least one XRF confirmation sample was collected per access road or footpath. In total, 71 in situ XRF measurements occurred across the Northern Agency Tronox Mine access roads and footpaths following the methods described in Section 4.4.5, and 21 XRF confirmation samples were collected according to the methods outlined in Section 4.4.6.

Conclusions from the access road investigation are as follows:

- The linear extent of radiological contamination along the access roads and footpaths surveyed was well documented via gamma radiation surveys, and the full linear extent of radiological contamination beyond areas with elevated gamma radiation hasbeen delineated.
- Some access roads may have been impacted by mining activities at nearby Tronox Mines, as indicated by concentrations of primary analytes or gamma measurements exceeding twice the applied BTV.

Appendix K of this RSE Report summarizes all results from the road investigation including results of in situ XRF measurements, XRF confirmation soil samples, and gamma radiation surveys.

Coordinate System: NAD 1983 UTM Zone 12NTransverse Mercator



- XRF Confirmation Soil Sample
- In Situ XRF Measurement
- Access Route - Foot
- Access Route - Vehicular
- Drainage*
- Index
- AUM Site Boundary
- AUM Related Site Boundary
- Non-AUM Target Site Boundary
- Background Location
- Non-Tronox AUM Site
- Affected Chapter Boundary

1 in = 2,200 ft

1:26,400

2,200 1,100 0 2,200 Feet

N W E S

ACCESS ROAD CLUSTER INDICES, AND LOCATIONS OF XRF MEASUREMENTS AND XRF CONFIRMATORY SOIL SAMPLING

Prepared For:

Prepared By:

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Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location:	Date:
NAVAJO NATION	7/25/2019

Notes:
*U.S Environmental Protection Agency, Region 9, Superfund Program, *Abandoned Uranium Mines and the Navjo Nation Part II Atlas With Geospatial Data.* *NN_Drainage_HR_AUM.shp.* July, 2007.

Figure No.: 39

6.0 CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions from the RSE investigations and offers recommendations. The conclusions pertain to: (1) identification of COPCs, (2) inventory of all waste piles, and (3) estimated volume of mine waste.

6.1 IDENTIFICATION OF COPCS

Tetra Tech developed a process for identification of COPCs for the Northern Agency Tronox Mines. Chemical and radiological results obtained during the RSE investigations by application of in situ XRF measurements, XRF confirmation soil sampling, surface soil sampling, and subsurface soil sampling were included in the process to identify COPCs at a given AUM or Target site. After selection of an appropriate BSA, an applied BTV was selected to represent pre-mining conditions for each analyte at a given site, and survey units within the survey area were classified (following a MARSSIM approach) as Class 1, Class 2, Class 3, or inaccessible based on gamma radiation survey data acquired during the RSE investigations and known locations of pertinent site features. This classification also applied to subsurface soil samples collected within the survey unit.

Comparisons to background concentrations occurred involving comparisons to BTVs of all or a combination of XRF and laboratory analytical data (from XRF in situ measurements [corrected], XRF confirmation soil samples, surface soil samples, and subsurface soil samples). Combinations of data used to evaluate each site could be, depending on circumstances, data from all measurements and laboratory analyses combined, Class 1 or Class 2 measurements combined, or Class 3 measurements only. To be considered a COPC, an analyte's concentration had to exceed the applied BTV in more than 5 percent of examined measurements and analytical data. If an analyte was identified as a COPC under any one scenario, it was carried over for final COPC determination.

Table 37 summarizes COPCs identified for the 41 sites evaluated. These 41 sites included 38 AUM sites and three AUM-related sites. One AUM site was not accessible (see Appendix H). Results of RSE investigations for non-AUM Target sites are in Appendix I to this RSE Report. A check mark in Table 37 indicates identification of that analyte as a COPC for the given site, based on the criteria described above and presented in more detail in Appendix H.

The total of 29 analytes evaluated included radionuclides and chemical constituents. Mercury was not evaluated at every site (Section 5.3.4). Four analytes were identified as COPCs at every site—arsenic, molybdenum, Ra-226, and uranium. Selenium, thallium, and vanadium were identified as COPCs at every site except one.

The average number of COPCs identified among all sites was 22. Twenty-eight of the 29 analytes were identified as COPCs at Mesa I Mine 15, Mesa V Incline, and Mesa V Mine – 508. For no site were all analytes identified as COPCs. For Mesa I 1/2, West Mine, only 12 of 29 analytes were identified as COPCs.

Although Tetra Tech identified COPCs as part of the RSE investigations, COPC concentrations are not necessarily above risk-based levels and may not require cleanup. Further evaluation will occur as part of the EE/CA investigations.

Table 37. Summary of COPCs Identified for Each AUM Site and AUM-Related Site

Site ID	Site Name	# of COPCs	Al[1]	Sb	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Hg	Mo	Ni	K-40	Ra-226	Ra-228	Se	Ag	Na	Tl	Th	U	V	Zn
M1	Brodie 1 Mine	24	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
M2	Block K	16		✓	✓	✓			✓					✓	✓				✓			✓		✓	✓	✓	✓	✓	✓	✓	✓
M3	Mesa I Mine 10	19		✓	✓				✓	✓	✓	✓	✓		✓	✓			✓	✓		✓		✓	✓	✓	✓		✓	✓	✓
M4	Mesa I Mine 11	27	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
M5	Mesa I Mine 12	23	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓			✓		✓	✓	✓	✓	✓	✓	✓	✓
M6	Mesa I Mine 13	22	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓		✓	✓	✓
M7	Mesa I Mine 14	25	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
M8	Mesa I Mine 15	28	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
M9	Mesa I 1/4 Mine	20	✓	✓	✓				✓		✓	✓		✓	✓	✓			✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	
M10	Mesa I 1/2 Mine	20	✓		✓		✓	✓	✓		✓	✓	✓	✓	✓	✓			✓			✓		✓	✓	✓	✓		✓	✓	✓
M11	Henry Phillips Mine	22	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓		✓	✓		✓		✓	✓	✓
M12	Mesa I 1/2, West Mine	12			✓					✓			✓	✓			✓		✓			✓			✓			✓	✓	✓	✓
M13	Mesa VI Mine	27	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
M14	Frank Jr. Mine	23	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓		✓	✓	✓	✓	✓
M15	Mesa V Incline	28	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
M16	Mesa V Adit	23	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
M17	Mesa V Mine – 103	20		✓	✓			✓	✓	✓	✓	✓	✓	✓			✓		✓	✓		✓		✓	✓		✓	✓	✓	✓	✓
M18	Mesa V Mine – 508	28	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
M19	Mesa IV 1/2 Mine and Simpson 181	14		✓	✓			✓					✓	✓			✓		✓			✓		✓	✓		✓	✓	✓	✓	
M20	Mesa IV, Mine No. 1	26	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
M21	Mesa IV, Mine No. 2	24	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓			✓		✓	✓	✓	✓	✓	✓	✓	✓
M22	Mesa IV, Mine No. 3	22	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓			✓	✓	✓	✓	✓
M23	Mesa IV, West Mine	23	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓		✓	✓	✓
M24	Mesa II Pit	27	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
M25	Mesa I 3/4 Incline	14	✓		✓								✓	✓	✓	✓			✓			✓		✓	✓		✓		✓	✓	✓
M26	Mesa I 3/4, Mine No. 2, P150	15	✓		✓					✓	✓				✓	✓			✓	✓		✓		✓		✓	✓		✓	✓	✓
M27	Mesa II, Mine No. 1 & 2, P-21	23	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓			✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
M28	Mesa II, Mine No. 1, P-150	24	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓	✓	✓		
M29	Mesa II, Mine 4	20		✓	✓	✓		✓			✓	✓	✓	✓	✓	✓			✓			✓		✓	✓	✓	✓	✓	✓	✓	✓
M30	Mesa II 1/2 Mine	25	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
M31	Mesa II 1/2, Mine 4	22	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓			✓	✓		✓		✓	✓	✓	✓		✓	✓	✓
M32	Mesa III Mine	22	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓		✓	✓	✓
M33	Knife Edge Mesa Mine	19		✓	✓	✓			✓	✓			✓		✓	✓	✓		✓	✓	✓	✓		✓			✓	✓	✓	✓	✓
M34	Black No. 1 Mine	27	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
M35	Black No. 2 Mine	26	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
M36	Black No. 2 Mine (West)	19	✓		✓	✓	✓				✓	✓	✓		✓	✓			✓			✓	✓	✓		✓	✓	✓	✓	✓	✓

Table 37. Summary of COPCs Identified for Each AUM Site and AUM-Related Site (Continued)

Site ID	Site Name	# of COPCs	Al[1]	Sb	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Hg	Mo	Ni	K-40	Ra-226	Ra-228	Se	Ag	Na	Tl	Th	U	V	Zn
M37	Flag No. 1 Mine	23	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
M38	Step Mesa Mine	24	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
M40	Cove Transfer Station	25		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
M41	Mesa I Camp	18		✓	✓			✓	✓			✓		✓	✓		✓		✓	✓		✓		✓	✓	✓	✓		✓	✓	✓
M42	NA-0344B	25	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓

Notes:

1 Chemicals are denoted by their symbol from the periodic table of elements

AUM Abandoned uranium mine

COPC Contaminant of potential concern

6.2 WASTE PILE INVENTORY

Most of the volume of mine waste is contained within the unreclaimed waste piles present at most AUMs. These waste piles are the major sources of contaminants that migrate off site via mass wasting and surface water transport. Therefore, site mapping and delineation of waste piles were important in the RSE investigations.

Tetra Tech confirmed or newly identified 60 unreclaimed waste piles during the RSE investigations across 38 AUM sites and three AUM-related sites. Tetra Tech did not visit Tommy James Mine and thus did not confirm or refute the presence of waste piles there. An example of an unreclaimed waste pile is shown on Figure 40. Forty-five unreclaimed waste piles were listed in the USEPA geodatabase prior to the RSE investigations (Neptune and TSG 2018). One waste pile at Mesa I Mine 14 was eliminated from the list of waste piles based on multiple lines of evidence, including site mapping, gamma radiation surveys, surface and subsurface soil sampling, and evaluation of radiological and geochemical data. Tetra Tech expanded the boundaries of 27 of the 44 unreclaimed waste piles listed in the USEPA geodatabase. In addition to those 44 confirmed waste piles, Tetra Tech mapped 16 new waste piles during the RSE investigations. All new waste piles are documented in the updated geodatabase, and the lateral and vertical extent of contamination has been estimated to the extent possible. A summary of all waste piles is in Table 38.

Figure 40. Waste Pile M17 at Mesa V Mine – 103

Table 38. Summary of Waste Piles at Northern Agency Tronox Mines

Tetra Tech ID	Site Name	Waste Pile ID	Former Waste Pile Name	Surface Area (acres)	Volume (cubic yards)	Expanded or New?	Drainages Mapped through Pile?	Located Directly in Major Drainage?	Off-site Migration Likely?
M1	Brodie 1 Mine	Waste Pile M1	None	0.052	638	New	Yes	No	Yes
M2	Block K Mine	NA	NA	NA	NA	NA	NA	NA	NA
M3	Mesa I Mine 10	Waste Pile M3	M10	0.401	8,372	Expanded	Yes	No	Yes
M4	Mesa I Mine 11	Waste Pile M4	9a, 9b	1.13	10,684	Expanded	Yes	No	Yes
M5	Mesa I Mine 12	Waste Pile M5A	14	0.56	2,791	No	Yes	No	Confirmed
		Waste Pile M5B	18a	1.96	32,591	No	Yes	No	Confirmed
		Waste Pile M5C	18b	0.34	4,585	Expanded	Yes	Yes	Confirmed
M6	Mesa I Mine 13	Waste Pile M6	None	2.38	61,713	New	Yes	Yes	Confirmed
M7	Mesa I Mine 14	Waste Pile M7A	24	0.932	10,565	Expanded	Yes	No	Confirmed
		Waste Pile M7B	25	1.00	6,458	Expanded	Yes	No	Confirmed
		Waste Pile M7C	None	0.0874	846	New	Yes	Yes	Confirmed
M8	Mesa I Mine 15	Waste Pile M8A	7	0.0229	4,943	No	No	No	Confirmed
		Waste Pile M8B	8	1.29		Expanded	Yes	No	Confirmed
M9	Mesa I 1/4 Mine	Waste Pile M9	26	0.76	1,874	Expanded	Yes	Yes	Confirmed
M10	Mesa I 1/2 Mine	Waste Pile M10A	27	0.87	15,069	Expanded	Yes	Yes	Yes
		Waste Pile M10B	None	0.05	199	New	Yes	Yes	Yes
M11	Henry Phillips Mine	Waste Pile M11	28	0.67	2,512	Expanded	No	No	Yes
M12	Mesa I 1/2, West Mine	Waste Pile M12	29	0.12	3,588	Expanded	Yes	Yes	Confirmed
M13	Mesa VI Mine	Waste Pile M13A	103a, 103b	0.81	30,498	Expanded	Yes	Yes	Confirmed
		Waste Pile M13B	102	0.23	15,548	Expanded	Yes	Yes	Confirmed
M14	Frank Jr. Mine	Waste Pile M14	99	1.14	20,332	Expanded	Yes	No	Yes
M15	Mesa V Incline	Waste Pile M15A	None	0.45	7,256	New	Yes	No	Yes
		Waste Pile M15B	None	0.16	1,555	New	No	No	Yes
M16	Mesa V Adit	Waste Pile M16A	93C	1.05	21,926	No	Yes	Yes	Confirmed
		Waste Pile M16B	93B	0.674		No	Yes	Yes	Confirmed
M17	Mesa V Mine – 103	Waste Pile M17	88a	1.44	57,708	Expanded	Yes	Yes	Confirmed
M18	Mesa V Mine – 508	Waste Pile M18	87d	0.14	3,189	Expanded	Yes	No	Yes
M19	Mesa IV 1/2 Mine and Simpson 181	Waste Pile M19	86c	0.511	3,349	Expanded	Yes	Yes	Confirmed
M20	Mesa IV, Mine No. 1	Waste Pile M20A	56b, 57b, 58b	1.67	22,325	Expanded	Yes	No	Yes
		Waste Pile M20B	None	1.09	7,654	New	No	No	No
M21	Mesa IV, Mine No. 2	Waste Pile M21A	64	0.387	12,837	No	Yes	No	Yes
		Waste Pile M21B	63b	0.221		No	Yes	No	Yes
		Waste Pile M21C	67c	0.061	5,023	No	No	No	Yes
		Waste Pile M21D	67a	0.338		No	No	No	Yes
		Waste Pile M21E	67b	0.058		No	No	No	Yes
		Waste Pile M21F	None	1.24	2,711	New	No	No	Yes
M22	Mesa IV, Mine No. 3	Waste Pile M22A	60b	0.39	11,163	Expanded	Yes	No	Yes
		Waste Pile M22B	None	0.18	1,794	New	Yes	No	Yes
		Waste Pile M22C	None	0.31	2,392	New	No	No	No

Table 38. Summary of Waste Piles at Northern Agency Tronox Mines (Continued)

Tetra Tech ID	Site Name	Waste Pile ID	Former Waste Pile Name	Surface Area (acres)	Volume (cubic yards)	Expanded or New?	Drainages Mapped through Pile?	Located Directly in Major Drainage?	Off-site Migration Likely?
M23	Mesa IV, West Mine	Waste Pile M23	70c	0.45	7,654	Expanded	Yes	Yes	Confirmed
M24	Mesa II Pit	Waste Pile M24	44	1.69	8,671	Expanded	Yes	No	Yes
M25	Mesa I 3/4 Incline	Waste Pile M25	None	0.24	1,674	New	Yes	Yes	Yes
M26	Mesa I 3/4 Mine No. 2, P-150	NA	NA	NA	NA	NA	NA	NA	NA
M27	Mesa II, Mine No. 1 & 2, P-21	Waste Pile M27	None	0.453	2,312	New	No	No	Confirmed
M28	Mesa II, Mine No. 1, P-150	Waste Pile M28	42	0.896	8,970	Expanded	Yes	No	Confirmed
M29	Mesa II, Mine 4	Waste Pile M29A	43a	0.29	4,306	No	No	No	Yes
		Waste Pile M29B	43b	0.12		No	No	No	Yes
M30	Mesa II 1/2 Mine	Waste Pile M30	48b	1.30	23,322	Expanded	Yes	Yes	Confirmed
M31	Mesa II 1/2, Mine 4	Waste Pile M31	49	0.22	2,233	Expanded	Yes	Yes	Confirmed
M32	Mesa III Mine	Waste Pile M32	51	0.78	12,837	Expanded	Yes	Yes	Confirmed
M33	Knife Edge Mesa Mine	Waste Pile M33	216	0.06	1,435	Expanded	No	No	Yes
M34	Black No. 1 Mine	Waste Pile M34A	None	0.355	1,037	New	No	No	Potential
		Waste Pile M34B	212	0.264	3,407	Expanded	No	No	Potential
M35	Black No. 2 Mine	Waste Pile M35A	None	0.046	1,355	New	No	No	Yes
		Waste Pile M35B	None	0.041		New	No	No	Yes
		Waste Pile M35C	None	0.051		New	No	No	Yes
M36	Black No. 2 Mine (West)	Waste Pile M36	None	0.174	598	New	No	No	Yes
M37	Flag No. 1 Mine	Waste Pile M37A	210a	0.72	10,166	Expanded	No	No	Yes
		Waste Pile M37B	210b	0.24	5,302	No	No	No	Yes
M38	Step Mesa Mine	Waste Pile M38	208	0.12	1,993	No	No	No	Yes
T17	Mesa I Camp	Waste Pile T17A	None	0.07	837	New	No	No	No
		Waste Pile T17B	None	0.02	479	New	Yes	No	Yes
T23	NA-0344B	NA	NA	NA	NA	NA	NA	NA	NA

Note:
NA Not applicable; there are no waste piles on site.

6.3 WASTE VOLUME ESTIMATION

Tetra Tech delineated the lateral and vertical extent of mine waste materials at each AUM site and AUM-related site, and used this information to estimate volumes of mine waste. Appendix H to the RSE Report includes detailed lists of assumptions for calculation of waste volume at each site. The waste volume estimation process included reviews of historical records and previous reclamation summaries, analytical data from surface and subsurface soil samples, gamma radiation survey results, and measurements and estimates that occurred in the field.

Most waste materials at AUMs and AUM-related Target sites fall into four categories: (1) waste piles, (2) burial cells, (3) areas outside of waste piles and burial cells with elevated gamma levels relative to background, and (4) areas outside of waste piles and burial cells that do not host elevated gamma levels but do host elevated concentrations of primary analytes relative to background.

Figure 41 is a graph showing the volume of waste at each AUM site. Figure 42 is a graph showing the percentage of waste in each of the four categories. Table 39 summarizes estimated waste volumes in each of the four categories across the AUM and AUM-related sites.

Most (61 percent) of the overall estimated volume of mine waste is within waste piles. The second highest estimated volume (19 percent) is outside of waste piles and burial cells in areas where gamma radiation levels exceed the applied gamma radiation BTV. The relatively high percentage of estimated waste in that second category may be a result of Tetra Tech's conservative approach to selection of BTVs (selection of the lower of the site-specific or regional gamma radiation BTV with which to compare site data). If Tetra Tech had selected higher background levels or risk-based levels, the volume of waste estimated outside of waste piles or burial cells would have been reduced.

A total of 810,778 yd^3 of mine waste material was estimated across all AUM sites and AUM-related sites. A volume was not estimated at the Cove Transfer Station (T9/T37) because of a previous removal action there in 2012 (E&E 2013). Moreover, no volumes were estimated at non-AUM-related Target sites. The non-AUM Target sites were evaluated in Appendix I to this main RSE Report and no removal volume is recommended at this time; however, further evaluation of the results at each site will be considered during the EE/CA. Mesa I Mine 13 (M6) hosts the highest waste volume (70,603 yd^3). Mesa V Mine – 103 (M17) hosts the second highest volume of waste (60,259 yd^3). The largest volume in any single waste pile is at Mesa I Mine 13 (61,713 yd^3).

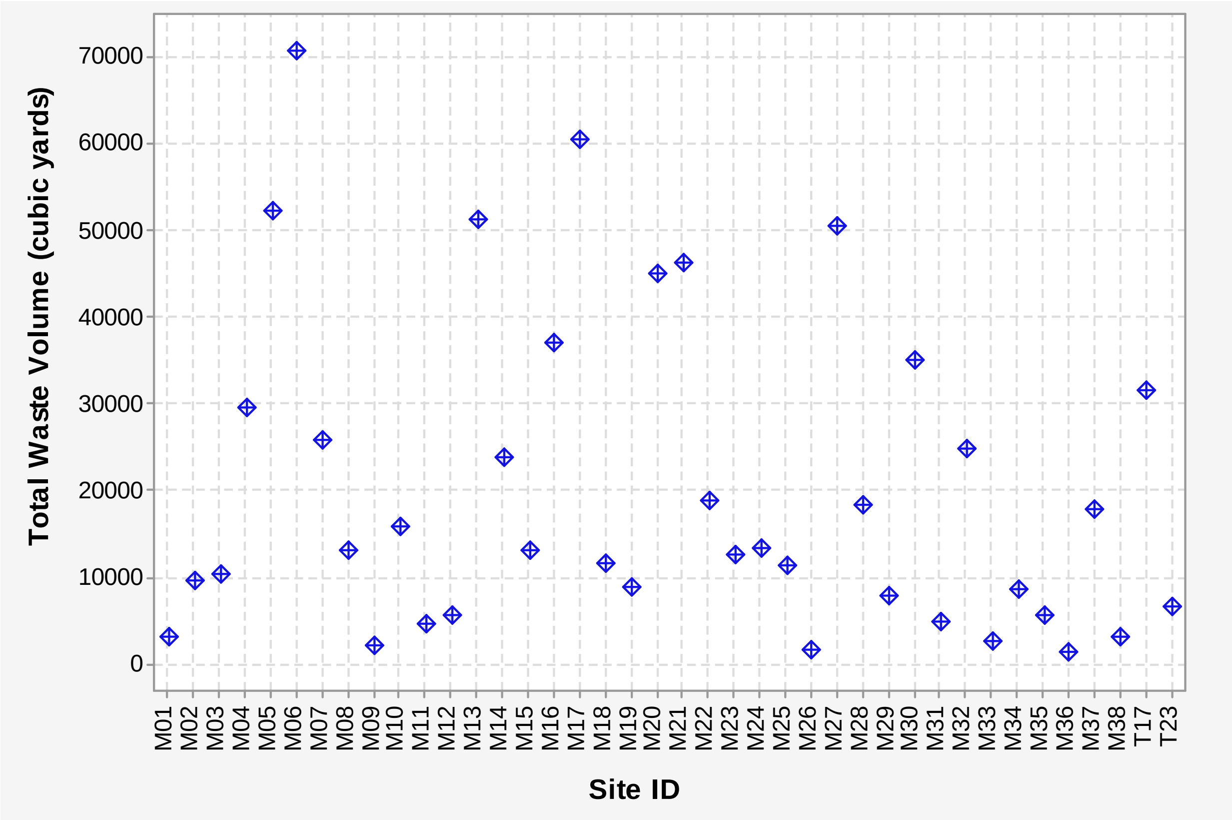

Figure 41. Waste Volume at Each AUM Site

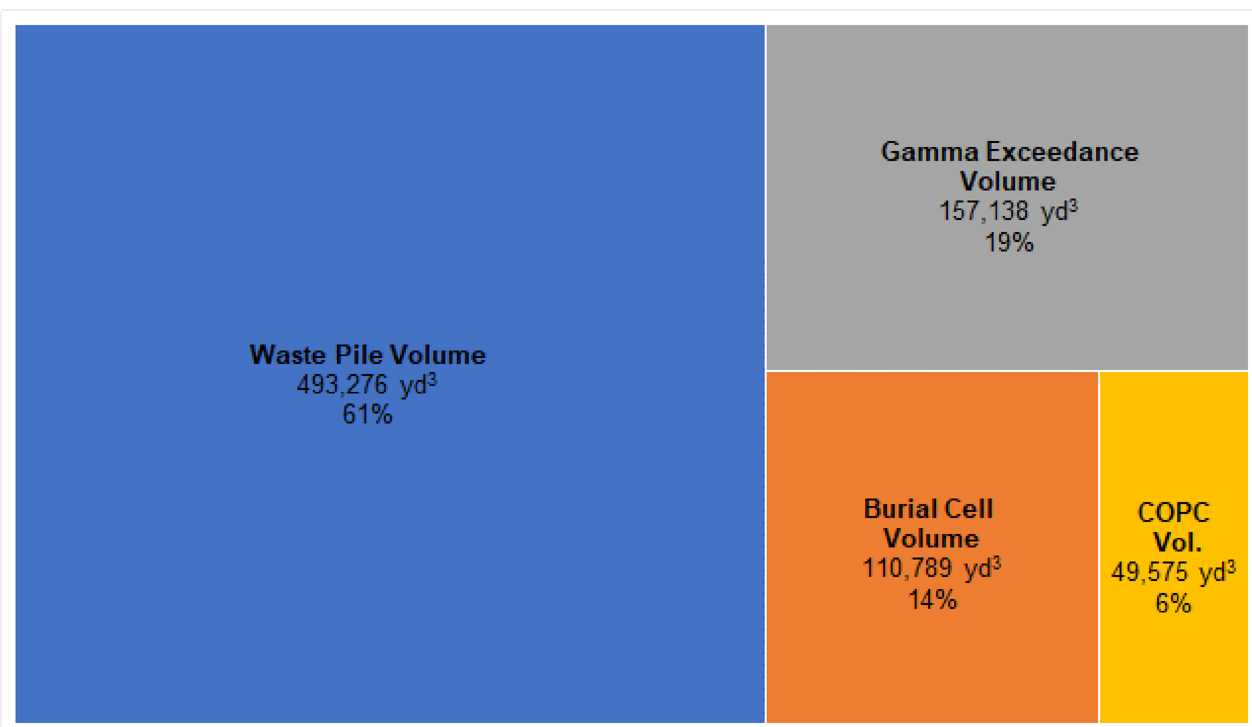

Figure 42. Percentage of Waste Volume by Type

Table 39. Summary of Estimated Waste Volumes for AUM Sites and AUM-Related Sites

Tetra Tech ID	Site Name	Waste Pile(s) Volume	Burial Cell(s) Volume	Gamma Exceedance Volume	COPC Volume	Total Volume
M1	Brodie 1 Mine	638	638	1,635	80	2,991
M2	Block K Mine	0	8,252	120	1,037	9,409
M3	Mesa I Mine 10	8,372	0	1,834	40	10,246
M4	Mesa I Mine 11	10,684	9,329	4,146	5,262	29,421
M5	Mesa I Mine 12	39,967	0	11,920	199	52,086
M6	Mesa I Mine 13	61,713	0	8,412	478	70,603
M7	Mesa I Mine 14	17,869	0	5,143	2,631	25,643
M8	Mesa I Mine 15	4,943	2,213	2,990	2,831	12,977
M9	Mesa I 1/4 Mine	1,874	0	140	0	2,014
M10	Mesa I 1/2 Mine	15,268	0	399	40	15,707
M11	Henry Phillips Mine	2,512	0	1,515	518	4,545
M12	Mesa I 1/2, West Mine	3,588	0	1,116	837	5,541
M13	Mesa VI Mine	46,046	0	3,788	1,355	51,189
M14	Frank Jr. Mine	20,332	0	2,352	1,076	23,760
M15	Mesa V Incline	8,811	0	4,027	199	13,037
M16	Mesa V Adit	21,926	10,166	4,505	279	36,876
M17	Mesa V Mine – 103	57,708	0	2,551	0	60,259
M18	Mesa V Mine – 508	3,189	2,492	3,389	2,312	11,382
M19	Mesa IV 1/2 Mine and Simpson 181	3,349	2,093	3,169	0	8,611
M20	Mesa IV, Mine No. 1	29,979	4,046	8,691	2,113	44,829
M21	Mesa IV, Mine No. 2	20,571	3,947	16,983	4,505	46,006
M22	Mesa IV, Mine No. 3	15,349	0	3,309	40	18,698
M23	Mesa IV, West Mine	7,654	997	598	3,309	12,558
M24	Mesa II Pit	8,671	2,332	1,934	359	13,296
M25	Mesa I 3/4 Incline	1,674	7,275	1,355	917	11,221
M26	Mesa I 3/4 Mine No. 2, P-150	0	0	1,335	40	1,375
M27	Mesa II, Mine No. 1 & 2, P-21	2,312	39,069	8,591	359	50,331
M28	Mesa II, Mine No. 1, P-150	8,970	0	8,532	757	18,259
M29	Mesa II, Mine 4	4,306	1,973	997	359	7,635
M30	Mesa II 1/2 Mine	23,322	4,126	6,977	439	34,864
M31	Mesa II 1/2, Mine 4	2,233	0	2,372	80	4,685
M32	Mesa III Mine	12,837	0	11,841	40	24,718
M33	Knife Edge Mesa Mine	1,435	0	399	678	2,512
M34	Black No. 1 Mine	4,444	0	3,588	359	8,391
M35	Black No. 2 Mine	1,355	0	3,967	40	5,362
M36	Black No. 2 Mine (West)	598	0	558	20	1,176
M37	Flag No. 1 Mine	15,468	0	1,037	1,196	17,701
M38	Step Mesa Mine	1,993	0	877	0	2,870
T17	Mesa I Camp	1,316	8,432	7,654	14,073	31,475
T23	NA-0344B	0	3,409	2,392	718	6,519
Total		**493,276**	**110,789**	**157,138**	**49,575**	**810,778**

Notes:
All volumes are in cubic yards.
AUM Abandoned uranium mine
COPC Contaminant of potential concern

6.4 SUMMARY OF DATA GAPS

This section summarizes data gaps across the AUM and AUM-related sites.

- ***Volume estimates:*** Although estimates were made as described in Section 6.3, the actual volume of waste materials remaining at the Northern Agency Tronox Mines is unknown. The estimate presented in this RSE Report may overestimate the actual volume as a result of the methods applied to estimate waste pile slopes and depth, and the estimates of volumes based on exceedances of gamma radiation and background levels of primary analytes.
- ***Physical properties of mine waste:*** During the RSE investigations, geotechnical laboratory testing was conducted on samples from 34 AUM and Target sites to support future modeling and remedy evaluation. Remaining geotechnical data gaps include laboratory testing for in situ moisture content (ASTM D2216) and density (ASTM D7263), specific gravity (ASTM C127), moisture-density relationships (standard Proctor test, ASTM D698), shear strength (direct shear, ASTM D3080), and permeability (ASTM D5084 or ASTM D5856). These data will be required for repository design and determination of properties of waste placed in repositories. In the absence of these test data, empirical correlations by soil classification are presented in this report for the EE/CA.
- ***Physical properties of potential borrow areas:*** Borrow source investigations will be necessary to determine the feasibility of using local soils, gravel, and cobbles. Geotechnical data including in-situ moisture content and density, specific gravity, classification, moisture-density relationships, shear strength, and permeability of borrow materials will be used in the borrow source investigations.
- ***Surface water***: The RSE drainage investigation confirmed elevated gamma radiation and concentrations of primary analytes in sediments within drainages downgradient of many mines. A total of eight opportunistic surface water samples were collected at six unique locations in one season during the RSE investigations as described in Appendix J of this RSE Report. A number of recommendations related to additional surface water sampling were identified in the CWWA report (Weston 2018) but not all of these were addressed during the RSE investigations because it was not within the scope of work. These recommendations include evaluating temporal trends in water quality and expanding the background investigation for surface water; therefore, temporal trends and background concentrations remain data gaps.
- ***Groundwater***: The RSE drainage investigation did not address groundwater. During the CWWA, samples were collected from groundwater wells, seeps, and springs for analysis (Weston 2018). Depth to groundwater and quality of groundwater remain data gaps for all sites.
- ***Radon gas concentrations***: Radon gas concentrations were measured at accessible mine openings, waste piles, and burial cells at 26 AUM and AUM-related sites. Additonally, radon gas was measured at seven BSAs. Results did not indicate ambient air concentrations of radon are a concern with respect to human health risk. Because radon was not measured at all AUMs, site-specific concentrations at these sites remain data gaps.
- ***Drainages***: Results from the RSE drainage investigation demonstrated that mine wastes from AUMs are migrating into drainages and likely negatively impacting water quality. However,

the extent of gross erosion and the contributions of mine waste from specific mine areas to the watershed are data gaps.

- ***Lateral extent of contamination***: Generally, the RSE investigations successfully delineated the lateral and vertical extent of contamination at AUM and AUM-related sites. However, because of the extreme terrain at certain AUM sites, the lateral extent of contamination was not fully delineated in some cases.
- ***Tommy James Mine***: Tetra Tech was unable to access the Tommy James Mine due to the presence of cliffs and dangerous terrain. The USEPA database indicates there are two waste piles at this site but Tetra Tech did not confirm the presence of the waste piles.

6.5 RECOMMENDATIONS

Tetra Tech offers the following recommendations:

- ***Volume estimates:*** Data from a light detecting and ranging (LIDAR) study in June 2019 should be used with the information obtained from the risk assessment to refine waste volumes.
- ***Drainages:*** Off-site migration via the surface water pathway is occurring from multiple AUM sites in a majority of the drainages. The most likely sources of migration of contaminants into drainages are cliff-located waste piles eroding into the drainages and on-site waste piles through which or along bases of which local drainages pass. The overall amount of erodible material has not been estimated, and Tetra Tech recommends a GIS-based contaminant transport model to estimate the erodible material quantities. Newly aquired LIDAR data and sediment sample analytical data would be inputs to the model. Use of a grid-based, universal soil loss equation model paired with contaminant data would allow predictions of gross erosion and downstream sediment concentrations, and help determine contributions of contaminants from specific mine areas into the watershed below. This could also aid in prioritization of mine cleanups.
- ***Physical properties of mine waste and borrow areas***: Collect additional data required for repository design and determination of properties of waste placed in repositories. Geotechnical data needed for remedial design include in-situ moisture content and density, specific gravity, classification, moisture-density relationships, shear strength, and permeability of borrow materials.
- ***Evaluation of ratios of analytes***: Except for certain radionuclides, this RSE Report did not evaluate ratios of analytes or elements. Further evaluation of ratios of analytes during the EE/CA may reveal that some analytes can serve as surrogates and represent a suite of analytes.
- ***Lateral extent of contamination***: The RSE investigations generally succeeded at delineating the lateral and vertical extent of contamination at AUM and AUM-related sites. Tetra Tech recommends remote applications of sensing techniques and unmanned aerial vehicle technology to characterize areas that were inaccessible during the RSE investigations.

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ATTACHMENT 1

FIELD TRIP SUMMARIES

Field Trip Progress Report Summary

To:	Chip Poalinelli
From:	Aaron Orechwa, P.E.
Cc:	Kenyon Larsen
Date:	May 3, 2018
Subject:	Task Order 0001, Mobilization 1

4/23/2018 Monday

Location: Farmington, NM

Activities:

- Set up Farmington, NM staging area
- Instrument pre-survey QC for project (XRF and gamma instruments)
- Final instrument checks
- Calibration of instruments and personnel

4/24/2018 Tuesday

Location: Subarea Group B – Block K [M2], Target sites (BK-01 [T7], BK-02 [T8]), and BSA-5 [B5] (background area)

Activities:

- Performed gamma scanning at M2, T7, T8, B5
- Site mapping completed for Black K [M2]
- Background field documentation form completed for BSA-5 [B5]
- Completed background soil sampling (surface and subsurface) at BSA-5
- Completed XRF field surveys at M2, T7, and T8
- Scanned adjacent drainage to M2
- Scanned access roads in area

Summary:

- Total XRF Measurement Samples = 230
- Total XRF Confirmation Samples Collected = 13
- Total Background Samples = 30 surface, 3 subsurface (2 duplicates)
- Gamma Measurements Collected = 23,327 (Note: one instrument failure, removed data)

Figure 1. Field Team Performing XRF Survey at Subarea Group B

4/25/2018 Wednesday

Location: Subarea Group C – Cove Transfer Station North (T9), Target sites (CT-01 [T10], CT-02 [T11]), and BSA-7.

Activities:

- Performed gamma scanning at T9, T10, T11, and B7.
- Conducted XRF field surveys at T9, T10, T11, and B7

Summary:

- Total XRF Measurement Samples = 169
- Total XRF Confirmation Samples Collected = 13
- Gamma Measurements Collected = 29,196 points (10 acres)

Figure 2. Field Team Performing XRF Survey at Subarea Group C

4/26/2018 Thursday through 4/30/2018 Monday

Location: Mesa I Mine 10 [M6], Mesa I Mine 13 [M3], Mesa I Camp [T17], and BSA-9 [B9]

Activities:

- Performed gamma scanning at M3, M6, T17, and B9.
- Conducted XRF field surveys at M3, M6, T17, and B9

Summary:

- XRF Measurements Collected = 564
- Total XRF Confirmation Samples Collected = 39
- Gamma Measurements Collected = 101,474 points

Note: Sunday could not perform XRF field surveys due to cultural survey requirements.

Figure 3. Pre-Trip Tailgate Safety Meeting

Figure 4. Field Staff Conducting Gamma Surveys at Mesa I Mine 10

Figure 5. Field Staff Conducting XRF Field Surveys at Mesa I Mine 10

ACTIVITIES TO PERFORM DURING FIELD TRIP #2

Subarea Group A

- Receive approval to conduct RSE investigations at Subarea Group A.
- Perform RSE investigations at Subarea Group A (Brodie 1 mine group)

Subarea Group B

- Submitted laboratory samples for background and XRF confirmation samples on 5/1/2018 (done)
- Finalize and review scanning and XRF data to determine necessity of Goback surveys at Subarea Group B.
- Identify and execute soil correlation sampling based on review of final gamma scanning data.
- Return to Subarea Group B to collect data from instrument failure area.

Subarea Group C

- Receive approval by EPA for CTS South expansion area
- Receive approval from EPA/DoJ for CT-03 to conduct RSE work (residential area)
- Finalize XRF survey at CTS North (T9)
- Background field documentation for BSA-7
- Soil sampling at background areas.

Subarea Group D

- Continue RSE investigation activities at Subarea Group D.
- Begin RSE investigation activities at Subarea Group E.

Other

- Site walk with drilling companies (TBD)

DEVIATIONS ENCOUNTERED DURING FIELD TRIP #1

- Slight delay related to cultural resource survey crew scheduling and availability.
- Cannot work Sundays doing intrusive activities due to cultural survey schedule and availability, can only perform gamma surveys.
- No access to CT-03 or Subarea Group A as previously planned (Scheduling change)
- Broken radiation detector determined from QC program; data was removed from database.
- Broken GPS screen from rock falling (sent back for repair)
- MSO reconnaissance required field staff to leave for survey.

TETRA TECH

Field Trip Progress Report Summary

To:	Chip Poalinelli
From:	Aaron Orechwa, P.E.
Cc:	Kenyon Larsen
Date:	May 18, 2018
Subject:	Task Order 0001, Mobilization 2

5/7/2018 Monday

Location:

Subarea Group D: Mesa I Mine Complex

Activities:

- XRF Field Surveys at Mesa I Camp (Continued…)
- BSA-9 soil background sampling
- BSA-10 soil background sampling
- Mesa I Mine 11 – gamma radiation surveys
- Mesa I Mine 12- XRF field surveys and gamma radiation surveys
- Mesa I Mine 14- gamma radiation surveys
- Mesa I Mine 15- gamma radiation surveys

Summary of Completed Activities:

- Completed background soil sampling at BSA-9
- Completed Baseline Study gamma radiation survey at BSA-12

Summary (Other):

- EPA directed TT to discontinue scanning at eastern portion of Mesa I Mine 15 due to hazardous conditions; this will be documented in the RSE Report.
- Delay due to cultural resources team start time and to lack of personnel needed to conduct planned activities.

5/8/2018 Tuesday

Location:

Subarea Group D: Mesa I Mine Complex

Activities:

- XRF Field Surveys at Mesa I Camp (Continued…), M1-01, M1-02, and M1-03 target sites.
- Gamma radiation surveys at BSA-11, M1-01, M1-02, M1-03, Mesa I Mines 12-14, BSA-12.

Summary of Completed Activities:

- Completed background soil sampling at BSA-10
- Completed Baseline Study gamma radiation survey at BSA-11, M1-01, and M1-03

Summary (Other):

- Delay due to cultural resources team start time.
- Various health and safety events documented and assessed to address internally with team.

Figure 1. Health and Safety Meeting at Cove Community Tower

5/9/2018 Wednesday

Location:

Subarea Group D: Mesa I Mine Complex

Activities:

- XRF Field Surveys at Mesa I Mine 11, Mesa I Mine 14, and Mesa I Mine 15.
- Site mapping Mesa I Mine 14.
- Gamma/radium soil correlation sampling.
- Gamma radiation surveys at M1-01
- Background soil sampling at BSA-12

Summary of Completed Activities:

- Completed background soil sampling at BSA-12
- Completed Baseline Study gamma radiation survey at M1-01

Summary (Other):

- Delay due to cultural resources team start time and to lack of personnel needed to conduct planned activities.

Figure 2. View from Mesa I Mine 14

5/10/2018 Thursday

Location:

Subarea Group D: Mesa I Mine Complex

Activities:

- XRF Field Surveys at Mesa I Mine 12, Mesa I Mine 13, Mesa I Mine 14, and Mesa I Mine 15.
- Site mapping Mesa I Mine 12.
- Gamma/radium soil correlation sampling.

Summary of Completed Activities:

- Completed XRF field surveys at Mesa I Mine 14 and Mesa I Mine 15.
- Completed Baseline Study gamma/radium correlation sampling.

Summary (Other):

- Delay due to cultural resources team start time (30 minutes late) and to lack of personnel needed to conduct planned activities.
- EPA requested TT document if QC issues require an instrument to be removed; it was conveyed this will occur in the RSE report.
- Discussed drill cutting issues with EPA.

Figure 3. Field Personnel Using XRF at Mesa I Mine 11

5/11/2018 Friday

Location:

Subarea Group D: Mesa I Mine Complex

Activities:

- Conducted gamma radiation surveys at Mesa I Mine 10, 11, 12, 13, 14, and 15.
- Performed XRF Field Surveys at Mesa I Mine 10, 12, and 13.
- Performed background soil sampling at BSA-11.
- Site mapping performed at Mesa I Mine 10 and 13, Mesa I Mine 14

Summary of Completed Activities:

- Completed Baseline Study gamma radiation surveys at Mesa I Mine 10, 11, 12, 13, 14, and 15.
- Completed Baseline Study XRF field surveys at Mesa I Mine 10, 12, and 13.
- Performed site reconnaissance of various drainages off access road below Mesa I Mine 15 which connect to main drainage from Mesa I Mine 13.

Summary (Other):

- Noted potential spring as Mesa I Mine 13.
- EPA conducted site walk with TT Project Manager; on Mesa I Mine 10 and 13. EPA verified hazardous conditions at both mine sites which will limit 100% scan coverage in these areas.

Figure 4. Open Portal noted on Mesa I Mine 12

5/12/2018 Saturday

Location:

Subarea Group A: Brodie 1 Mine and associated Target sites.

Activities:

- Conducted gamma radiation surveys and background soil sampling at BSA-1, BSA-2, and BSA-3.
- Conducted gamma radiation surveys at BSA-4.
- Conducted site mapping at Brodie 1.
- Conducted gamma radiation surveys and XRF field surveys at Brodie 1, BR-03, BR-04.
- Conducted XRF field surveys at BR-06.

Summary of Completed Activities:

- Completed gamma radiation surveys and background soil sampling at BSA-1, BSA-2, and BSA-3.
- Completed gamma radiation surveys at BSA-4.
- Completed site mapping at Brodie 1.
- Completed gamma radiation surveys and XRF field surveys at Brodie 1, BR-03, BR-04.
- Completed XRF field surveys at BR-06.

Summary (Other):

- Delay due to access issues of finding the mine sites.
- Extreme wind conditions present at some of the sites.

Figure 5. Field Crew Collecting Background Soil Samples at BSA-3

5/13/2018 Sunday

Location:

Subarea Group A: Brodie 1 Mine and associated Target sites.

Activities:

- Conducted gamma radiation surveys at remaining sites in Subarea Group A.
- Conducted background soil sampling at BSA-4.
- Site mapping at Brodie 1.

Summary of Completed Activities:

- Completed gamma radiation surveys at all Subarea Group A.
- Conducted XRF field surveys at M1, T1, T3, T6.

5/13/2018 Monday

Location:

Subarea Group A: Brodie 1 Mine and associated Target sites.

Subarea Group D: Mesa I Mine Complex

Activities:

- Pre-bid site walk meeting with EPA and Tetra Tech.
- Conducted gamma radiation surveys at Block K, Cove Transfer Station (South) [EPA approved expansion area], and other sites in Subarea Group C.
- Conducted XRF field surveys at various sites Subarea Group C.

Summary of Completed Activities:

- Completed gamma radiation surveys at all Subarea Group B and C.
- Completed XRF field surveys at Subarea Group C.

Summary (Other):

- Blockage of Mesa II mine access road prevented site walk on this area of the Cove mining region; required meeting to end early.

TETRA TECH

Field Trip Progress Report Summary

To:	Chip Poalinelli
From:	Aaron Orechwa, PE
Cc:	Kenyon Larsen
Date:	June 1, 2018
Subject:	Task Order 0001, Mobilization 3 (05/20/18 through 05/27/18)

05/20/18 Sunday

Field team mobilized to Farmington, New Mexico, and met at field office for meeting.

05/21/18 Monday

Locations:

- Mesa V Incline (M15)
- Mesa V Adit (M16)
- Target Site M5-05 (T21)
- Target Site M5-06 (T22)
- Target Site NA-0344B (T23)

Activities:

- XRF surveys at M15, M16, T21, T22, and T23
- Gamma scanning at M15, M16, T21, T22, and T23
- Mexican Spotted Owl (MSO) surveys initiated

Physical Hazards:

- There is a cliff drop off on the southern portion of Mesa V Adit. The southern portion of the survey boundary cannot be safely accessed from the northern area.

Other:

- Chip and a small group from Tetra Tech performed site reconnaissance and found that the road leading to Mesa V Haul Shaft (synonymous with Mesa V Mine-103) will allow some access to the southern (lower) area of the Mesa V Adit.
- MSO surveys in Cove Wash North and the eastern branch of Cove Wash Middle 3

1999 Harrison Street, Suite 500, Oakland, CA 94612
Tel 510.302.6300 Fax 510.433.0830
www.tetratech.com

Summary:

- Completed gamma scanning and XRF field surveys at T21, T22, and T23
- Completed XRF field surveys at M16 and T21

05/22/18 Tuesday

Locations:

- Mesa VI Mine (M13)
- Mesa V Incline (M15)
- Mesa V Adit (M16)
- Mesa V Mine-103 (M17)
- Target Site M5-05 (T21)
- Target Site Target Site NA-0344B (T23)
- Target Site M5-03 (T20)
- Target Site M5-02 (T19)
- Target Site M5-06 (T22)
- Target Site NA-0344B (T23)
- Background Site 21 (BSA-21)
- Background Site 23 (BSA-23)

Activities:

- Site reconnaissance, XRF surveys, and gamma scanning at M13 and M17
- Continued work on XRF field surveys and gamma scanning at Mesa V Adit
- Initiated gamma scanning and XRF surveys at T19 and T20
- Completed XRF surveys and gamma scanning at T20, T22, and T23
- Completed gamma scanning at Mesa V Incline
- Completed gamma scanning at background sites BSA-21 and BSA-23
- MSO surveys in Cove Wash Middle 1

Physical Hazards:

- The northern part of background site BSA-23 is located on the side of a steep cliff.

Other:

- The hike to Mesa VI took field staff approximately 35 minutes. The hike to background site BSA-23 takes approximately 45 minutes.
- Ongoing road construction on Mesa V road.
- Tetra Tech Task Order 0004 members Chris Reynolds (geochemist), Caleb Stock (mining engineer), and Matt Udell (mining engineer) participated in a site walk with USEPA.
- Gamma scanning of background site BSA-23 was completed. Aaron Orechwa informed Chip that a cliff cuts off the eastern portion of the site. Chip advised that 30 soil samples should be collected from the accessible area of BSA-23.

- Earthwork associated with the road construction resulted in inaccessible areas of M5-02. USEPA was informed that parts of site M5-02 were disturbed.

Summary:

- Completed XRF surveys and gamma scanning at T20, T22, and T23
- Completed gamma scanning at Mesa V Incline
- Completed gamma scanning at background sites BSA-21 and BSA-23

Photograph 1: Field team hiking to Mesa VI.

Photograph 2: Male and female Mexican Spotted Owls identified during the night survey on 5/22/18.

05/23/18 Wednesday

Locations:

- Mesa V Mine-508 (M18)
- Mesa IV 1/2 Mine and Simpson 181 (M19)
- Background Site 20 (BSA-20)

Activities:

- XRF and gamma scanning at M18 and M19
- Completed gamma scanning and soil sampling at BSA-20
- MSO surveys in Cove Wash Middle 2

Other:

- The team performing MSO surveys identified a stuck cow and calf in a canyon. The Tetra Tech team called the Cove Chapter House and provided the coordinates of the cow. In the future, Tetra Tech will inform USEPA of issues like this prior to notifying the chapter house.

Summary:

- Completed Gamma scanning and soil sampling at BSA-20

05/24/18 Thursday

Locations:

- Frank Jr. Mine (M14)
- Mesa V Mine-103 (M17)
- Background Site 17 (BSA-17)
- Background Site 22 (BSA-22)

Activities:

- Completed XRF surveys and gamma scanning at M14
- XRF surveys and gamma scanning in progress at M17
- Completed scanning and soil sampling BSA-17 and BSA-22
- MSO surveys in Cove Wash Middle 3

Photograph 3: Field staff scanning at Frank Jr. Mine.

Photograph 4: Mexican Spotted Owl identified during night survey.

Other:

- Field team was delayed for approximately 20 minutes while driving up the Mesa V road in the morning while waiting for an excavator to clear rocks from the road.

Summary:

- Completed XRF surveys and gamma scanning at M14
- Completed scanning and soil sampling BSA-17 and BSA-22

05/25/18 Friday

Locations:

- Mesa V Mine-103 (M17) and Mesa V Mine – 508 (M18)
- Mesa IV 1/2 Mine and Simpson 181 (M19)
- M5-08 (T25)
- Background Site 18 (BSA-18)

Activities:

- XRF surveys in progress at M17. The upper portion of M17 XRF field surveys were completed.
- Completed XRF surveys and gamma scanning at M18
- Completed gamma scanning at M19

- Completed gamma scanning at T25
- Completed gamma scanning and soil sampling at BSA-18
- MSO surveys concluded in Cove Wash Middle 3

Physical/Biological Hazards:

- A fresh mountain lion kill was identified on Mesa VI. Therefore, no additional field work will be performed on Mesa VI until the next field trip.
- A cliff runs east-west below the Mesa V Mine-508 (M18) and field staff marked this area as inaccessible.
- There is a steep drop off below Mesa IV 1/2 Mine and Simpson 181 (M19) that field staff marked as inaccessible.

Other:

- Gaelle Glickfield (USEPA) hiked to Mesa IV 1/2 Mine and Simpson 181 (M19) to observe inaccessible areas at M19 and Mesa V Mine-508 (M18). She was shown areas that were marked as cliffs on the mesa tablets during gamma scanning that field staff considered inaccessible. She agreed those areas were inaccessible.

Summary:

- Completed XRF surveys and gamma scanning at M18
- Completed gamma scanning at M19
- Completed gamma scanning at T25
- Completed gamma scanning and soil sampling at BSA-18

05/26/18 Saturday

Locations:

- Background Site 19 (BSA-19)
- Mesa V Adit (M16)
- Mesa V Mine-103 (M17)
- Target Site M5-01 (T18)
- Target Site M5-02 (T19)

Activities:

- XRF surveys and gamma scanning at lower areas of M16 and M17
- Gamma scanning and soil sampling at BSA-19
- Gamma scanning at T18 and T19
- MSO surveys attempted in canyons on the back side of the Chuska Mountains near the Knife Edge Mesa and Flag Mesa. High winds prevented surveys.

Other:

- Cultural staff arrive approximately 45 minutes late to Cove water tower and delayed the start time.
- Tetra Tech and cultural staff drove UTVs on UTV road leading to lower Mesa V Adit and Mesa V Mine-103. Cultural staff advised that no vehicles can be driven on this road to deter community members from visiting mines.

Summary:

- Completed gamma scanning at M16 and M17
- Completed gamma scanning and soil sampling at BSA-19
- Completed gamma scanning at T18 and T19

Photograph 5: Mesa V haul shaft and waste rock pile.

05/27/18 Sunday

Field staff demobilized from Farmington, New Mexico.

TETRA TECH

Field Trip Progress Report Summary

To:	Chip Poalinelli
From:	Aaron Orechwa, P.E.
Cc:	Kenyon Larsen
Date:	June 13, 2018
Subject:	Task Order 0001, Mobilization 4 (06/03/18 through 06/12/18)

06/03/18 Sunday

Field team mobilized to Farmington, New Mexico, and met at field office for pre-trip logistical meeting.

06/04/18 Monday

Locations:

- Mesa IV, Mine No. 1 (M20)
- Mesa IV, Mine No. 2 (M21)
- Mesa IV, Mine No. 3 (M22)
- Mesa IV, West Mine (M23)
- BSA-25 (B25)

Activities:

- Gamma scanning at M20, M21, M22, M23, and B25.
- XRF field surveys at M20 and M22.
- Soil sampling at B25.

Physical Hazards:

- There is a strenuous hike near steep cliffs to get to Mesa IV, West Mine waste pile.

Other:

1999 Harrison Street, Suite 500, Oakland, CA 94612
Tel 510.302.6300 Fax 510.433.0830
www.tetratech.com

Photograph 1: Background team preparing to take a soil sample at B25.

Summary:

- XRF surveys in progress at M20, and M22.
- Gamma scanning completed at M20.
- Gamma scanning in progress at M21, M22, M23.
- Gamma scanning and soil sampling completed at B25.

06/05/18 Tuesday

Locations:

- Mesa IV, Mine No. 1 (M20)
- Mesa IV, Mine No. 2 (M21)
- Mesa IV, Mine No. 3 (M22)
- BSA-26 (B26)

Activities:

- Gamma scanning and soil sampling at BSA-26.
- XRF field survey at M21 and M22.
- Gamma scanning at M21.

Physical Hazards:

- Steep slopes and thick vegetation at B26.

Other:

- Correlation sampling was conducted at Group F.
- Mr. Poalinelli performed a site walk with a scan team and an XRF team; he later requested calibration documents, analytical results, and quality control data for the instruments utilized during this site walk.
- AO was not present in field.

Summary:

- Completed gamma scanning and soil sampling at B26.
- Completed XRF field survey at M22.
- Gamma scanning and XRF field survey in progress at M21.

06/06/18 Wednesday

Locations:

- Mesa VI Mine (M13)
- Mesa IV Mine No. 1 (M20)
- Mesa IV Mine No. 2 (M21)
- Background site 23 (BSA-23)

Activities:

- XRF surveys at M20
- Gamma scanning at M13, M20, M21
- Gamma scanning and soil sampling at BSA-23

Other:

- Mountain lion known at Mesa VI

Summary:

- Completed XRF survey at M20

06/07/18 Thursday

Locations:

- Cove Chapter House, in Cove, AZ

Activities:

- Tronox Northern Agency Removal Site Evaluations "Stand Down Meeting"
- Groups present: USEPA, NNHPD, Tetra Tech, Gilbane, DCRM, Cove Chapter

Other:

- Field team was unable to conduct work in field.

Summary:

- Sites that have Class 3 Surveys complete do not need to have cultural monitoring personnel present with field teams.
- Monitoring is required when sampling/drilling areas have not been surveyed.
- Field personnel doing gamma scanning do not need cultural monitoring.
- Chip suggested a group call before mobilization to discuss objective for trip, weekly meetings in the field, and meetings for lessons learned at end of trip.
- Meeting notes were documented and submitted to USEPA TOCOR on June 12, 2018.

06/08/18 Friday

Locations:

- Mesa IV, Mine No. 1 (M20)
- Mesa IV, Mine No. 2 (M21)
- Mesa IV, Mine No. 3 (M22)

Activities:

- XRF field surveys at M21.
- Gamma scanning at M20, M21, and M22.

Physical/Biological Hazards:

- There are cliff drop offs on the east and west side of M21.
- Two bears were observed east of M21 in the wash.

Other:

- Arlo informed Katherine that cultural staff would not be working the next two days.

Summary:

- Approximately 103 XRF points remain at M21.
- Gamma scanning completed at M21, and M22.
- Additional cleanup scanning remains at M20.

06/09/18 Saturday

Locations:

- Mesa IV, Mine No. 1 (M20)
- Mesa IV, Mine No. 2 (M21)
- Mesa IV, West Mine (M23)
- Target Site M5-09 (T26)
- BSA-16 (B16)

Activities:

- Gamma scanning and soil sampling at B16.
- Site recon at T26
- XRF surveys at M21
- Gamma scanning at M20 and M23.

Physical/Biological Hazards:

-

Other:

- Chip said cultural resources are on stand down until Monday. He said the RSE schedule for next trip should not be impacted.

Summary:

- Gamma scanning and XRF field survey completed at M21.
- Gamma scanning completed at M20, and M23.
- Gamma scanning and soil sampling completed at BSA-16.

06/10/18 Sunday

Locations:

- Target Site M5-01 (T18)
- Target Site M5-02 (T19)
- Target Site M5-09 (T26)
- Mesa IV, West Mine (M23)

- Target Site M4-02 (T27)
- BSA-27 (B27)

Activities:

- Gamma scanning and XRF surveys T26, and T27.
- XRF surveys at T18 and T19.
- Gamma scanning and soil sampling at B27.

Physical/Biological Hazards:

Other:

- Chip attended a chapter meeting in Cove and was not present with sampling teams.

Summary:

- Completed gamma scanning and XRF surveys at T26 and T27.
- Completed gamma scanning and soil sampling at B27.
- Fill in scanning at M23 completed.
- Completed XRF surveys at T19.
- XRF surveys at T18 and M23 in progress.

06/11/18 Monday

Locations:

- Mesa II Pit (M24)
- Mesa IV, West Mine (M23)
- Target Site M5-01 (T18)

Activities:

- XRF surveys and gamma scanning at M24.
- XRF surveys at T18 and M23.

Physical/Biological Hazards:

- Tatiana fell and slid approximately 15 feet while gamma scanning at M24. Dan Workman was working with her, and was there to help her after she fell. She went to see a doctor and was checked out with no significant injuries. Some important lessons learned from this is not walking near cliffs, and always using the buddy system. This was documented and the Near Miss Incident Report was submitted to USEPA and ERG on June 13, 2018 by the Project Manager, Aaron Orechwa.

Other:

- The Jeep lost its left rear break while driving on the mountain. It drove down the mountain in 4L with a UTV chase vehicle, and then was towed to Farmington.

Summary:

- Completed gamma scanning and XRF surveys at M23 and T18.
- XRF survey and gamma scanning in progress at M24.

Photograph 2: XRF survey team at M24.

Photograph 3: Nighttime photograph from Mexican Spotted Owl Surveys.

06/12/18 Tuesday

Field staff demobilized from Farmington, New Mexico.

Attachments:

Subarea Group F Field Progress Checklist

Subarea Group G Field Progress Checklist

MSO Spotted Owl Survey for Trip #4 Mobilization

MU CRT
TRIP #4
JUNE 3 - JUNE 12

Group G Progress

Group G AUM and Target Sites

FSP No.	TT ID	Site Name	XRF Points	Survey Area Acres	Scan Completed?	XRF Completed?
FSP 26	M20	Mesa IV, Mine No. 1	430	10.62	✓	✓
FSP 27	M21	Mesa IV, Mine No. 2	662	16.35	✓	✓
FSP 28	M22	Mesa IV, Mine No. 3	130	3.21	✓	✓
FSP 29	M23	Mesa IV, West Mine	150	3.7	✓	✓
FSP 30	M24	Mesa II Pit	150	3.58		
FSP 29	T27	M4-02	26	0.64	✓	✓
FSP 28	T28	M4-03	Target is encompassed within M22 survey boundary			
FSP 26	T29	M4-04	Target is encompassed within M20 survey boundary			

Group G Background Sites

ID	Background Site	Associated Mine or Target	Scan Completed?	Sampled?
B24	BSA-24	Mesa II Pit		
B25	BSA-25	Mesa IV, Mine No. 1	✓	✓
B26	BSA-26	Mesa IV, West Mine	✓	✓
B27	BSA-27	M4-02	✓	✓

TOTAL XRF FOR GROUP G = 1,548 points (78 soil samples)
TOTAL ACRES FOR GROUP G = 38.1 acres
TOTAL BG SAMPLES FOR GROUP G = 120 +
TOTAL BG ACRES = 3 ACRES

194 pts / day
10 samples / day

B25 completed 6/4 (gamma, soil)
M20 completed 6/4 (gamma)
B26 completed 6/5 (gamma, soil)
M20 completed 6/6 (XRF)
M21 completed scan 6/6/18, completed XRF 6/9/18
M23 Scan Completed 6/9/18
T27 XRF, scan completed 6/10/18
B27 scan, sampling completed 6/10/18
M23 XRF in progress ~30 points remain 6/10/18

BO Copy

TRIP#4

Group F Progress

Group F AUM and Target Sites

TT ID	Site Name	XRF Points	Acres	Scan Completed?	XRF Completed?
M13	Mesa VI Mine	268	5.19	✓	✓
M14	Frank Jr Mine	102	2.5	✓	✓
M15	Mesa V Incline	106	2.6	✓	✓
M16	Mesa V Adit	222	3.6	✓	
M17	Mesa V Mine-103 (Haul Shaft)	99	2.5	✓	✓
M18	Mesa V Mine-508	179	4.3	✓	✓
M19	Mesa IV 1/2 Mine + Simpson 181	55	1.4	✓	✓
T18	M5-01	33	0.8	✓	✓
T19	M5-02	21	0.5	✓	✓
T20	M5-03	20	0.5	✓	✓
T21	M5-05	68	1.7	✓	✓
T22	M5-06	96	2.4	✓	✓
T23	NA-0344B	63	1.6	✓	✓
T24	M5-07	59	1.5	✓	✓
T25	M5-08	26	0.6	✓	✓
T26	M5-09	38	0.9	✓	✓

Group F Background Sites

ID	Background Site	Associated Mine or Target	Scan Completed?	Sampled?
B16	BSA-16	M5-09	✓	✓
B17	BSA-17	Frank Jr. Mine	✓	✓
B18	BSA-18	Frank Jr. Mine	✓	✓
B19	BSA-19	Mesa V Mine - 103	✓	✓
B20	BSA-20	Mesa V Mine - 508	✓	✓
B21	BSA-21	Mesa V Incline	✓	
B22	BSA-22	Mesa V Incline	✓	✓
B23	BSA-23	Mesa VI Mine	✓	✓

*Return to Group F on 6/6 w/RAPS team, led by AO

- BSA-23 sampled on 6/6/18
- M13 scan/XRF completed on 6/6/18
- T25 XRF complete 6/6/18
- B16 Scan, Sample completed 6/9/18
- T18 24 points remaining on 6/10/18
- T19 completed on 6/10/18
- T20 completed on 6/10/18

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	Canyon Habitat near Call Station 35 in Cove Wash Middle 2. Excellent Mexican spotted owl habitat.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	A cove feature in Cove Wash Middle 3 providing excellent nesting habitat features.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	Canyon habitat in Cove Wash Middle 2.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	Canyon habitat at the head of the eastern branch of Cove Wash Middle 2. This was adjacent to when one male Mexican spotted owl was observed.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	Canyon habitat in Cove Wash Middle 3.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	A large cove feature in Cove Wash Middle 2.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	A male and female Mexican spotted owl pair observed in Cove Wash Middle 1 near Call Station 51.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	One male Mexican spotted owl observed at the head of the eastern branch of Cove Wash Middle 2.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	One male Mexican spotted owl next to Call Station 20 and a nesting site.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	One red-spotted toad observed in Cove Wash Middle 1.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	One gray fox observed near the entrance of Cove Wash Middle 1.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	One juvenile bullsnake observed in Cove Middle Wash 3.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	Canyon habitat in Cove Wash Middle 1.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	Canyon habitat in the Knife Edge Canyon.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	Canyon habitat in the Flag Mesa Canyon.

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Photograph Number 15

Photographs taken by Sean Kite on May and June, 2018.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	Canyon habitat in Cove Wash Middle 3 eastern branch.

PHOTOGRAPHIC DOCUMENTATION			
Client:	EPA	**Project Name:**	Northern Agency RSE Task Order #1
Survey Type:	Mexican Spotted Owl	**Location:**	Cove, Arizona

Description:	Canyon habitat in Cove Wash Middle 2 western branch.

Field Trip Progress Report Summary

To:	Chip Poalinelli
From:	Aaron Orechwa, P.E.
Cc:	Kenyon Larsen
Date:	June 28, 2018
Subject:	Task Order 0001, Mobilization 5 (06/17/18 through 06/26/18)

06/17/18 Sunday

Field team mobilized to Farmington, New Mexico, and met at field office for pre-trip logistical meeting.

06/18/18 Monday

Locations:

- Mesa I 3/4, Mine No. 2, P-150 (M26)
- Mesa II, Mine No. 1 & 2, P-21 (M27)
- Group G (correlation team)

Activities:

- XRF field surveys and gamma scanning performed at M27.
- XRF field surveys performed at M26.
- Correlation sampling and HPIC measurements taken at Group G.
- Gamma scanning and sediment sampling in drainages Middle 3B (DC3B), upper Middle 3, and Middle 3C (DC3C).
- MSO surveys performed at night.

Physical Hazards:

- Bulls were seen walking in drainages.
- Cultural staff informed Aaron Orechwa (Tetra Tech) that a mountain lion had killed a sheep herder recently in the area near M26, M27, and M28 the previous week.

Summary:

- XRF field surveys at M26 and M27 completed.
- Gamma scanning at M27 completed.
- Completed drainage sampling in upper Middle 3 (DC3A) and Middle 3C (DC3D).

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Photo 1 Cultural, Drainage, XRF, and Gamma Teams Prepare for Entry into Mesa II Complex on 6/18/18

Photo 2 Mexican Spotted Owl Found During Trip 5 MSO Survey

06/19/18 Tuesday

Locations:

- Mesa I 3/4, Mine No. 2, P-150 (M26)
- Mesa II, Mine No. 1 & 2, P-21 (M27)
- Mesa II, Mine No. 1, P-150 (M28)
- Mesa II 1/2 Mine (M30)
- M2-01 (T32)
- Drainage Middle 3D (DC3D)
- Drainage Middle 3B (DC3B)

Activities:

- XRF field surveys and gamma scanning at M26 and M27.
- XRF field surveys at M30.
- Gamma scanning at M28 and T32.
- Gamma scanning and sediment sampling in drainages DC3D and DC3B.
- Gamma correlation and HPIC measurements performed at Group G.

Physical Hazards:

- Steep, unstable slopes and cliffs at M28.
- One correlation sample was eliminated at Mesa IV, West Mine because of hazardous slopes.

Other:

- Bull was still stuck in drainage in M27. Cove Chapter House and USEPA notified.
- EPA made a request via phone for informal data package of initial results of RSE investigation at CT-03 located in residential property in Cove, AZ. This request was fulfilled on 6/27/2018 by Tetra Tech PM Aaron Orechwa via email.

Summary:

- XRF field surveys and gamma scanning at M27 complete.
- Gamma scanning at T32 complete.
- XRF field survey and gamma scanning at M26 complete.
- Gamma scanning and sediment sampling in drainages DC3D and DC3B complete.
- Group G correlations complete.

Photo 3 One of the Many Slot Canyons Encountered During the Drainage Survey Teams

06/20/18 Wednesday

Locations:

- Mesa V Haul Shaft located at Mesa V Mine 103 (M17)
- Mesa II, Mine No. 1, P-150 (M28)
- Mesa II 1/2 Mine (M30)
- Drainage Middle 1A (DC1A)
- Mesa V Adit (M16)

Activities:

- Confined space entry to Mesa V Haul Shaft (M17).
- XRF field surveys at M16.
- XRF field surveys and gamma scanning at M28 and M30. Scanned waste rock pile at M28 by hiking in from below.
- Gamma scanning and sediment sampling in drainage DC1A.

Physical Hazards:

- Hot temperatures and strenuous hiking. Sunny day with temperatures in the mid-80s.
- Bear tracks were observed at M30 between the time of hiking down to site and back up to vehicles.

Other:

- Media were on site to film the road construction.
- 50 picocuries/L radon in the “back room” of the haul shaft was measured.
- Chip Poalinelli (USEPA) guided the grazing official to the bull that was stuck in drainage. They will attempt to get the bull out tomorrow.

Summary:

- Entry and surveillance monitoring and sampling activities at Mesa V Haul Shaft completed.
- XRF field surveys at M16 complete.
- Gamma scanning at M28 complete. Additional XRF field surveys at M28 in progress.
- XRF field surveys and gamma scanning at M30 in progress.

Photo 4 Trained Confined Space Entrants Performing Radiological Measurements in Mesa V Haul Shaft

06/21/18 Thursday

Locations:

- Cove Wash Watershed drainages Middle 1 (DC1), Middle 1G (DC1G), Middle 1B (DC1B), Middle 2 (DC2), and Middle 2A (DC2A).
- Background study area BSA-21.

Activities:

- Background soil sampling at BSA-21.
- Soil sampling and XRF field surveys at drainages DC1, DC1G, DC1B, DC2, and DC2A.

Other:

- Melvin Yazzie from NAML visited for the day.
- RERT visited and provided oversight.
- Bull stuck in drainage at Mesa II rescued.

Summary:

- Completed investigations at drainages Middle 2 (DC2), Middle 2A (DC2A), and Middle 1G (DC1G).

06/22/18 Friday

Locations:

- Drainages Middle 2B (DC2B) , Middle 1B (DC1B from top), and background drainage DB34.
- Mesa II, 1/2 Mine, Mine 4 (M31)
- Mesa II, 1/2 Mine (M30)

Activities:

- Sediment sampling at drainages Middle 1B, Middle 2B, and DB34.
- XRF field surveys and gamma scanning at M30 and M31.

Physical/Biological Hazards:

- Fresh mountain lion tracks found in drainages.

Summary:

- Gamma scanning and sediment sampling completed at drainages Middle 1B, Middle 2B, and DB34.

06/23/18 Saturday

Locations:

- Drainages upper Middle 1 (DC1A), Middle 3 (DC3), Middle 3A (DC3A), Middle 3E (DC3E), Middle 3G (DC3G), Middle 3F (DC3F), and background drainage DB35.

Activities:

- Gamma scanning and sediment sampling at drainages described above.

Physical/Biological Hazards:

- Bear encountered by the Mexican spotted owl survey team on Friday night.
- Bear encountered by Chip Poalinelli (USEPA) while out with a drainage team.
- Mexican spotted owl during day during drainage investigation.
- Fractured and falling rocks in fractured domes encountered.

Other:

- Aaron Orechwa (Tetra Tech) identified potential water sampling locations in drainages.
- Josh Mellema (Tetra Tech) identified potential water sampling locations at background drainage DB35.

Summary:

- Gamma scanning and sediment sampling completed at DC1A, DC3, DC3A, DC3E, DC3G, DC3F, and DB35.

Photo 5 Daily Tailgate Meeting at the Cove Water Tower Meeting Location Prior to Fieldwork of the Day

06/24/18 Sunday

Locations:

- Drainages Cove Wash North (DCWN) and Cove Wash Middle (DT9)
- Background site 6 (BSA-6)

Activities:

- Gamma scanning and sediment sampling at drainages Cove Wash North and Cove Wash Middle.
- Collected 3 background soil samples at BSA-6. There was a lithoscatter in an area of BSA-6 and previously 3 samples were eliminated. The Tetra Tech team collected 3 samples from the area surrounding the lithoscatter.

Physical/Biological Hazards:

- Rattlesnake observed at Cove Wash North.

Other:

- USEPA gave Tetra Tech a 3 x 3 detector and 2 x 2 detector to store at Iina ba. Neil Wrubel (ERG) checked the pelican case and there is not a source.

Summary:

- Gamma scanning and sediment sampling completed at DCWN.
- Gamma scanning and sediment sampling completed at DT9.

06/25/18 Monday

Locations:

- M30, M31, and M32
- Mesa II Mine IV (M29)

Activities:

- Attempted recon of Knife Edge.
- XRF field surveys and gamma scanning at M30, M31, M32, and M29.

Physical/Biological Hazards:

- Steep slopes at M30, M31, and M32 and unstable rocks.

Other:

- Team could not drive on UTV road to M30 because the cultural team closed the road. Additional hiking by team was required.
- USEPA indicated that the conex trailer at the Water Tower will be removed and Tetra Tech can then scan it.
- The consensus from the recon team was that Knife Edge should be approached from Buffalo Pass.

Summary:

- XRF field surveys and gamma scanning at M30 in progress. Approximately 80 XRF field survey points remain.
- XRF field surveys and gamma scanning at M29 completed for baseline study.
- XRF field surveys and gamma scanning at M31 and M32 in progress.

06/26/18 Tuesday

Field staff demobilized from Farmington, New Mexico.

Field Trip Progress Report Summary

To:	Chip Poalinelli
From:	Aaron Orechwa, P.E.
Cc:	Kenyon Larsen
Date:	August 10, 2018
Subject:	Task Order 0001, Mobilization 6 (07/09/18 through 07/18/18)

07/09/18 Monday

Tetra Tech team mobilized to Farmington, New Mexico.

07/10/18 Tuesday

Locations:

- Mesa I ¾ Incline (M25)
- Background Site BSA-30 (B30)
- Round Rock Chapter
- Mesa II 1/2 Mine (M30)
- Mesa II 1/2 Mine, Mine 4 (M31)
- Background Site BSA-29 (B29)
- Mesa III Mine (M32)

Activities:

- Background soil sampling at B30 and B29.
- XRF survey and gamma scanning at M30, M31, and M32.
- Scanning at M25.
- Community meeting with Lukachukai grazing official.

Physical Hazards:

- Bear observed at Mesa III.

Other:

- Melvin Yazzie (Navajo Abandoned Mine Lands [NAML]) and Joanie (NAML) were on site and observed XRF teams at M30, M31, and M32.

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Summary:

- Gamma scanning completed at sites M25, M30, M31, and M32.
- XRF completed at M31 and M32.
- Background sampling completed at B30.
- Tetra Tech met with Lukachukai community members.

07/11/18 Wednesday

Locations:

- Subarea Group E: Henry Phillips Mine (M11)
- Subarea Group H: Mesa I 1/2 Mine (M10) and Background Sites BSA-14 (B14) and BSA-29 (B29)

Activities:

- XRF survey completed at M10.
- Gamma scanning completed at M10.
- Gamma scanning completed at M11.
- XRF survey at M11.
- Soil sampling at B29.
- Gamma scanning and soil sampling completed at B14.

Physical Hazards:

- Challenging road and weather conditions:
  - A utility task vehicle (UTV) was temporarily stuck in rut on the way to Mesa II area.
  - A U.S. Environmental Protection Agency (USEPA) vehicle had a flat tire on the way to Mesa II.
  - Inclement weather occurred in the afternoon; thunder and lightning caused a work delay.
- A Tetra Tech scientist had food poisoning.

Other:

- Photo/video documentation of inaccessible areas on eastern portion of M10.
- Rain/lightning delay at M11; the field team had to leave early. The field team went to B29 and encountered another rain/lightning delay.

Summary:

- Severe weather and challenging road conditions limited the amount of work completed.
- USEPA oversight person left early because of a flat tire and to assist a sick Tetra Tech scientist.


Photograph 1: Field team driving a UTV down from Mesa II after the afternoon thunderstorm.

07/12/18 Thursday

Locations:

- Knife Edge Mesa Mine (M33)
- Background Site BSA-32 (B32)
- Target Sites 33 (T33) and 34 (T34)

Activities:

- XRF and scan at M33.
- XRF and scan at T33.
- Background soil sampling and scan at B32.

Photograph 2: Field team hiking to Knife Edge Mesa Mine.

Physical Hazards:

- T34 was not accessible because of dangerous cliffs.
- A thunderstorm occurred at 2 p.m.; teams stopped work and returned to UTVs.
- Roads were wet and slick on the way home.
- The hike to M33 from the vehicles took over an hour.

Photograph 3: Weather conditions at Knife Edge Mesa during the hike back to the vehicles.

Other:

- USEPA advised Tetra Tech not to collect water samples in the drainages because of severe weather; USEPA advised Tetra Tech to ship back the water quality sonde.

Summary:

- Scan and background soil sampling complete at B32.
- Scan complete at M33 and T33.
- XRF in progress at T33 and M33.
- T34 was not accessible and photos were taken.
- Weather delayed work at M33.

07/13/18 Friday

Locations:

- Background Sites BSA-24 (B24), BSA-29 (B29), and BSA-31 (B31)

Activities:

- Soil sampling at B29 and B31.
- Gamma scanning at B24.

Physical Hazards:

- Cliff at B24; part of the site is inaccessible.
- Thunder was heard on Mesa III and clouds were building at approximately 11 a.m.

Other:

- Departed Mesa III at approximately 11:45 a.m. because of thunderstorms.
- Departed Cove water tower at approximately 12:30 p.m.

Summary:

- Completed soil sampling at B29 and B31.
- Completed gamma scanning at B24.
- Weather delayed work at Mesa III.

07/14/18 Saturday

Locations:

- Mesa II Pit (M24)
- Background Site BSA-24 (B24)
- Black No. 1 Mine (M34) and Black No. 2 Mine (M35)
- Background Site BSA-6 (B6)

Activities:

- XRF and gamma scanning at M24.
- Gamma scanning at M34 and M35.
- Background site reconnaissance at B24 and sampling at B6.

Physical Hazards:

- Dangerous 100-foot cliffs at M34 and M35.
- Fresh bear tracks observed at Mesa III.

- A severe thunderstorm occurred at approximately 1 p.m.; all teams returned to the Cove water tower. One team stayed in Cove to complete soil sampling at B6 after the storm was over.

Other:

- The hike from Mesa III to Black Mesa takes approximately 45 minutes.

Summary:

- Completed XRF and soil sampling and scanning at Mesa III Pit (M24).
- Scan in progress at Black No. 1 Mine (M34) and Black No. 2 Mine (M35).
- Completed soil sampling in lithoscatter areas at B6 with cultural oversight.

07/15/18 Sunday

Locations:

- Subarea Group E: Henry Phillips Mine (M11); Mesa I 1/2, West Mine (M12); Background Sites BSA-14 (B14), BSA-13 (B13), and BSA-21 (B21);
- Subarea Group F: Target Site MS-09 (T26)

Activities:

- Gamma scanning and soil sampling at B14 and B13.
- Soil sampling at B21.
- XRF field survey at M11.
- Gamma scanning and XRF field surveys at M12.
- Gamma scanning in eastern portion of T26.

Physical Hazards:

- Slips, trips, and falls on steep slopes.
- Afternoon thunderstorms.

Summary:

- Changed start time to one hour earlier; met at 7 a.m. in Cove.
- Completed background survey and sampling at B13, B14, and B21.
- Completed removal site evaluation (RSE) activities for baseline study at M11, M12, and T26.

07/16/18 Monday

Locations:

- Group J: Background Site BSA-33 (B33) and Tommy James Mine (M39)
- Group H: Mesa II 1/2 Mine (M30)
- Group G: Background Site B-24 (B24)

Activities:

- Scanning and background sampling at B33.
- Reconnaissance to M39.
- Sampling at B24.
- XRF survey at M30.

Physical Hazards:

- Cliff runs north-south at B24.
- Severe weather occurred at approximately 1 p.m.; clouds were building and thunder was audible, and all teams departed from the mountain.
- The Mexican spotted owl team notified the RSE team of a forest fire near Flag Mesa; Tetra Tech called the USEPA, Cove Chapter House, and the U.S. Forest Service.

Other:

- The hike to M39 takes approximately 1 hour.
- The Tetra Tech team arrived at the Cove water tower at 6:50 a.m.; Gilbane arrived at 7:00 a.m.; and the cultural team arrived at 7:40 a.m.

Summary:

- Completed B33 scanning and sampling.
- Completed B24 sampling.
- Completed M30 XRF.
- Conducted site reconnaissance to M39.

07/17/18 Tuesday

Locations:

- Group H: Mesa I 3/4 Mine (M25) and Targets 30 (T30) and 31 (T31)
- Group I: Knife Edge Mine (M33) and Target 33 (T33)
- Group J: Black No. 1 Mine (M34) and Black No. 2 Mine (M35)

Activities:

- Gamma scanning at M34, M35, T30, T31, and T33.
- XRF surveys at M25, T31, and T33.

Physical Hazards:

- Cliffs with large drop-offs at M34 and M35.
- Numerous dead trees and trip hazards at T31.

Photograph 4: Field staff performing gamma scanning at Black No. 1 Mine. Significant cliffs are visible.

Other:

- The hike to M34 and M35 takes approximately 45 minutes.

Summary:

- Completed gamma scanning at T30, T31, T33, M34, and M35.
- Completed XRF surveys at T31, T33, M25, and M33.

Photograph 5: Field staff performing gamma scanning at Black No. 2 Mine.

07/18/18 Wednesday

Tetra Tech team demobilized from Farmington, New Mexico.

TETRA TECH

Field Trip Progress Report Summary

To:	Chip Poalinelli
From:	Aaron Orechwa, P.E.
Cc:	Kenyon Larsen
Date:	September 5, 2018
Subject:	Task Order 0001, Mobilization 7 (8/11/18 through 08/22/18)

08/11/18 Saturday

Field team mobilized to Farmington, New Mexico, and met at the field office for a pre-trip logistical meeting.

08/12/18 Sunday

Locations:

- Black No. 1 Mine (M34)
- Black No. 2 Mine (M35)
- Black No. 2 Mine West (M36)
- Step Mesa Mine (M38)
- Tommy James Mine (M39)
- Cove Chapter House

Activities:

- XRF surveys at M34 through M36.
- Gamma scanning at M35.
- Site reconnaissance to M38 and M39.
- Community meeting at the Cove Chapter House.

Physical Hazards:

- Access to all the mine sites required at least a strenuous 1-hour hike.
- Steep slopes and cliffs were present at all mine sites.
- A near miss occurred where a staff scientist had early signs of heat exhaustion and medical attention was provided and the problem was resolved.

Other:

- During the site reconnaissance to M38 and M39, Tetra Tech was within approximately 20 yards of M38. However, a 7-foot drop-off precluded access to the site from that route.

Summary

- Completed XRF surveys at M34 and M36.
- Completed gamma scanning at M35.
- XRF survey in progress at M35.
- Five Tetra Tech staff members participated in a community meeting at the Cove Chapter House.

Photograph 1. View from Mouth of Canyon at Black No. 2 Mine.

08/13/18 Monday

Locations:

- Black No. 2 Mine (M35)
- Flag No. 1 Mine (M37)
- Background Site 30 (BSA-30)

Activities:

- XRF surveys at M35 and M37.
- Radon Track Etch detector installation at M35 and 37.
- Gamma scanning at BSA-30.

Physical Hazards:

- Access to both mine sites required at least a strenuous 1-hour hike.
- Steep slopes and cliffs were present at all sites.
- A Tetra Tech staff member experienced heat illness symptoms in the afternoon.

Other:

- USEPA advised Tetra Tech to collect water samples later in the week.
- Keys were locked in a vehicle and staff members waited for the locksmith to arrive. The locksmith never came, and the vehicle was left at the water tower overnight.

Site Visitors:

- Rob Manriquez of Tetra Tech joined the field team for the day.

Summary

- Completed XRF surveys at M35 and M37.
- Completed installation of Radon Track Etch detectors at M35 and M37.
- Completed gamma scanning at BSA-30.

Photograph 2. An XRF survey in progress adjacent to a closed portal at Flag No.1 Mine.

08/14/18 Tuesday

Locations:

- Mesa I Mine 12 (M5)
- Mesa I Mine 14 (M7)
- Mesa I Mine 15 (M8)

Activities:

- XRF surveys and gamma scanning at waste rock piles below the cliffs at M5, M7, and M8.
- Goback XRF survey at M8.
- Opportunistic sediment sampling in drainages below M5 and M7.

Physical Hazards:

- Access to the mine sites required strenuous hiking in heat.
- Steep slopes and cliffs were present at all mine sites.

Other:

- The vehicle that was left overnight in Cove was unlocked that morning.
- A Tetra Tech scientist came down with food poisoning that morning and left the site at approximately 9:20 a.m. prior to starting work.
- Gilbane indicated that they had found access routes to Mesa I 1/4, Step Mesa, and Tommy James Mines. USEPA requested that Tetra Tech survey and scan those mines.

Summary

- Completed original XRF grid at M8. Goback XRF survey in progress at M8.
- Completed original scan area and Goback scan area at M8.
- XRF survey and scanning in progress at waste rock piles below M5 and M7.

Photograph 3. A Tetra Tech scientist hiking up a drainage that was used to access the waste rock piles below the cliff at Mesa I Mine 15.

08/15/18 Wednesday

Locations:

- Mesa I Mine 12 (M5)
- Mesa I Mine 14 (M7)
- Mesa I Mine 15 (M8)
- M1-03 (T15)
- Mesa I Camp (T17)
- Mesa V - Mine 103 (Haul Shaft)

Activities:

- XRF surveys at waste rock piles at M7 and M8.
- Gamma scanning at M5, T15, and T17.

Physical Hazards:

- Rain, slippery rocks, steep slopes, thick vegetation, and falling rocks.

Other:

- Tetra Tech and EPA met with NAML to discuss Action Memo and drainage issues at the open portal above the Haul Shaft at Mesa V- Mine 103.
- Tetra Tech attended a meeting at the Navajo Abandoned Mine Lands (NAML) headquarters.

Site Visitors:

- Drillers and NAML staff.

Summary

- Completed XRF surveys at M7 and M8.
- Completed gamma scanning at T17.
- Gamma scanning in progress at M5 and T15.


Photograph 4. Reclamation compromised due to unnatural drainage at a portal above Haul Shaft.

08/16/18 Thursday

Locations:

- Mesa I Mine 11 (M4)
- Mesa I Mine 13 (M6)
- Mesa I Mine 15 (M8)
- Mesa I Camp (T17)
- M1-01 (T13)
- Drainage DM39
- Lukachukai/Round Rock Chapter House

Activities:

- Gamma scanning at T15, M4, M6, and M8.
- XRF field surveys at M6.
- Goback XRF field surveys at M6, T13, and T17. At T17, grids within culturally restricted areas were not completed.
- Gamma scanning and sediment sampling at drainage DM39.

Physical Hazards:

- Cliffs and falling rocks.

Other:

- Tetra Tech attended a community meeting at Lukachukai/Round Rock Chapter House.
- A cultural site walk to Knife Edge Mesa took place.
- A Tetra Tech scientist came down with food poisoning.

Summary

- Except for grids within culturally restricted areas at T17, completed Goback XRF field surveys and gamma scanning at T13 and T17.
- Completed gamma scanning at T15, M4, M6, and M8.
- Completed gamma scanning and sediment sampling at drainage DM39.
- XRF field survey in progress at M6.

Photograph 5. DCRM giving presentation to Lukachukai Chapter Meeting.

08/17/18 Friday

Locations:

- Mesa I Mine 10 (M3)
- Mesa 1 1/4 (M9)
- Mesa I 1/2 (M10)
- M1-03 (T15)
- Middle 3E drainage (DC3E)
- Lukachuakai drainage (DM35)

Activities:

- XRF surveys at M3, M9, and T15.
- Gamma scanning at M9 and M10.
- Scanning at drainage DM35.
- Sediment sampling and gamma scanning at drainage DC3E.

Physical Hazards:

- Severe weather, including rain and hail; muddy conditions; flash flooding; falling rocks; and dead trees creating trail hazards.

Other:

- USEPA was not present on site.

Summary

- Completed XRF surveys at M9.
- Completed gamma scanning at M9 and M10.
- Completed Goback XRF survey at T15.
- Goback XRF survey in progress at M3.
- DM35 drainage scanning in progress.
- Completed sediment sampling and gamma scanning at Middle 3E drainage.

Photograph 6. View of open prospect at Mesa I 1/4.

08/18/18 Saturday

Locations:

- Knife Edge drainage (DM33)
- Flag Mesa drainage (DM35)
- Step Mesa Mine (M38)
- Tommy James Mine (M39)
- Mesa I Mine 10 (M3)
- Mesa I Mine 14 (M4)
- Mesa I Mine 12 (M5)
- Cove Transfer Station (T9)
- Cove Transfer Station South (T37)
- CT-01 (T10)

Activities:

- XRF Goback surveys at M3, M4, and M5.
- Baseline XRF field surveys and gamma scanning at M38.
- Established that there is no safe access to M39.
- Site mapping at M38 and M39.
- Gamma scanning and sediment sampling at DM33 and DM35.
- Gamma scanning and XRF Goback surveys at T9, T37, and T10.

Physical Hazards:

- Falling rocks and steep slopes.
- Heat exposure.

Other:

- A Tetra Tech scientist accompanied Gilbane to stake routes to Mesa I Camp and Mesa I Mine 15.

Summary

- Completed Group C Goback XRF surveys and gamma scanning.
- Completed XRF Goback surveys at M3 and M4. XRF Goback survey in progress at M5.
- Completed baseline XRF field survey and gamma scanning at M38. Staff determined there is no safe access to M39.
- Completed site mapping at M38 and M39.
- Completed gamma scanning and sediment sampling at DM33 and DM35.

Photograph 7. EPA and Tetra Tech at a closed portal at Step Mesa.

08/19/18 Sunday

Locations:

- Group A: Brodie 1 (M1); BR-01 (T1); BR-04 (T4); BR-05 (T5); and BR-06 (T6)
- Group B: Block K (M2) and BK-02 (T8)
- Drainage DM1

Activities:

- Goback XRF field surveys and gamma scanning at M1, M2, T1, T4, T5, and T8.
- Soil sampling for correlation at Group A and Group B.
- Gamma scanning and sediment sampling at drainage DM1.

Physical Hazards:

- Cliffs.
- Heat exposure.
- Driving and working near a road.

Other:

- Identified NORM/TENORM.
- USEPA confirmed with Tetra Tech that there will not be drilling at M1 and T1.
- USEPA gave a technical directive radon monitoring at background.

Site Visitors:

- Alberta Scott of Tetra Tech was on site as an observer.

Summary

- Completed Goback XRF surveys and gamma scanning at M1, T1, T4, T5, and T6 except for areas not culturally cleared.
- Completed XRF and gamma surveys at M2 and M8.
- Completed gamma soil correlation at Group A and Group B.
- Completed sediment sampling and gamma scanning at drainage DM1.

Photograph 8. Brodie 1 closed portal view from below.

08/20/18 Monday

Locations:

- Subgroups H and J
- Mesa I Mine 12 (M5)
- Lukachukai drainage (DM35)

Activities:

- XRF surveys at M5.
- Gamma correlation soil sampling at Groups H and J.
- Road scanning at Groups H and J.
- Gamma scanning and sediment sampling at DM35.

Physical Hazards:

- Falling rocks and cliffs.

Summary:

- Completed XRF survey at M5.
- Completed gamma correlation soil sampling at Group J.
- Gamma correlation soil sampling is in progress at Group H.
- Completed road scanning for project.
- Completed gamma scanning and sediment sampling at DM35.

Photograph 9. Mess I Mine 12 waste pile.

08/21/18 Tuesday

Locations:

- Subgroups H and F
- Mesa I 1/2 Mine (M10)
- Drainages Middle 3 (DC3) and Middle 3E (DC3E)

Activities:

- XRF field surveys at M10.
- Gamma correlation soil sampling at Group H.
- Gamma scanning at Group F.
- Water sampling at drainages DC3 and DC3E.

Physical Hazards:

- Falling rocks, steep slopes, rain and severe weather, and potential for flash floods.

Other:

- Bear sightings.

Site Visitors:

- Two Navajo Nation USEPA staff (Binaad and Daniel) were on site.

Summary

- Completed XRF field survey at M10.
- Gamma correlation soil sampling is 75 percent complete at Group H.
- Completed water sampling at DC3 and DC3E.
- Gamma scanning is 50 percent complete at Group F.

Photograph 10. Water sampling personnel collecting field parameters.

08/22/18 Wednesday

Field team departed Farmington, New Mexico.

TETRA TECH

Field Trip Progress Report Summary

To:	Chip Poalinelli
From:	Aaron Orechwa, P.E.
Cc:	Kenyon Larsen
Date:	September 21, 2018
Subject:	Task Order 0001, Mobilization 8 (9/10/18 through 09/19/18)

09/10/18 Monday

Field team mobilized to Farmington, New Mexico, and met at field office for pre-trip logistical meeting.

09/11/18 Tuesday

Locations:

- Group F: Mesa V Incline (M15), Mesa V Adit (M16),
- M5-02(T19), M5-03 (T20), M5-05 (T21), M5-06 (T22), NA-0344B (T23), and M5-08 (T24)
- Group C: Cove Transfer Station North (T9)

Activities:

- Subsurface drilling and hand augers at T9.
- Gamma scanning and XRF field surveys at Group F sites.

Physical Hazards:

- Wild dogs; Heat and dehydration; Steep cliffs; Slips, trips, and falls

Other:

- Chip Poalinelli (USEPA) approved biological clearing for T9.; Chip/DCRM approved cultural clearing for T9.
- Drilling company presented different driving approaches, including hollow stone, solid stem auger, and direct push on two different rigs.

Summary

- Completed XRF Gobacks at M15, T19, T20, T21, T22, T23, and T24.

1999 Harrison Street, Suite 500, Oakland, CA 94612
Tel 510.302.6300 Fax 510.433.0830
www.tetratech.com


Photograph 1. Field Geologists Logging Drilling Samples at Cove Transfer Station

Photograph 2. Drilling Crew at Cove Transfer Station

09/12/18 Wednesday

Locations:

- Mesa IV West Mine No. 2 (M21)
- CT-03 (T12)
- Cove Transfer Station North (T9)
- Cover Transfer Station South (T37)

Activities:

- Goback XRF and scanning at M21.
- Surface and subsurface soil sampling at T12.
- Drilling at T9 and T37.
- Site mapping, subsurface sampling, and Geotech sampling at M21.
- Radon installation at M21.

Physical Hazards:

- Extreme hiking at M21.
- Rock fall, slides, trips, and falls

Other:

- Encountered potential elevated material at T34 with hydrovac.
- Four mule deer spotted at M21.

Summary

- Completed drilling at T9.
- Completed surface and subsurface sampling at T12.

Photograph 3. Mesa IV West Mine No. 2 Looking Up At Field Crew on Newly Discovered Route Down

Photograph 4. Mesa IV West Mine No. 2 Waste Pile off Eastern Boundary

09/13/18 Thursday

Locations:

- Mesa V Mine 103 (M17)
- Mesa V Adit (M16)
- Simpson 181 (M19)
- Mesa V 508 (M18)
- Cove Transfer Station South (T37)

Activities:

- Goback XRF and scanning at M16, M17, M18, and M19.
- Subsurface by hand at M16 and M17.
- Drilling at T37 and M18.
- Radon placement at M17.
- Site mapping at M16 and M17.

Physical Hazards:

- Extreme hiking
- Rattlesnake

Other:

- Site reconnaissance performed at Frank Jr. Mine to assess Gobacks.
- Hydrorac was decontaminated and released from site.
- Mobile drill rig was decontaminated and released prior to mobilizing to Mesa V.

Site Visitors:

- Navajo Nation EPA
- Gaelle Glickfield, USEPA
- Parry Charlie, Navajo Uranium Commission
- Dińe College professors and camera crew

Summary

- Completed Gobacks at M17, M18, and M19.
- Completed drilling at T37.
- Completed radon placement at M17 (two stations).
- Completed site mapping at M17.

Photograph 5. Field Crew Headed to Mesa V Mine – 103

Photograph 6. Mesa V Mine – 103 (Lower Section)

09/14/18 Friday

Locations:

- Burial Cell 344B (T23)
- Mesa V Mine 508 (M18)
- Mesa IV, West Mine (M23)
- Mesa V Incline (M15)
- Mesa IV, Mine No. 1 (M20)
- Mesa IV, Mine No. 2 (M21)
- Mesa IV, Mine No. 3 (M22)
- Mesa V Adit (M16)

Activities:

- XRF Goback field surveys at M20, M21, M22, and M23.
- Site mapping at M15, M16, and M18.
- Subsurface sampling by hand at M15, M16, and M18.
- Drilling at M18 and T23.
- Radon placement at many different sites not mentioned above under Locations.

Physical Hazards:

- Slips, trips, and falls
- Possible heat exhaustion

Other:

- XRF green had filter malfunction, was discontinued and sent back to factory.
- Bulldozer (CAT D6) delivered.

Site Visitors:

- Jacob Phipps, USEPA Region 9
- NECA security personnel

Summary

- Completed drilling at M18.
- Completed subsurface by hand at M18, M15, and M16.
- Completed site mapping at M15, M16, M18, and M22.
- Completed XRF Gobacks at M22.

Photograph 7. Drilling Along Road at Mesa V Mine – 508

Photograph 8. Rimstrip and Salt Wash Outcrop at Mesa V Mine – 508

09/15/18 Saturday

Locations:

- Mesa VI Mesa (M13)
- Mesa V Adit (M16)
- Mesa IV 1/2 Mine and Simpson 181 (M18)
- Mesa V Mine 508 (M18)
- Mesa V Incline (M15)
- NA-0343B (T23)
- M5-01 (T18)
- M5-09 (T26)
- Various sites for radon placement

Activities:

- Drilling at T23 and M15.
- XRF, scanning, site mapping, and subsurface sampling at M15.
- Scanning at M16 and M19.
- XRF field surveys at M16, T18, and T26.
- Radon canister placement.

Physical Hazards:

- Rock falls
- Heat
- Extreme hiking
- Radon hazards
- Drilling hazards

Other:

- D6 bulldozer used to stabilize drill rig.
- Chip Poalinelli (USEPA) directed IDW to be disposed onto Mesa V Incline and properly scanned and/or sampled.

Summary

- Completed drilling at T23 and M15.
- Completed Goback XRF and scanning at M13.
- Completed XRF Gobacks at M16, T18, and T26.
- Completed site mapping at M13.
- Completed subsurface soil sampling at M13.
- Completed Goback scanning at M18 and M19.


Photograph 9. The Team Found Access to Mesa VI Mine (Middle Section)


Photograph 10. Previously Reclaimed Portal at Mesa VI Mine

09/16/18 Sunday

Locations:

- Mesa I Mine 13 (M6)
- Mesa I Mine 14 (M7)
- Mesa I Mine 10 (M3)
- Block K (M2)
- BSA-3 (B3)
- Group A: Brodie 1 (M1) and BR-01 (T1)

Activities:

- XRF Gobacks and scanning at M6.
- Site mapping and subsurface sampling by hand at M6 and M7.
- Drilling at M2.
- Radon placement.
- Supplemental background surface sampling at B3.

Physical Hazards:

- Rock fall hazards
- Dust control on waste piles
- ALARA

Other:

- Initiate IDW disposal procedure as directed by USEPA.

Site Visitors:

- Reuben (local) passed by and talked to sampling team at Mesa I.

Summary

- Completed XRF and scan Gobacks at M6.
- Completed site mapping at M3, M6, and M7.
- Completed subsurface sampling at M3, M6, M7, and M1.
- Completed radon placement for TO 0001.
- Completed supplemental sampling at B3.


Photograph 11. Preparing for Subsurface by Hand Sample at Mesa I Mine 13

Photograph 12. Radon Station and Waste Pile at Mesa I Mine 10

09/17/18 Monday

Locations:

- Mesa IV, Mine No. 1 (M20)
- Mesa IV, Mine No. 2 (M21)
- Mesa IV, Mine No. 3 (M22)
- Mesa IV, West Mine (M23)
- Block K (M2)

Activities:

- XRF field survey and scan Goback surveys at M20.
- Site mapping and subsurface sampling at M20, M21, and M23.
- Subsurface sampling at M23.
- Drilling at M2.

Physical Hazards:

- Slips, trips, and falls
- Rock fall at high walls
- Heat exhaustion

Other:

- NECA distributed IDW in drums and removed trash from Cove water tower.
- Chip Poalinelli (USEPA) requested a team for reviewing cultural surveys next trip.
- Site reconnaissance with Aaron Orechwa, Megan Sears, and Sean Kite and eliminated, due to extreme slopes [see Photograph 13], XRF and scanning at west side of M21.

Summary

- Completed subsurface sampling at M20, M21, and M22.
- Completed site mapping at M20, M21, and M22.
- Completed drilling at M2.

Photograph 13. Extreme Slope at Western Waste Piles of Mesa IV West Mine No. 2

Photograph 14. Field Team Slope at Easter Waste Piles of Mesa IV West Mine No. 1

09/18/18 Tuesday

Locations:

- Knife Edge Mesa (M33)
- Frank Jr. Mine (M14)
- Mesa I Mine 11 (M4)
- Mesa I Mine 12 (M5)
- Mesa I Mine 15 (M8)
- Mesa IV, 1/2 Mine and Simpson 181 (M19)
- Mesa IV, West Mine (M23)

Activities:

- XRF scanning at M14.
- Gamma surveys at M14, M5, and M23.
- Site mapping and subsurface sampling by hand at M14, M4, M5, M8, M19, and M33.
- Radon deployment at M33.

Physical Hazards:

- Heat exhaustion
- Carrying too much soil

Other:

- NECA moved drums to conex box on yard in Shiprock. Chip Poalinelli (USEPA) completed oversight of the removal.

Summary

- Completed XRF survey at M14.
- Completed subsurface sampling by hand and site mapping at M33, M14, M4, M8, and M19.
- Completed radon deployment at M33.
- Completed gamma survey at M14 and M23.

Photograph 15. Field Team Member at Knife Edge Mesa

Photograph 15. Field Team Member at Knife Edge Mesa

09/19/18 Wednesday

Field team departed Farmington, New Mexico.

TETRA TECH

Field Trip Progress Report Summary

To:	Chip Poalinelli
From:	Aaron Orechwa, P.E.
Cc:	Kenyon Larsen
Date:	November 5, 2018
Subject:	Task Order 0001, Mobilization 9 (9/24/18 through 10/3/18)

09/24/18 Monday

Field team mobilized to Farmington, New Mexico, and met at field office for pre-trip logistical meeting.

09/25/18 Tuesday

Locations:

- Mesa I Camp (T17)
- Mesa II Pit (M24)
- Mesa II, Mine 4 (M29)
- M1-07 (T30)
- M1-08 (T31)
- Soil correlation at various sites within Groups H and C

Activities:

- Earth work for drilling access at T17.
- Soil correlation at Groups H and C.
- Subsurface sampling by hand at M24 and M29.
- XRF/scan Gobacks at T30, T31, M24, and M29.
- Site mapping at M24 and M29.
- Drilling at T17.

Physical Hazards:

- Hazards associated with drilling.
- Slip, trip, and fall hazards at M24 and M29.

Other:

- Cultural monitoring was conducted during earth work activities.

- Additional soil sample collected by hand at T17, which was not previously identified.

Site Visitors:

- USEPA TOCOR Chip Poalinelli was present.
- Greg, owner of Resilient Drilling, visited Mesa I.

Summary

- Completed XRF/scan Gobacks at T30, T31, M24, and M29.
- Completed subsurface sampling by hand at M24 and M29.
- Completed site mapping at M24 and M29.
- Completed soil correlation at Groups H and C.

09/26/18 Wednesday

Locations:

- Mesa I 3/4, Mine No. 2, P-150 (M26)
- Mesa II, Mine No. 1 & 2, P-21 (M27)
- Mesa II, Mine No. 1, P-150 (M28)
- Mesa III Mine (M32)
- Mesa I Camp (T17)
- Mesa I, Mine 15 (M8)
- Various sites at Group I

Activities:

- XRF/scan Gobacks at M26, M27, and M28.
- Site mapping at M26, M27, and M28.
- Subsurface sampling by hand at M26, M27, and M28.
- Drilling at T17 and M8.
- Soil correlation at Group I (Knife Edge Mesa).

Physical Hazards:

- Extreme slopes at M26, including evidence of recent landslide activity.
- Long hours and fatigue for team; driving while tired.

Other:

- Eliminated Goback XRF/scan at M26 by RAES project manager.
- Drilling permit issue resolved by NECA, USEPA, and Tetra Tech.
- Cultural monitoring support by DCRM at M27, M28, and T17.

Site Visitors:

- USEPA TOCOR left at 2:30 p.m.
- Quentin, from NECA, met with USEPA and Tetra Tech.
- DCRM cultural monitoring support team.

Summary

- Completed XRF Gobacks at M26 (eliminated) and M27.
- Completed site mapping at M26, M27, and M28.
- Completed subsurface sampling by hand at M26, M27, and M28.
- Completed drilling at T17.
- Completed soil correlation at Group I.

09/27/18 Thursday

Locations:

- Black No. 1 Mine (M34)
- Black No. 2 Mine (M35)
- Black No. 2 West Mine (M36)
- Flag No. 1 Mine (M37)
- Step Mesa Mine (M38)
- Mesa IV West Mine (M23)
- Mesa I Mine 15 (M8)
- Mesa I Mine 13 (M6)

Activities:

- Drilling at M6 and M8.
- XRF/scan Gobacks at M34, M35, M36, and M37.
- Site mapping and subsurface sampling by hand at M34, M35, M36, M37, M38, and M23.

Physical Hazards:

- Long strenuous hikes with large groups of people.
- Sampling on extreme cliffs with imminent fall hazards.
- Hydration and heat exhaustion.

Other:

- Discussed drilling permit and IDW approach with USEPA TOCOR Chip Poalinelli.
- USEPA TOCOR Chip Poalinelli advised Aaron Orechwa of Tetra Tech to call Quentin from NECA.
- Confirmed PM's decision to eliminate Gobacks at M26 for safety reasons.

Site Visitors:

- USEPA TOCOR Chip Poalinelli

Summary

- Completed drilling activities at M6 and M8.
- Completed XRF/scan Gobacks at M34, M35, M36, and M37.
- Completed site mapping at M34, M35, M36, M37, and M23.
- Completed subsurface sampling by hand at M34, M35, M36, M37, M38, and M23.

09/28/18 Friday

Locations:

- Brodie I (M1)
- BR-05 (T5)
- Mesa I 1/2 Mine (M10)
- Mesa I 1/2 West Mine (M12)
- Henry Philips Mine (M11)
- Mesa I 3/4 Incline (M25)

Activities:

- XRF Gobacks at M1 and T5.
- XRF/scan Gobacks at M10, M11, M12, and M25.
- Site mapping and subsurface sampling by hand at M10, M11, M12, and M25.
- IDW disposal at Group F.

Physical Hazards:

- Rock hazard falls and imminent fall danger

Other:

- RSO managed IDW disposal under USEPA management

Summary

- Completed XRF/scan Gobacks at M10, M11, M12, and M25.
- Completed XRF Gobacks at M1 and T5.
- Completed site mapping and subsurface sampling by hand at M10, M11, M12, and M25.

09/29/18 Saturday

Locations:

- Mesa II Mine (M32)
- Mesa II 1/2 Mine, Mine 4 (M31)
- Mesa II, Mine 4 (M30)
- Mesa II, No. 1 Mine, P-150 (M28)

Activities:

- XRF/scan Gobacks at M28, M30, M31, and M32.
- Site mapping and subsurface sampling by hand at M28, M30, M31, and M32.

Physical Hazards:

- Rock fall and extreme fall potential
- Falling trees (windblown areas) down drainages

Other:

- Discussed water quality sampling with USEPA TOCOR Chip Poalinelli for 9/30/18:
  - Remove orthophosphate
  - Okay to sample without water quality meter

Site Visitors:

- USEPA TOCOR present.

Summary

- Completed XRF/scan Gobacks at M28, M30, M31, and M32.
- Completed site mapping at M28, M30, M31, and M32.
- Completed subsurface sampling by hand at M28, M30, M31, and M32.

09/30/18 Sunday

Locations:

- Mesa I 1/4 (M9)
- Mesa I Mine 12 (M5)
- Middle 3E Drainage (DC3E)
- NA-0334B (T23)
- M5-03 (T20)
- Cove Transfer Station 2 (T38)
- Various haul roads, across roads, background study areas, and canyons
- Group D sites for gamma

Activities:

- XRF on roads.
- Gamma Gobacks at various grids in Group D.
- Subsurface sampling by hand at M5 and M9.
- Site mapping at M5 and M9.
- Site reconnaissance to drainages, background study areas, and T20.
- Water and sediment sampling at Middle 3E.
- Radon placement at T38.

Physical Hazards:

- Weather, UTV safety, and falling rocks

Other:

- Concluded with USEPA TOCOR that elevated amma at T20 was from naturally occurring radioactive materials.
- USEPA TOCOR concluded RSE field activities are complete.
- Technical directive to install radon monitors at Cove Water Tower.

Site Visitors:

- USEPA TOCOR
- Mountain bike racer

Summary

- Completed subsurface sampling by hand at M5 and M9.
- Completed site mapping at M5 and M9.
- Completed sediment and water sampling at DC3E.
- Completed XRF on roads.

10/1/18 Monday

Locations:

Farmington, New Mexico

Activities:

Tetra Tech team began to demobilize. Some staff stayed in Farmington to perform laboratory XRF measurements and prepared cleaned field office in preparation of demobilizing.

Physical Hazards:

Driving long distances

Other:

NA

Site Visitors:

NA

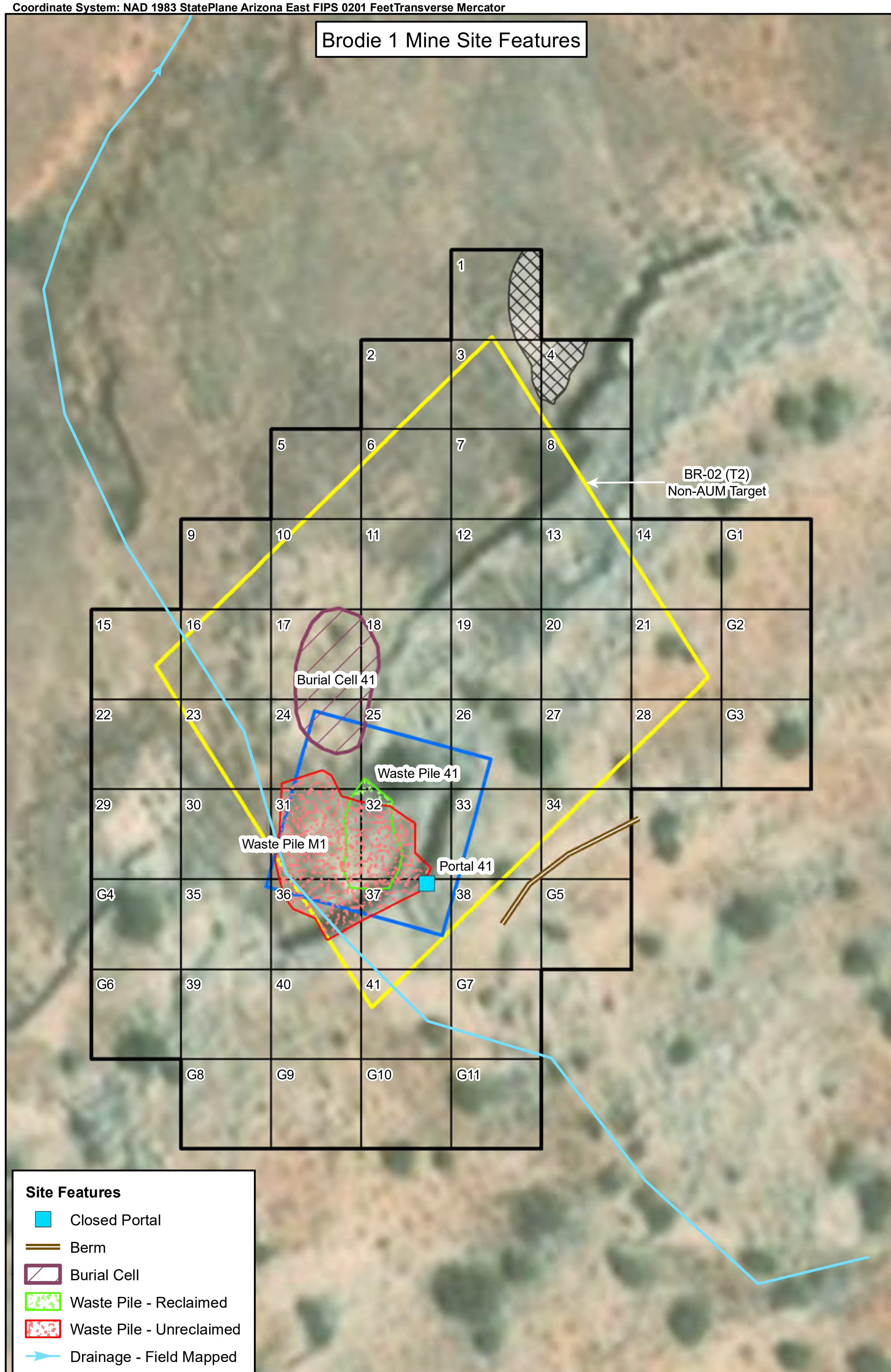
Summary

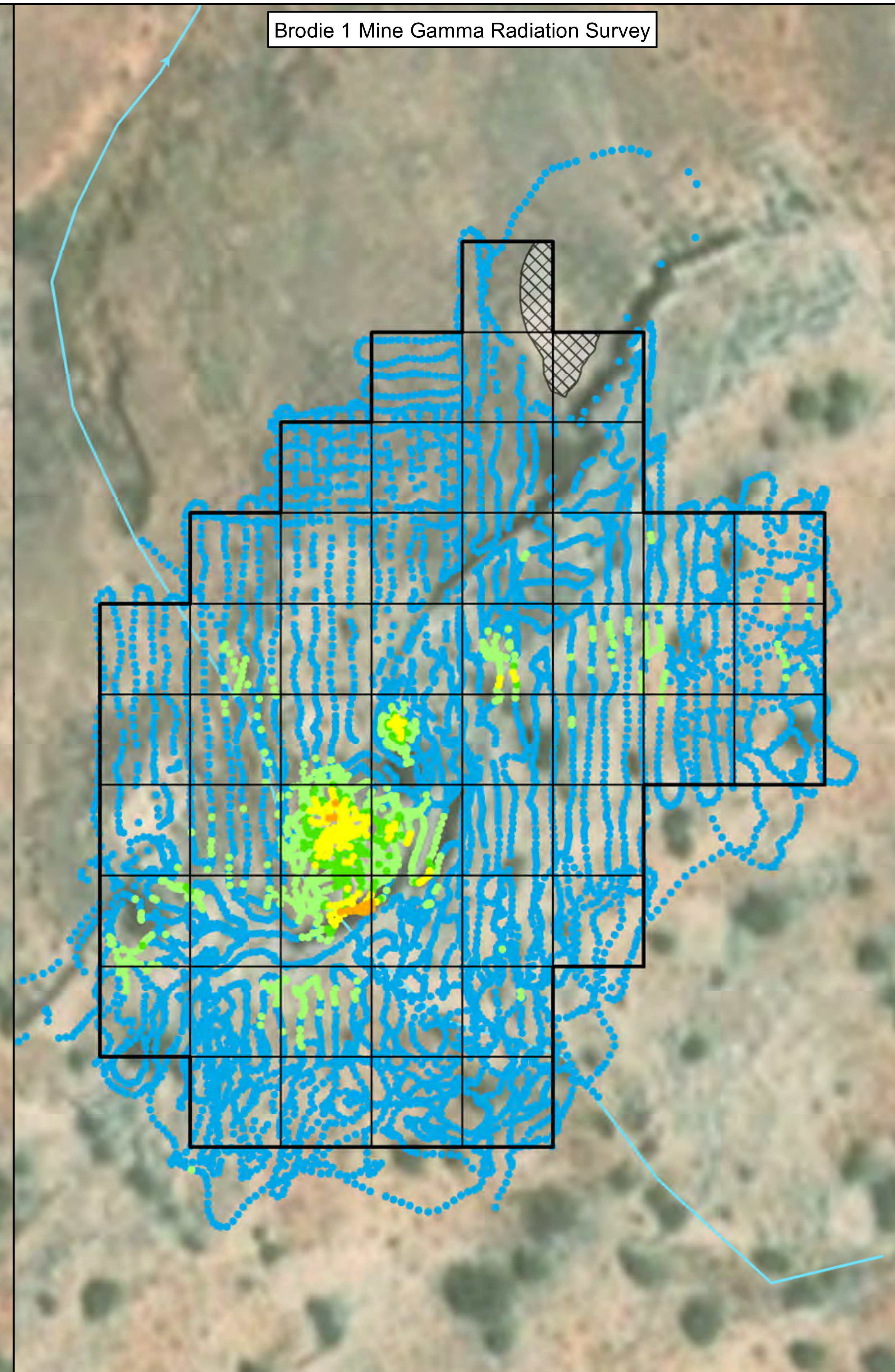
All field work was completed and all staff demobilized either 10/1/18 or 10/2/18.

ATTACHMENT 2

GAMMA EXPOSURE RATE MAPS

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Restricted Area (Cultural)

1 in = 50 ft

1:600

0 25 50 100 Feet

N S E W

BRODIE 1 MINE

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

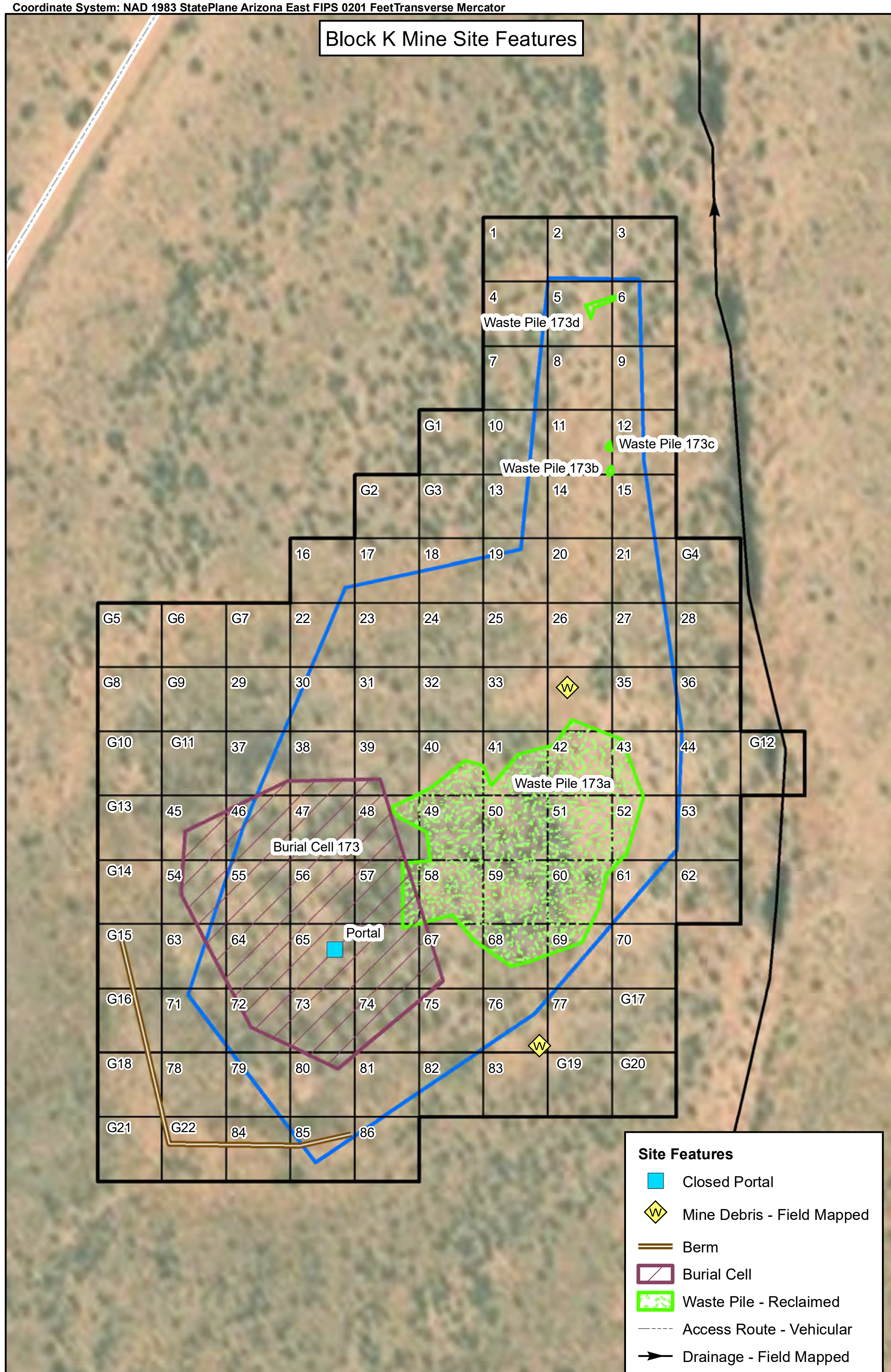
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

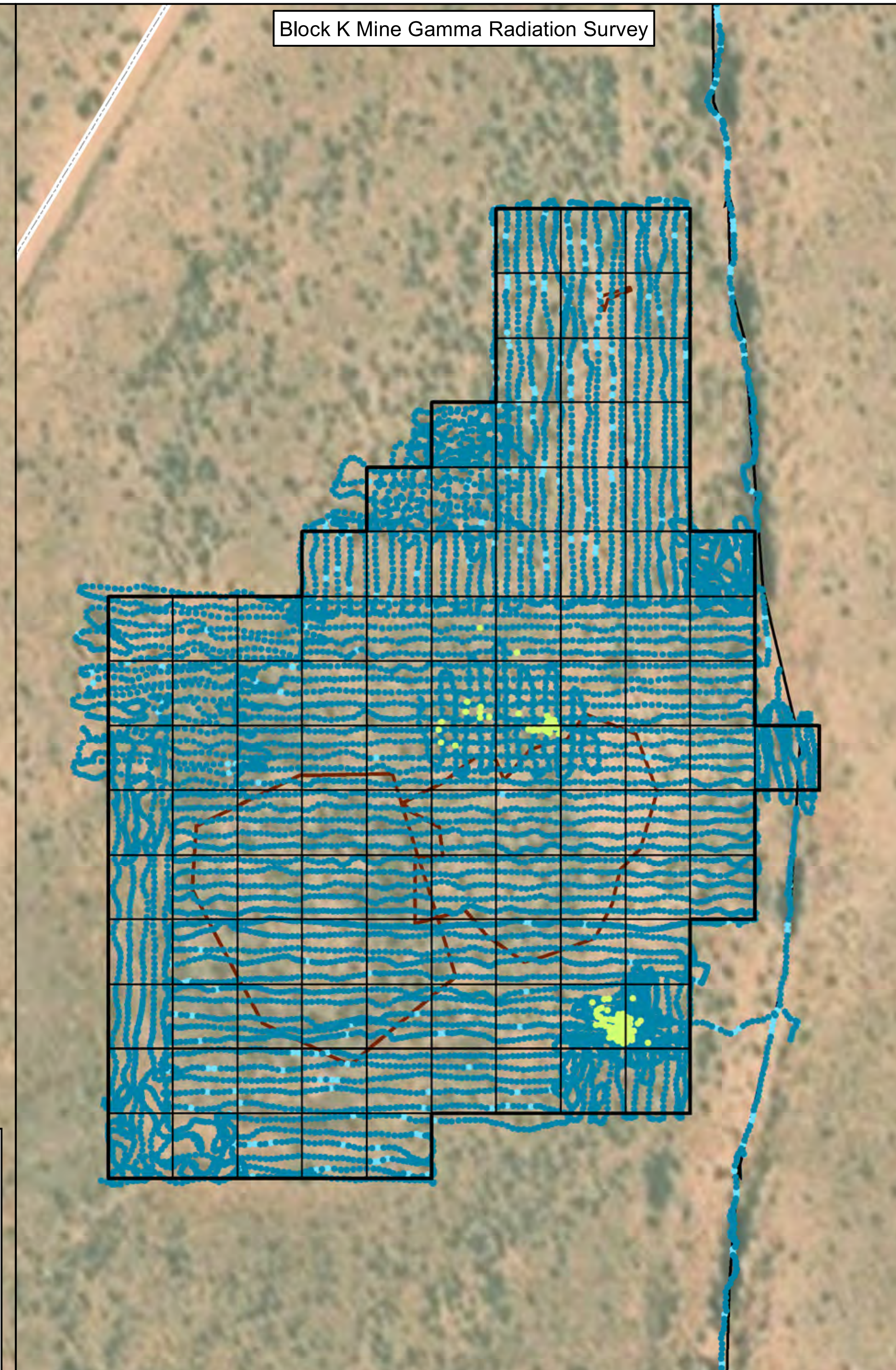
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M1**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Burial Cell / Waste Pile Boundary

1 in = 70 ft

1:840

0 35 70 140 Feet

N W E S

BLOCK K MINE

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

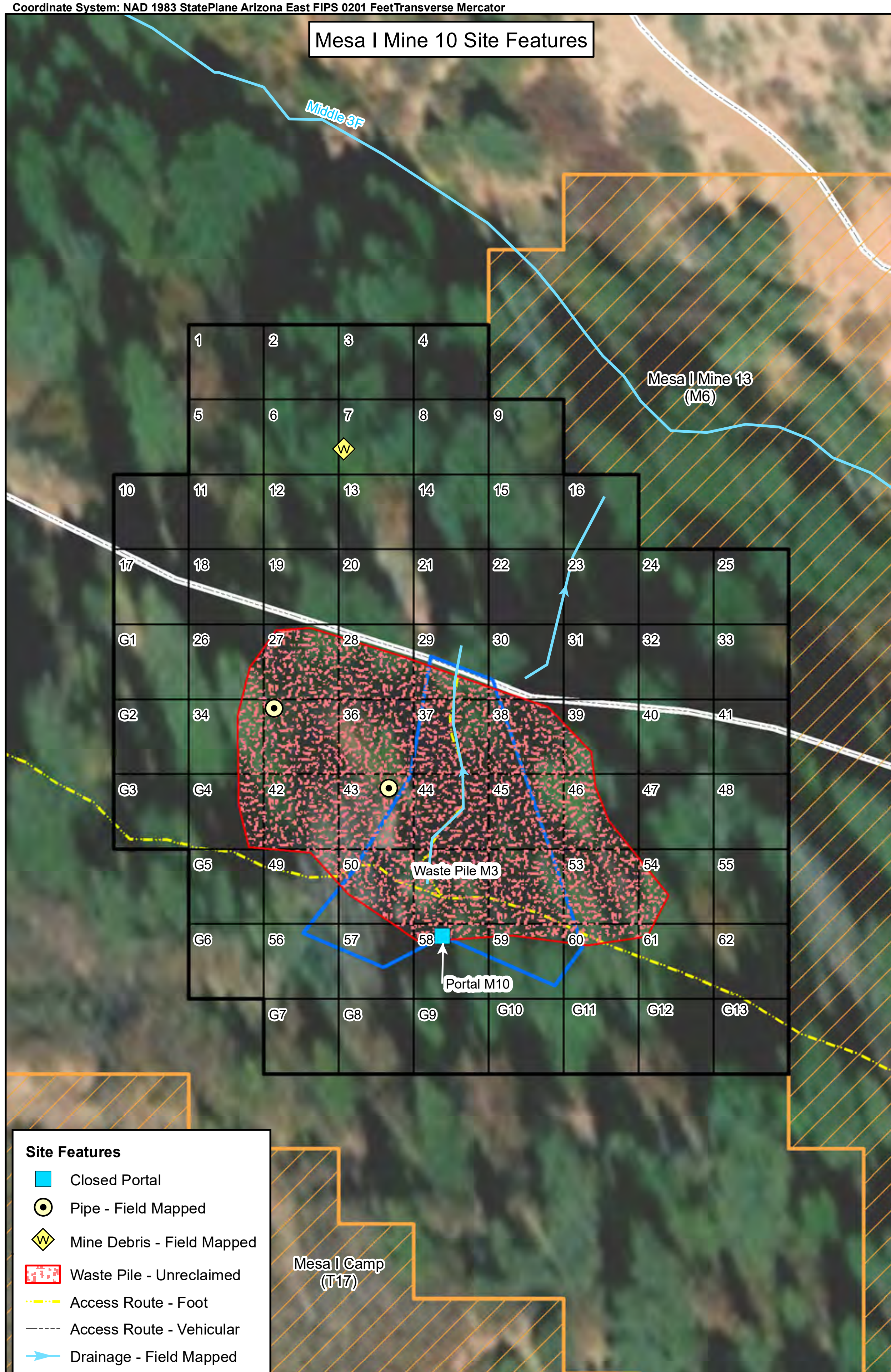
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

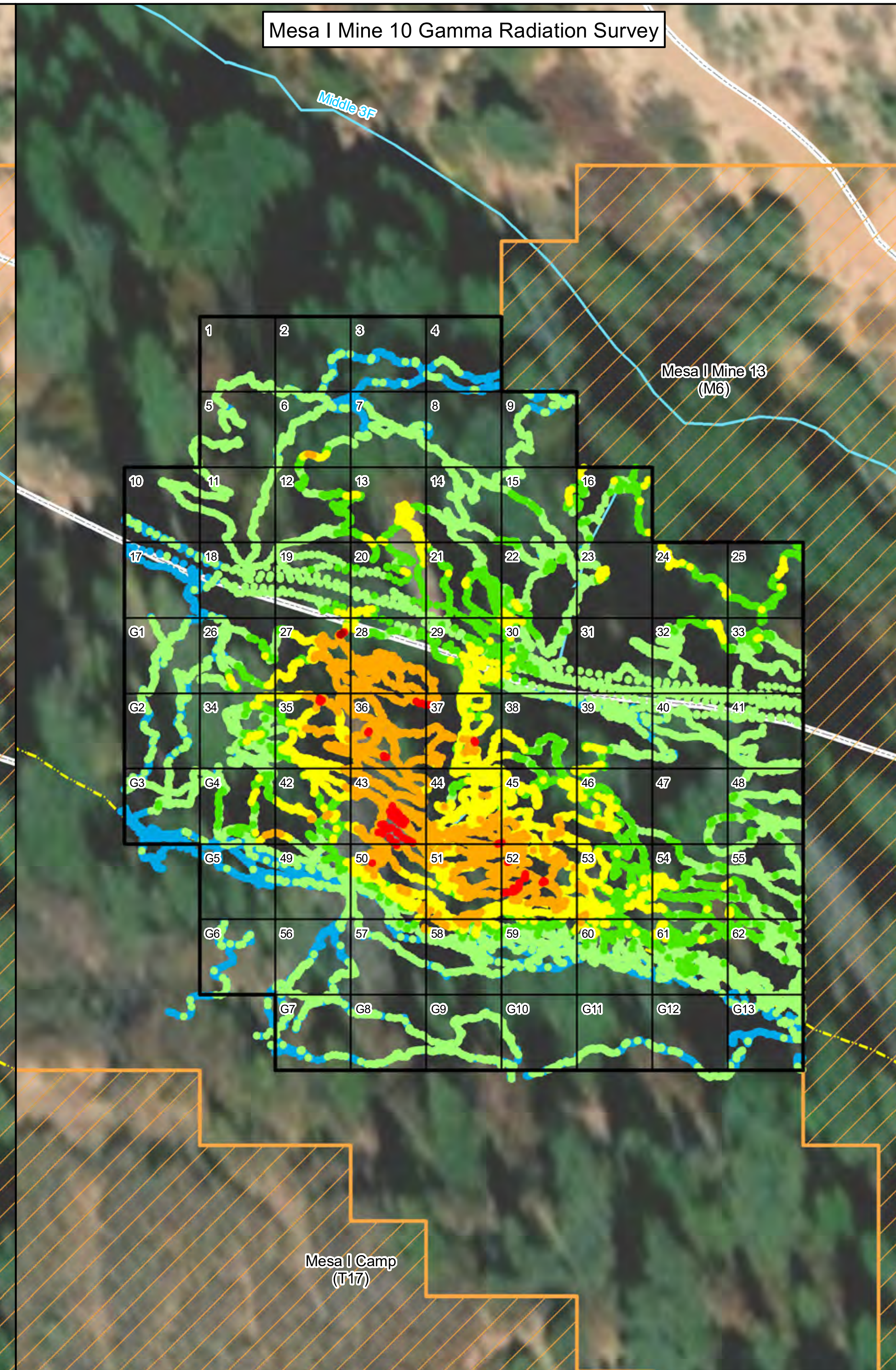
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: TEEC NOS POS CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M2**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area

1 in = 60 ft

1:720

0 30 60 120 Feet

N W E S

MESA I MINE 10
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

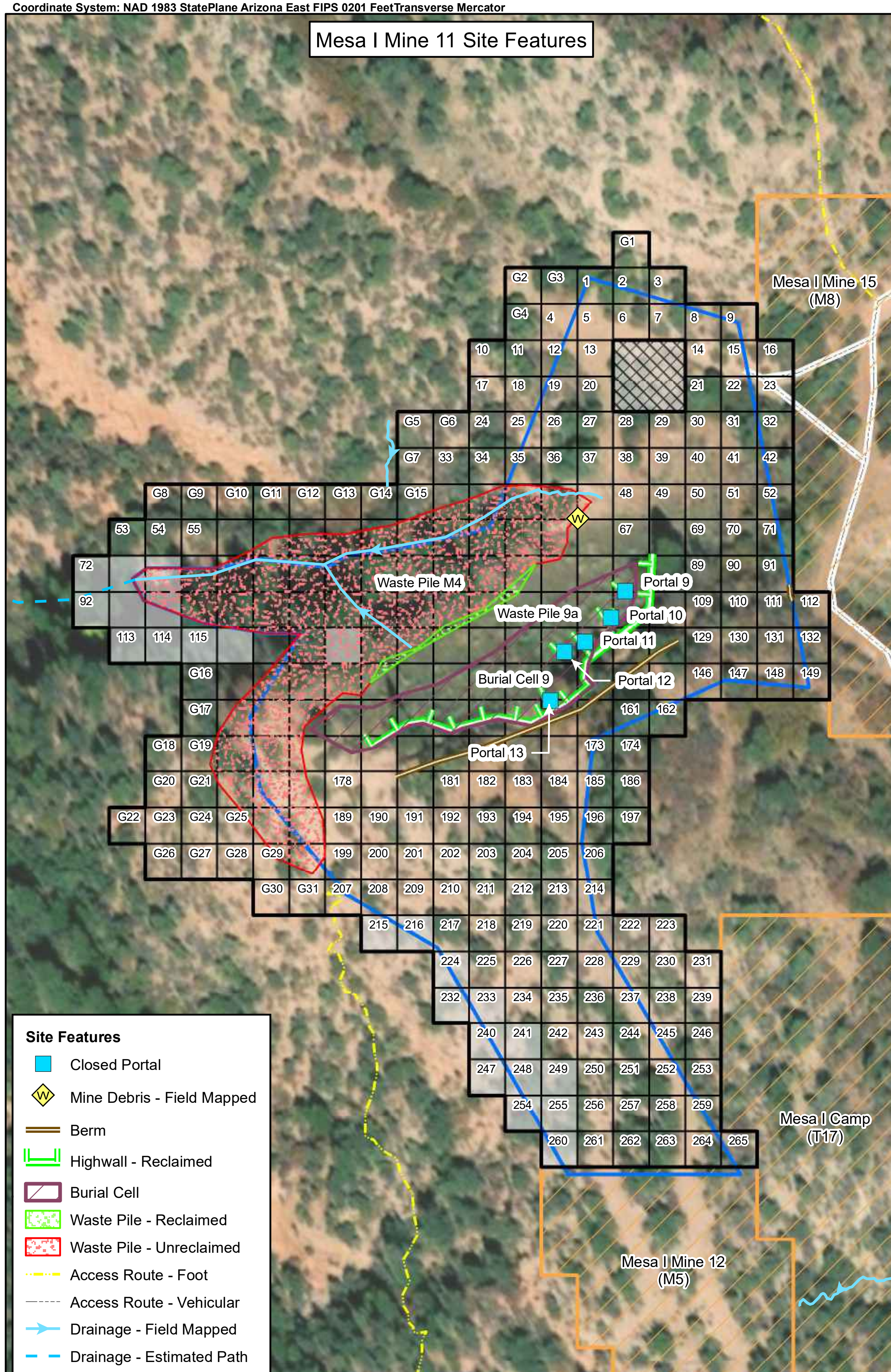
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

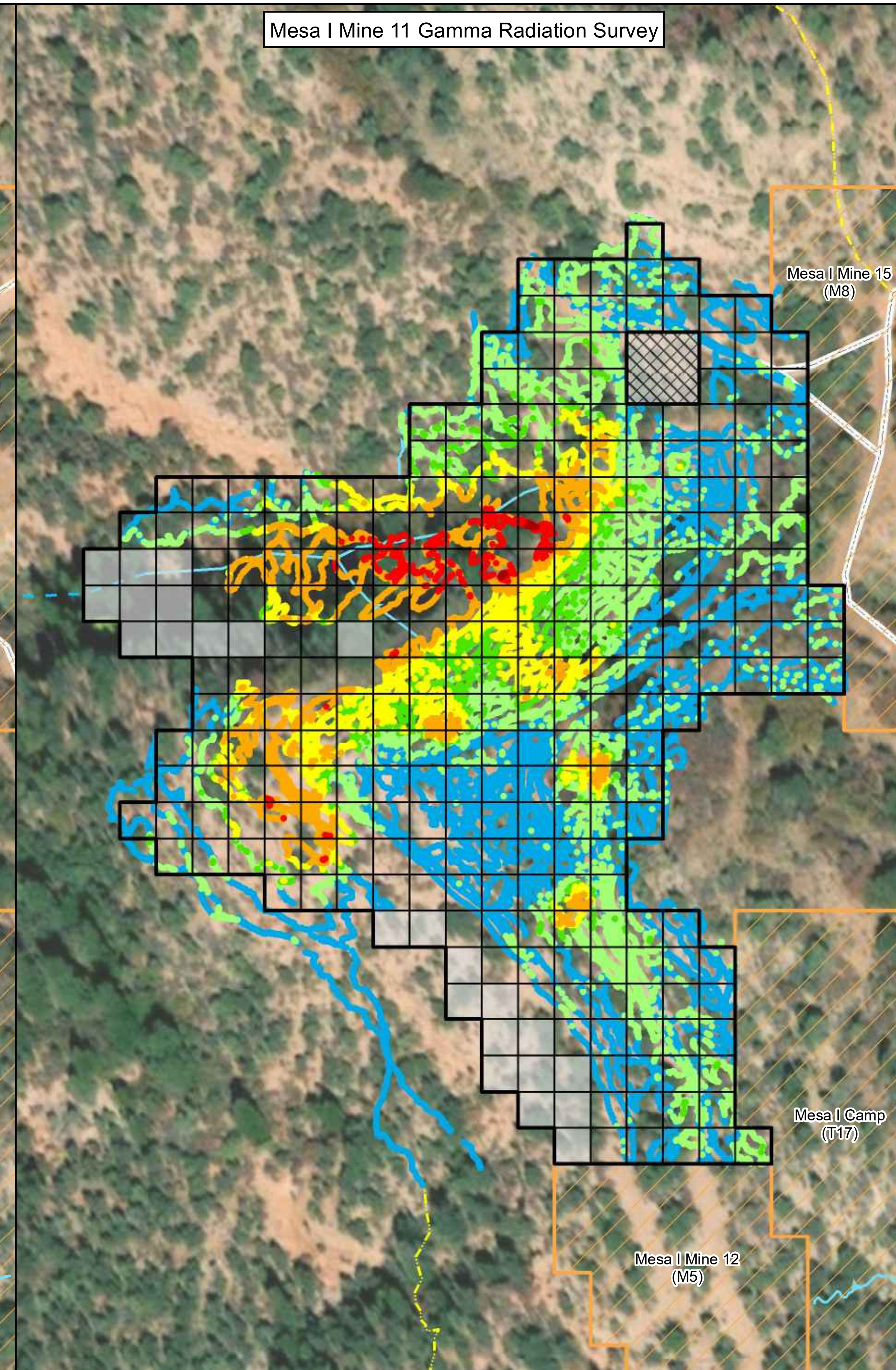
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M3**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey
- Restricted Area (Cultural)

1 in = 125 ft

1:1,500

0 62.5 125 250 Feet

N W E S

MESA I MINE 11

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

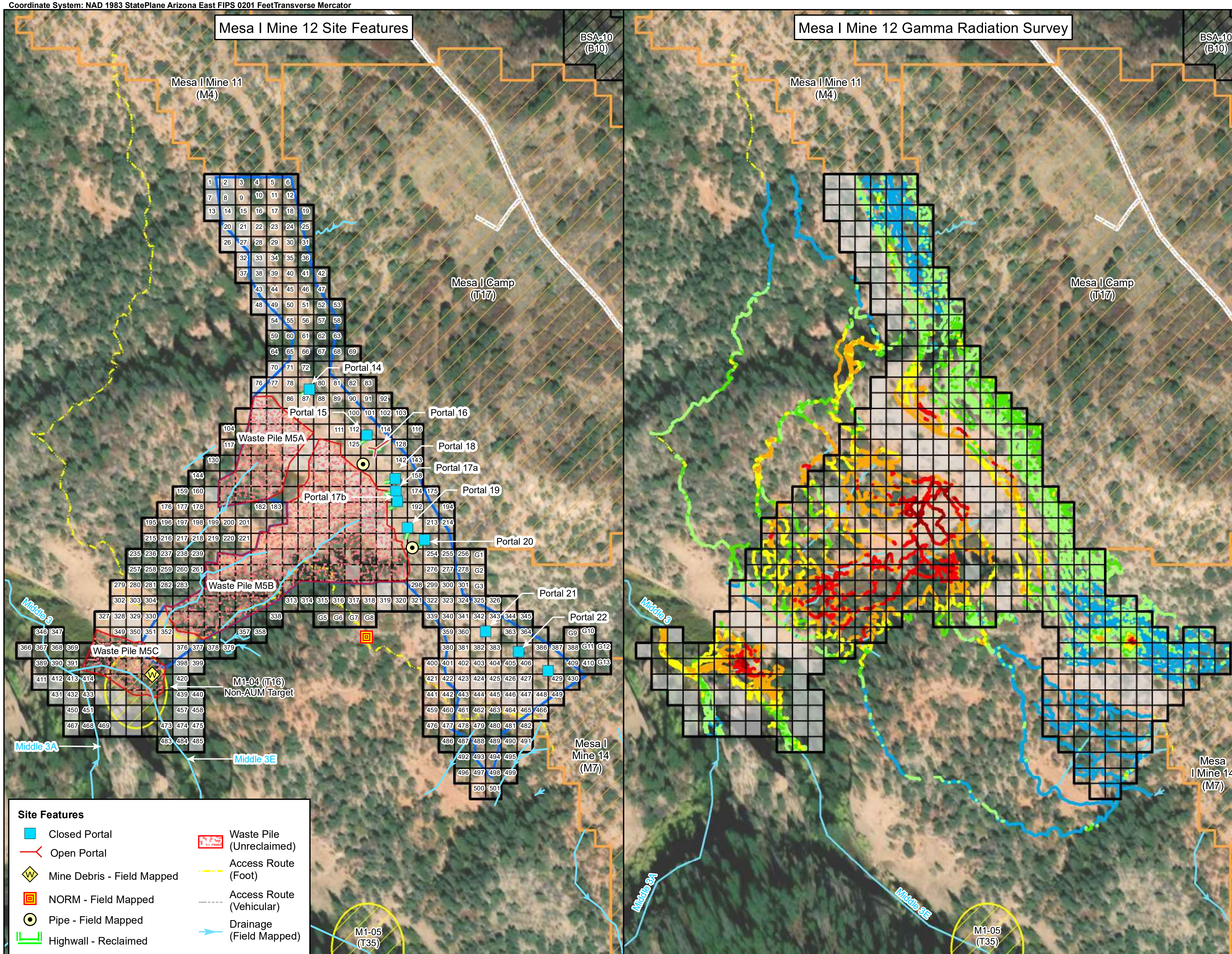
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019

Notes:

*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M4

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



MESA I MINE 12
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

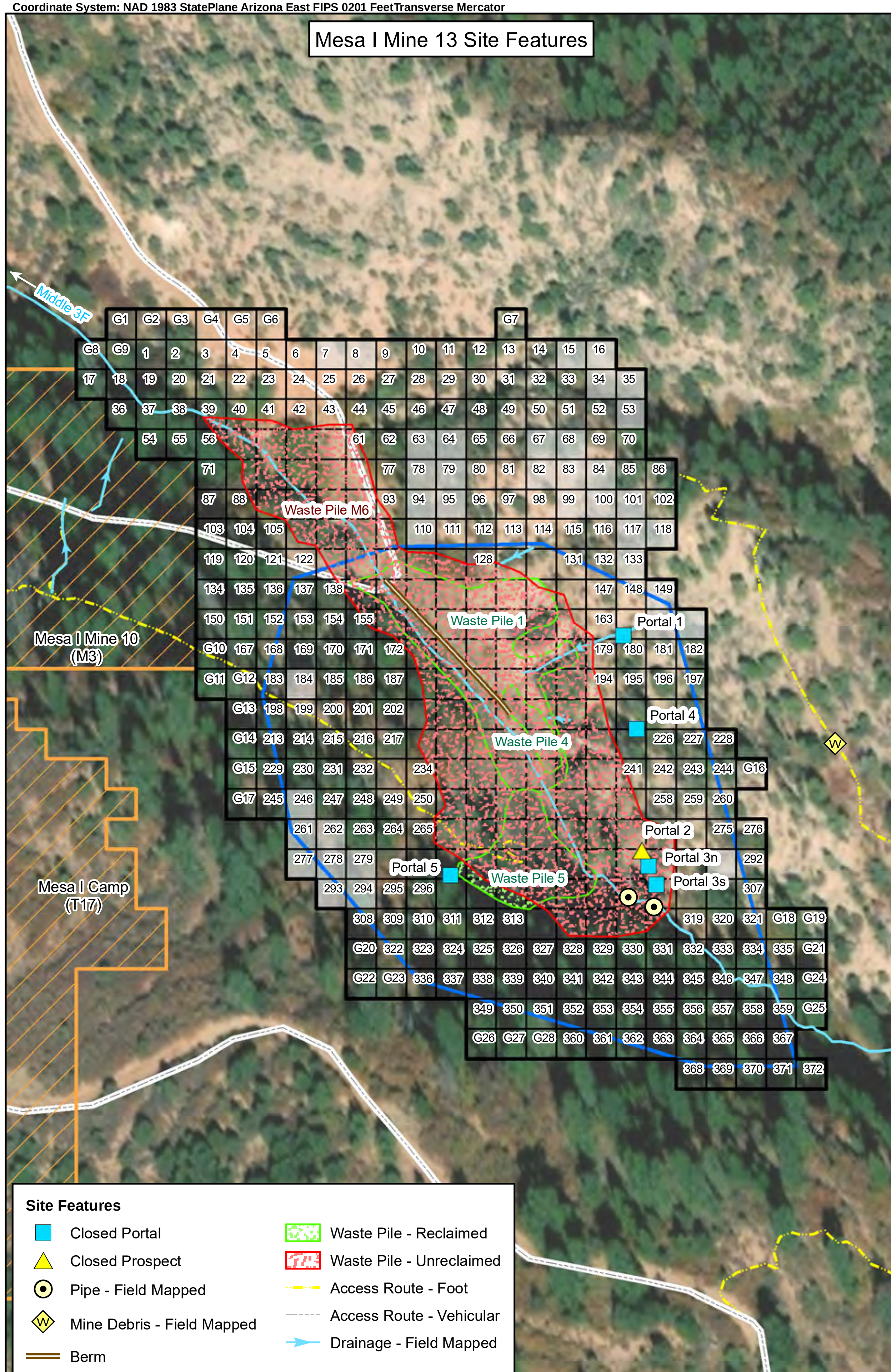
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

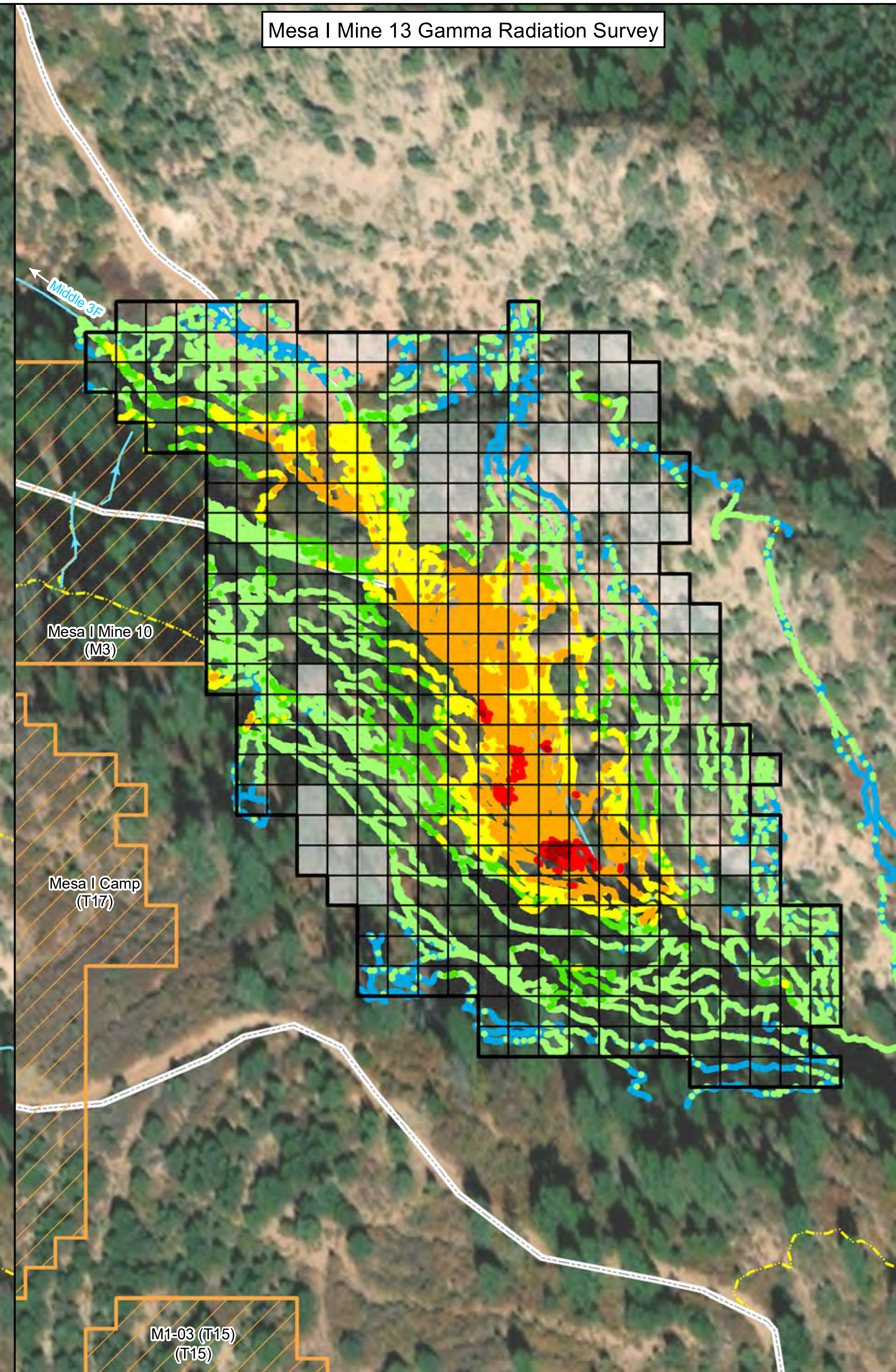
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M5

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 150 ft

1:1,800

0 75 150 300 Feet

N W E S

MESA I MINE 13

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

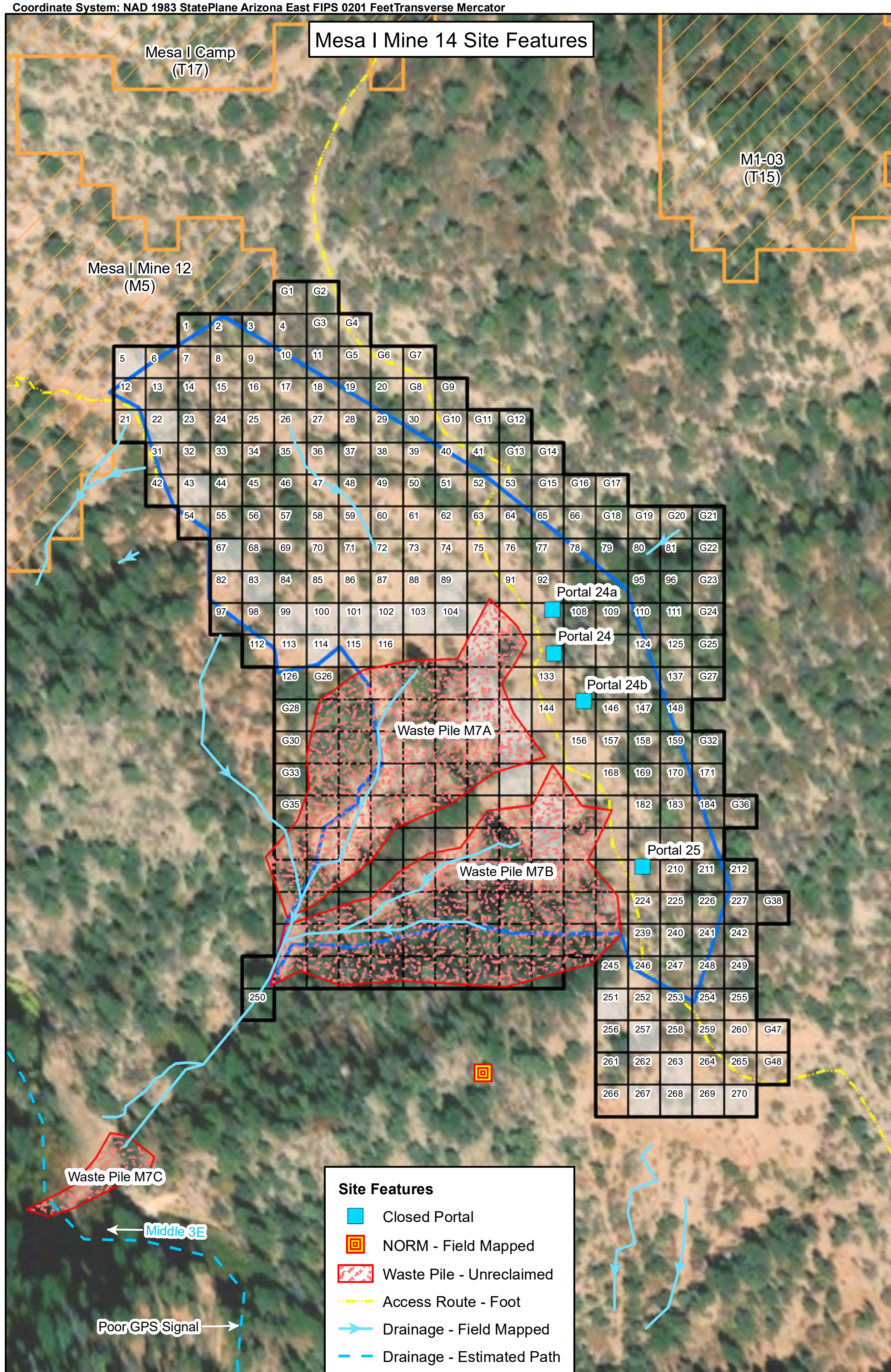
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

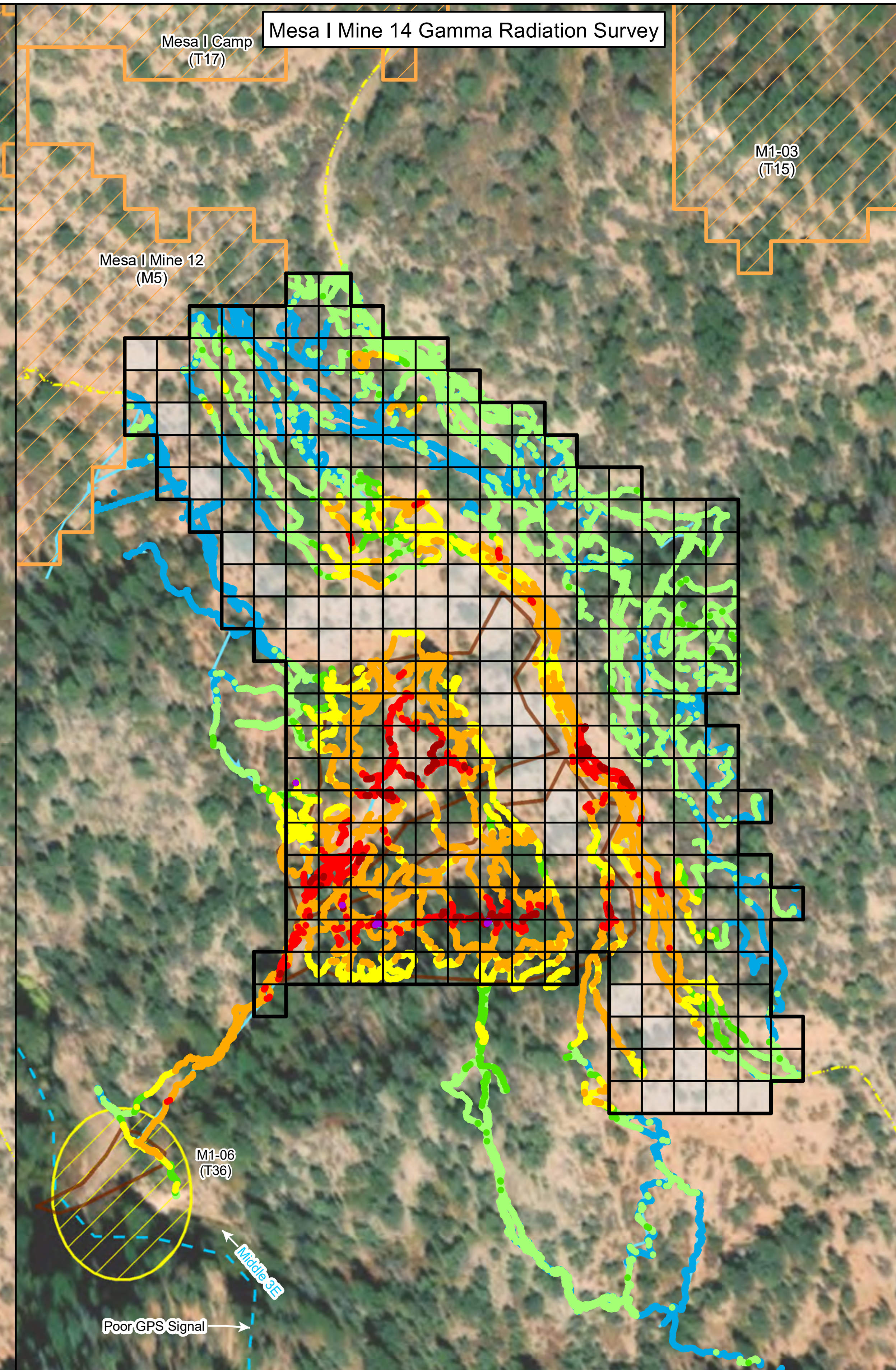
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M6

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Waste Pile Boundary
- Other Survey Area
- Non-AUM Target Site Boundary
- Inaccessible To Gamma Survey

1 in = 140 ft

1:1,680

0 70 140 280 Feet

N W E S

MESA I MINE 14

GAMMA EXPOSURE RATE MAP

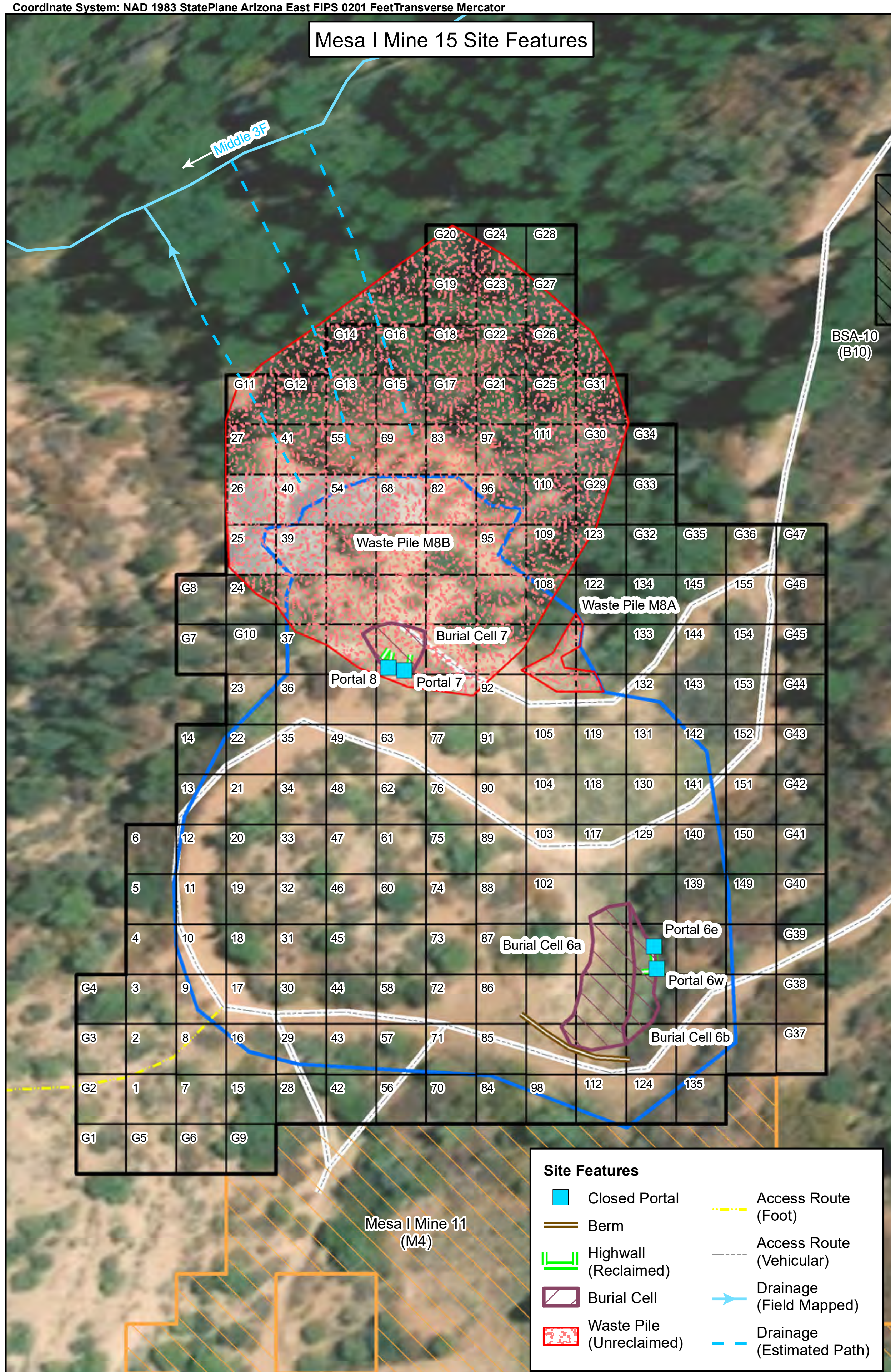
Prepared For:

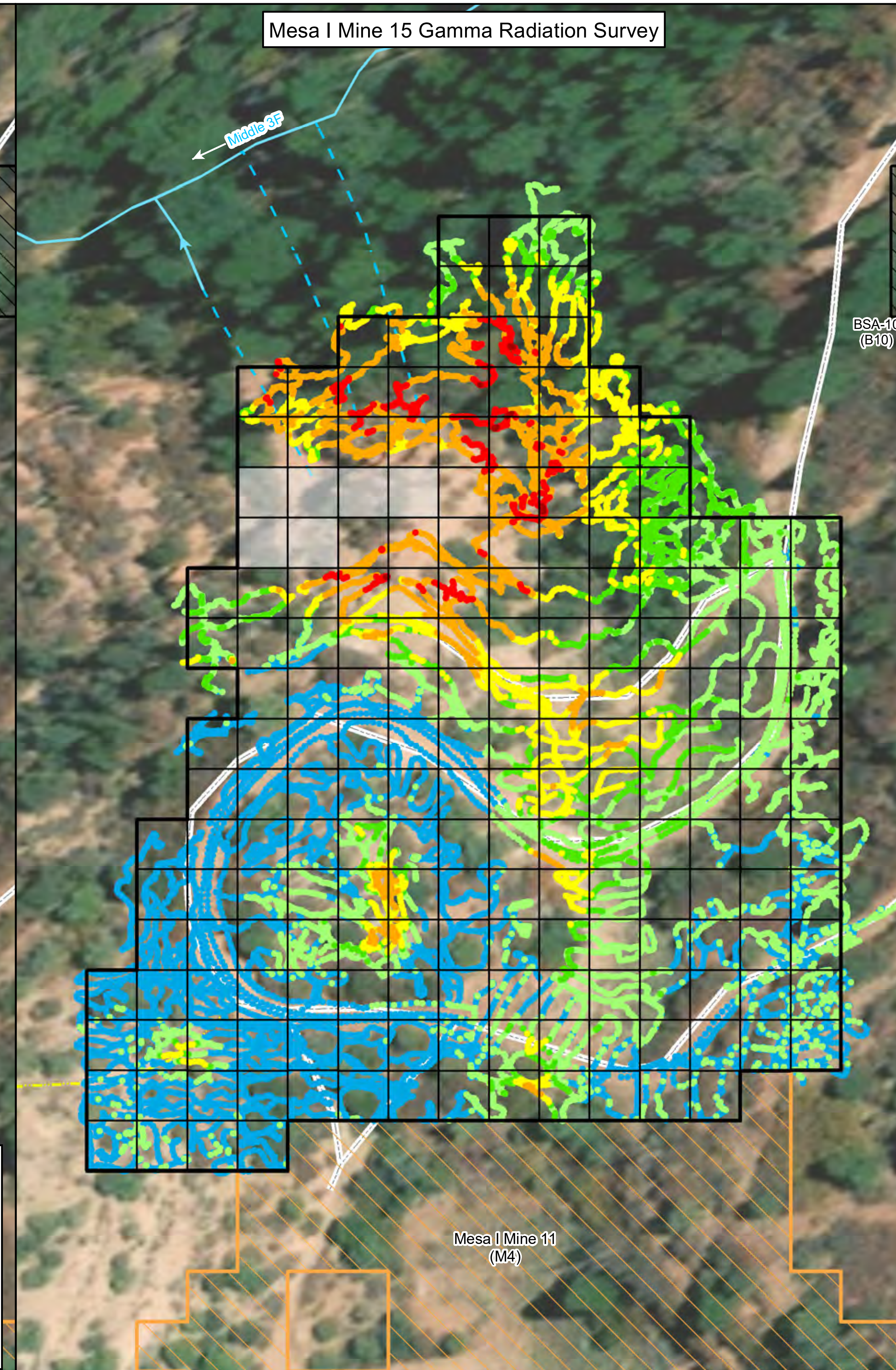
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.: TO0001	Contract No.: EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019
Notes: *Gross gamma count rate measurements are converted to gamma exposure rate using the following equation: γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).	Figure No.: M7

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Background Location
- Inaccessible To Gamma Survey

1 in = 90 ft

1:1,080

0 45 90 180 Feet

MESA I MINE 15

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

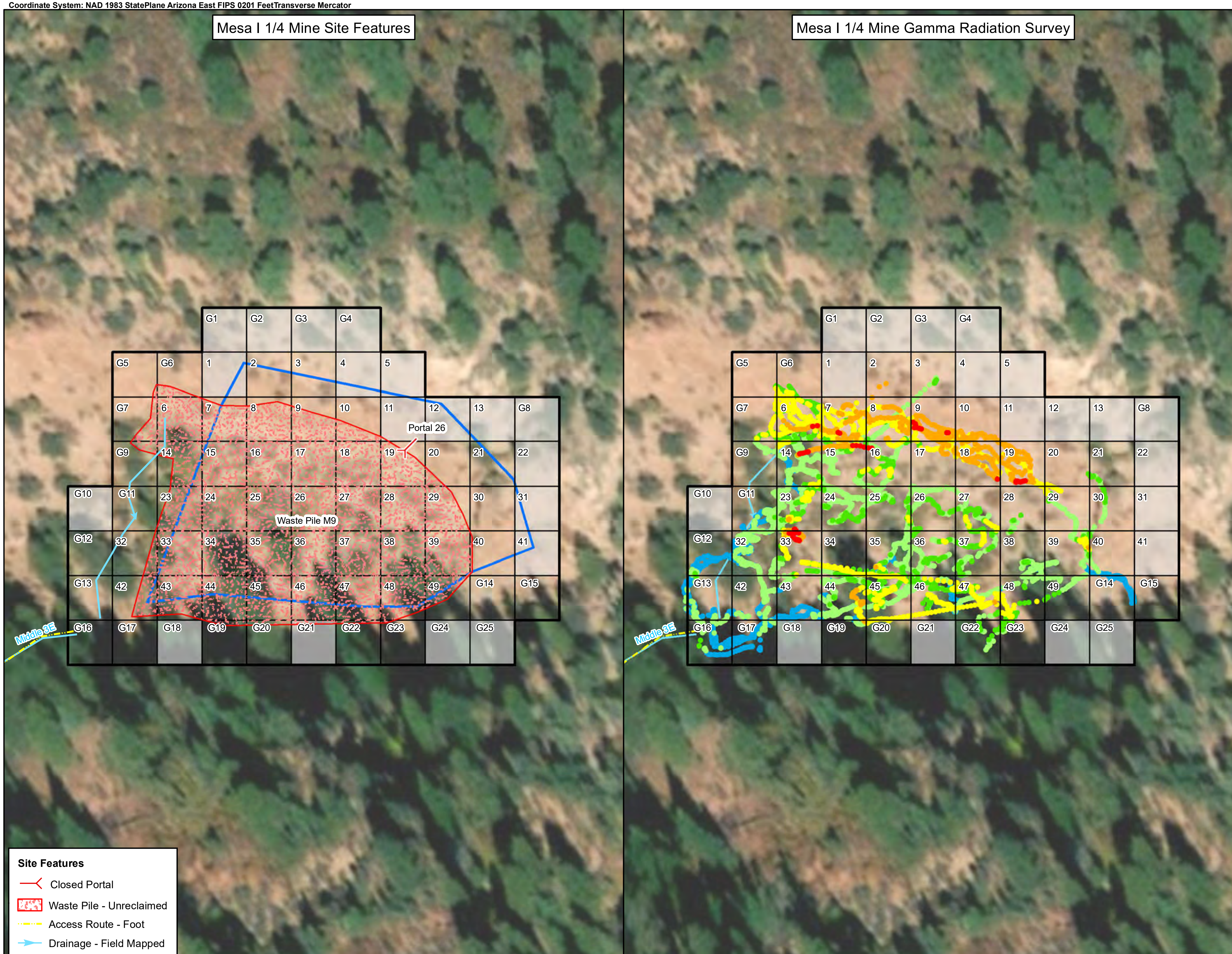
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exsposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M8

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Inaccessible To Gamma Survey

1 in = 70 ft

1:840

0 35 70 140 Feet

N E S W

MESA I 1/4 MINE

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

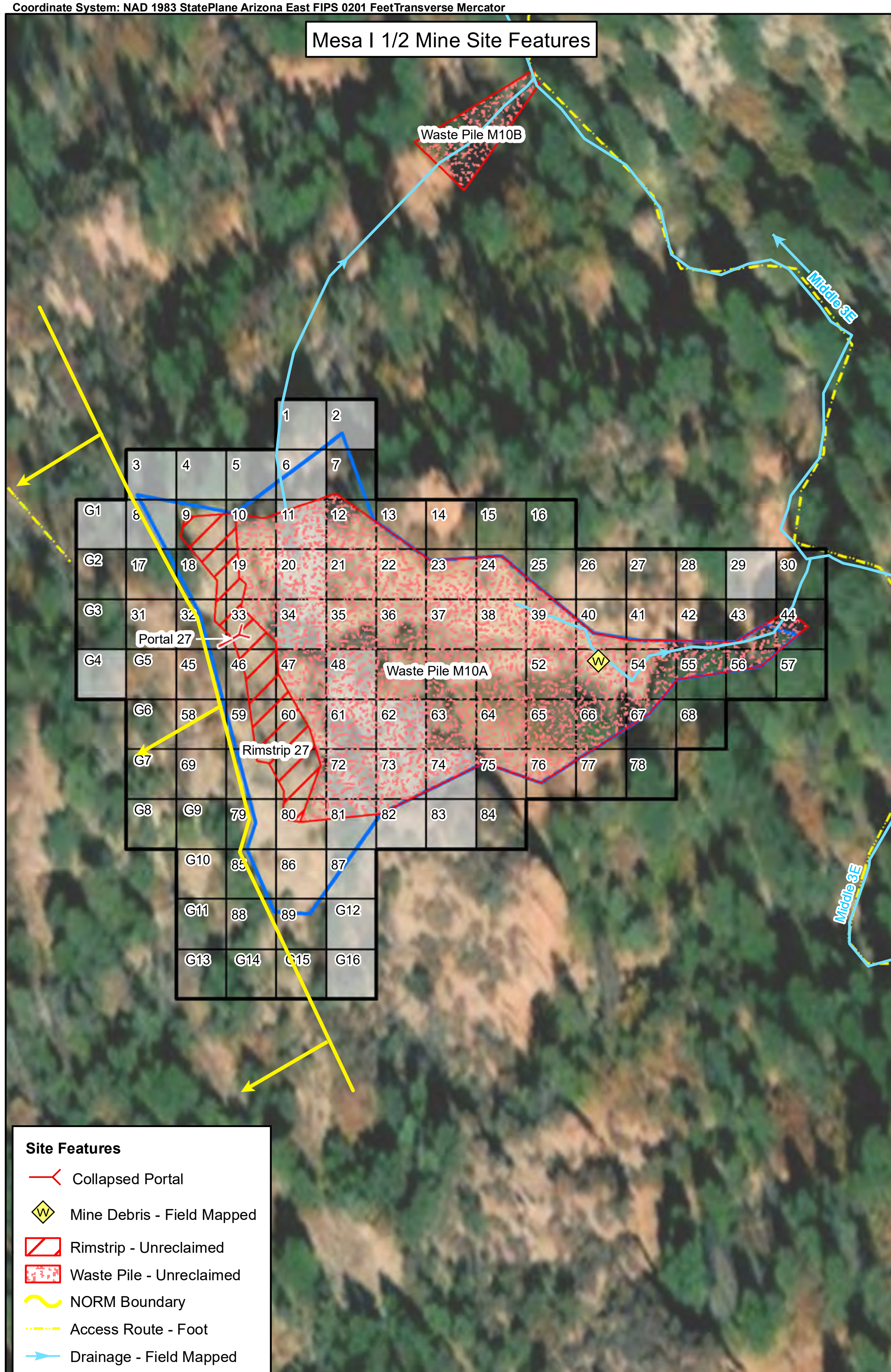
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

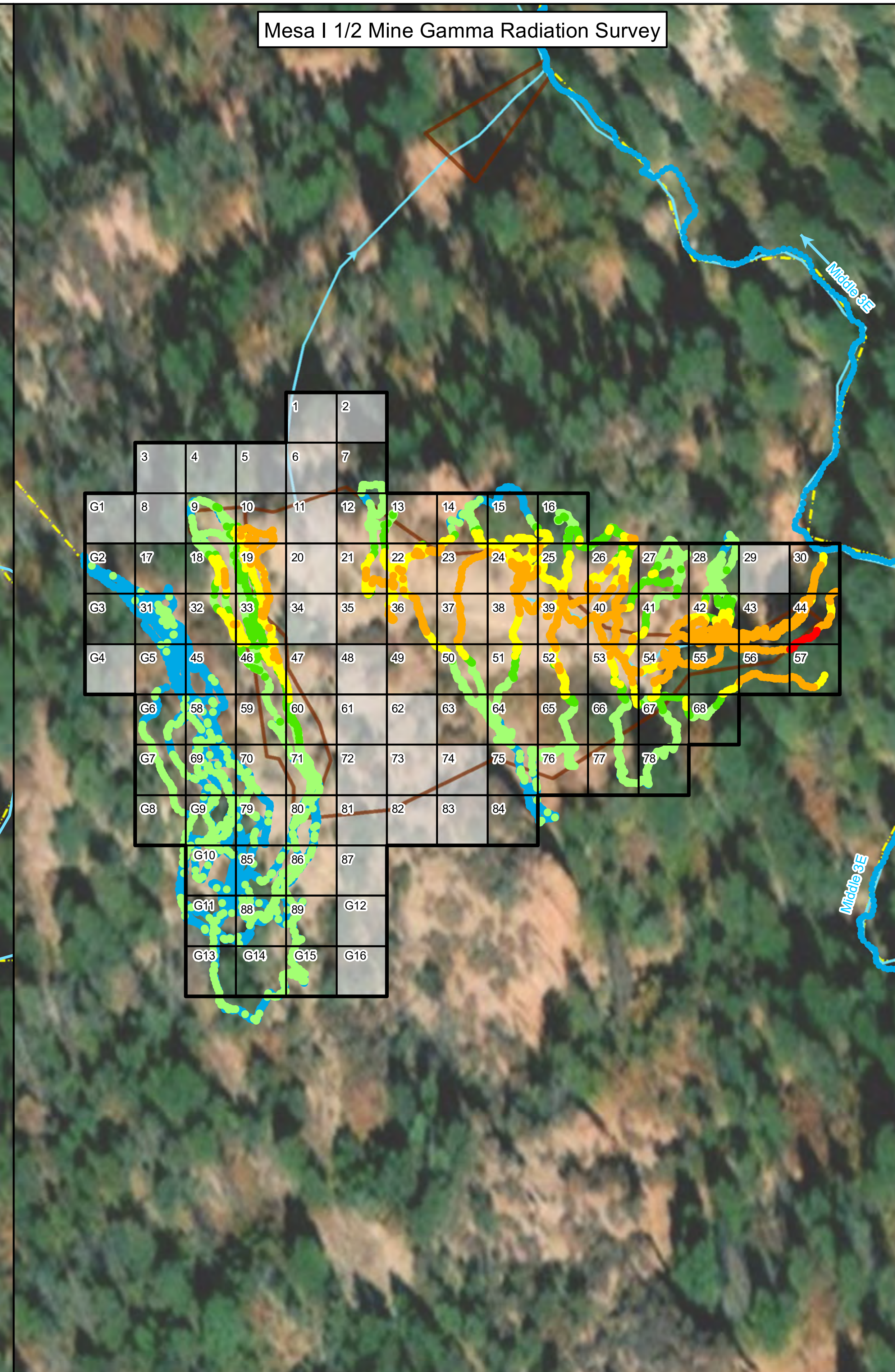
Notes:

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Figure No.: **M9**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Waste Pile/Rim Strip Boundary
- Inaccessible To Gamma Survey

1 in = 90 ft

1:1,080

0 45 90 180 Feet

N W E S

MESA I 1/2 MINE

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

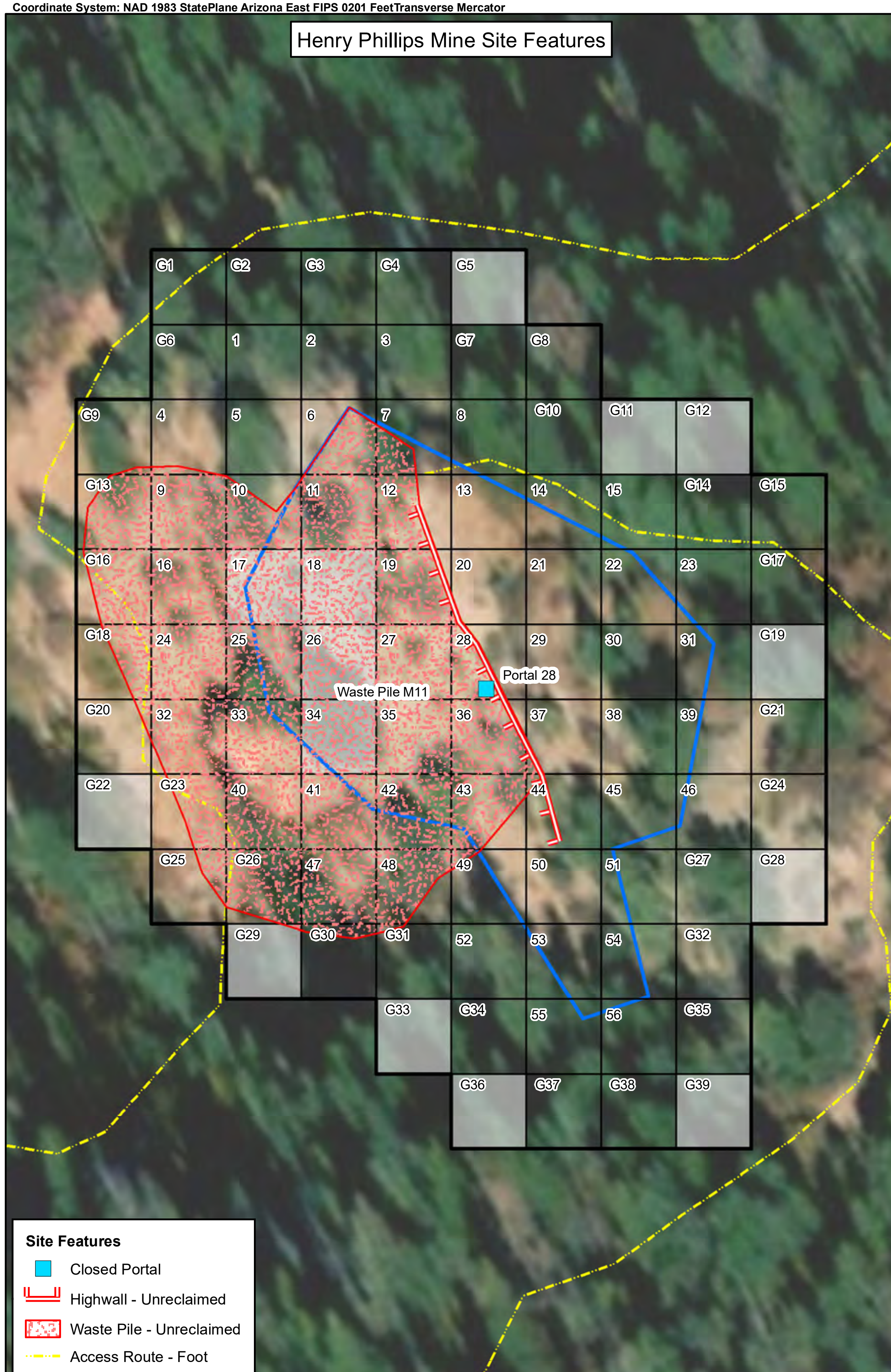
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

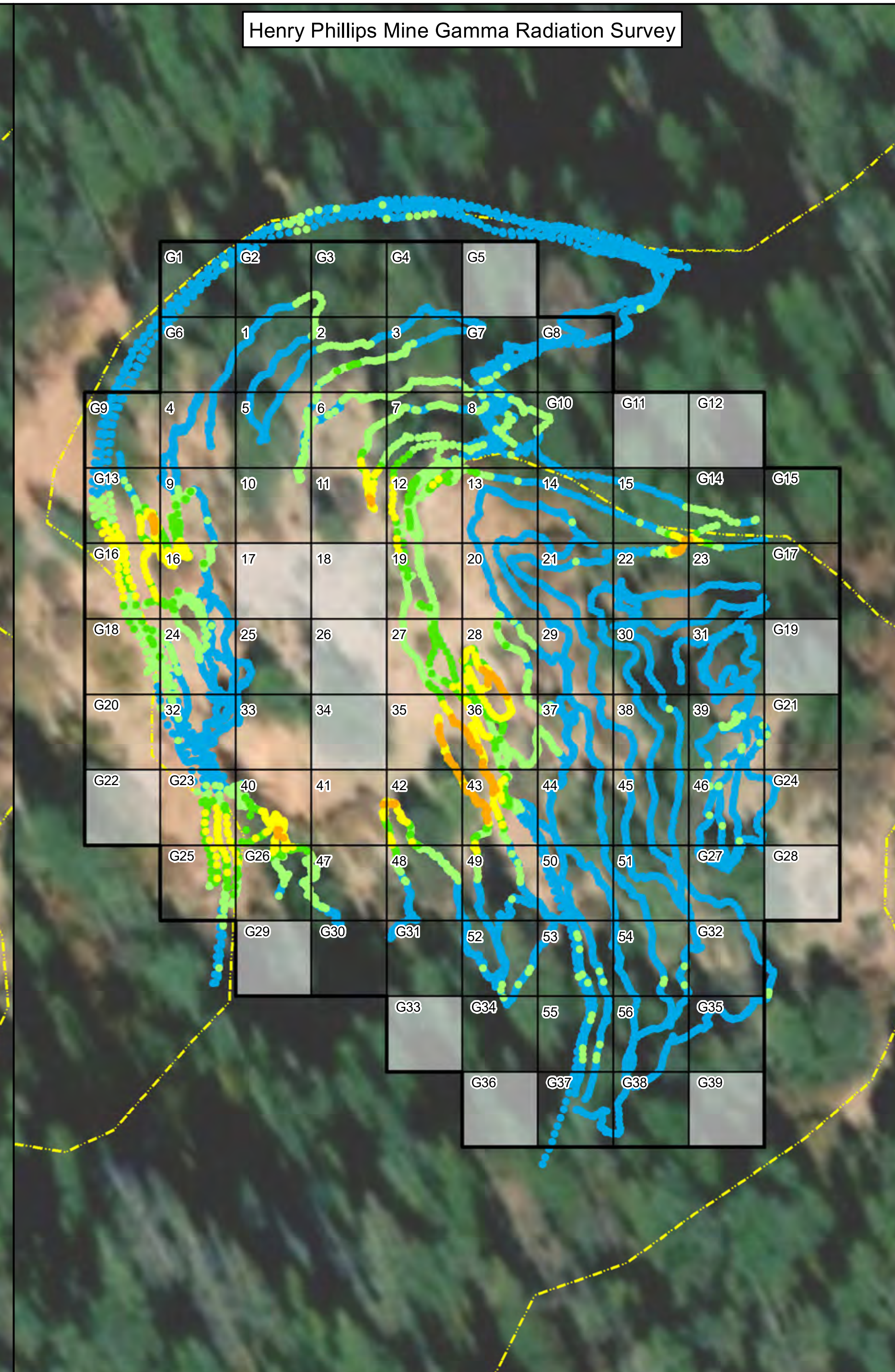
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Figure No.: **M10**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Inaccessible To Gamma Survey

1 in = 60 ft

1:720

0 30 60 120 Feet

N E S W

HENRY PHILLIPS MINE GAMMA EXPOSURE RATE MAP

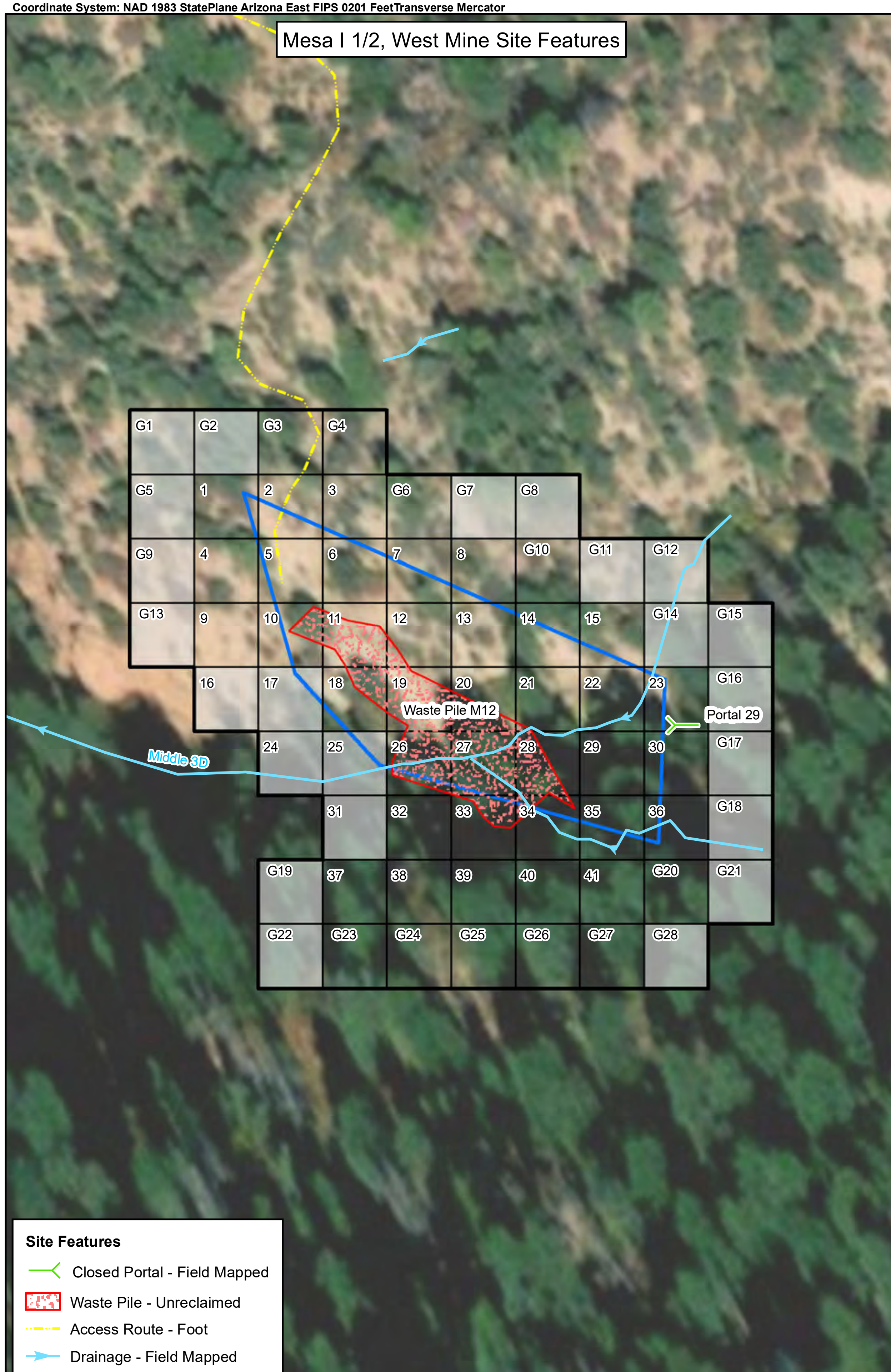
Prepared For:

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.: TO0001	Contract No.: EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019
Notes: *Gross gamma count rate measurements are converted to gamma exposure rate using the following equation: γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).	Figure No.: **M11**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Waste Pile Boundary
- Inaccessible To Gamma Survey

1 in = 70 ft

1:840

0 35 70 140 Feet

N W E S

MESA I 1/2, WEST MINE GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

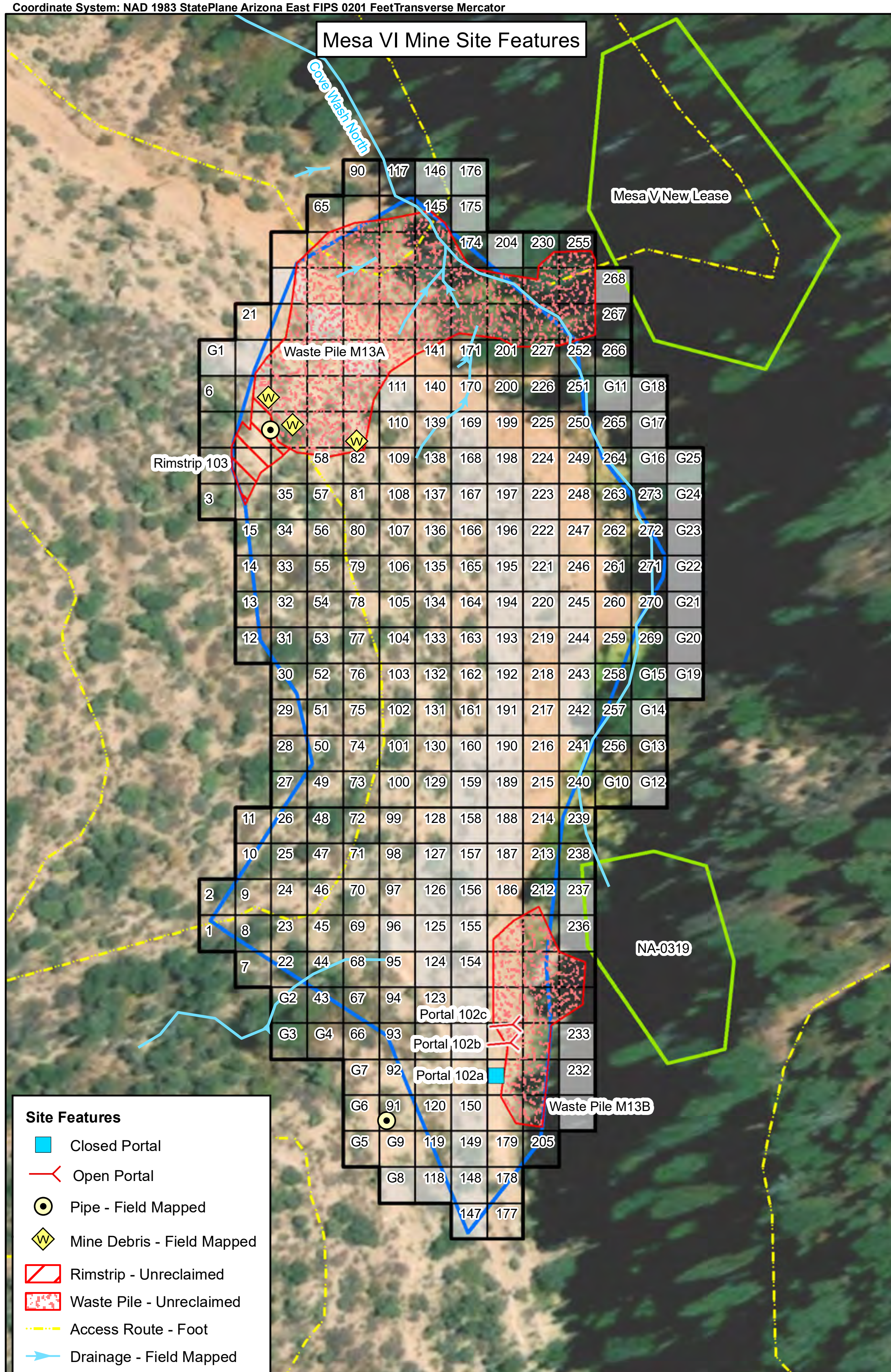
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

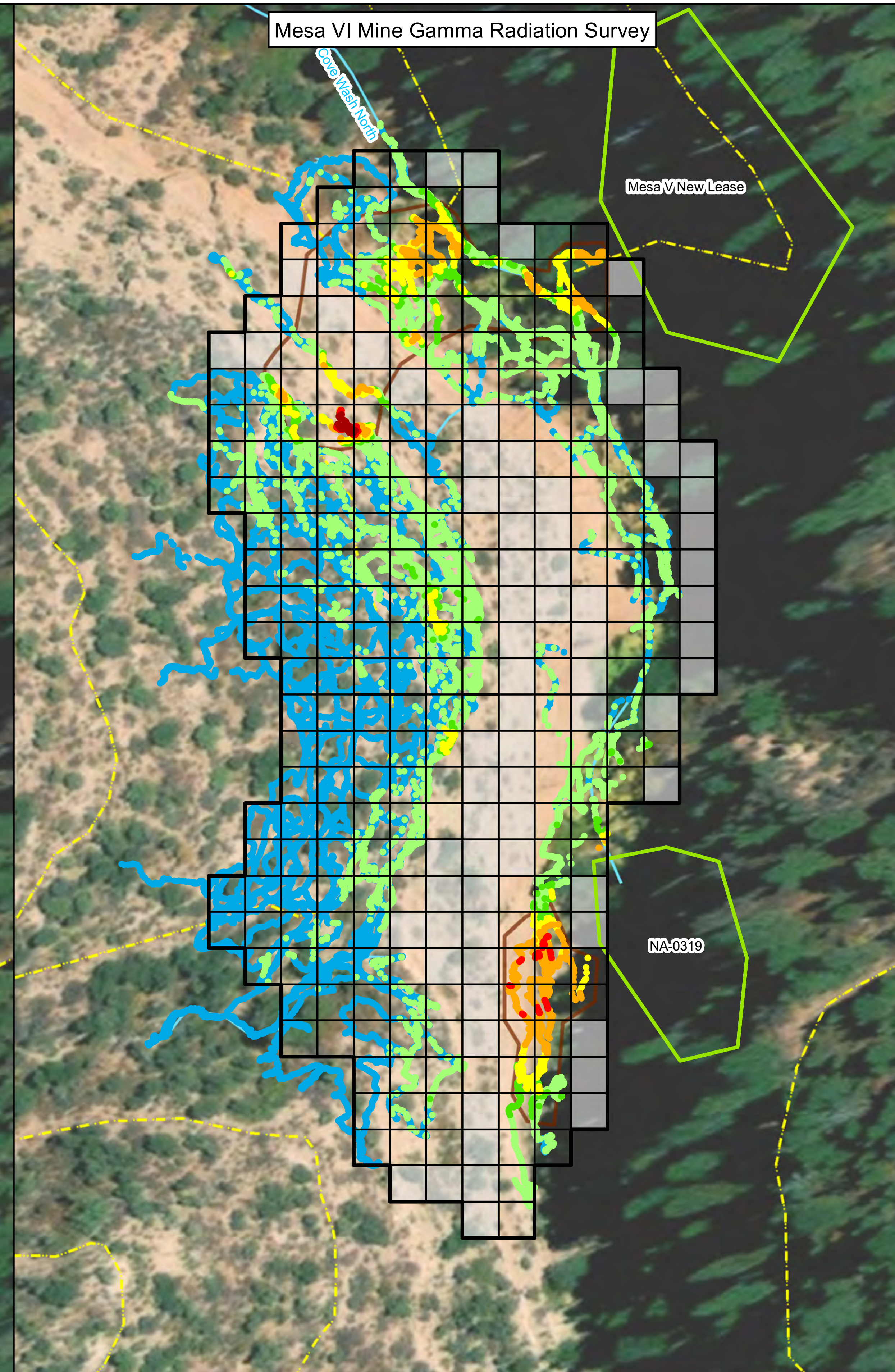
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Figure No.: **M12**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Waste Pile / Rimstrip Boundary
- Non-Tronox AUM Site
- Inaccessible To Gamma Survey

1 in = 125 ft

1:1,500

0 62.5 125 250 Feet

N E S W

MESA VI MINE

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

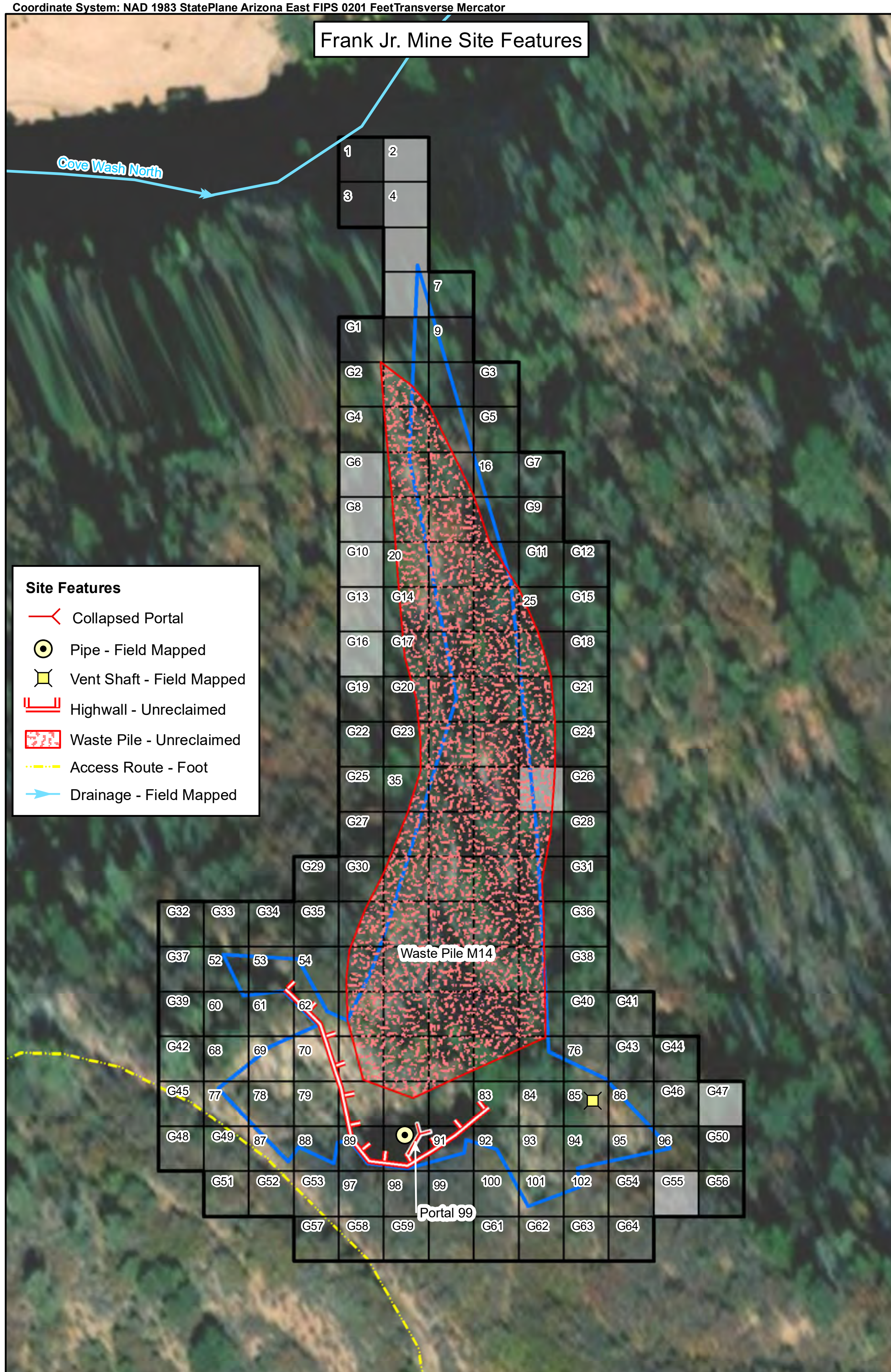
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

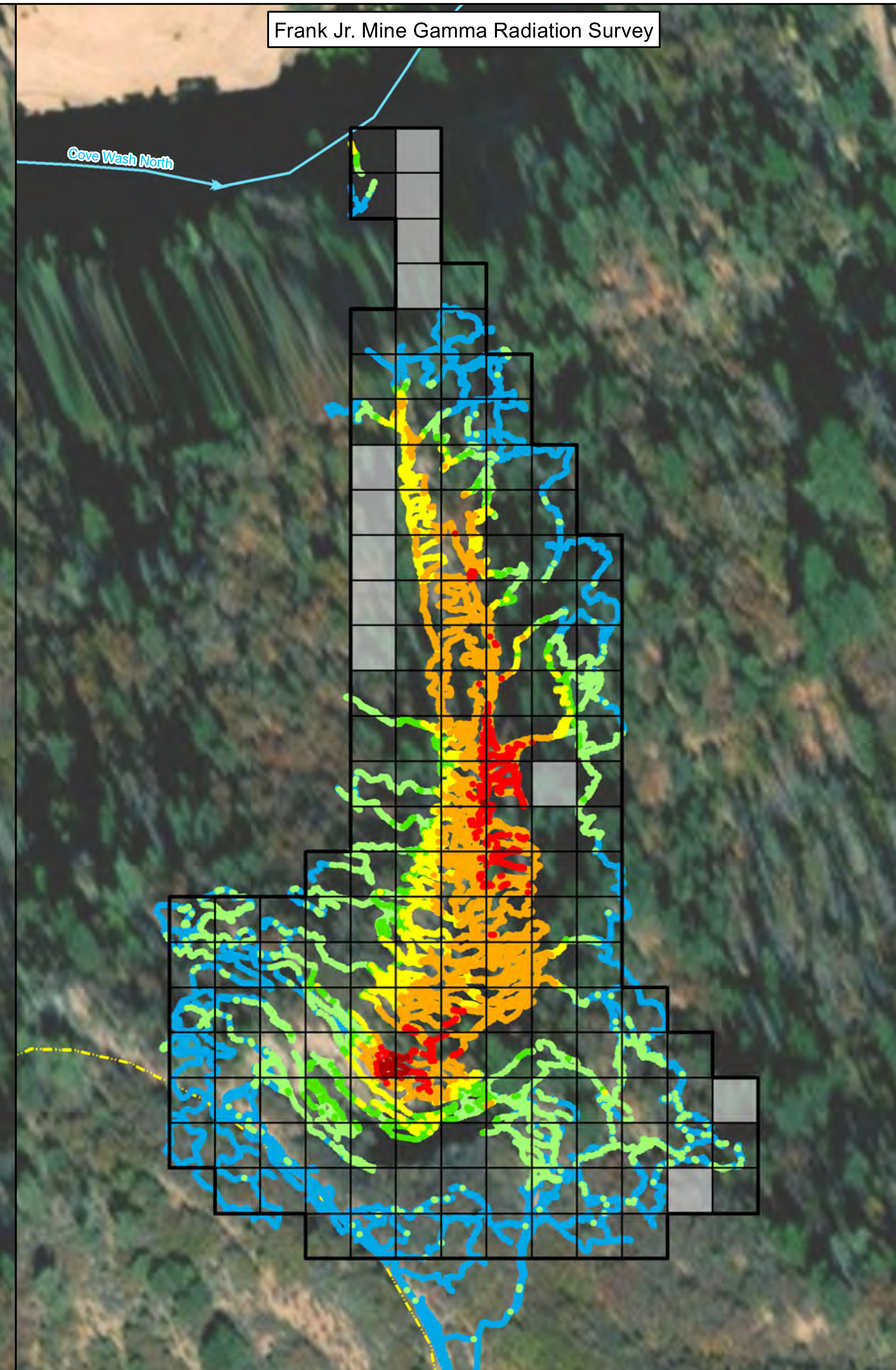
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M13**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Inaccessible To Gamma Survey

1 in = 100 ft

1:1,200

0 50 100 200 Feet

N S W E

FRANK JR. MINE

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

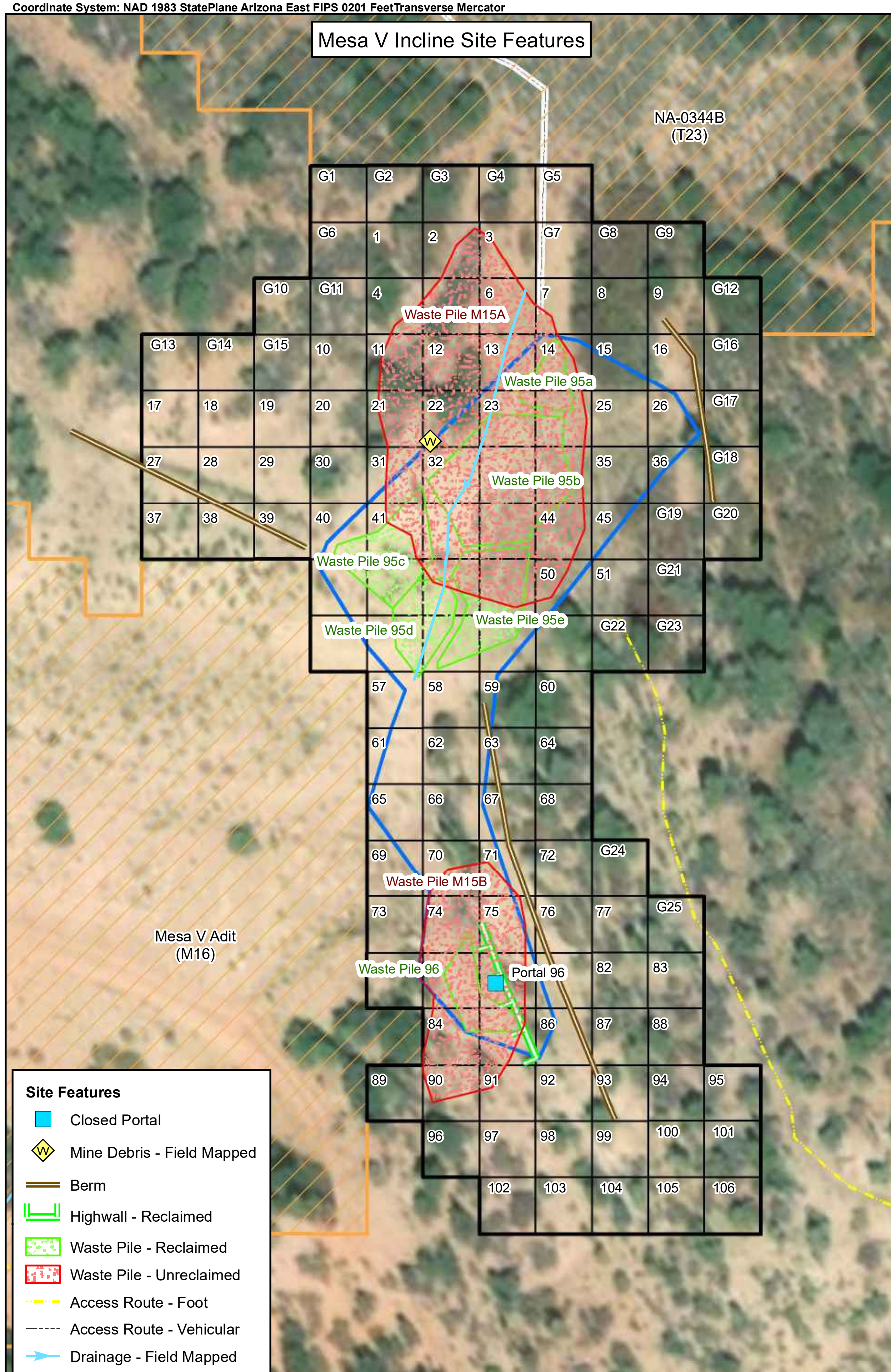
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

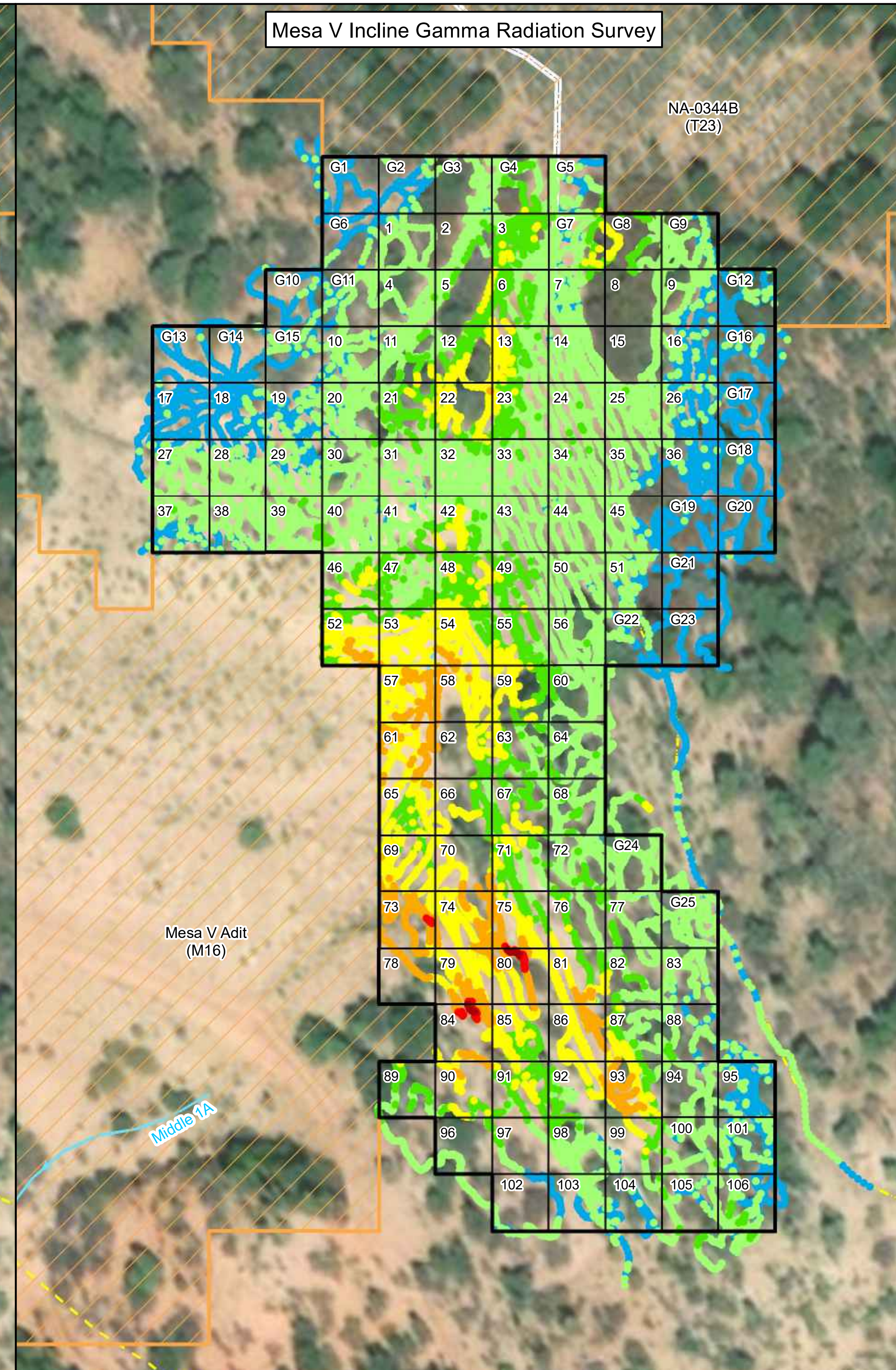
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M14**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area

1 in = 80 ft

1:960

0 40 80 160 Feet

N S E W

MESA V INCLINE
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

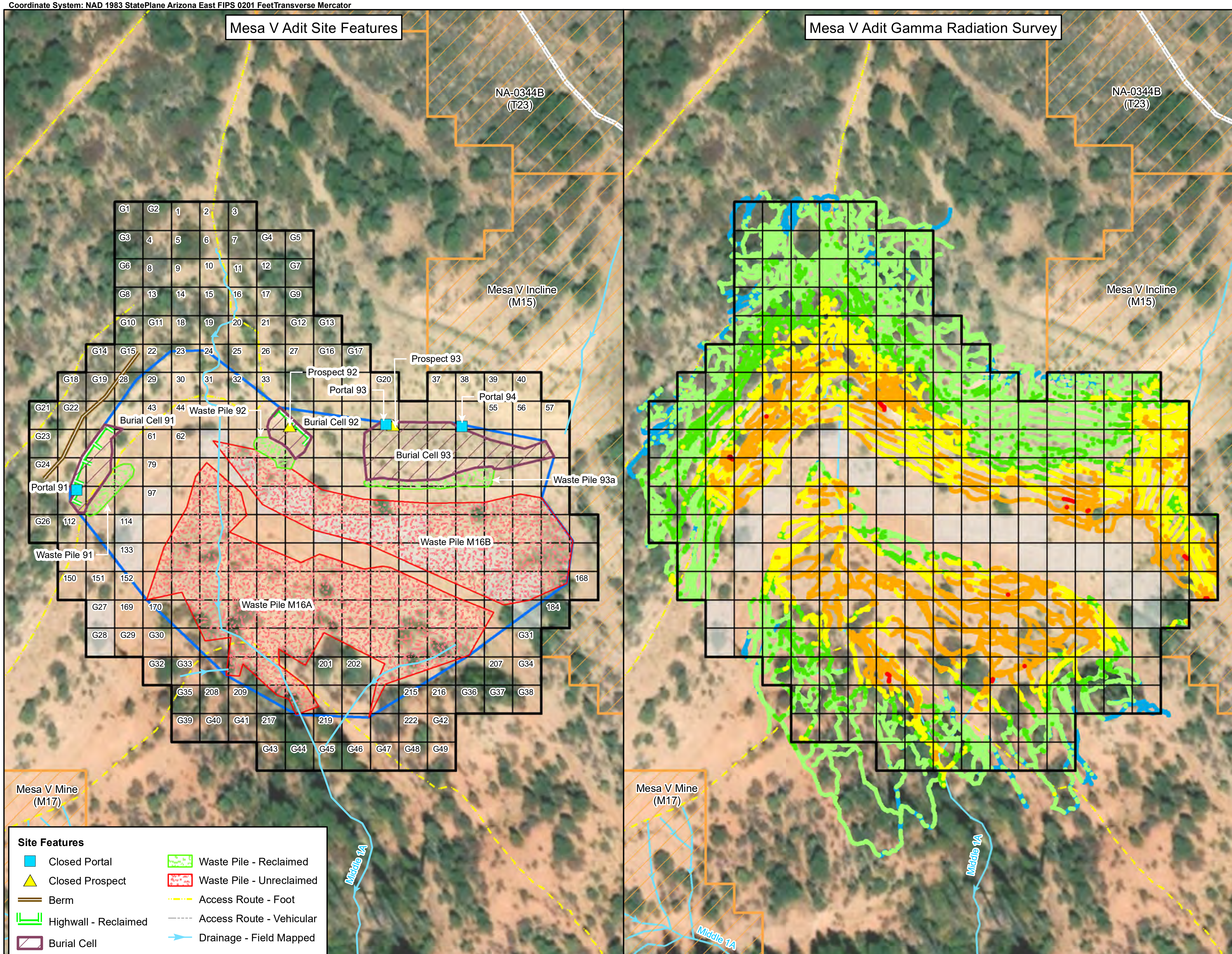
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M15

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 110 ft

1:1,320

0 55 110 220 Feet

N W E S

MESA V ADIT
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

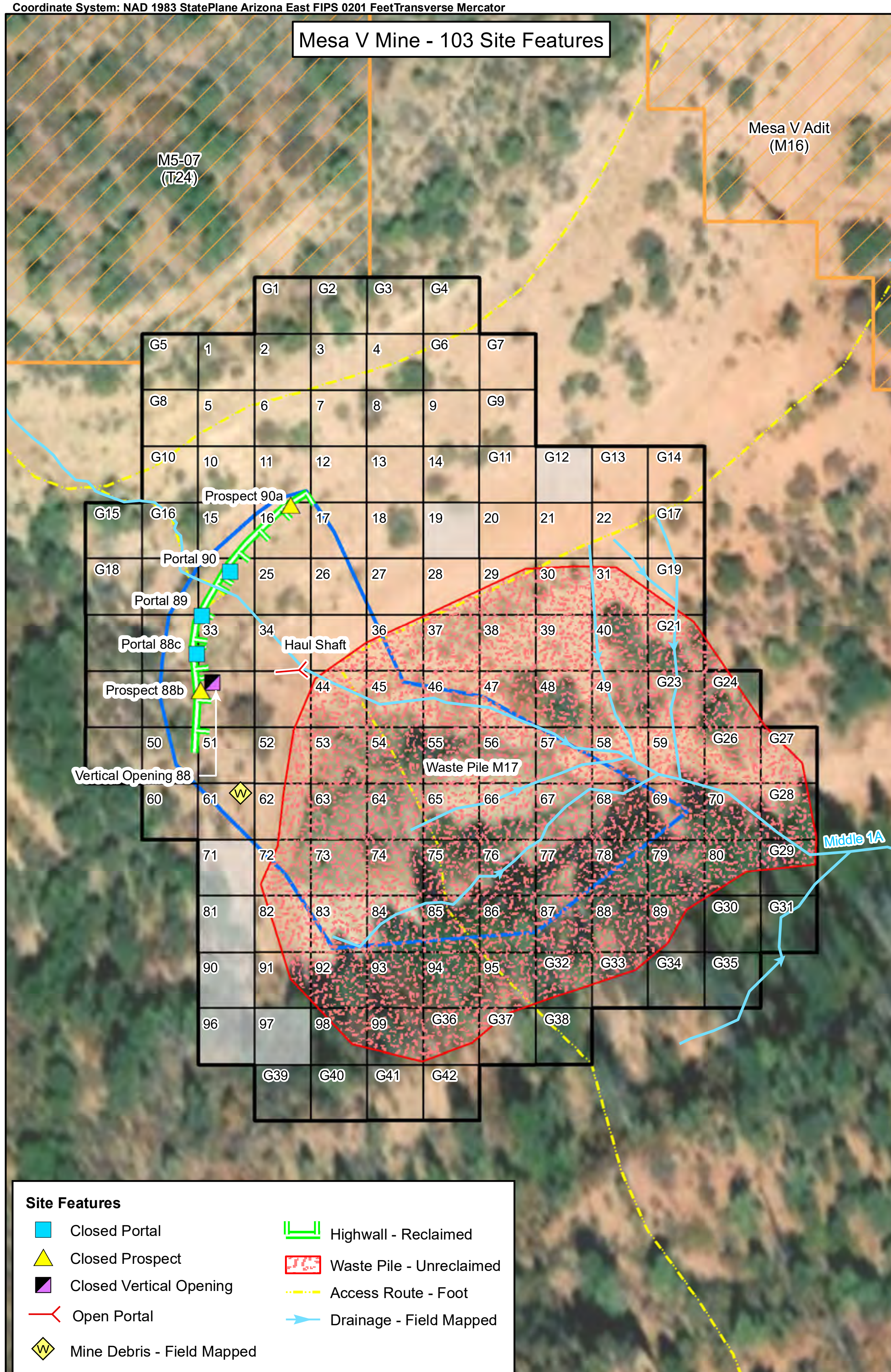
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

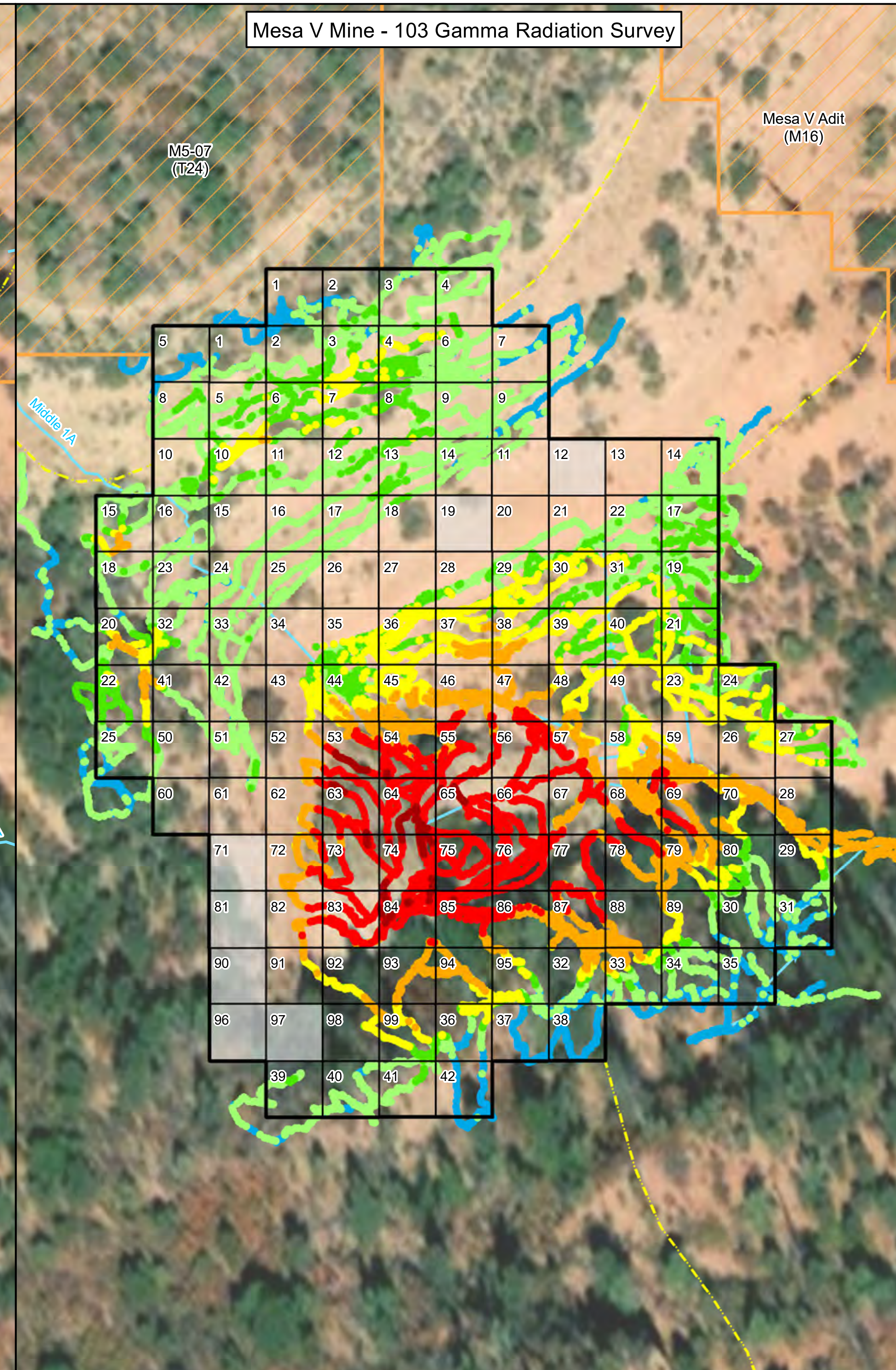
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M16**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 80 ft

1:960

0 40 80 160 Feet

N W E S

MESA V MINE - 103
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

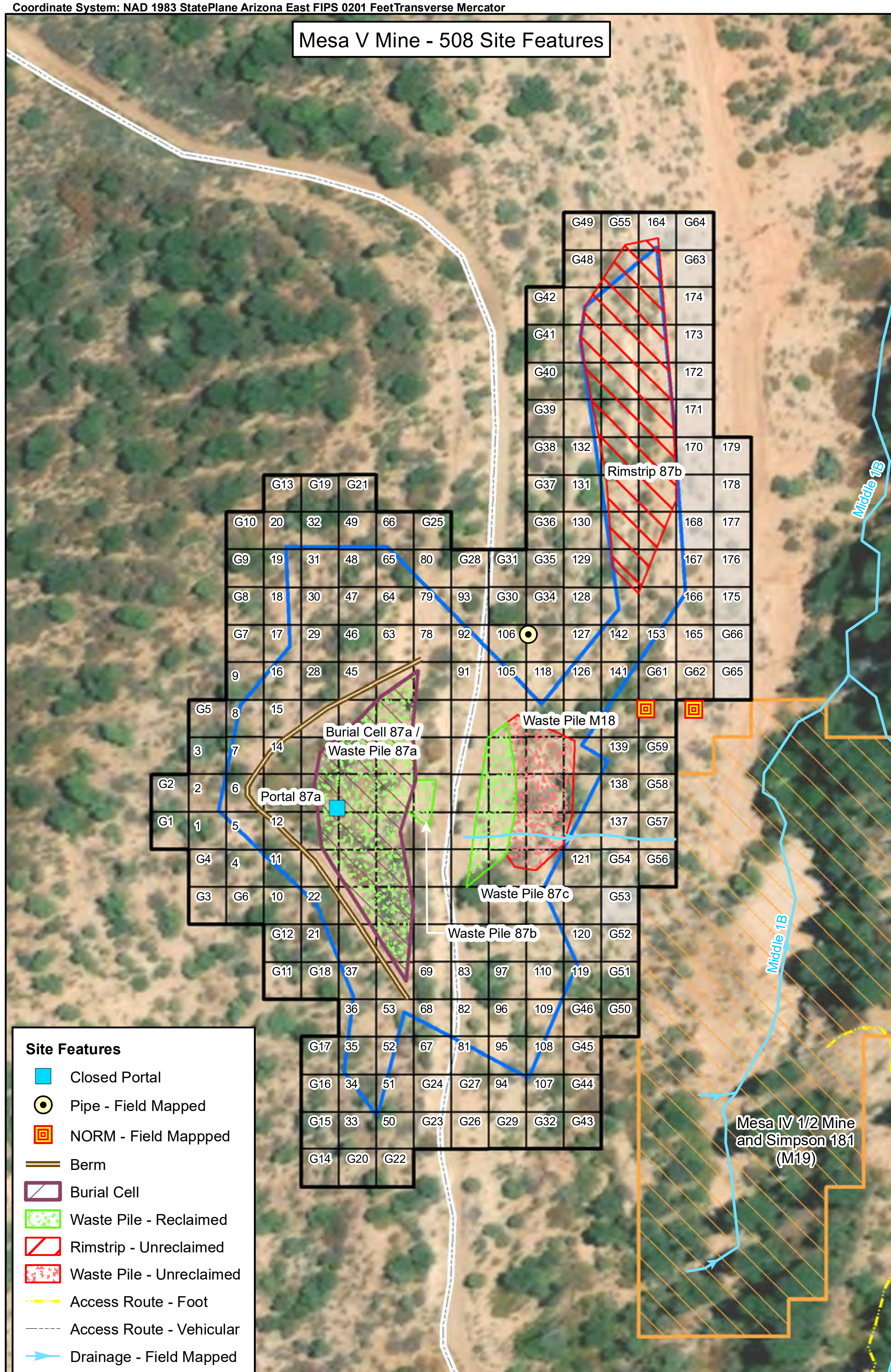
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

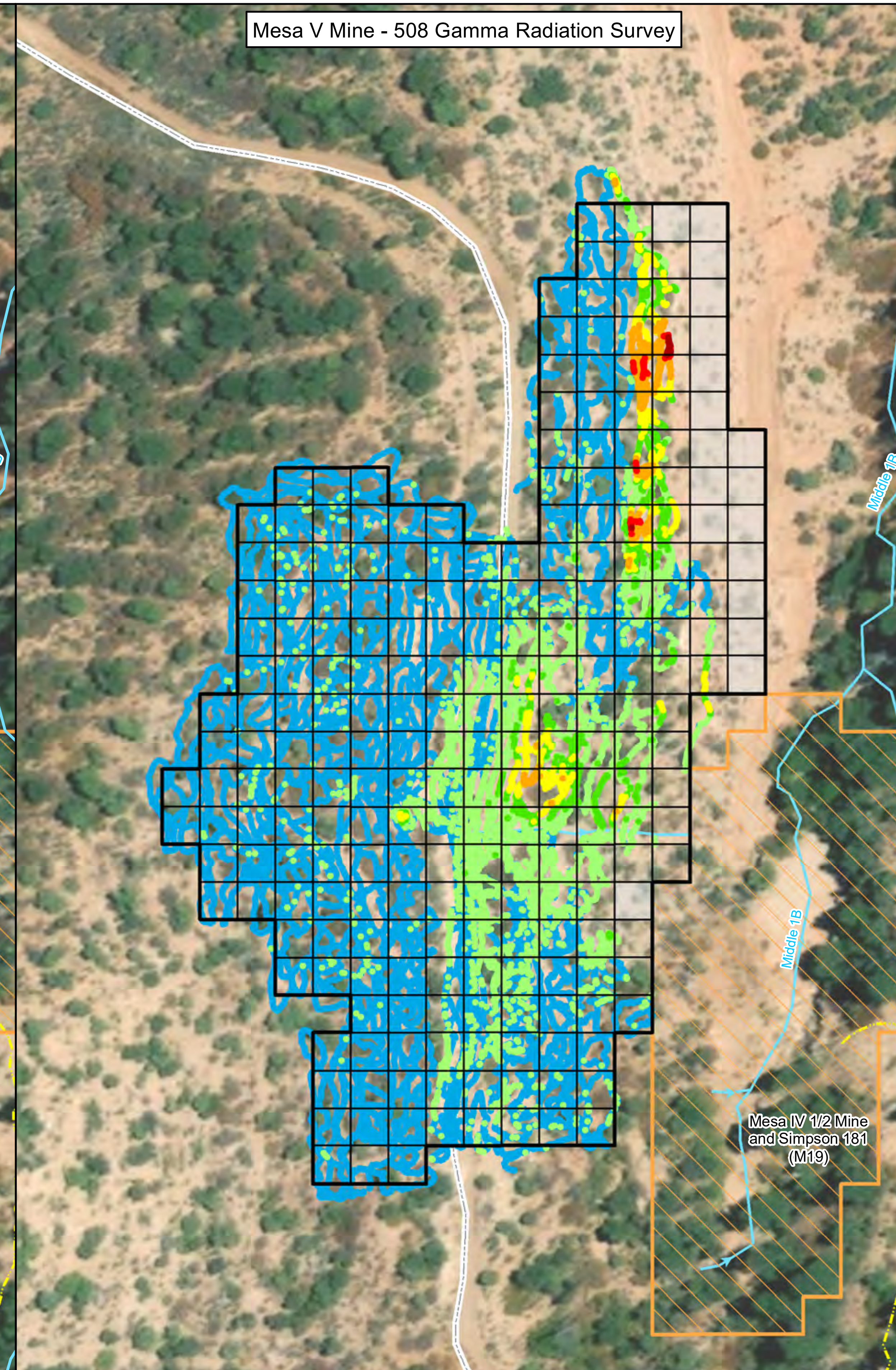
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M17**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 120 ft

1:1,440

0 60 120 240 Feet

N E S W

MESA V MINE - 508

GAMMA EXPOSURE RATE MAP

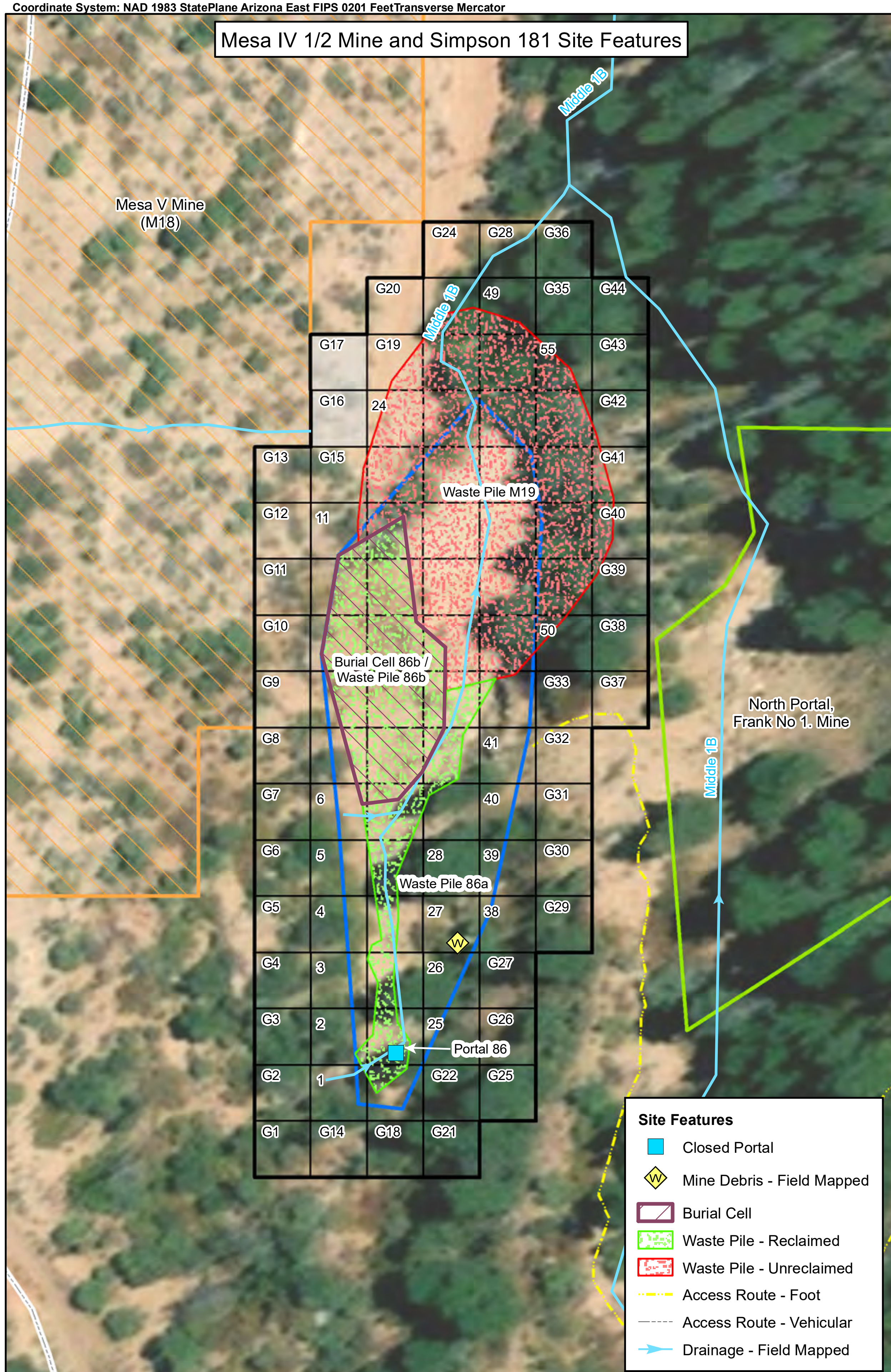
Prepared For:

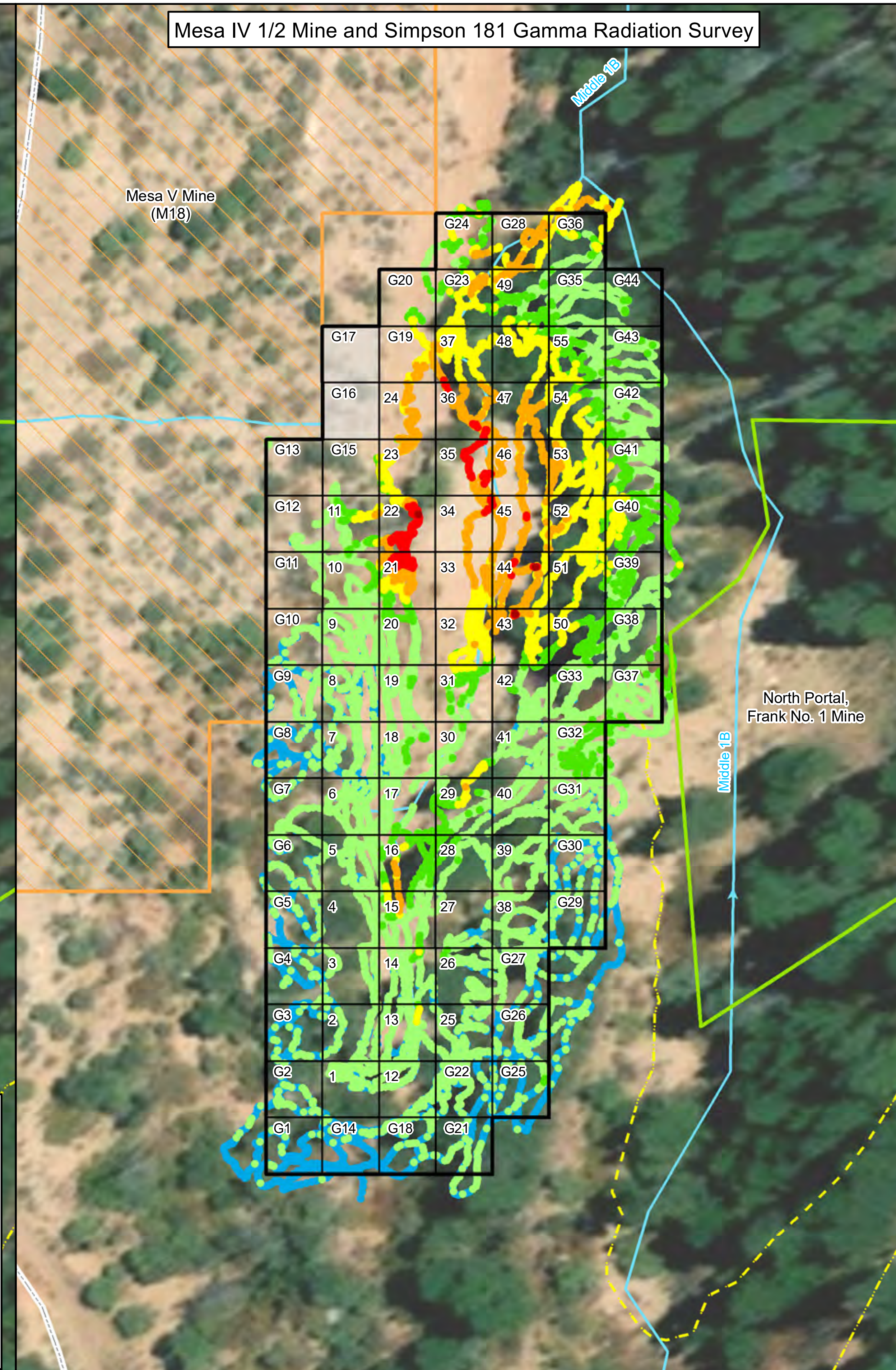
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.: TO0001	Contract No.: EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019
Notes: *Gross gamma count rate measurements are converted to gamma exposure rate using the following equation: γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).	Figure No.: **M18**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Non-Tronox AUM Site
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 80 ft

1:960

0 40 80 160 Feet

MESA IV 1/2 MINE AND SIMPSON 181
GAMMA EXPOSURE RATE MAP

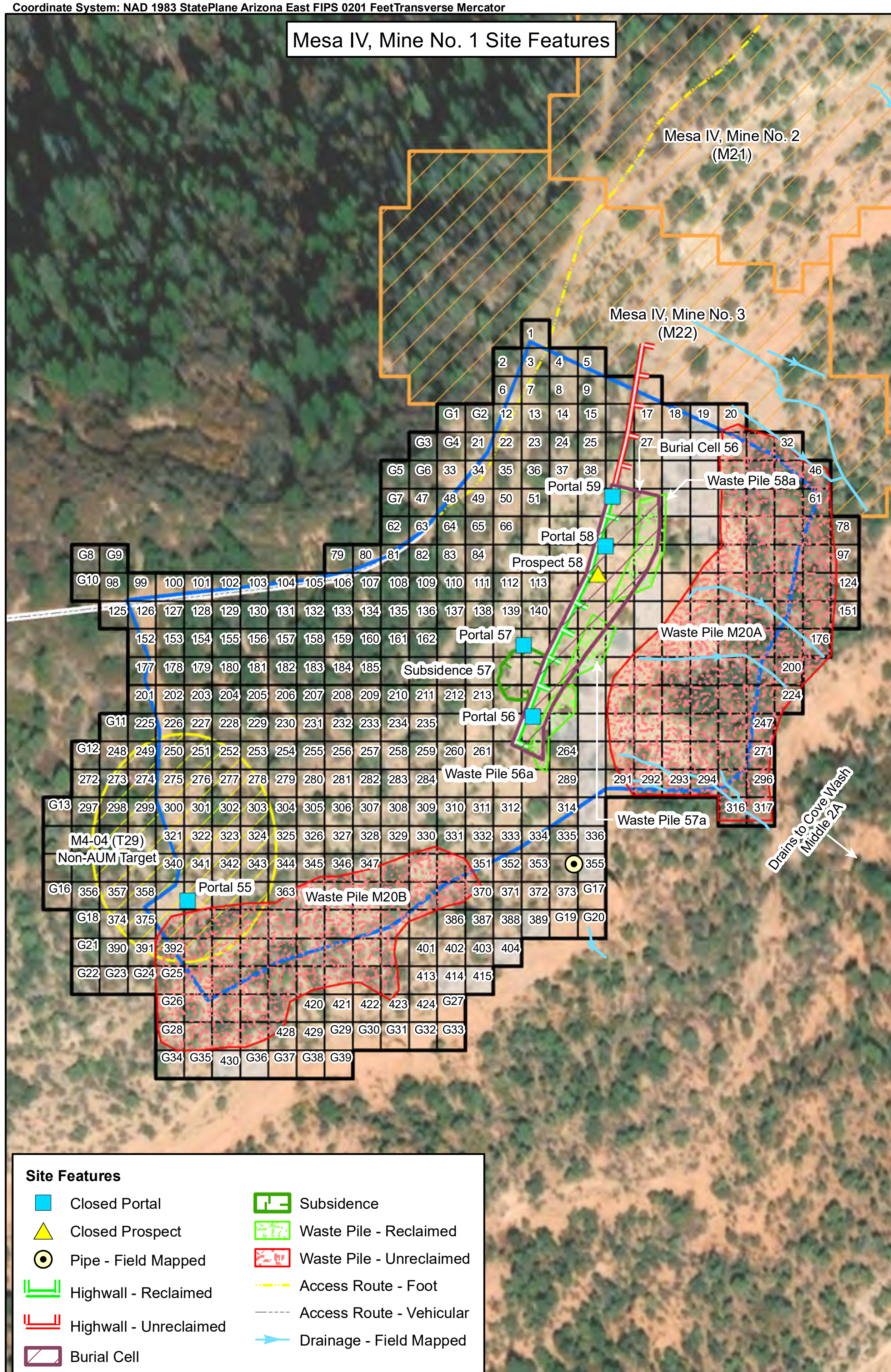
Prepared For:

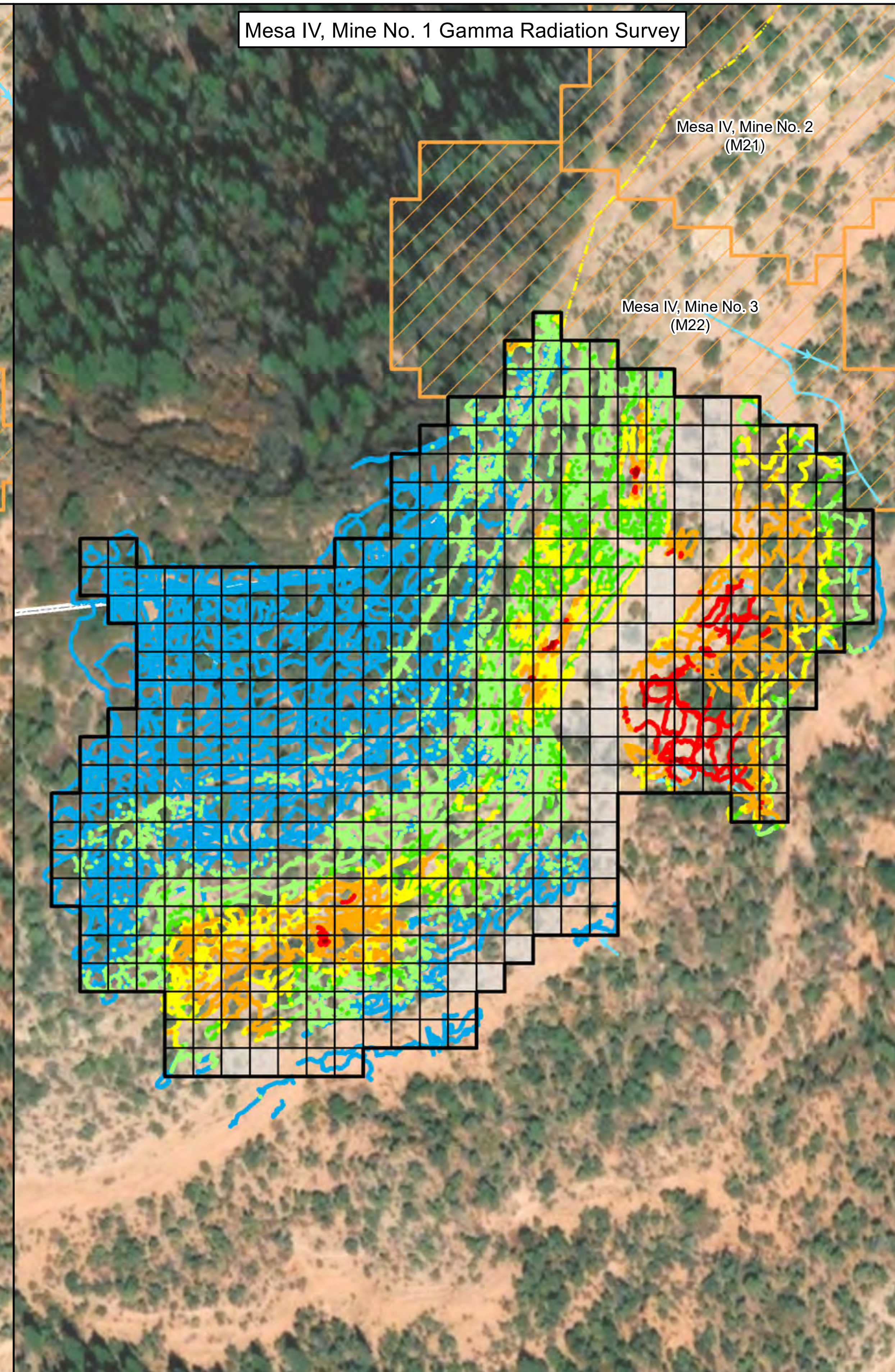
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.: TO0001	Contract No.: EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019
Notes: *Gross gamma count rate measurements are converted to gamma exposure rate using the following equation: γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).	Figure No.: M19

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 160 ft

1:1,920

0 80 160 320 Feet

N W E S

MESA IV, MINE NO. 1

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

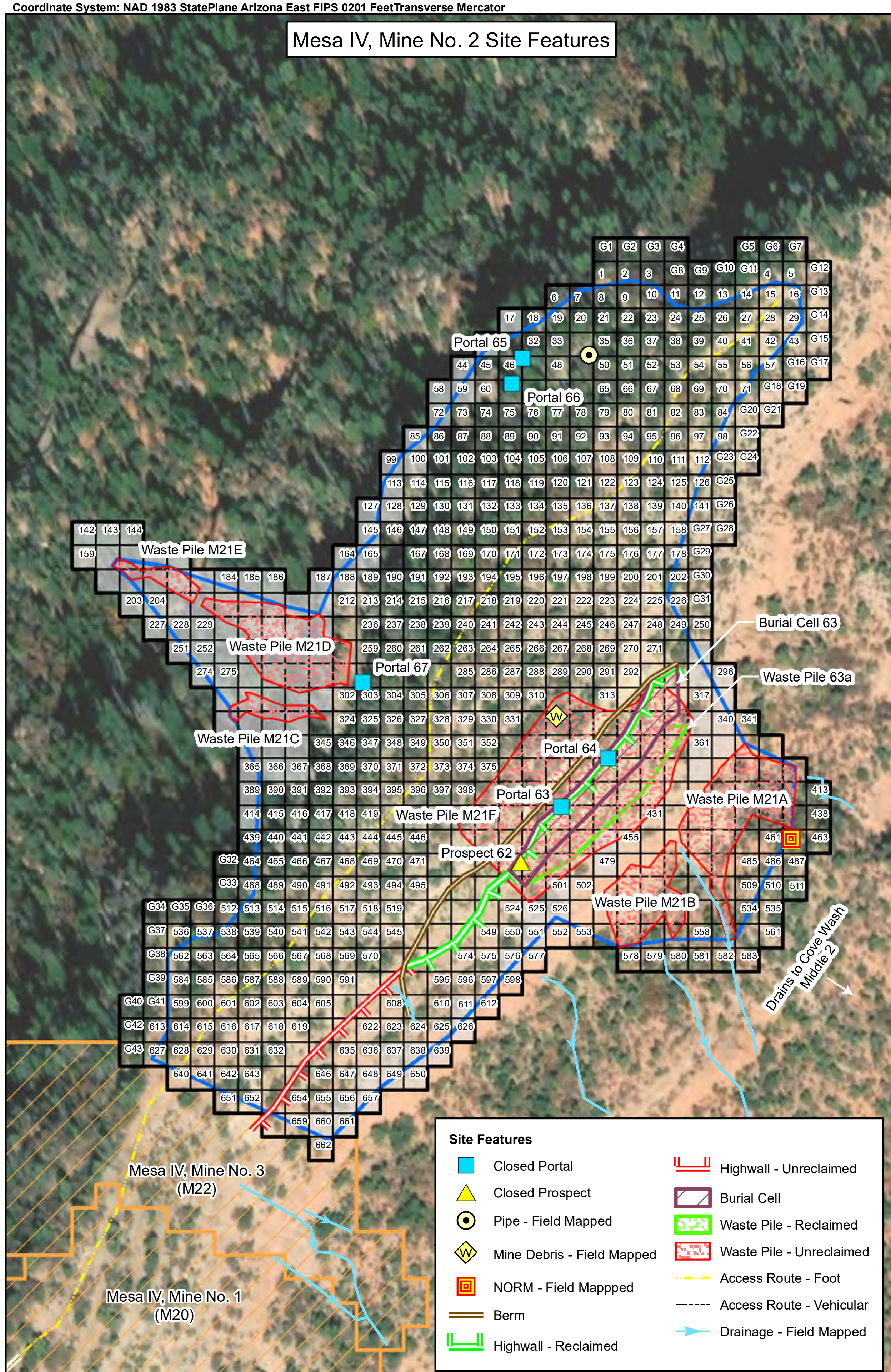
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

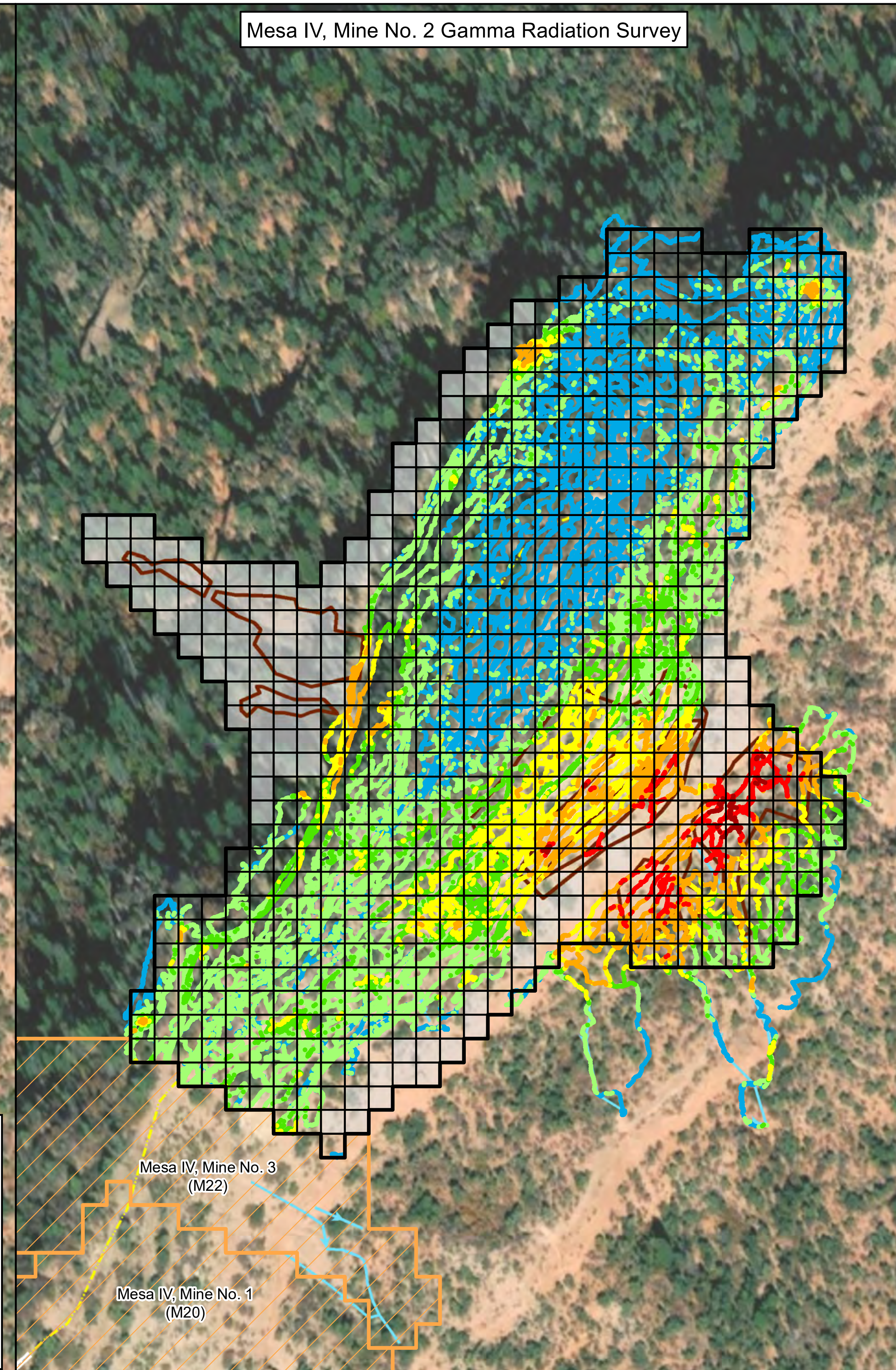
Notes:

*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Figure No.: **M20**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Burial Cell / Waste Pile Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 190 ft

1:2,280

0 95 190 380 Feet

N W E S

MESA IV, MINE NO. 2
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

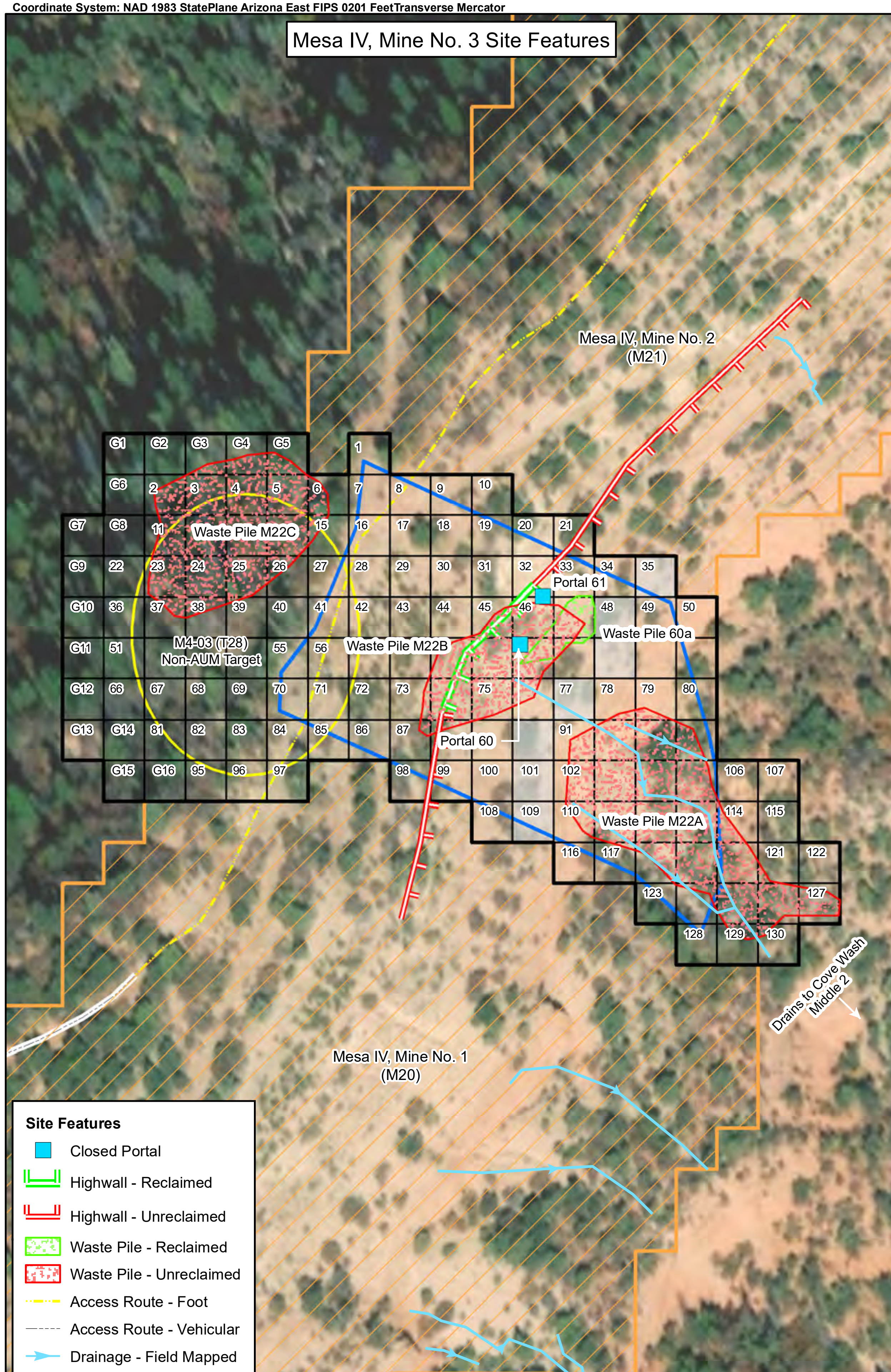
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

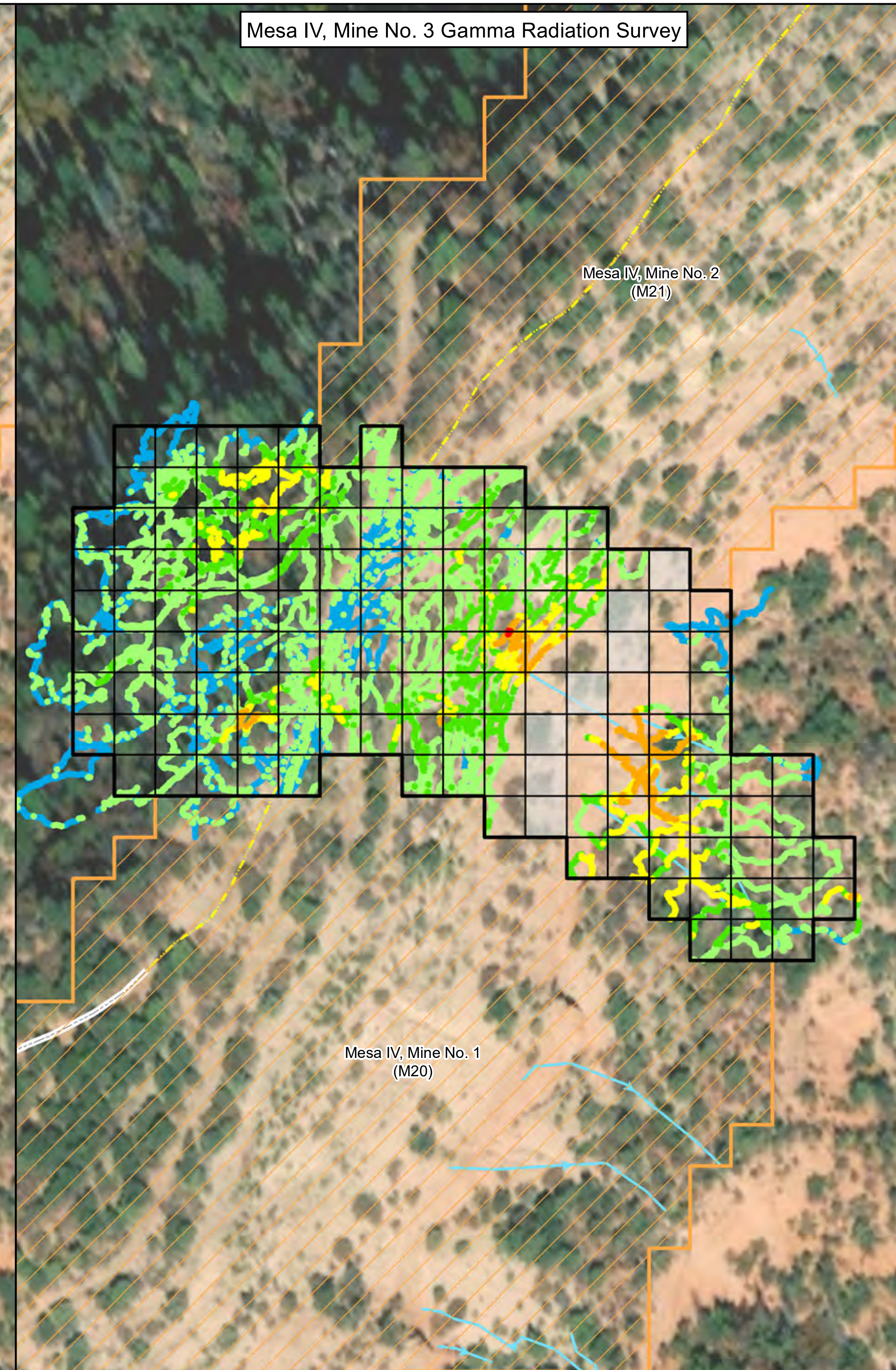
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M21

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Non-AUM Target Site Boundary
- Inaccessible To Gamma Survey

1 in = 110 ft

1:1,320

0 55 110 220 Feet

N W E S

MESA IV, MINE NO. 3
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

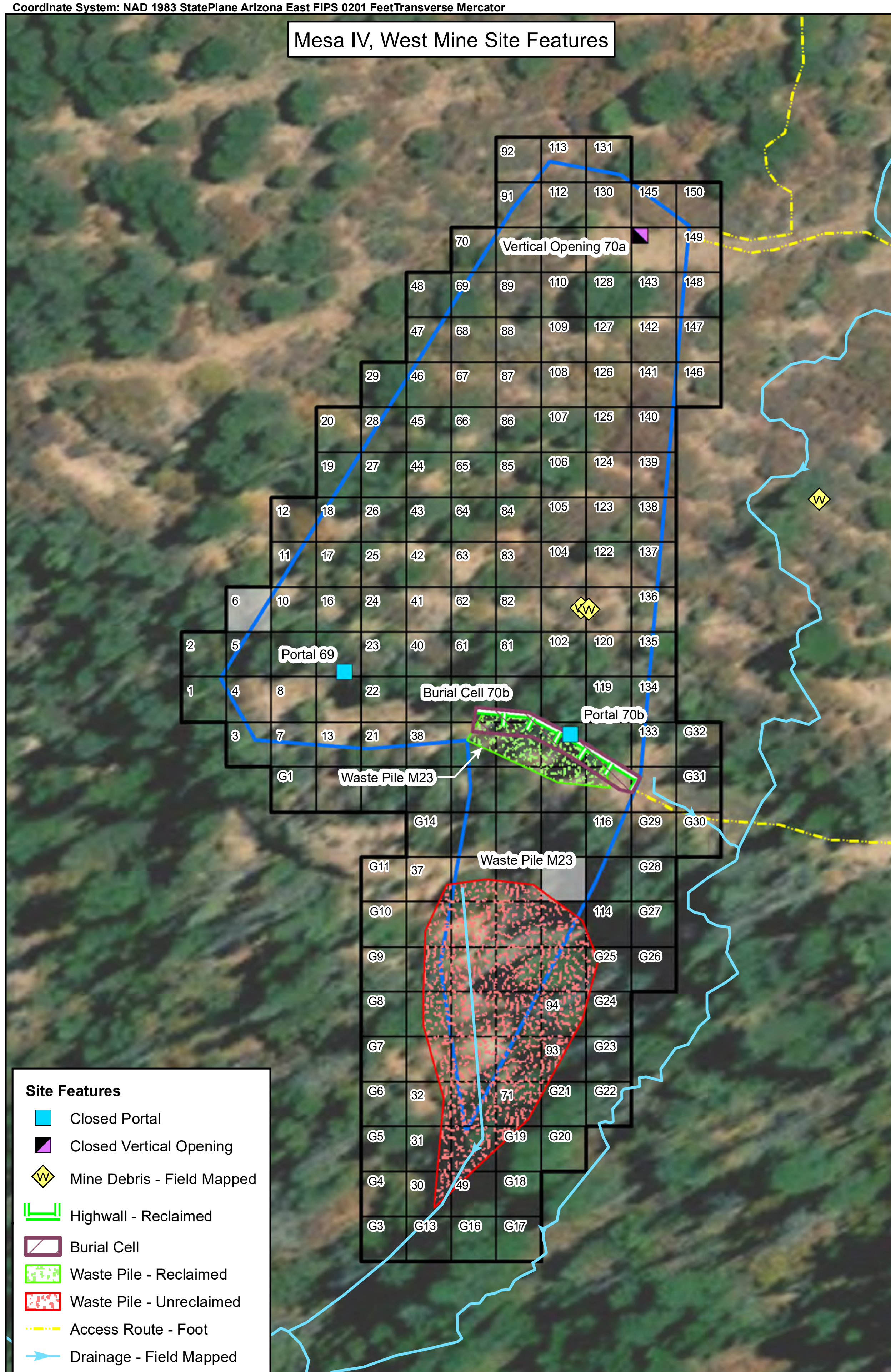
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

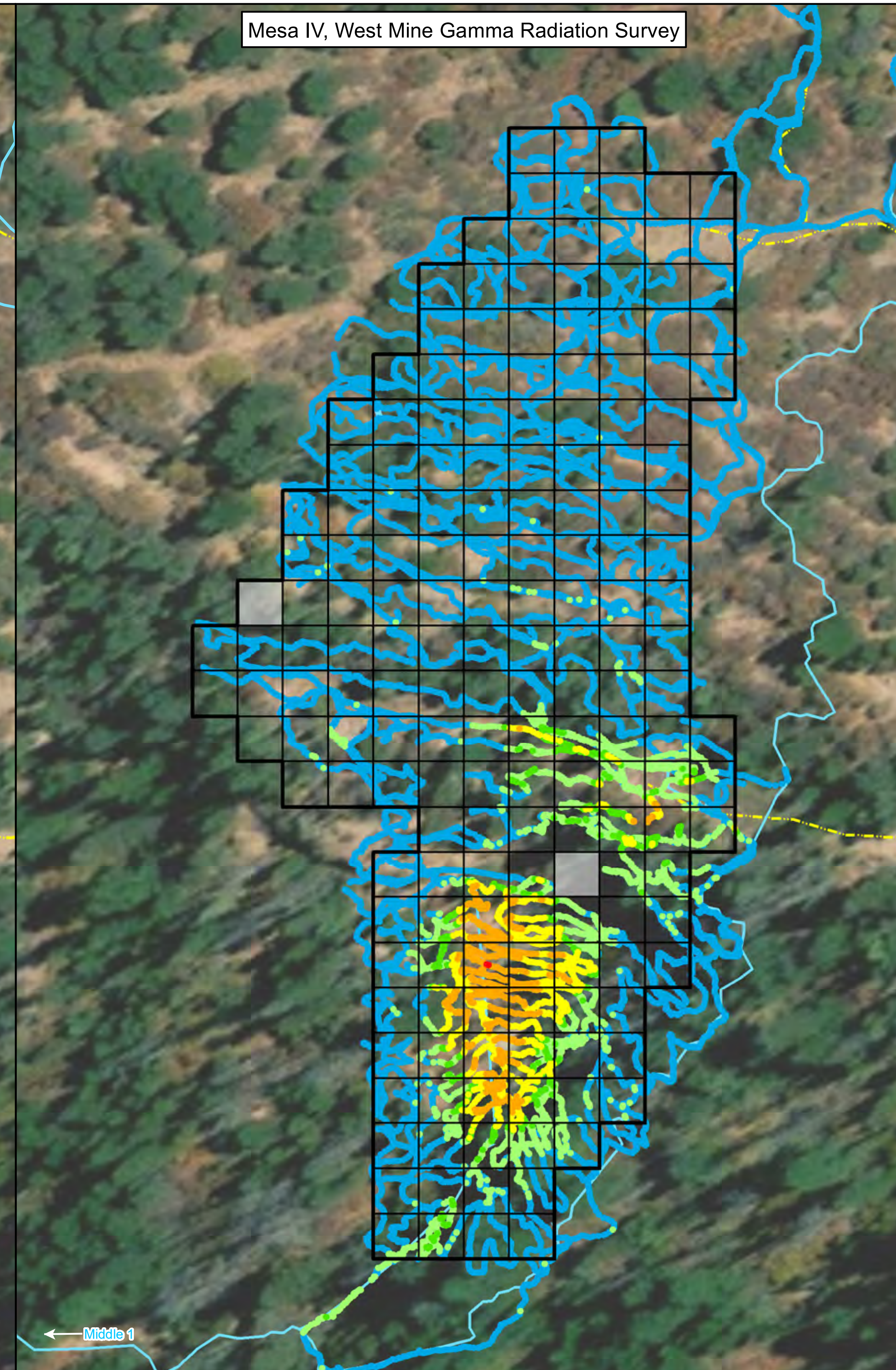
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M22

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Inaccessible To Gamma Survey

1 in = 100 ft

1:1,200

0 50 100 200 Feet

MESA IV, WEST MINE GAMMA EXPOSURE RATE MAP

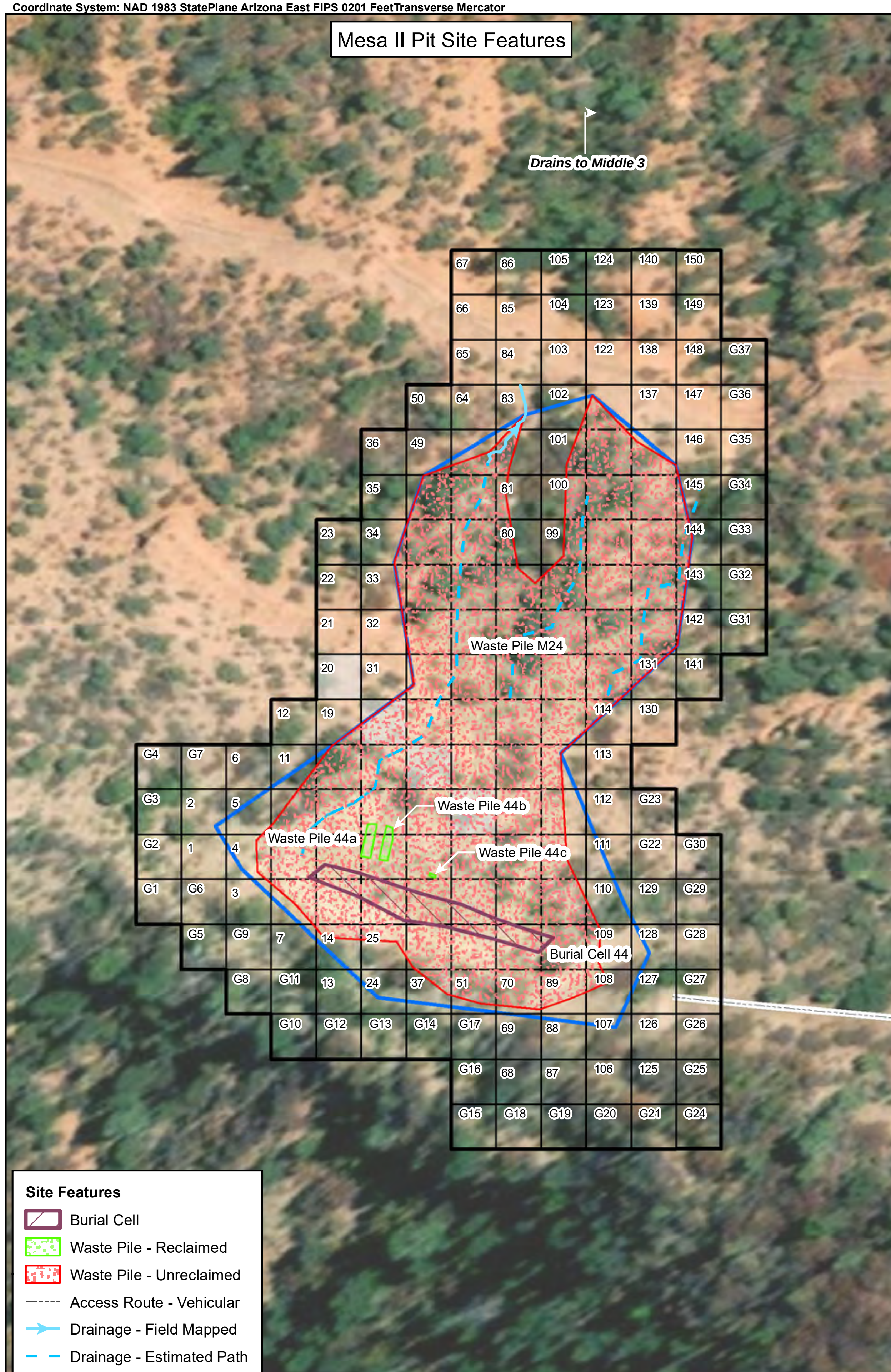
Prepared For:

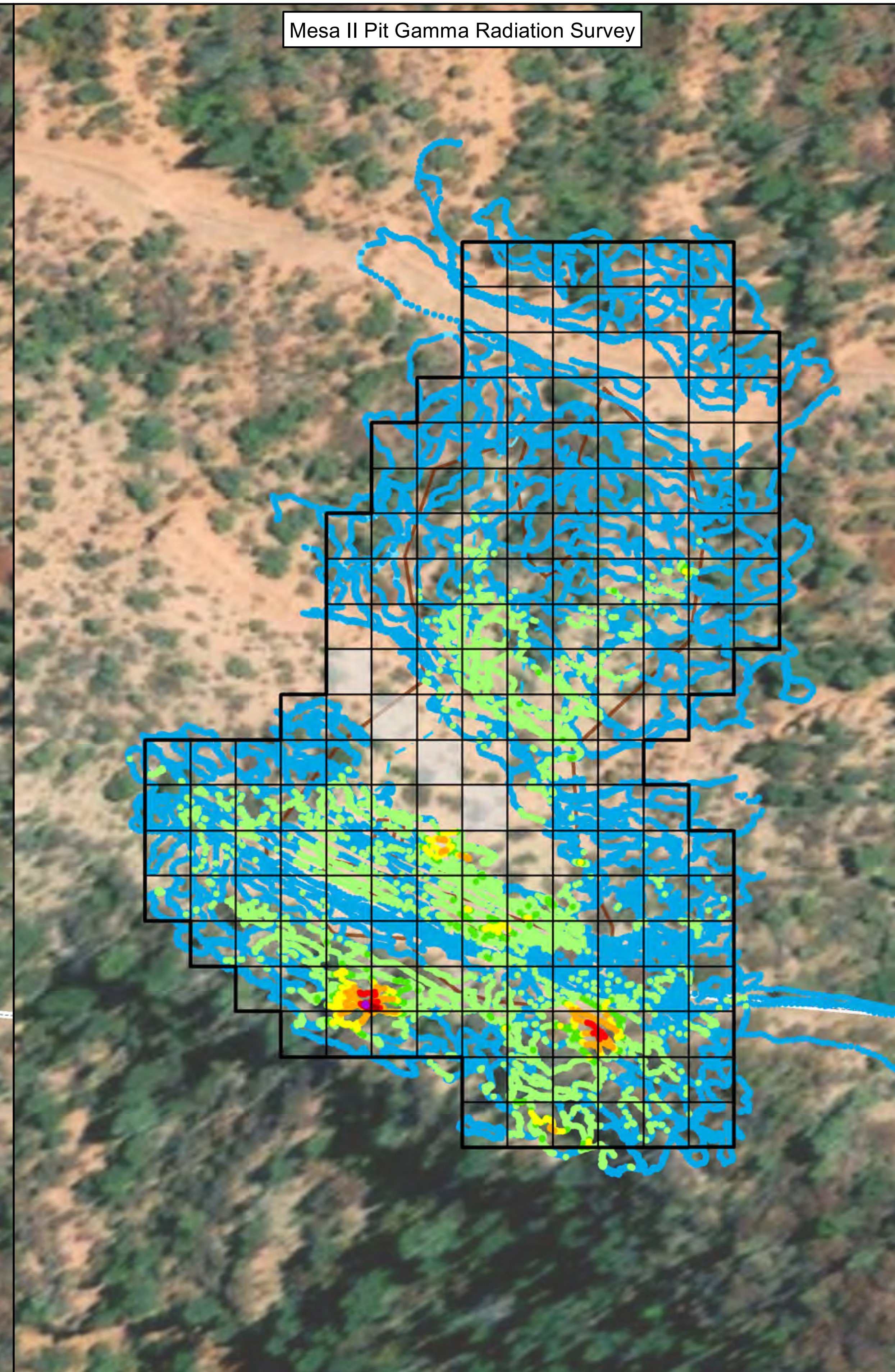
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019
Notes: *Gross gamma count rate measurements are converted to gamma exposure rate using the following equation: $\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.	Figure No.: M23

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Inaccessible To Gamma Survey
- Burial Cell / Waste Pile Boundary

1 in = 100 ft

1:1,200

0 50 100 200 Feet

N E S W

MESA II PIT
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

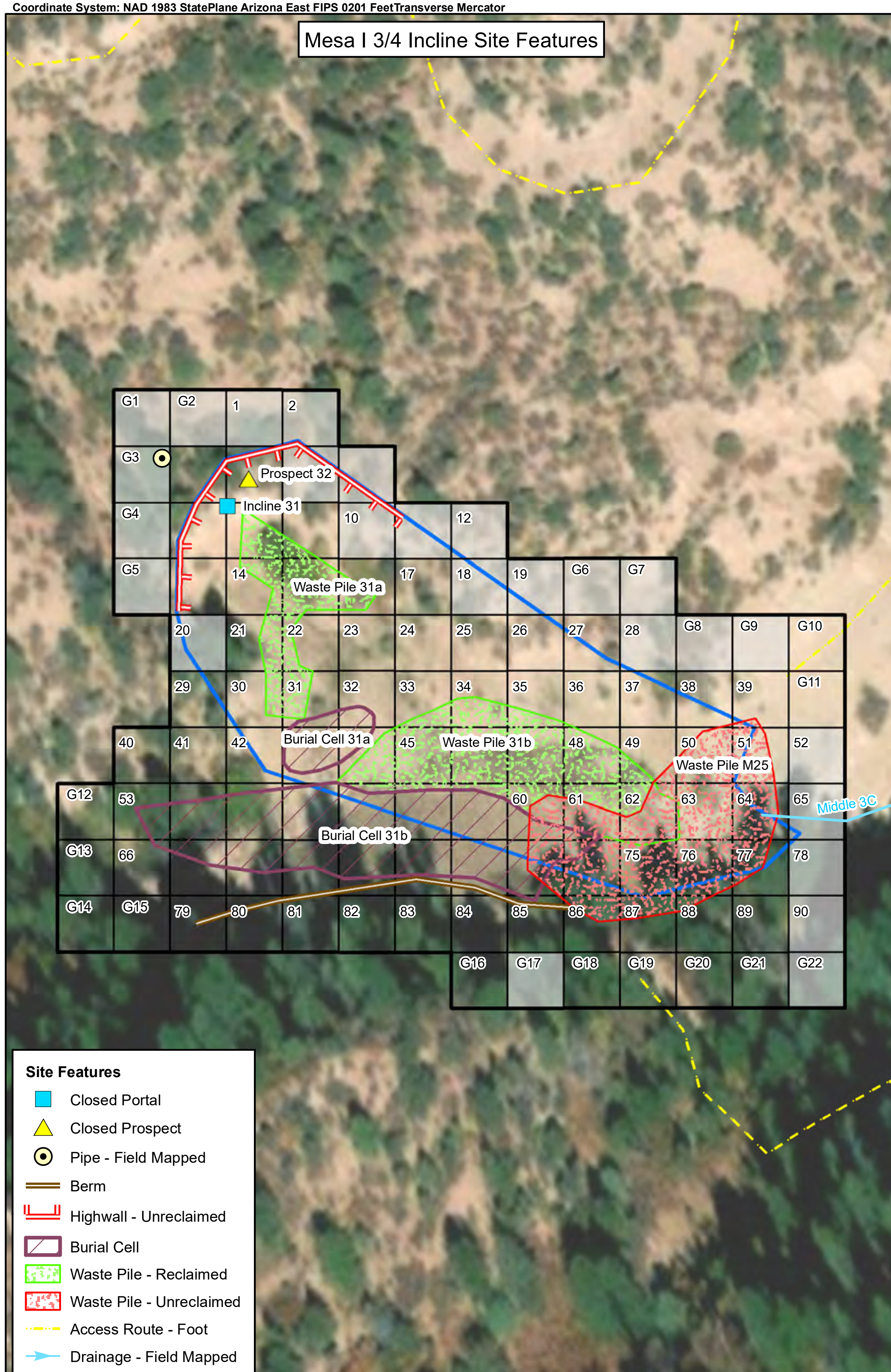
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

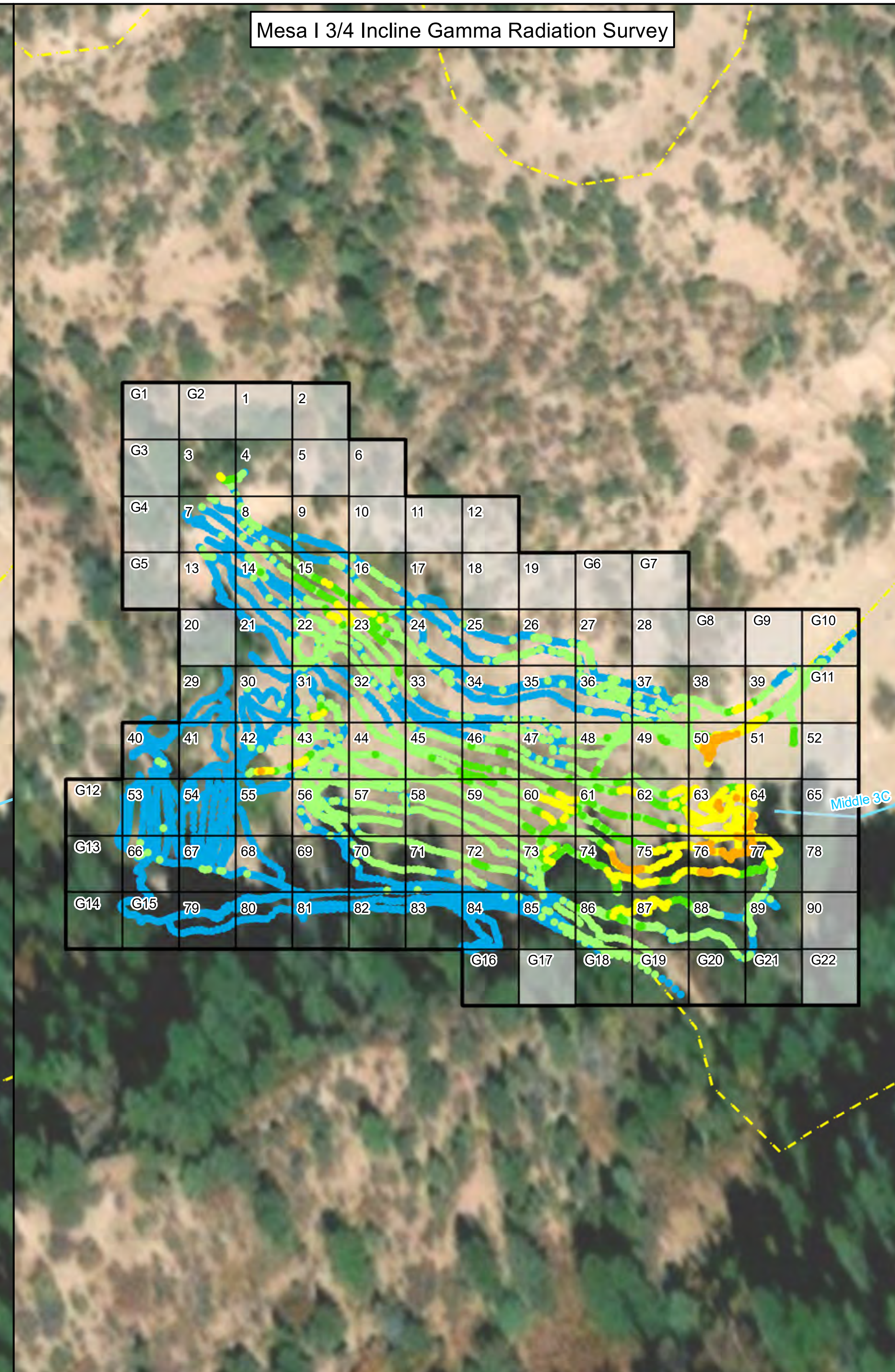
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Figure No.: **M24**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Inaccessible To Gamma Survey

1 in = 80 ft

1:960

0 40 80 160 Feet

N W E S

MESA I 3/4 INCLINE GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

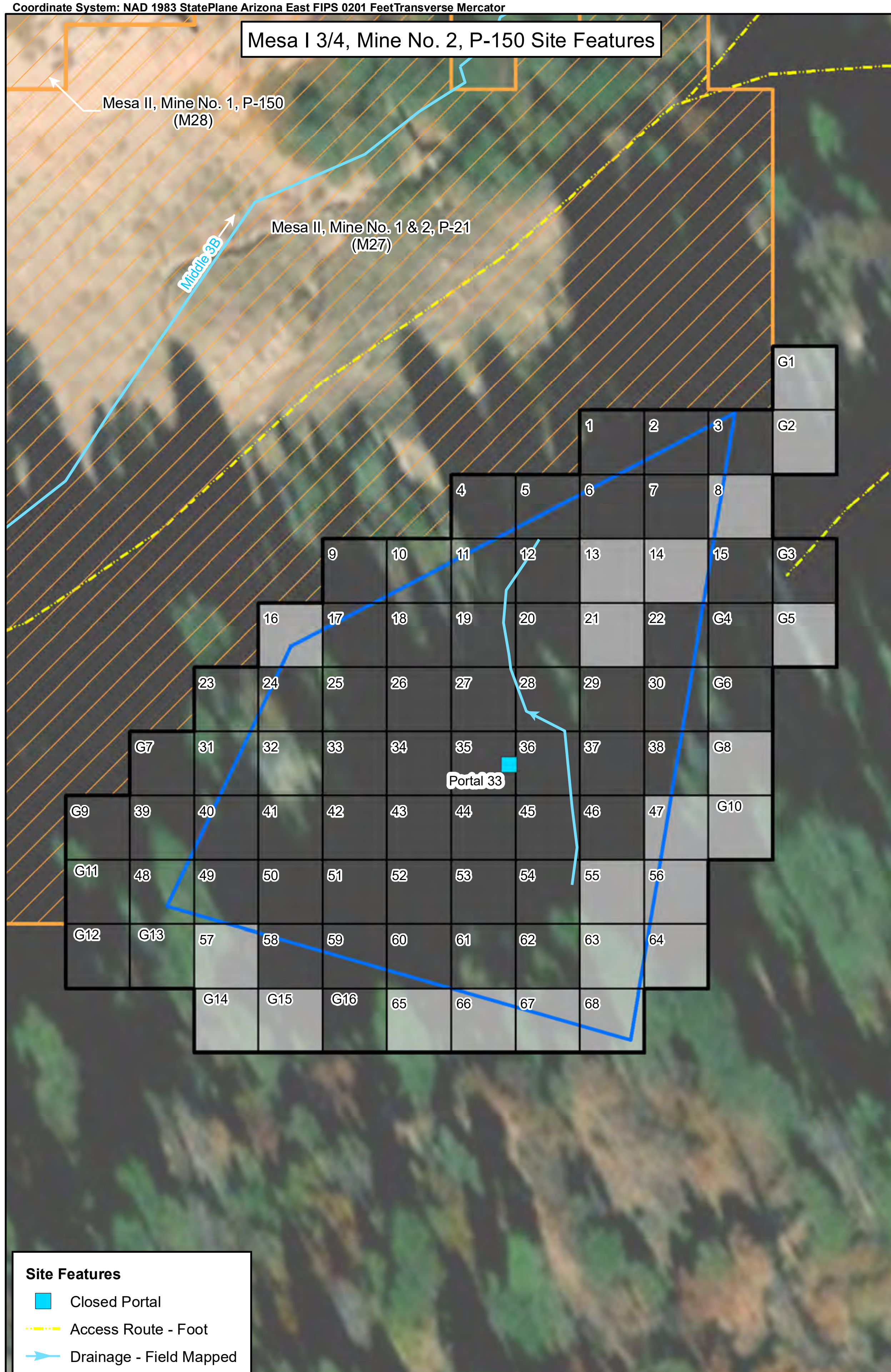
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

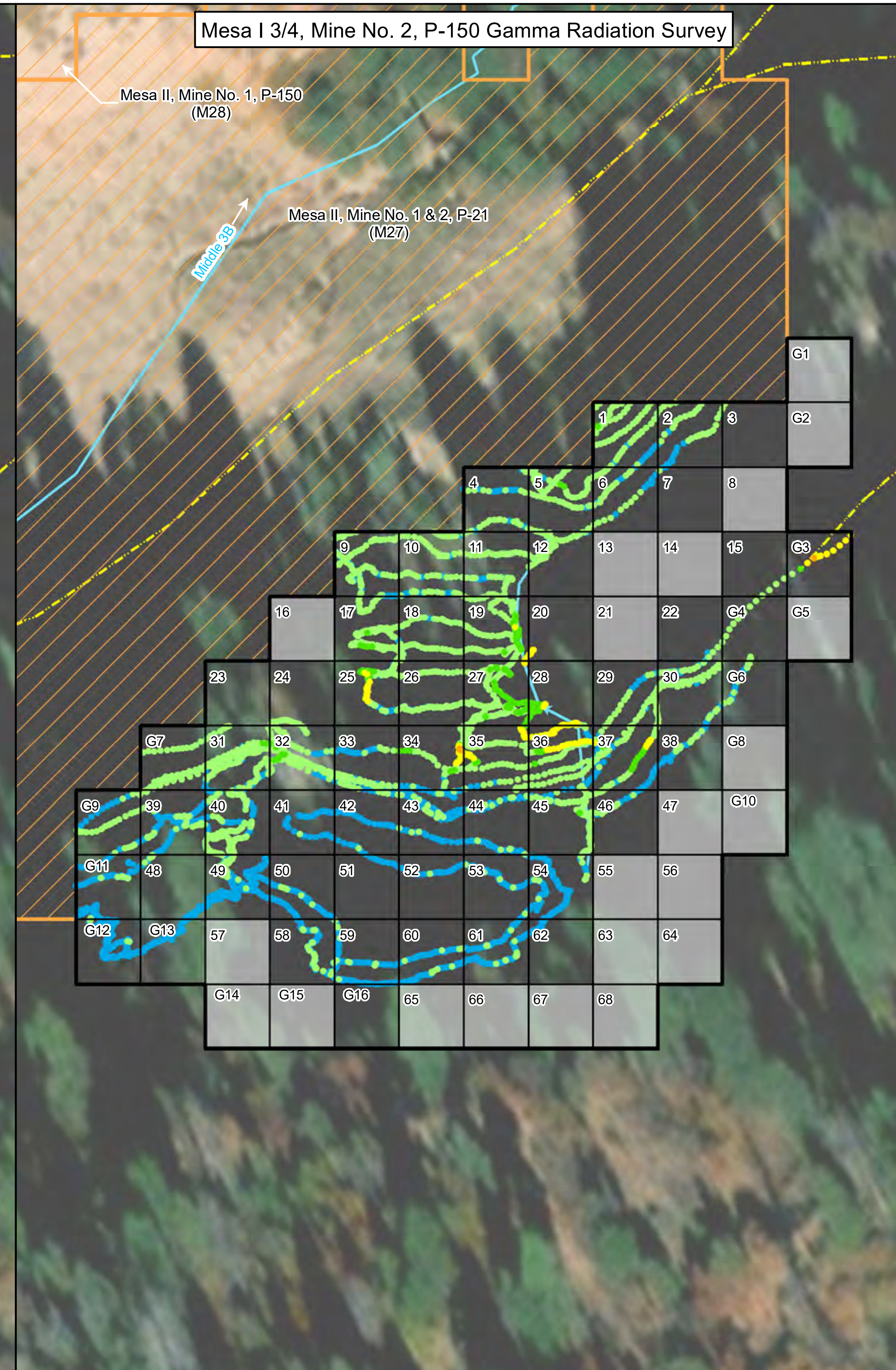
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M25

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 70 ft

1:840

0 35 70 140 Feet

N E S W

MESA I 3/4, MINE NO. 2, P-150
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

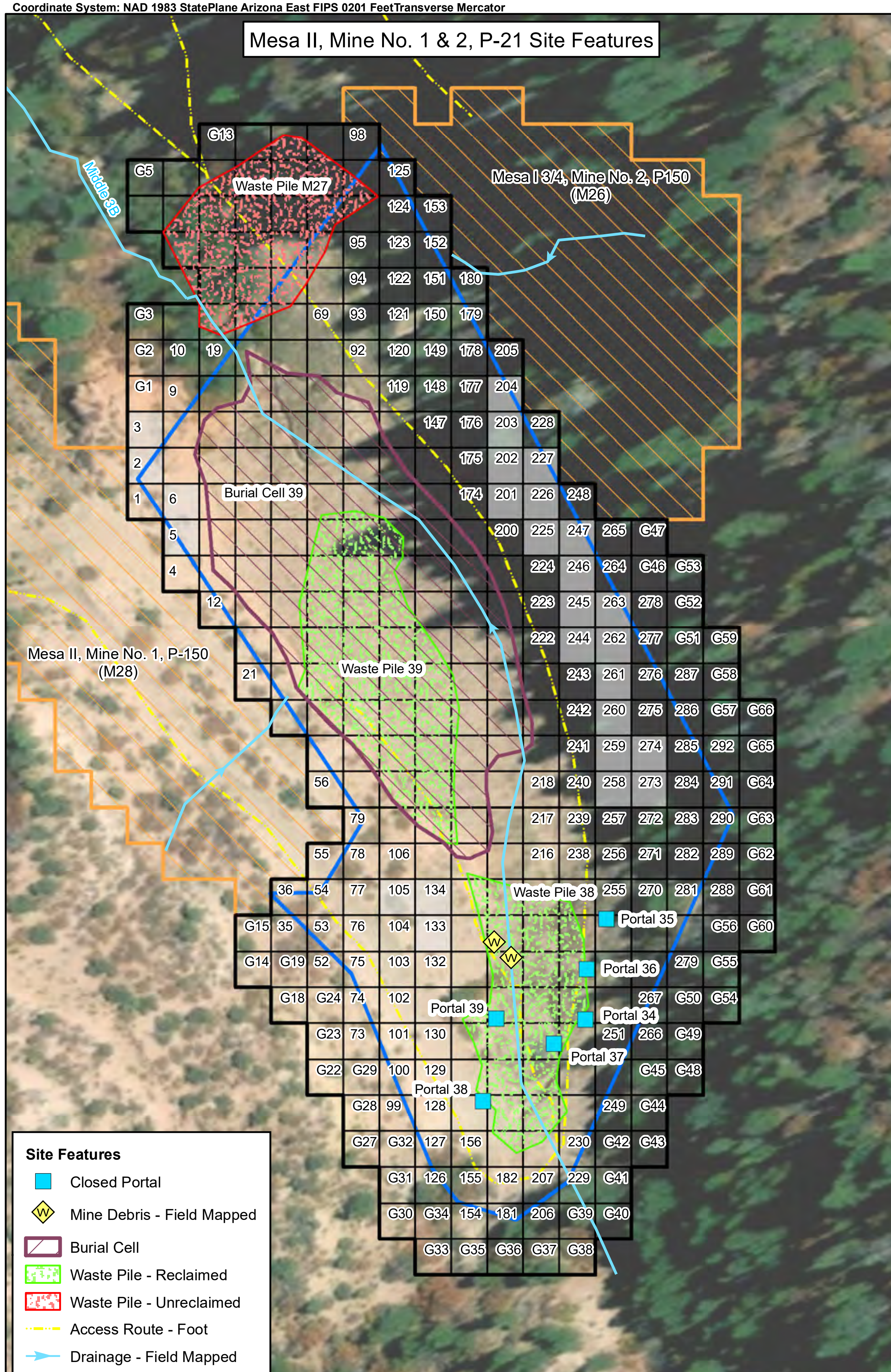
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

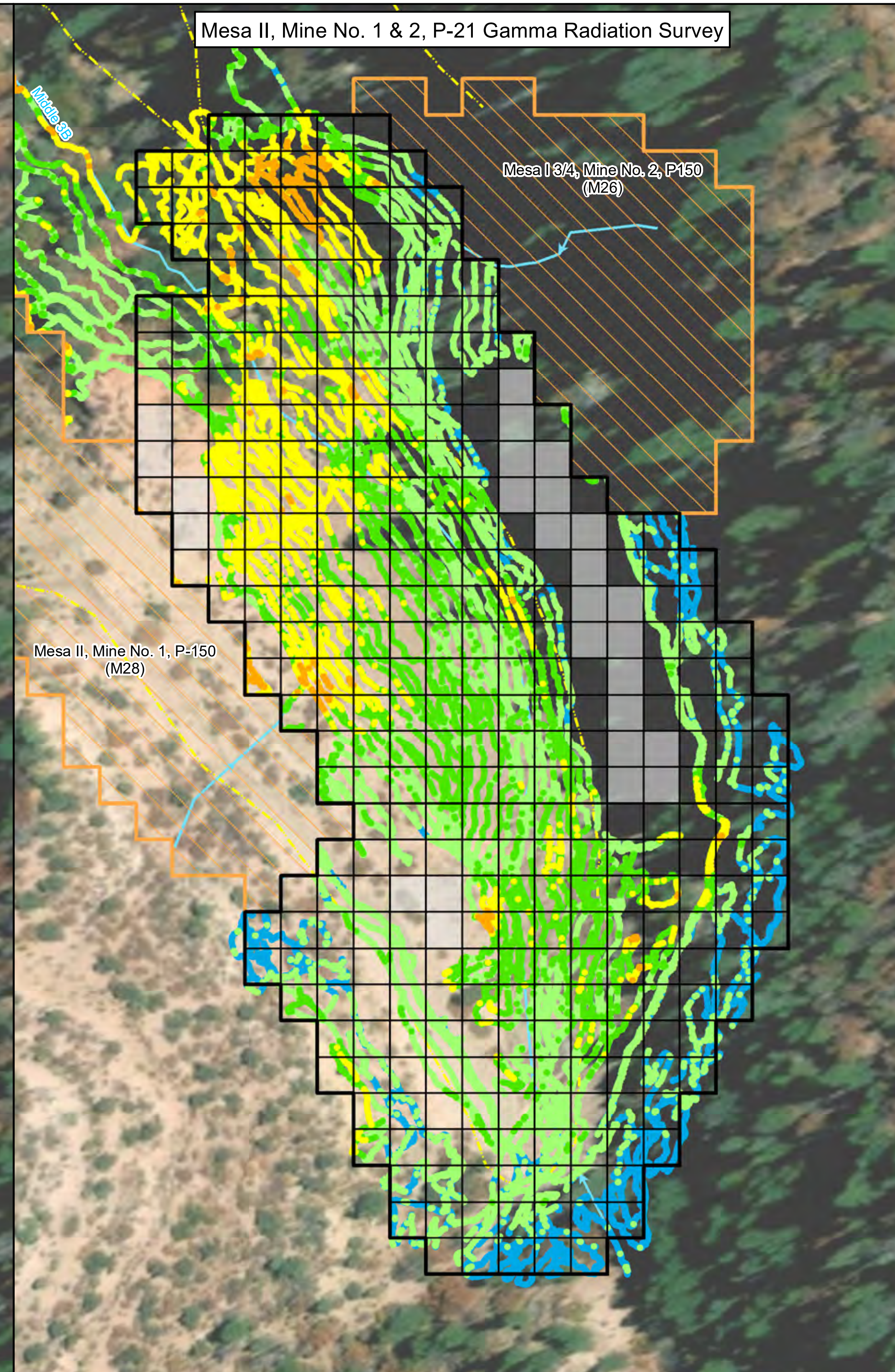
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M26**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 125 ft

1:1,500

0 62.5 125 250 Feet

N E S W

MESA II, MINE NO. 1 & 2, P-21
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

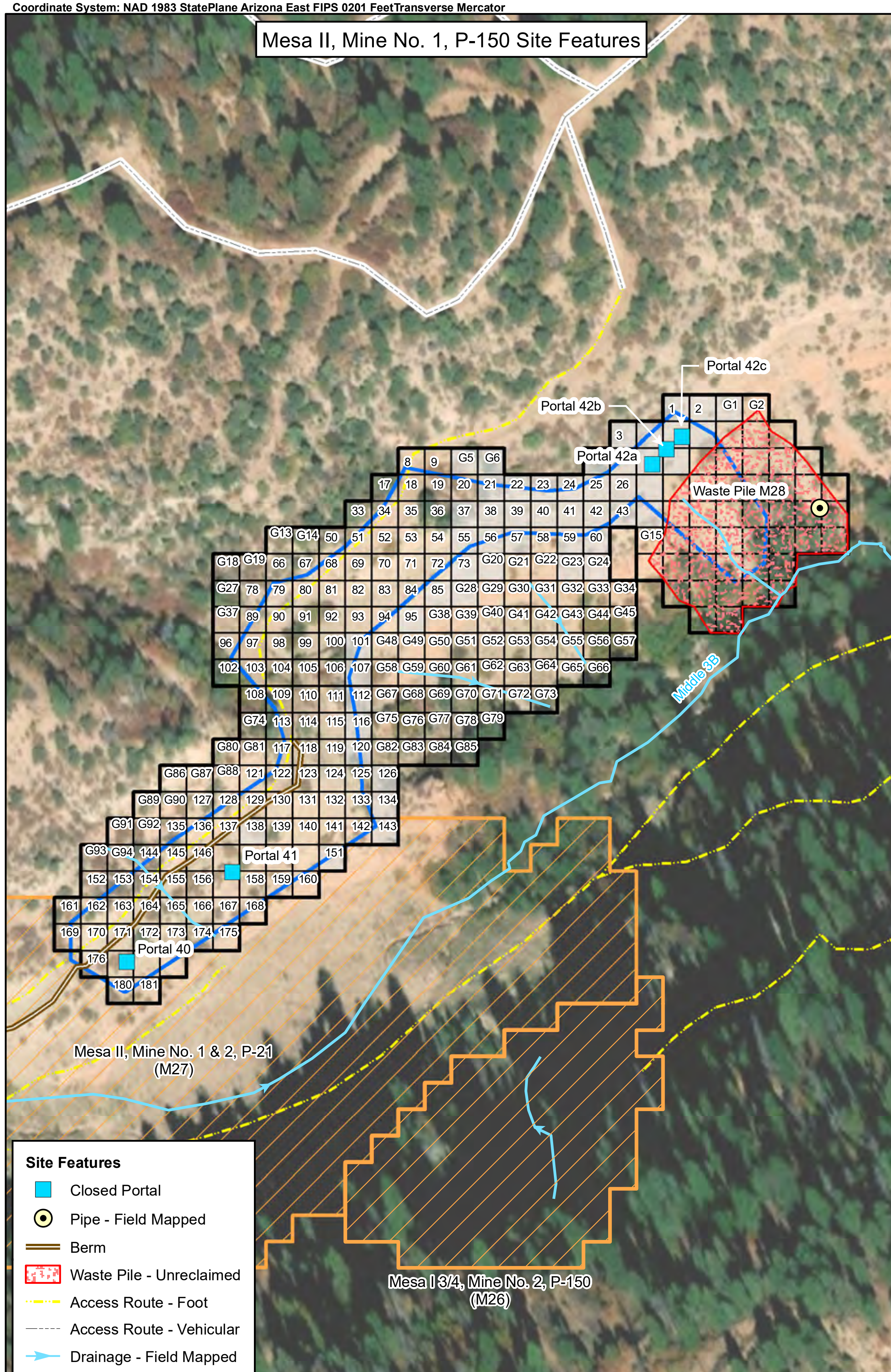
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

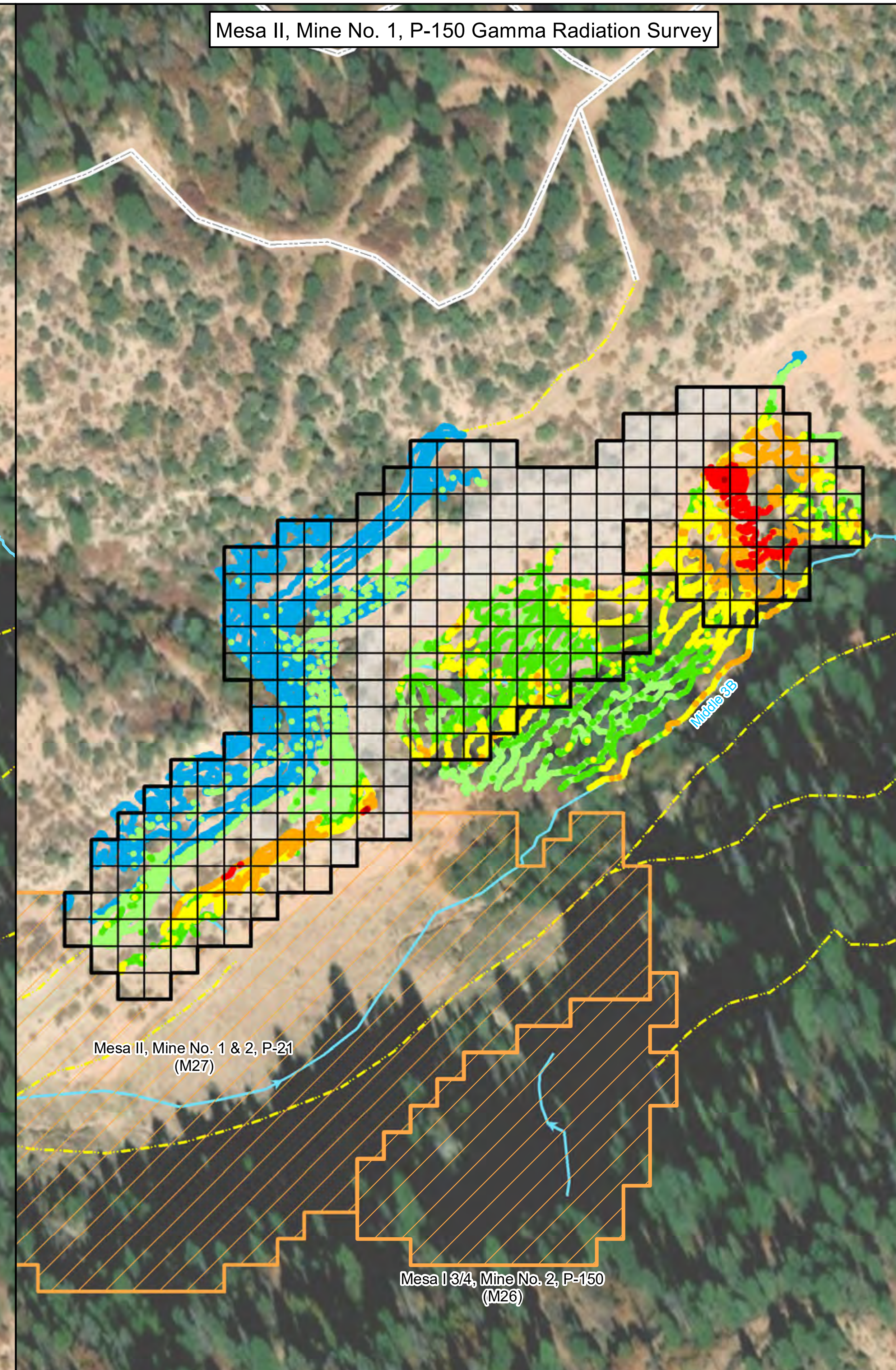
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M27

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 170 ft

1:2,040

0 85 170 340 Feet

N S W E

MESA II, MINE NO. 1, P-150 GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

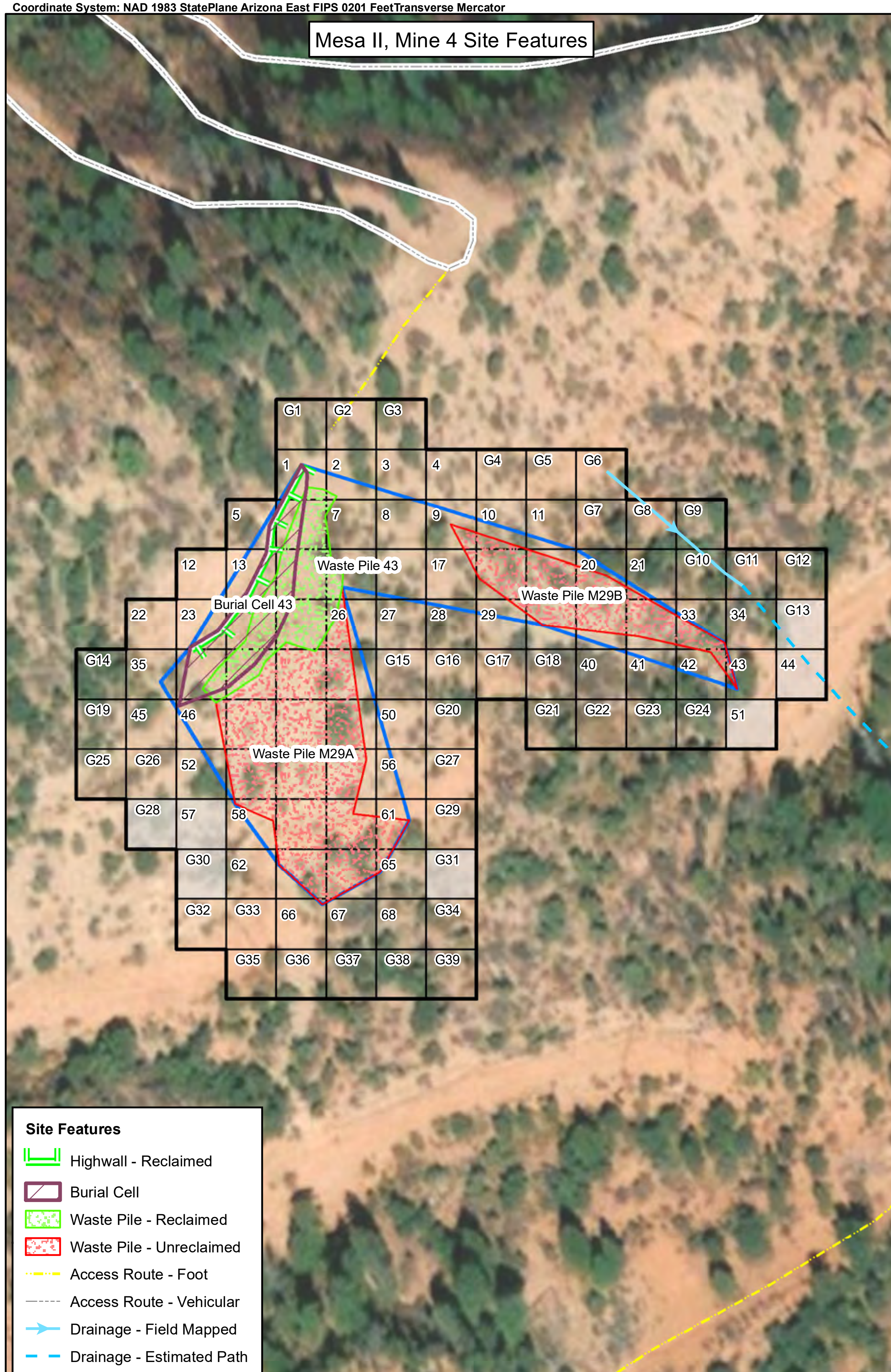
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

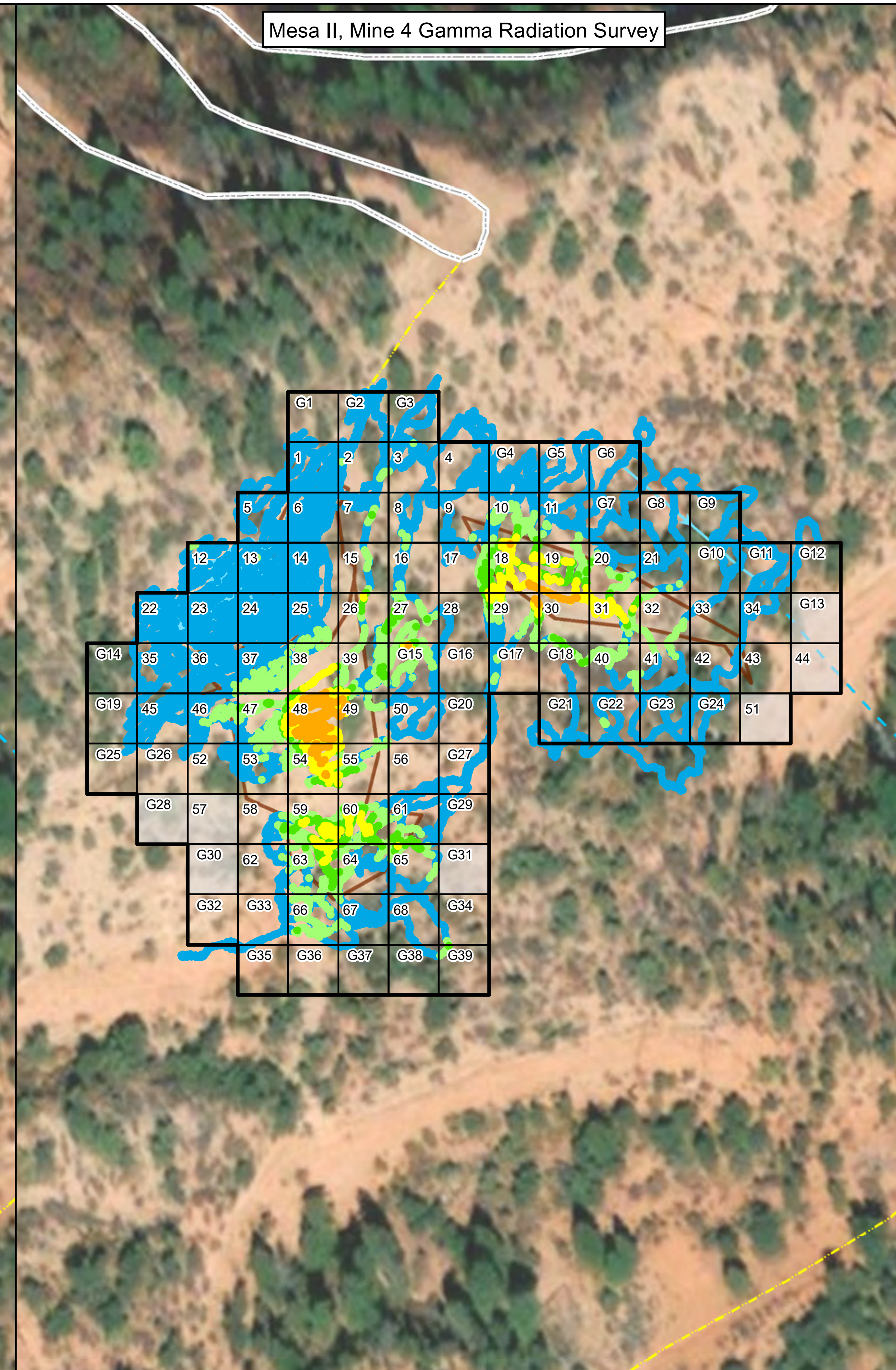
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: M28

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Burial Cell / Waste Pile Boundary
- Inaccessible To Gamma Survey

1 in = 90 ft

1:1,080

0 45 90 180 Feet

N W E S

MESA II, MINE 4

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

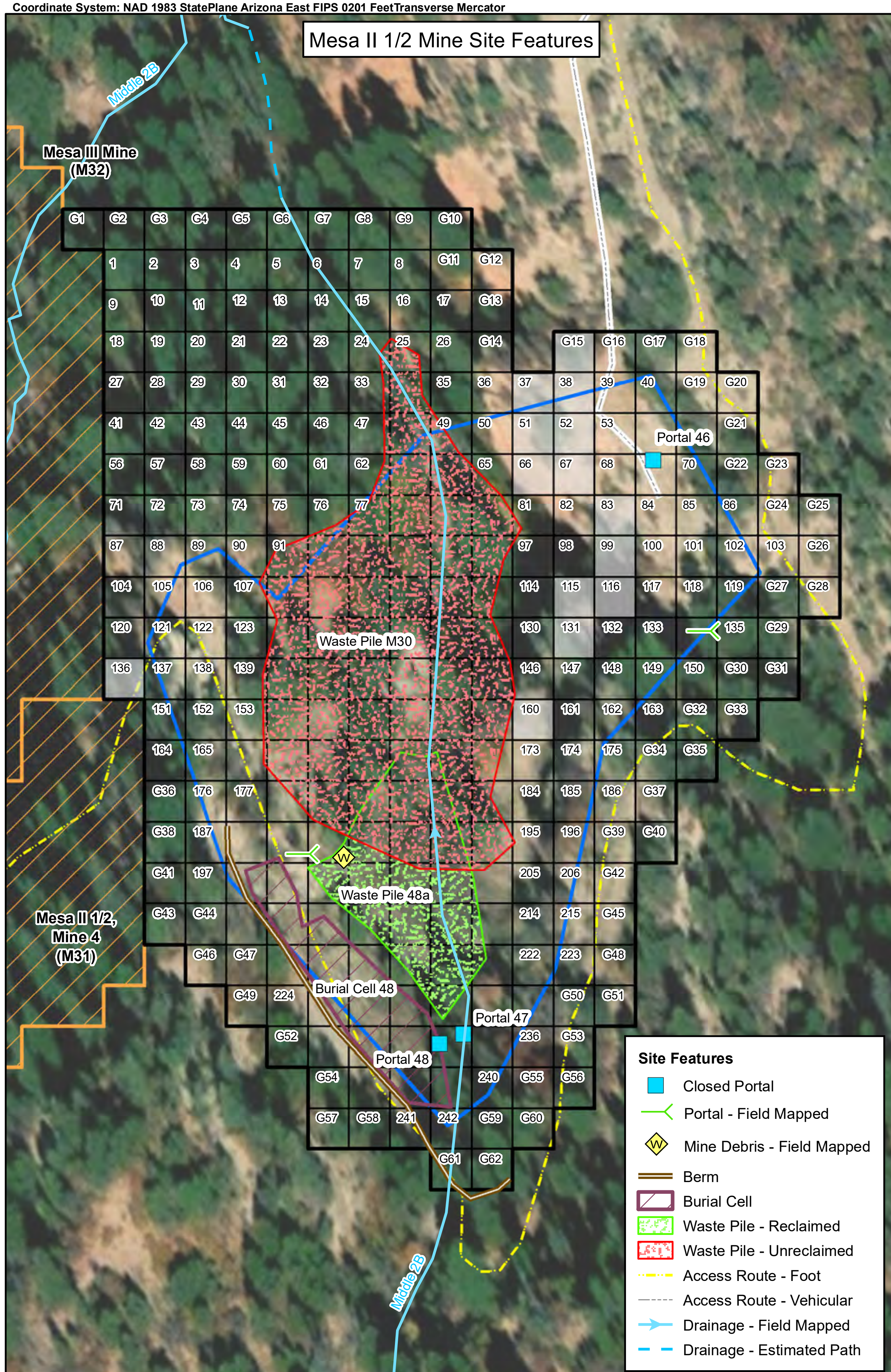
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

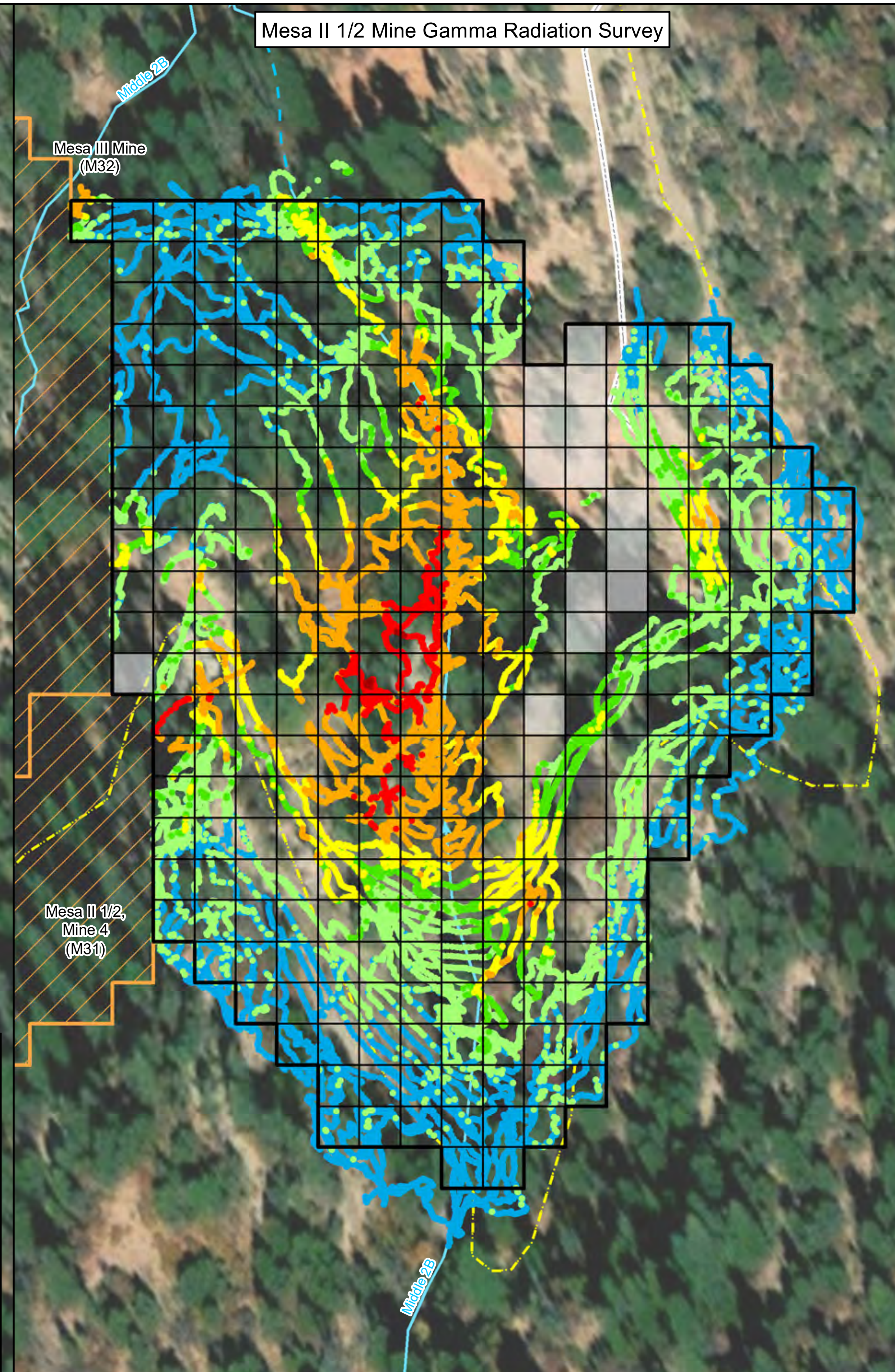
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M29**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 110 ft

1:1,320

0 55 110 220 Feet

N W E S

MESA II 1/2 MINE
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

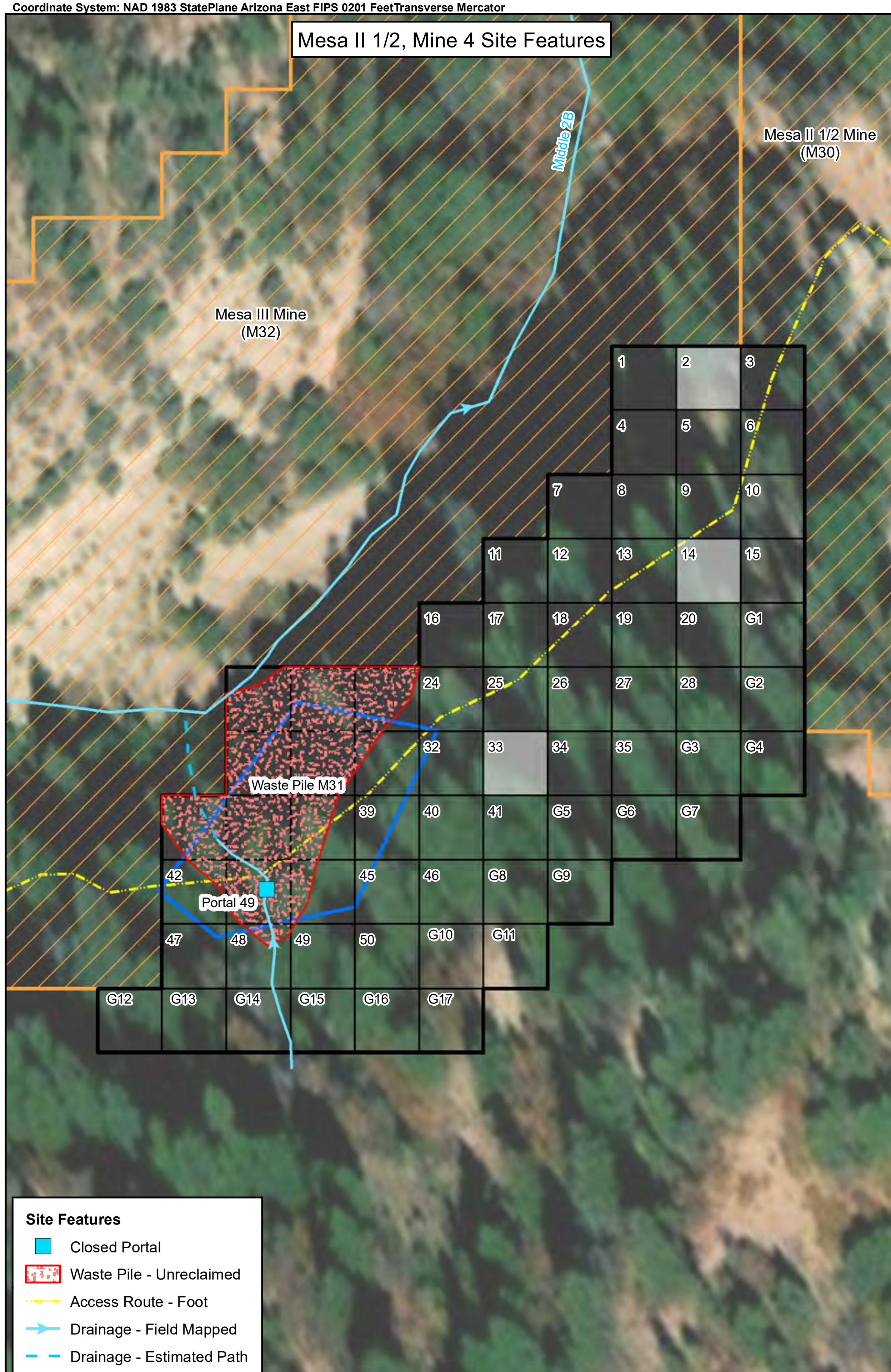
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

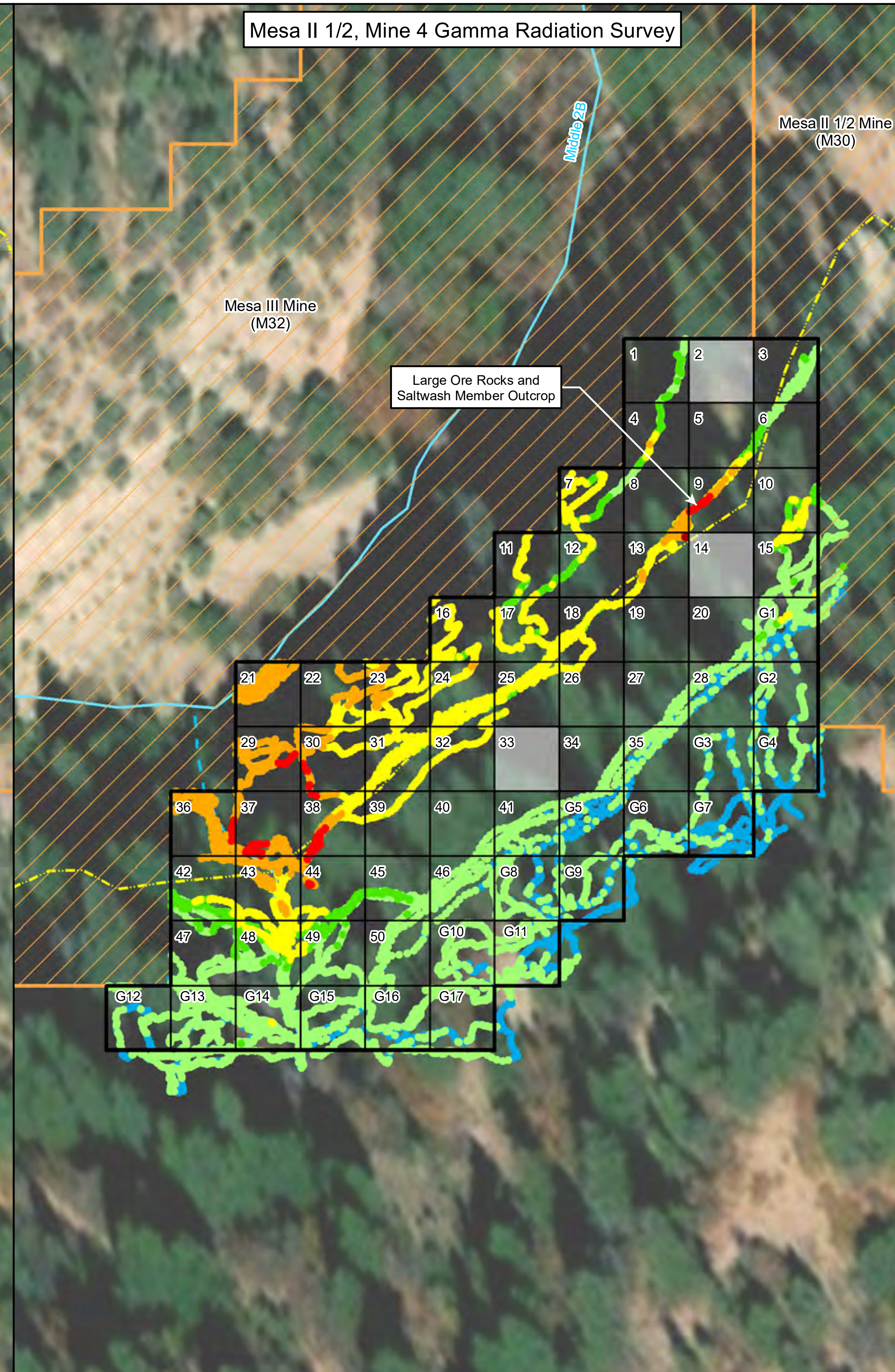
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M30**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 70 ft

1:840

0 35 70 140 Feet

N W E S

MESA II 1/2, MINE 4 GAMMA EXPOSURE RATE MAP

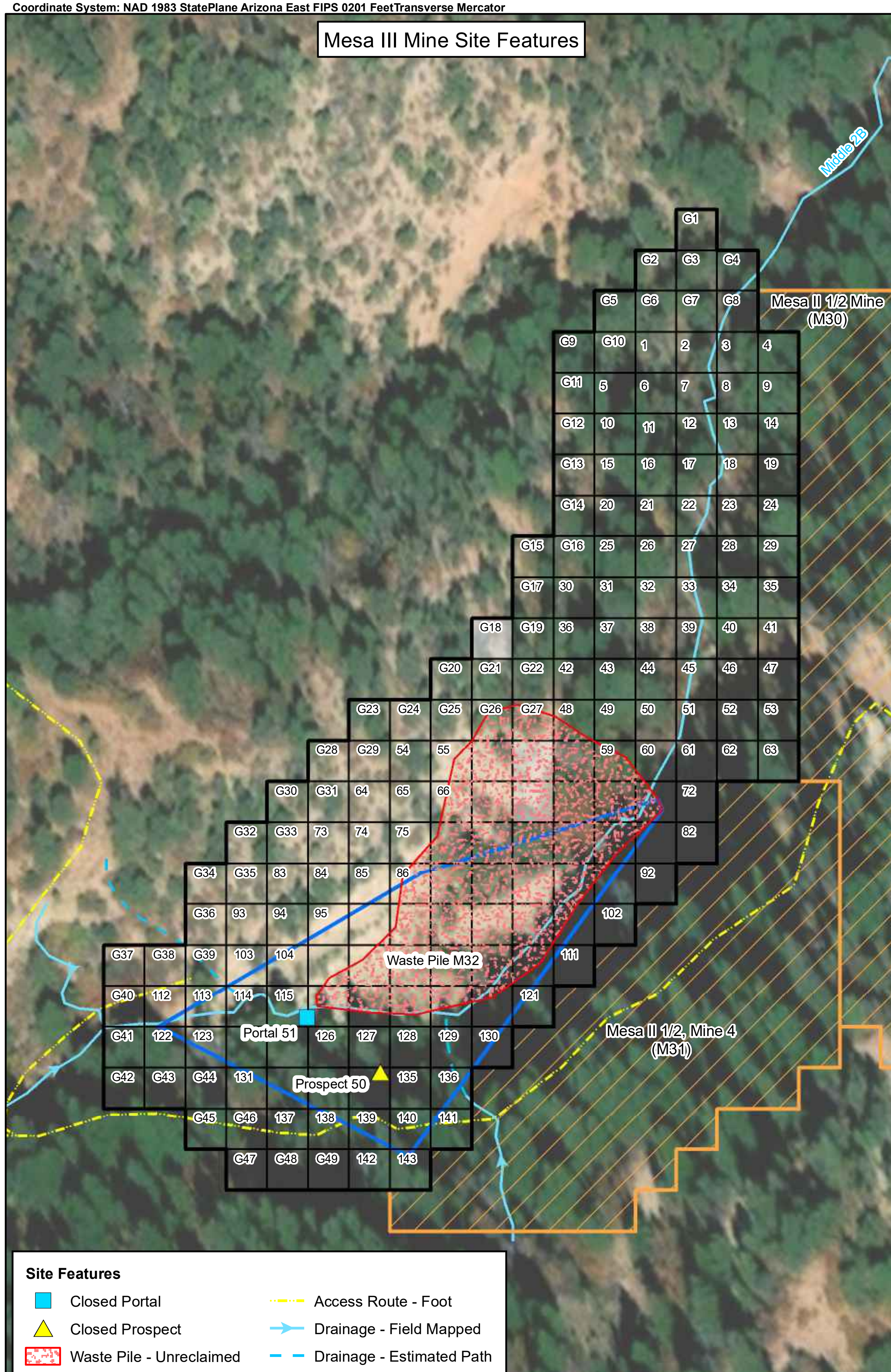
Prepared For:

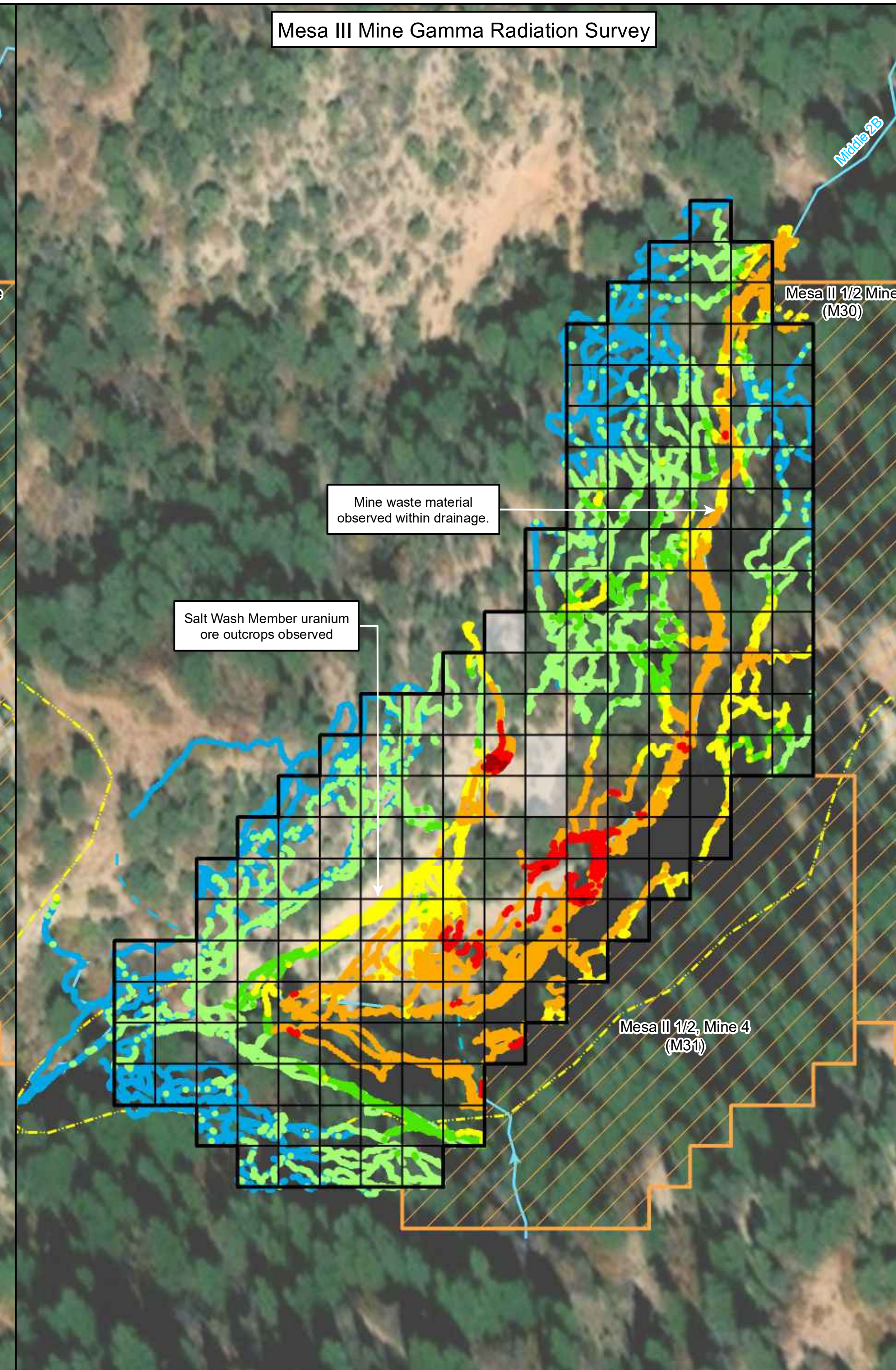
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019
Notes: *Gross gamma count rate measurements are converted to gamma exposure rate using the following equation: γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).	Figure No.: **M31**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 110 ft

1:1,320

0 55 110 220 Feet

N W E S

MESA III MINE
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

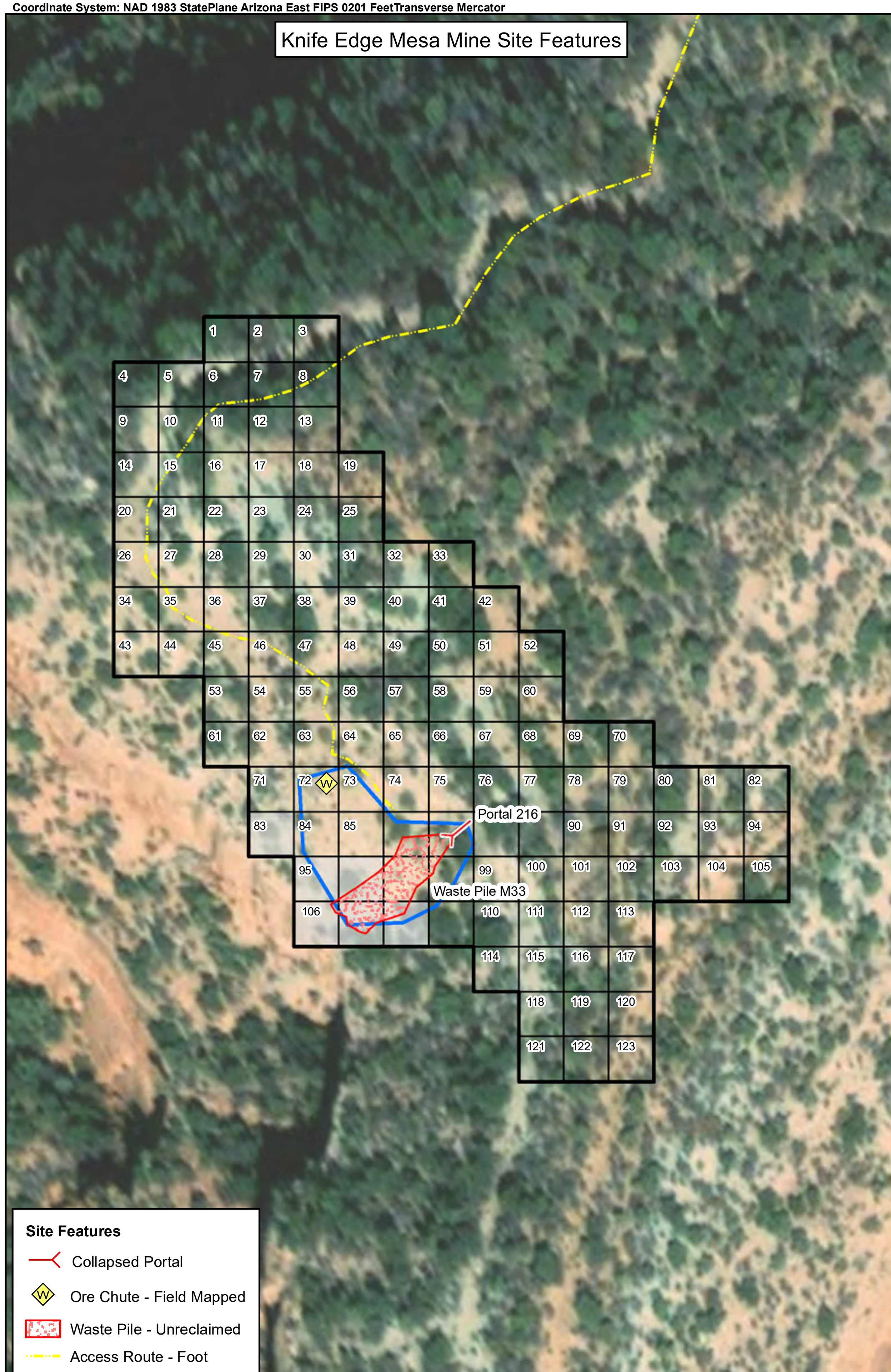
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

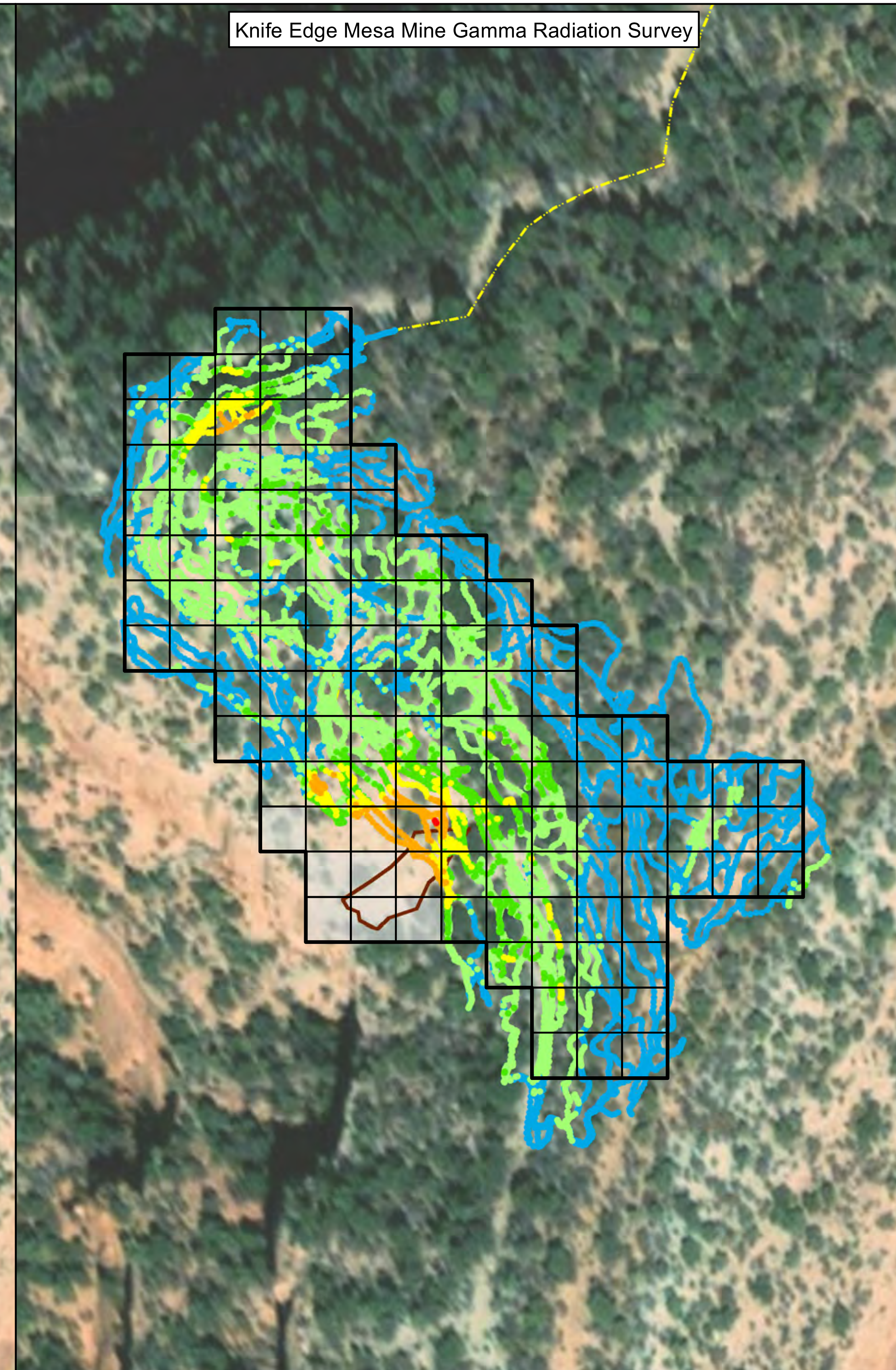
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M32**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Waste Pile Boundary
- Inaccessible To Gamma Survey

1 in = 100 ft

1:1,200

0 50 100 200 Feet

N W E S

KNIFE EDGE MESA MINE GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

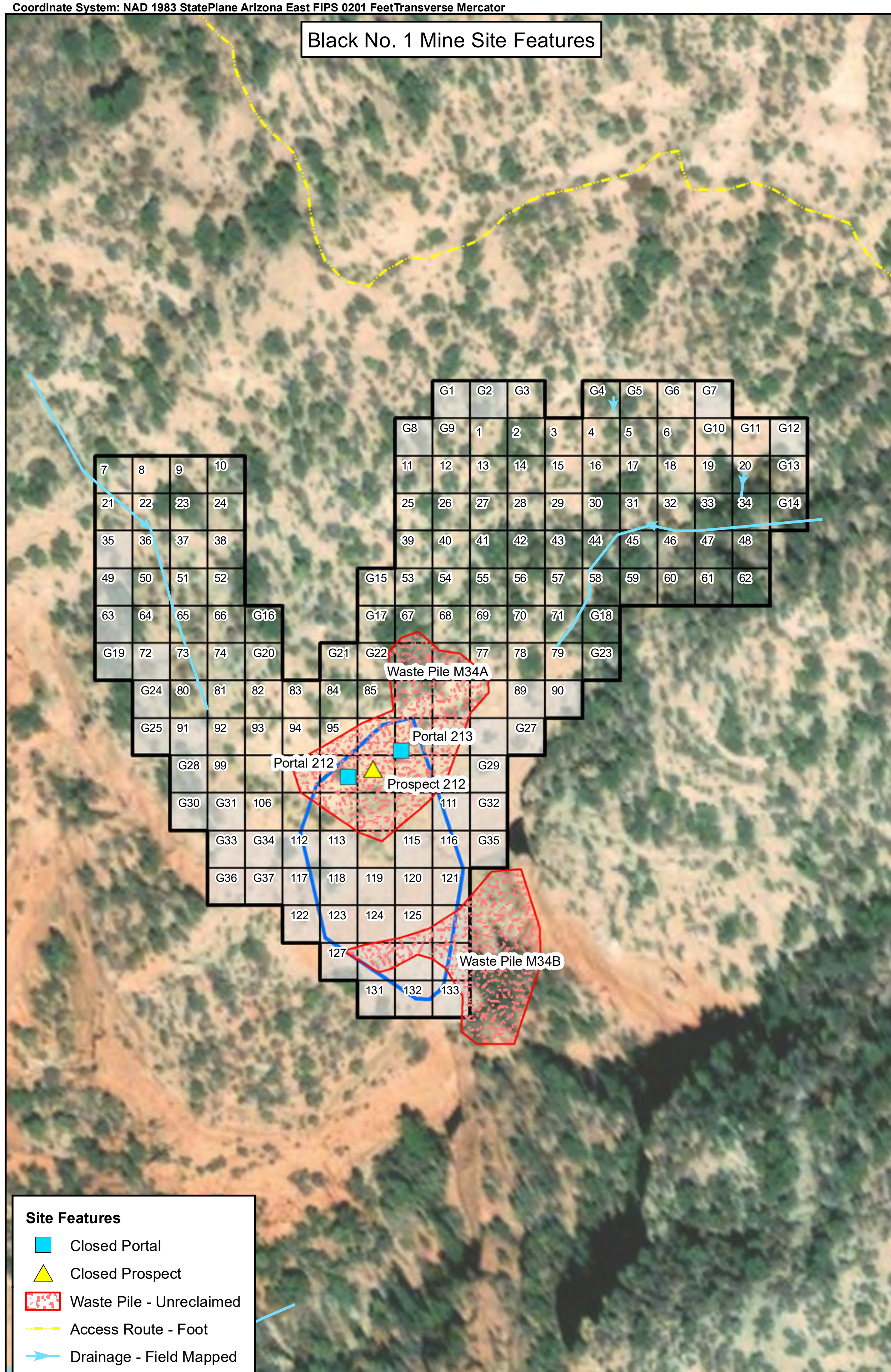
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

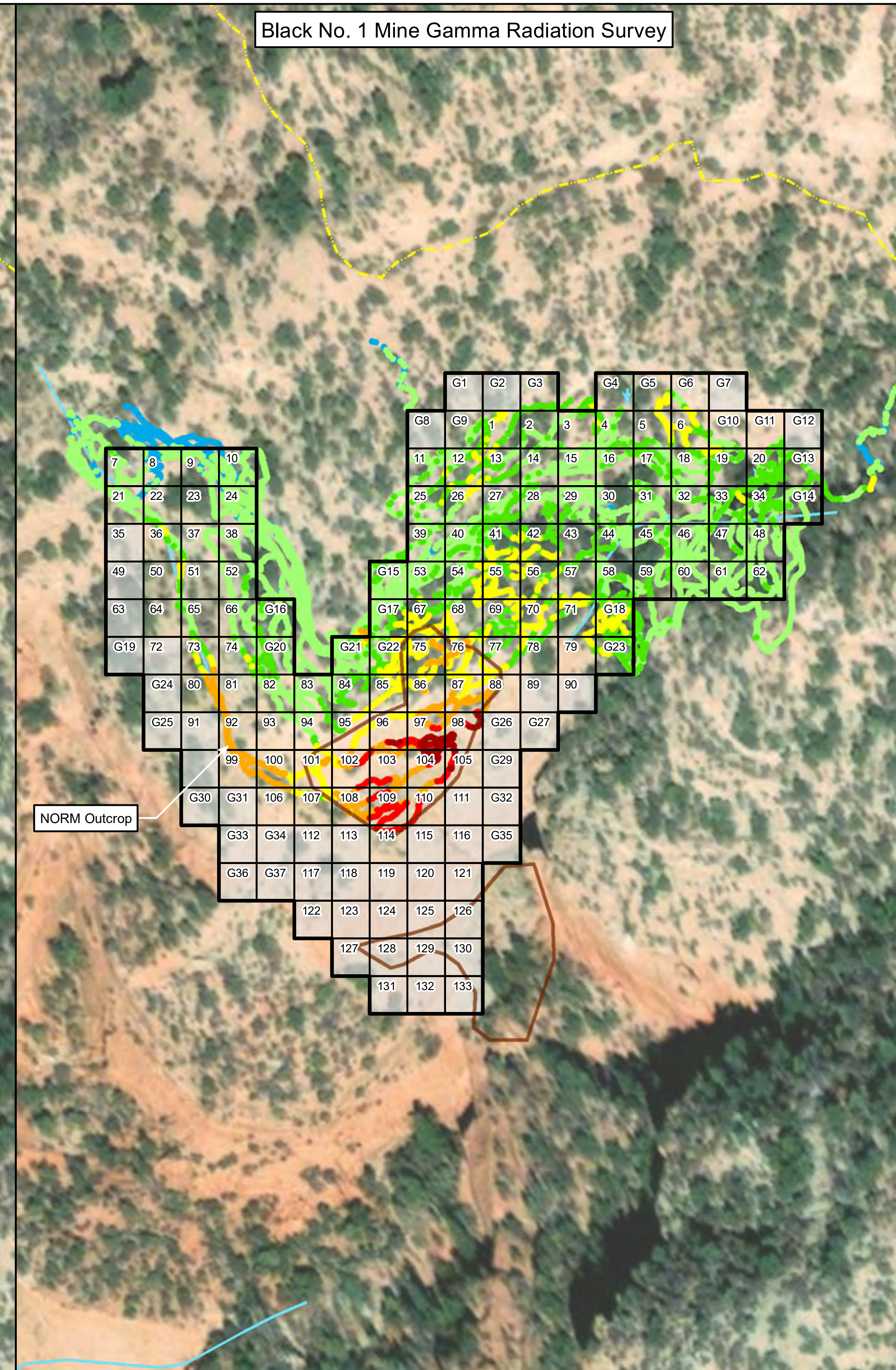
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: LUKACHUKAI CHAPTER NAVAJO NATION	Date: 7/11/2019

Reference:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M33**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Waste Pile Boundary
- Inaccessible To Gamma Survey

1 in = 120 ft

1:1,440

0 60 120 240 Feet

N W E S

BLACK NO. 1 MINE

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

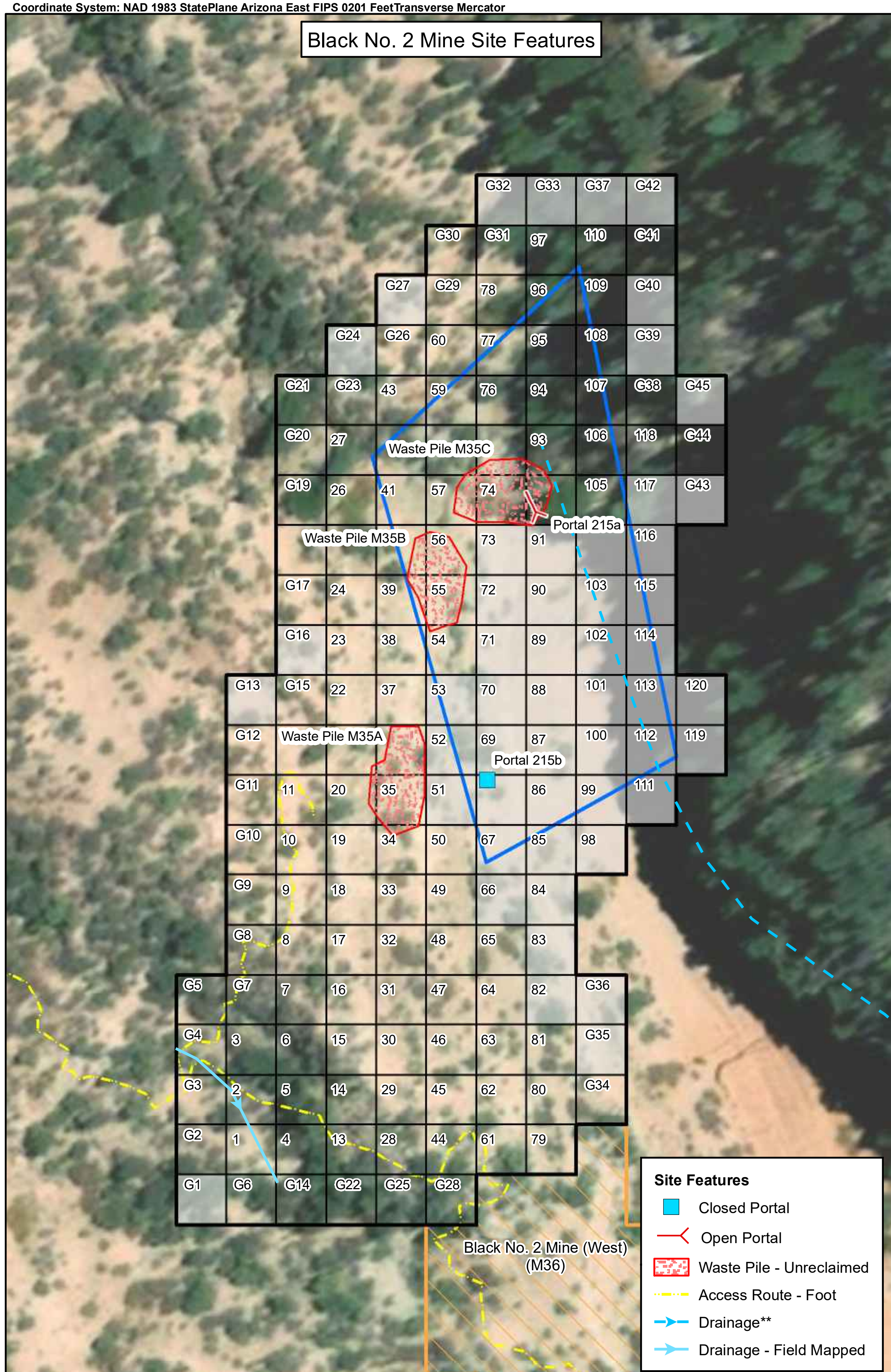
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

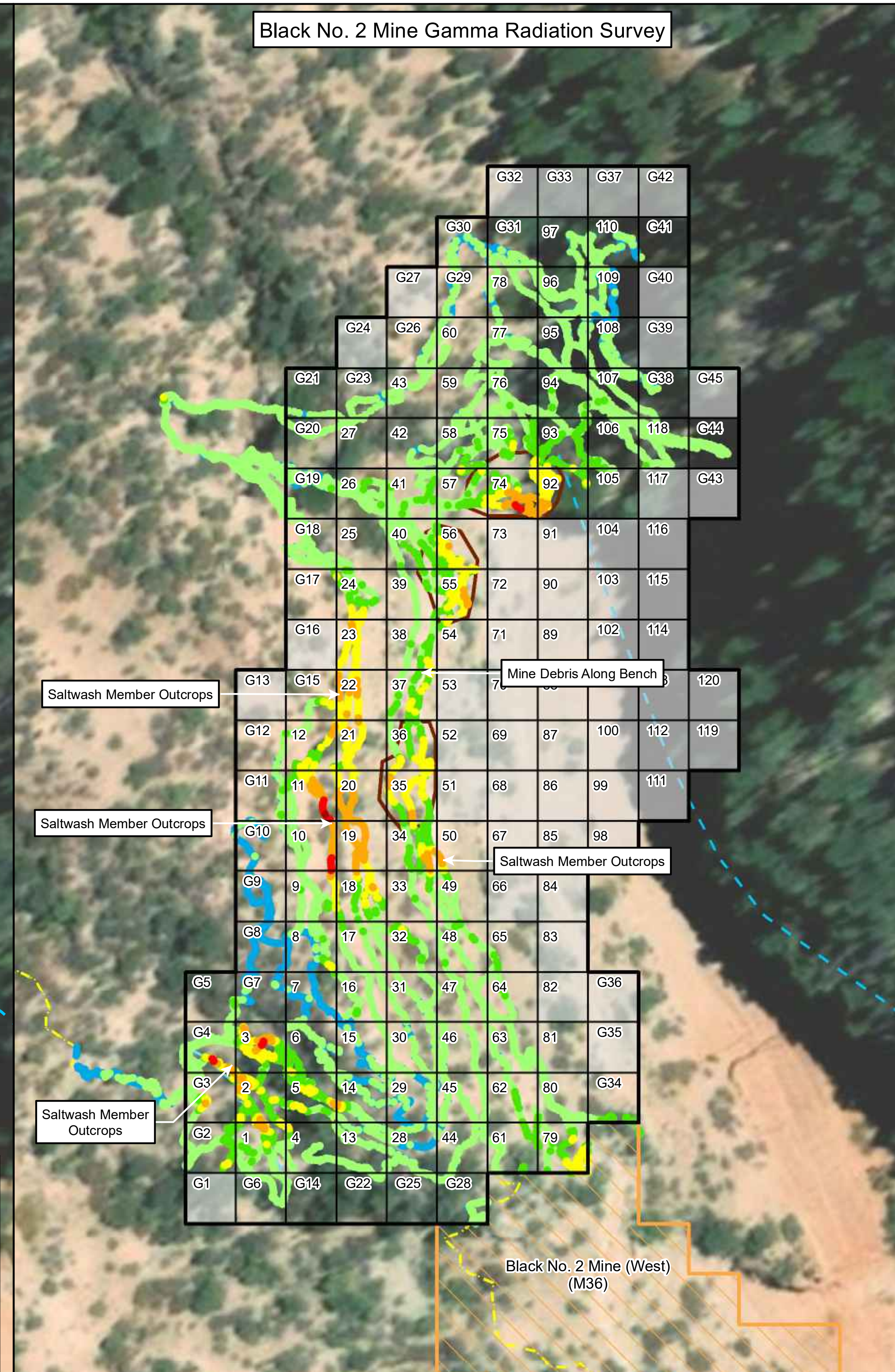
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: LUKACHUKAI CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Figure No.: **M34**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Waste Pile Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

Note:
*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

1 in = 90 ft

1:1,080

0 45 90 180 Feet

N E S W

BLACK NO. 2 MINE
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

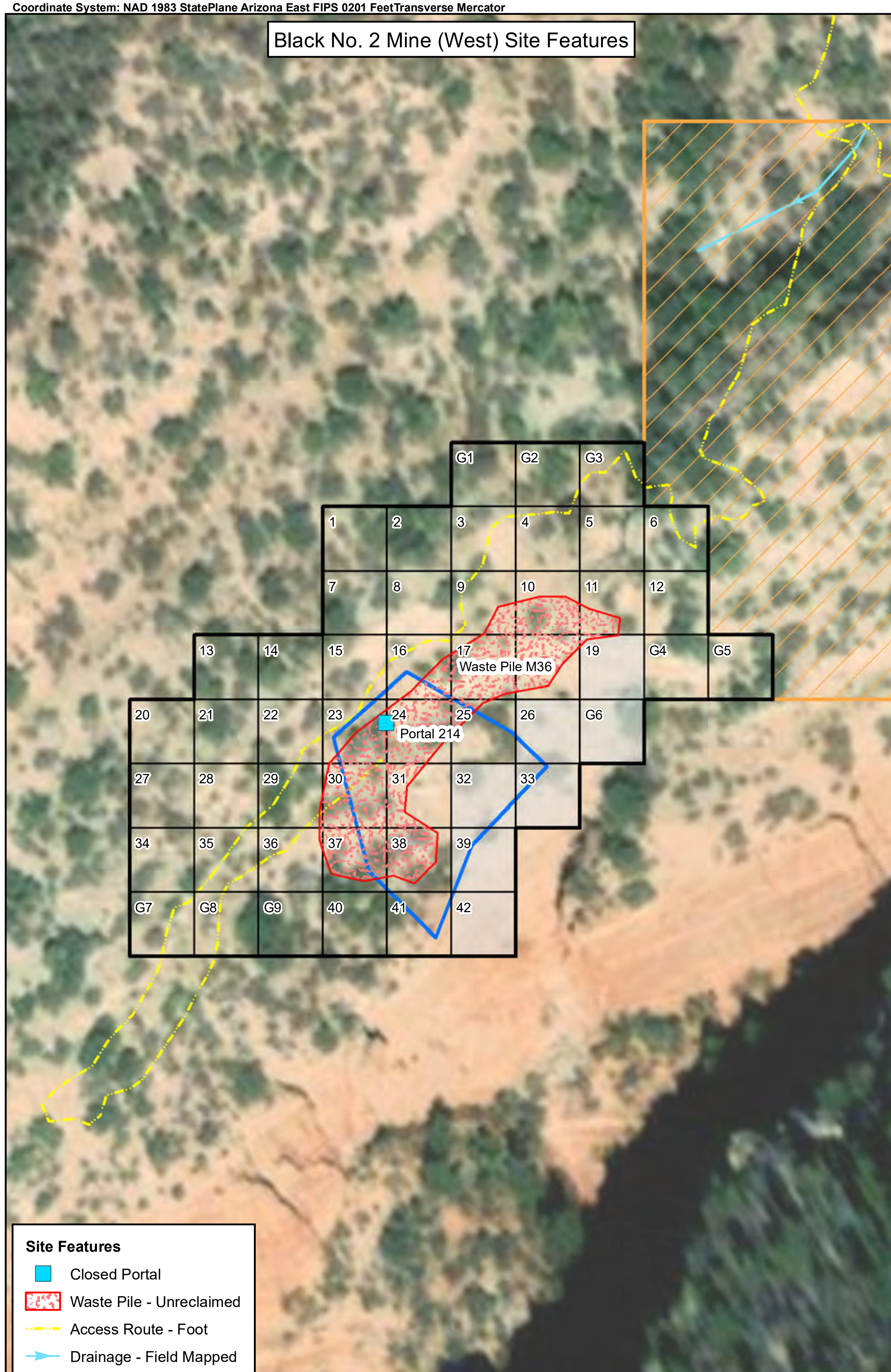
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

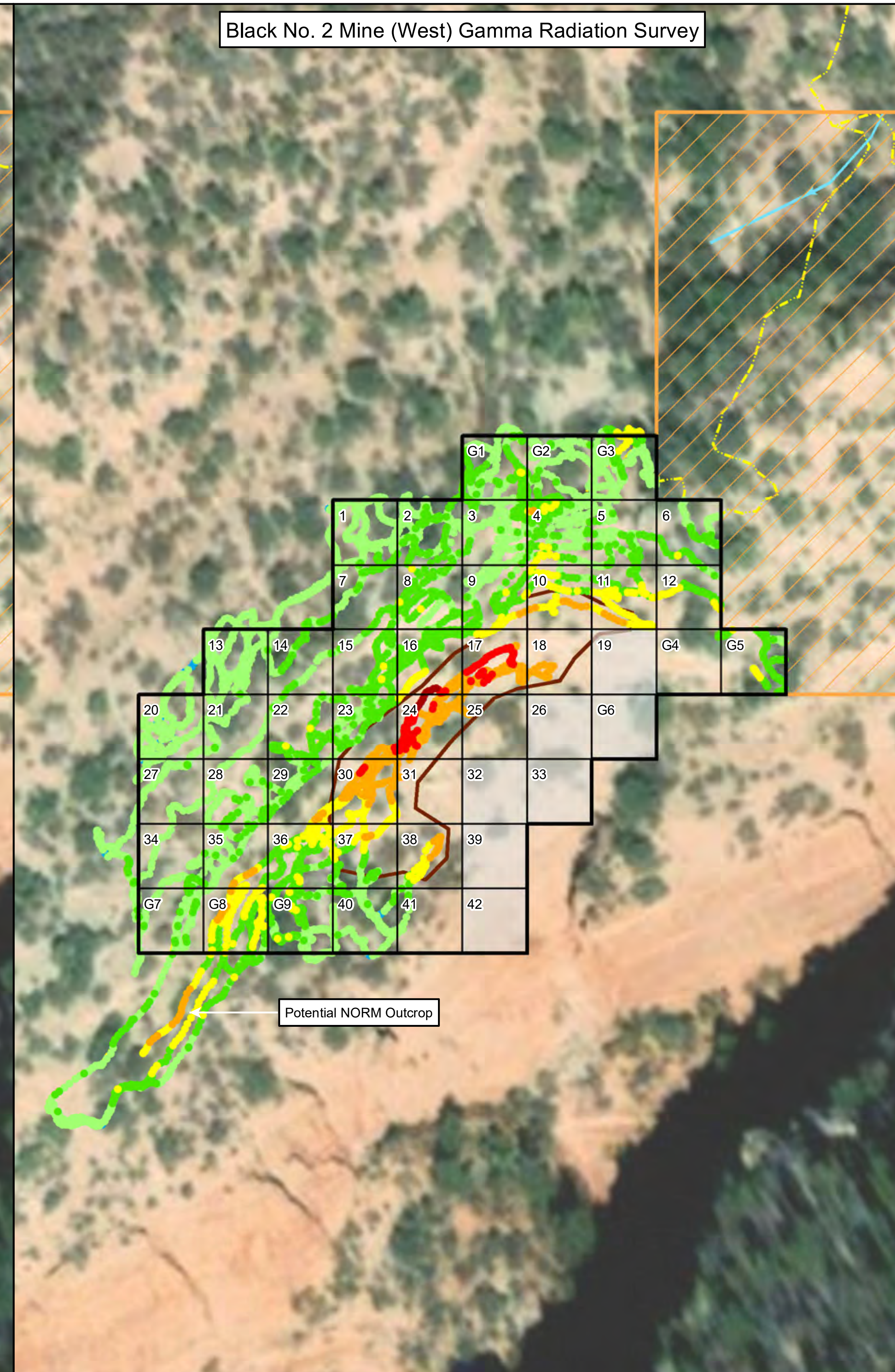
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: LUKACHUKAI CHAPTER NAVAJO NATION	Date: 7/22/2019

Notes:
**U.S Environmental Protection Agency, Region 9, Superfund Program, *Abandoned Uranium Mines and the Navjo Nation Part II Atlas With Geospatial Data.* *NN_Drainage_HR_AUM.shp.* July, 2007.

Figure No.: **M35**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Waste Pile Boundary
- Other Survey Area
- Inaccessible To Gamma Survey

1 in = 70 ft

1:840

0 35 70 140 Feet

N W E S

BLACK NO. 2 MINE (WEST) GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

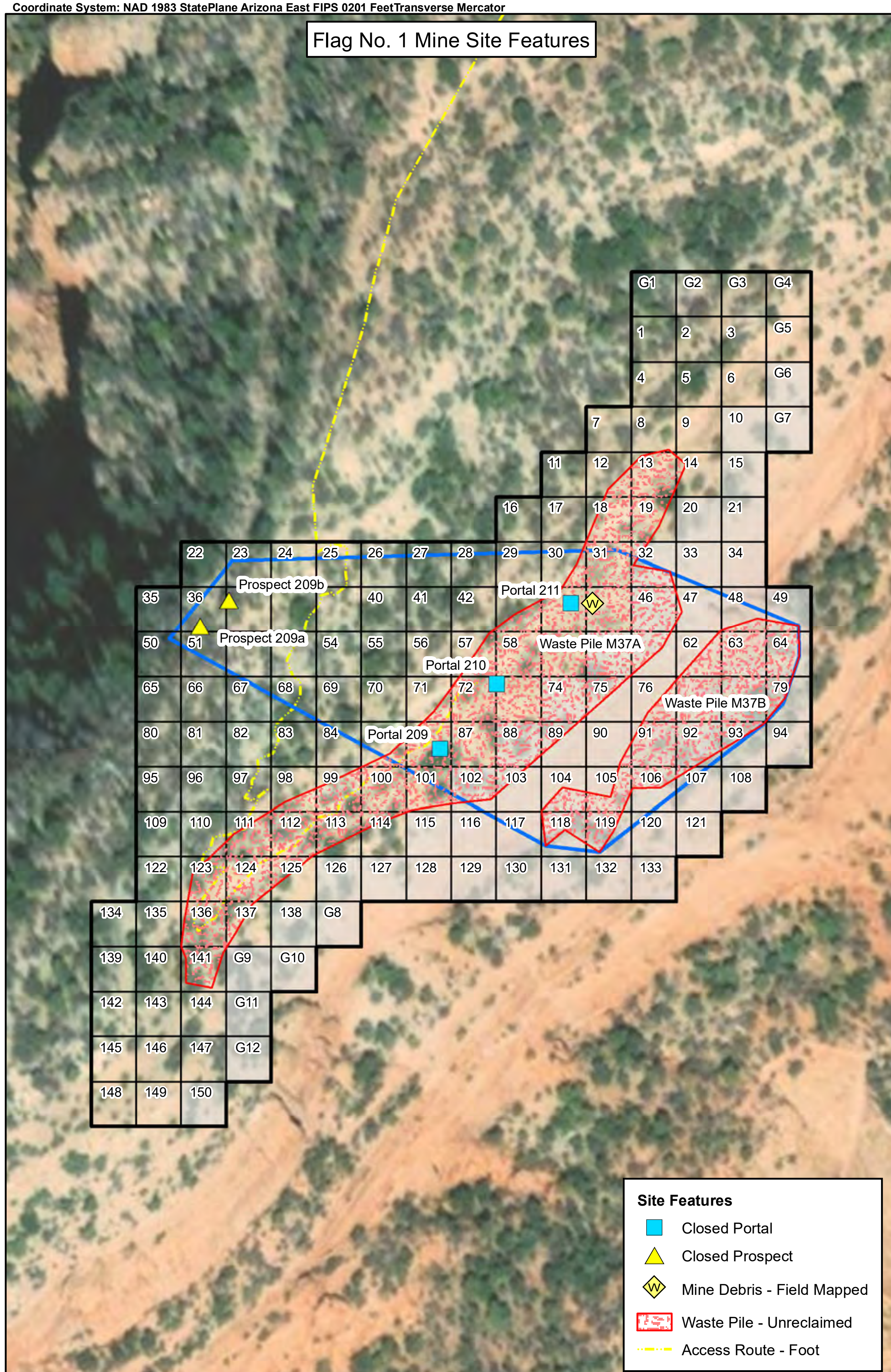
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

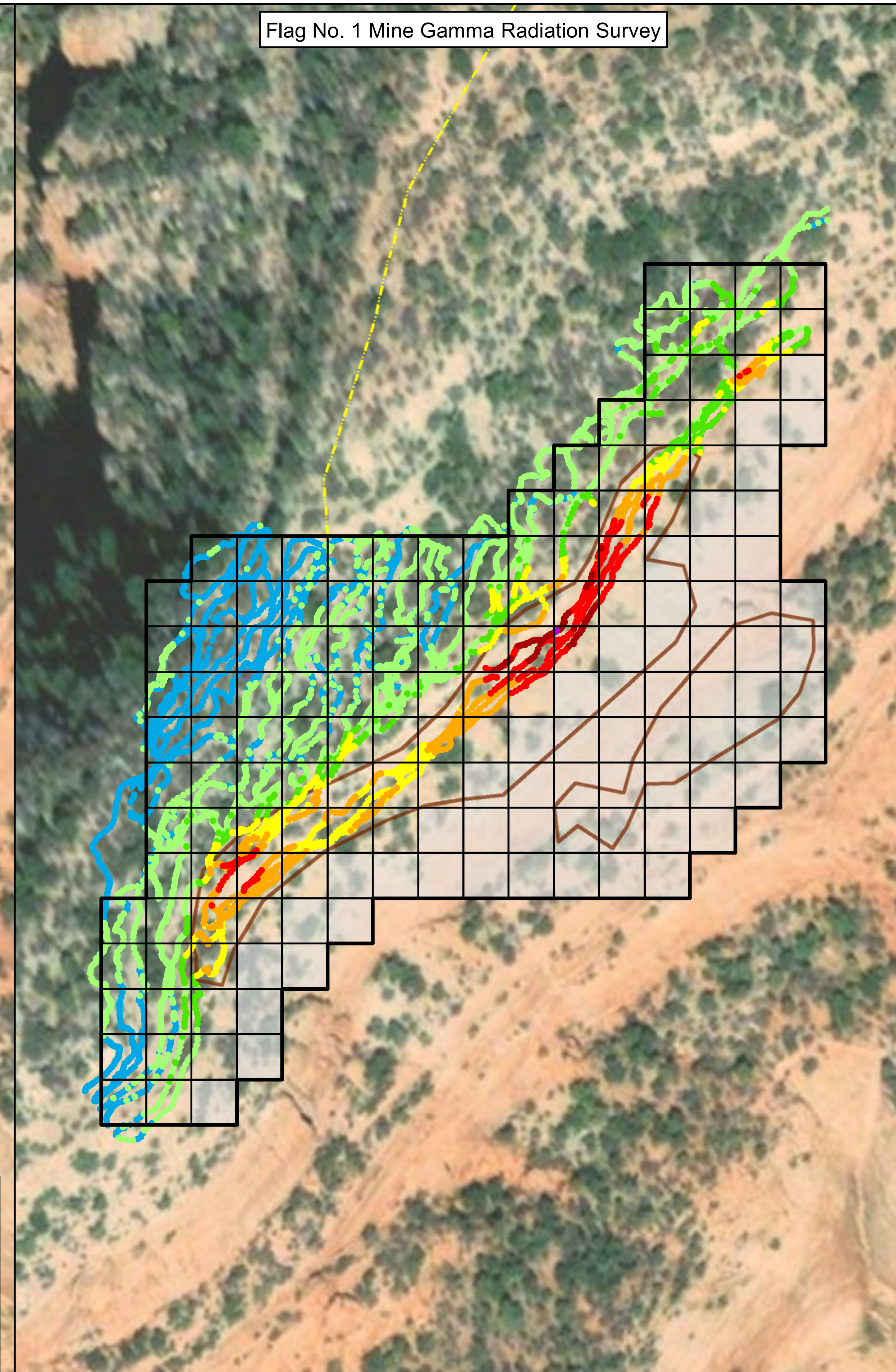
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: LUKACHUKAI CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Figure No.: **M36**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Inaccessible To Gamma Survey

1 in = 100 ft

1:1,200

0 50 100 200 Feet

N W E S

FLAG NO. 1 MINE
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

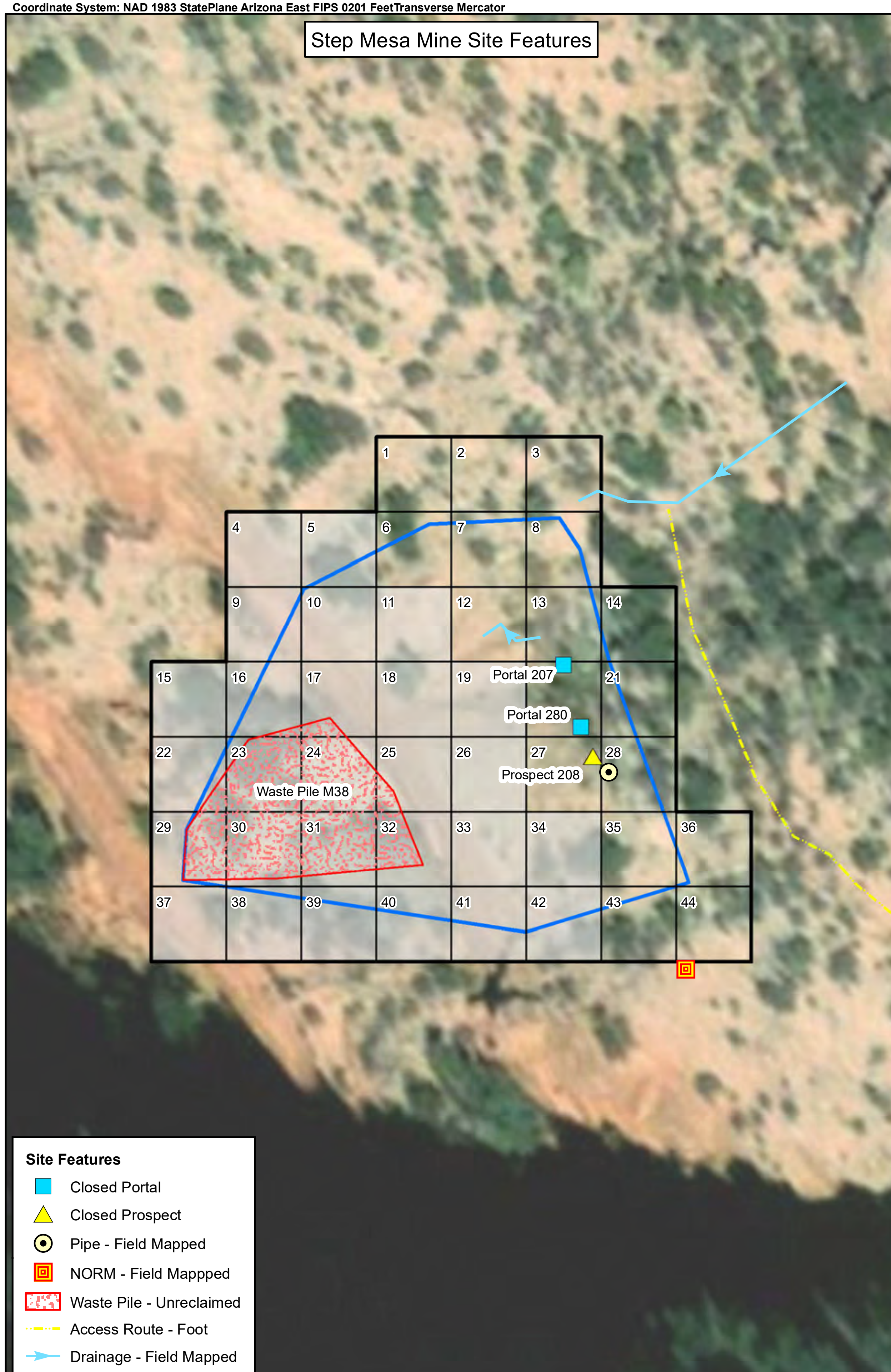
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

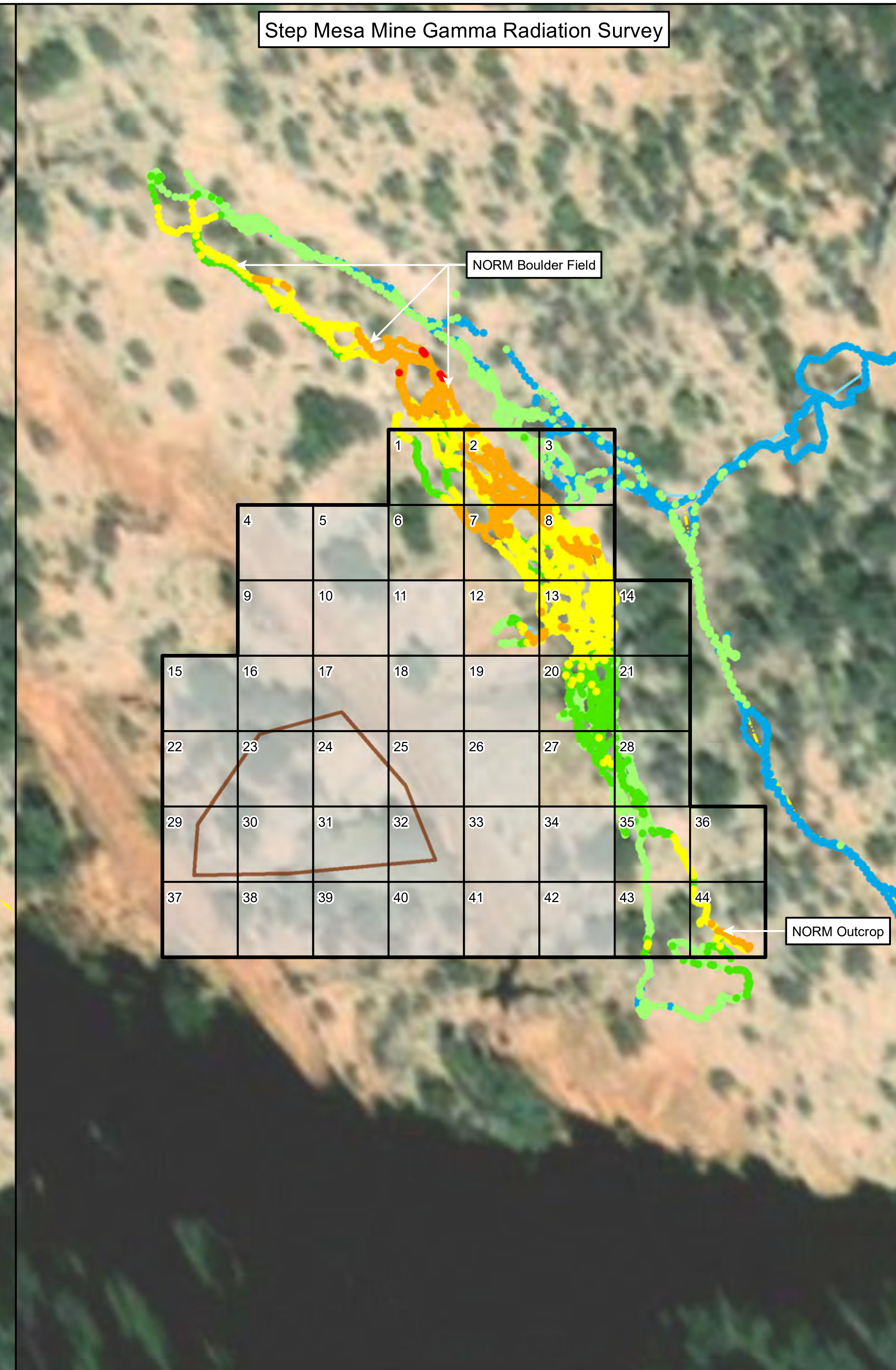
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: LUKACHUKAI CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: **M37**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Waste Pile Boundary
- Inaccessible To Gamma Survey

1 in = 60 ft

1:720

0 30 60 120 Feet

N W E S

STEP MESA MINE

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

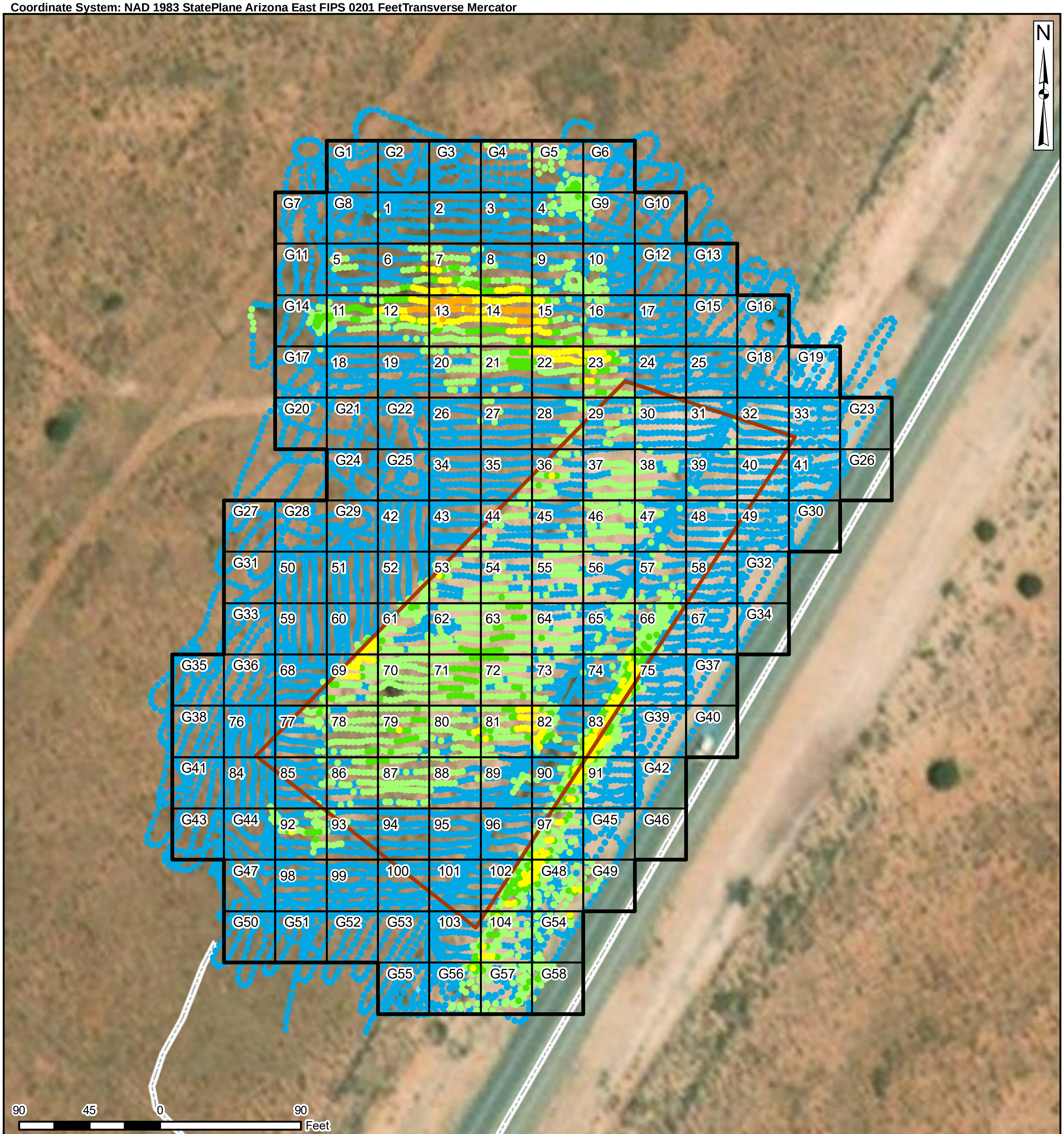
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: LUKACHUKAI CHAPTER NAVAJO NATION	Date: 7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Figure No.: **M38**

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Prepared for: USEPA Region 9

Prepared By:

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Oakland, CA 94612

NON-AUM TARGET BR-01
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T1
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator

Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

Non-AUM Target Site Boundary

Survey Unit (100 m²)

Survey Area Boundary

Access Route - Foot

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

Prepared By:

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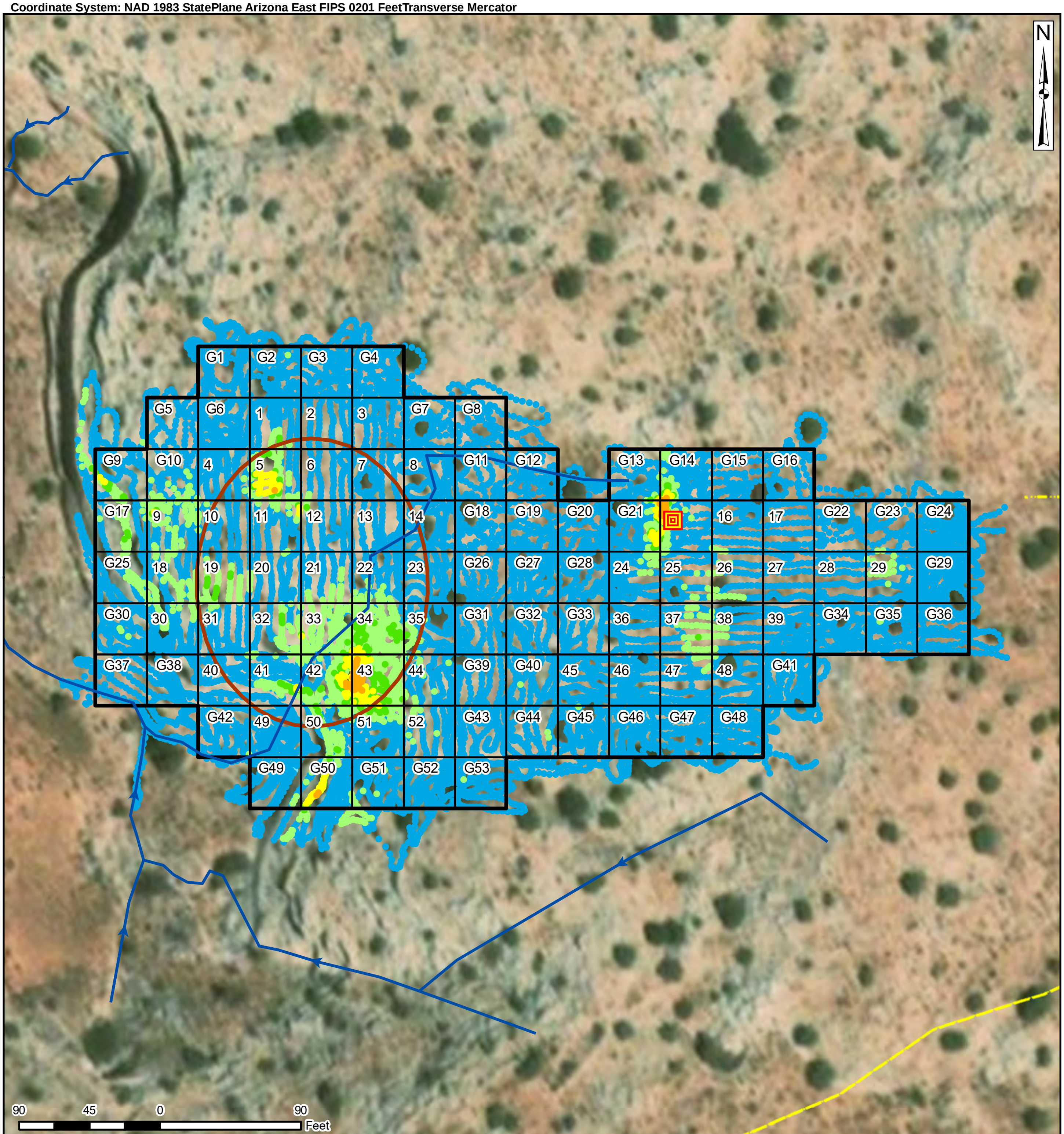
NON-AUM TARGET BR-03
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T3
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- NORM - Field Mapped
- Access Route - Foot
- Drainage - Field Mapped

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

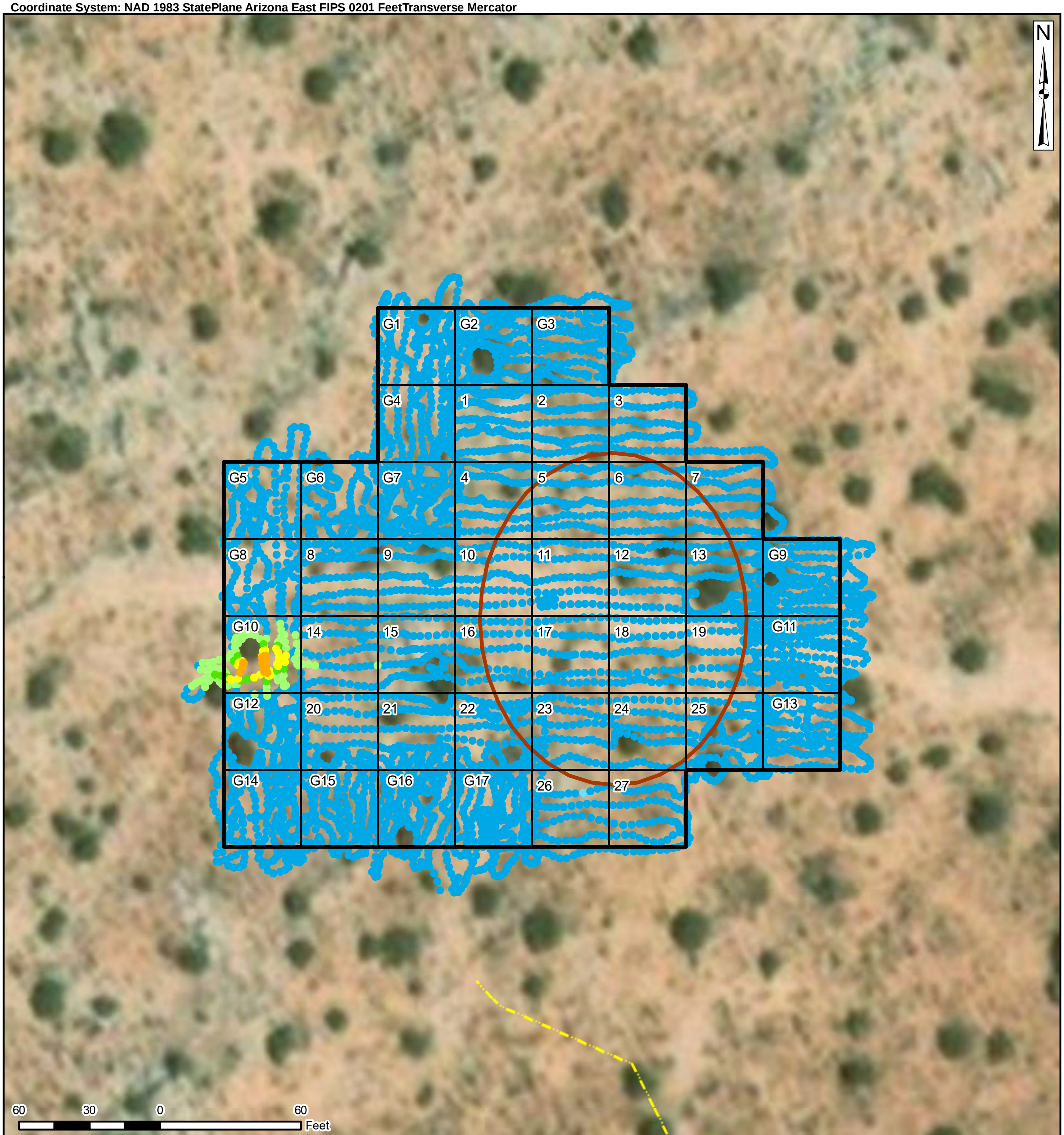
Prepared for: USEPA Region 9

Prepared By: TETRA TECH, 1999 Harrison Street, Suite 500, Oakland, CA 94612

NON-AUM TARGET BR-04 GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T4
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Foot

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

Prepared By:

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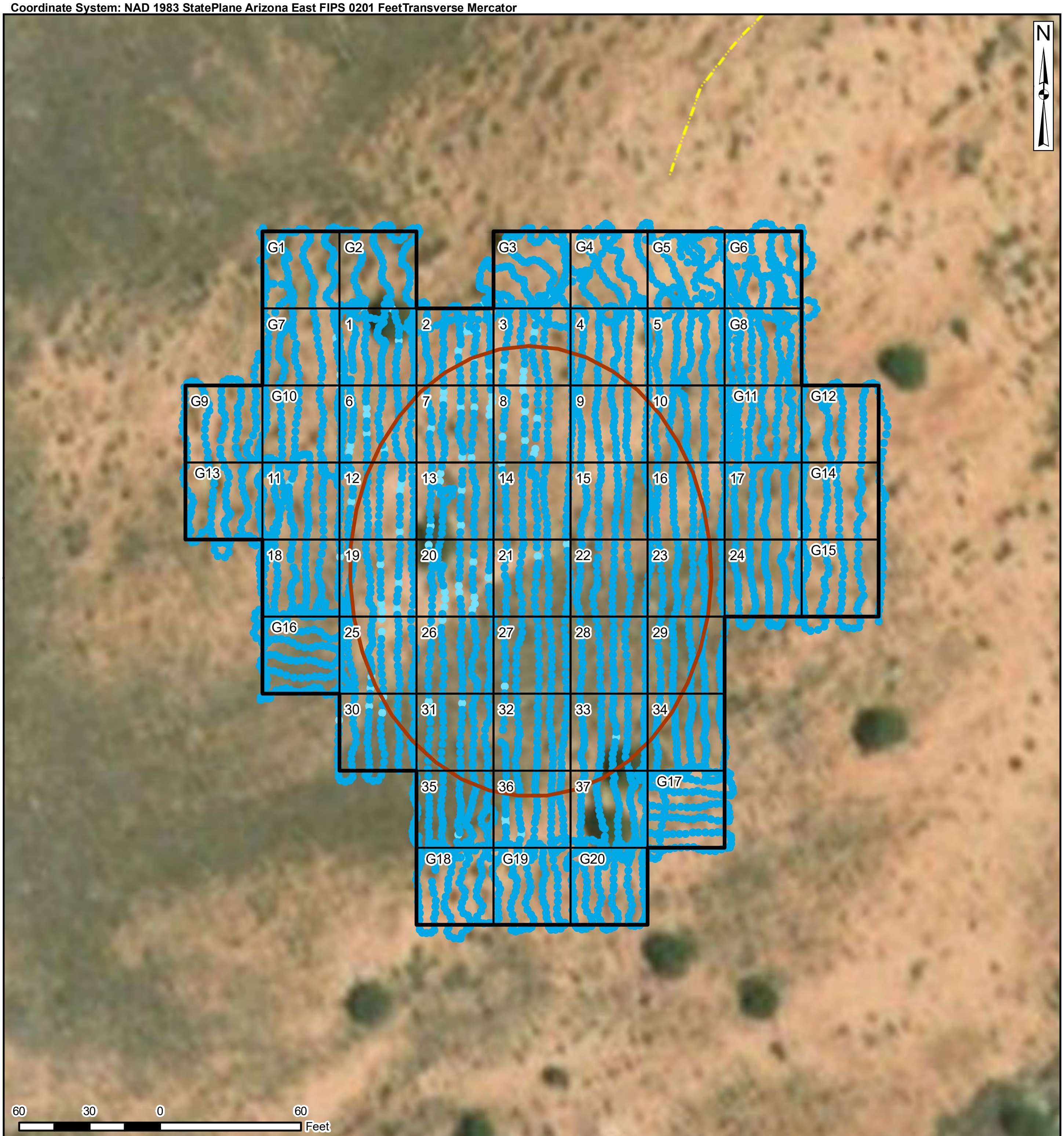
Oakland, CA 94612

NON-AUM TARGET BR-05
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T5
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Foot

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

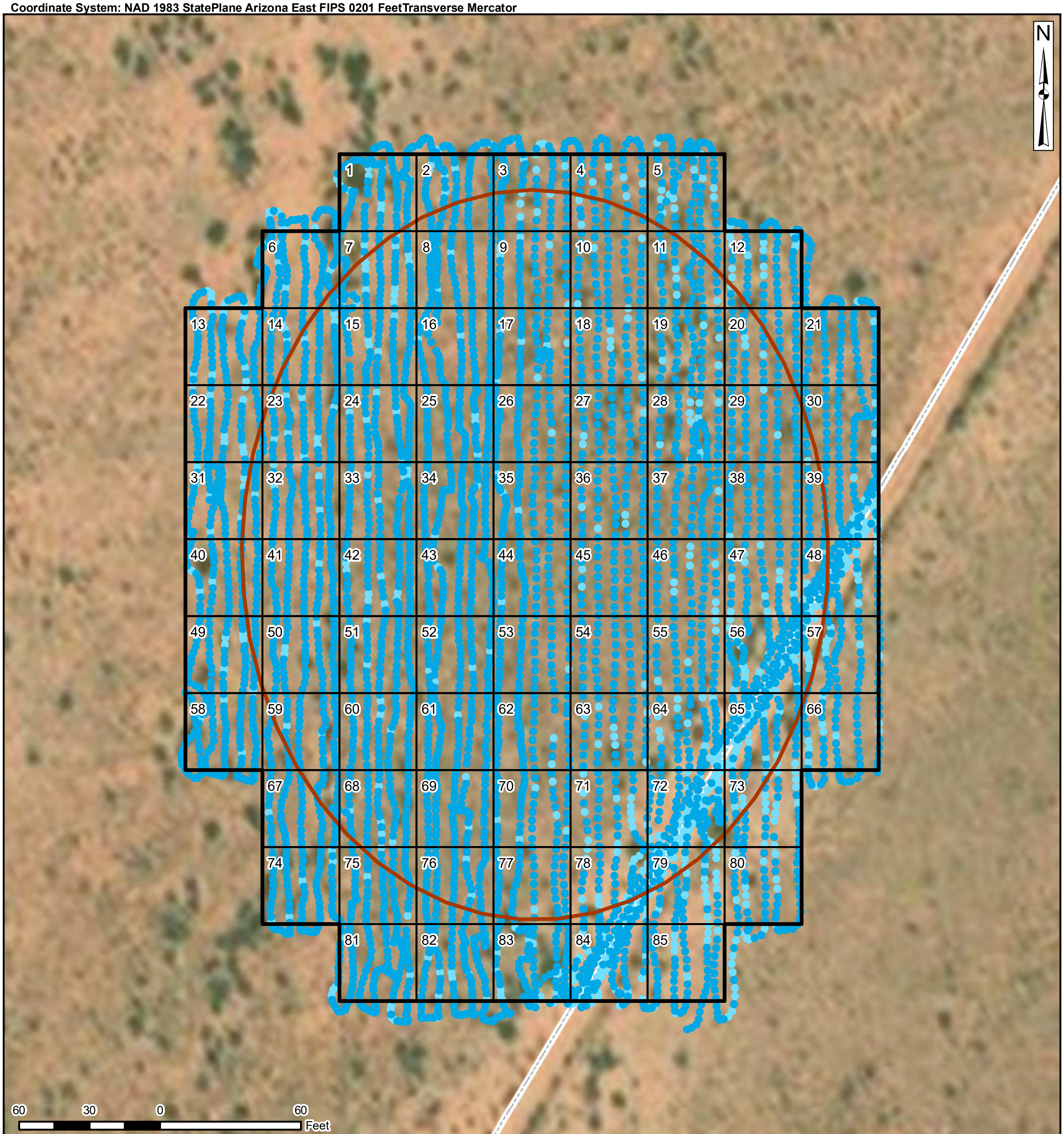
Prepared for: USEPA Region 9

Prepared By: TETRA TECH, 1999 Harrison Street, Suite 500, Oakland, CA 94612

NON-AUM TARGET BR-06
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T6
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

Prepared By:

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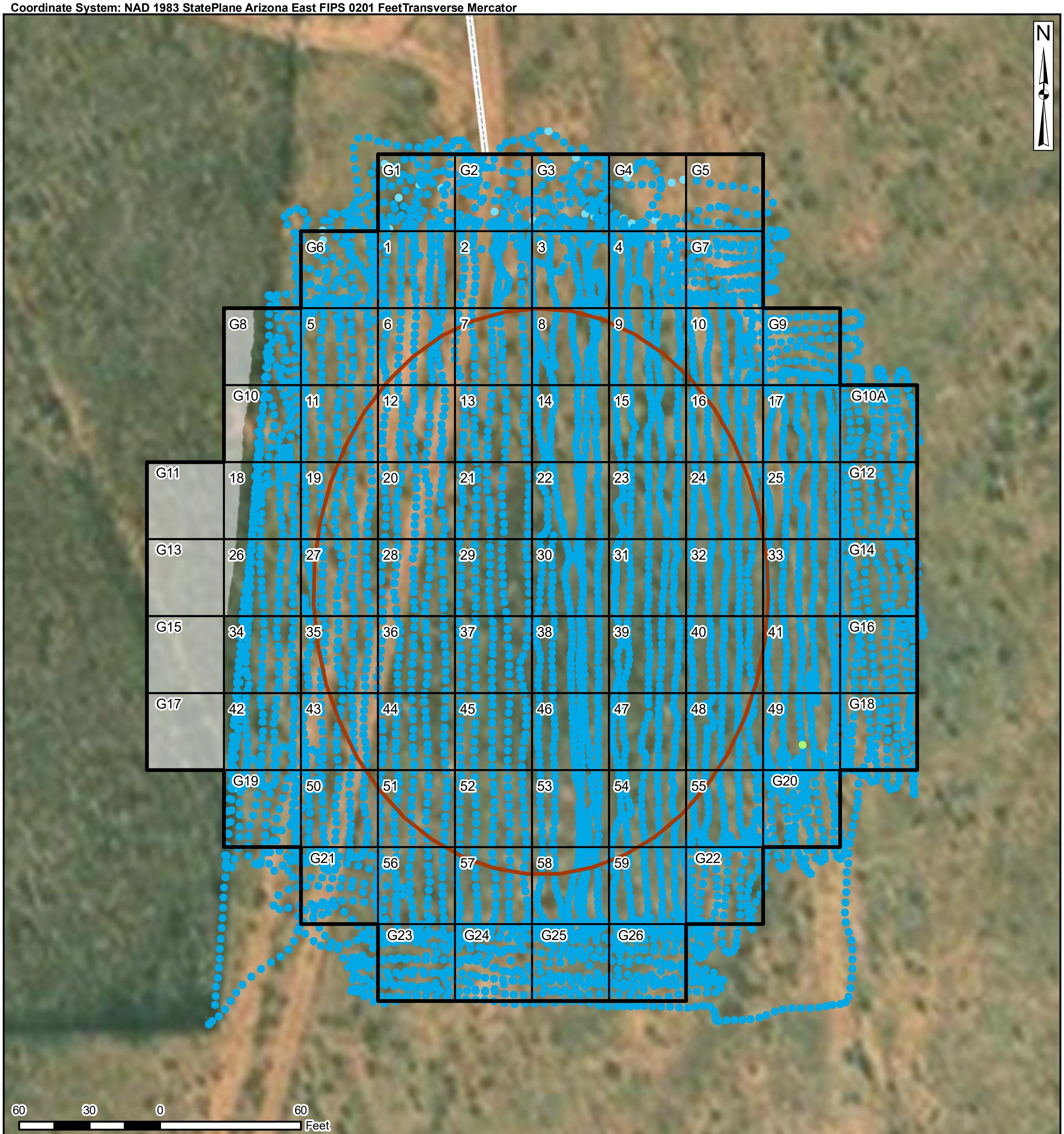
Oakland, CA 94612

NON-AUM TARGET BK-01
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T7
Location: TEEC NOS POS CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Inaccessible
- Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

Prepared By:

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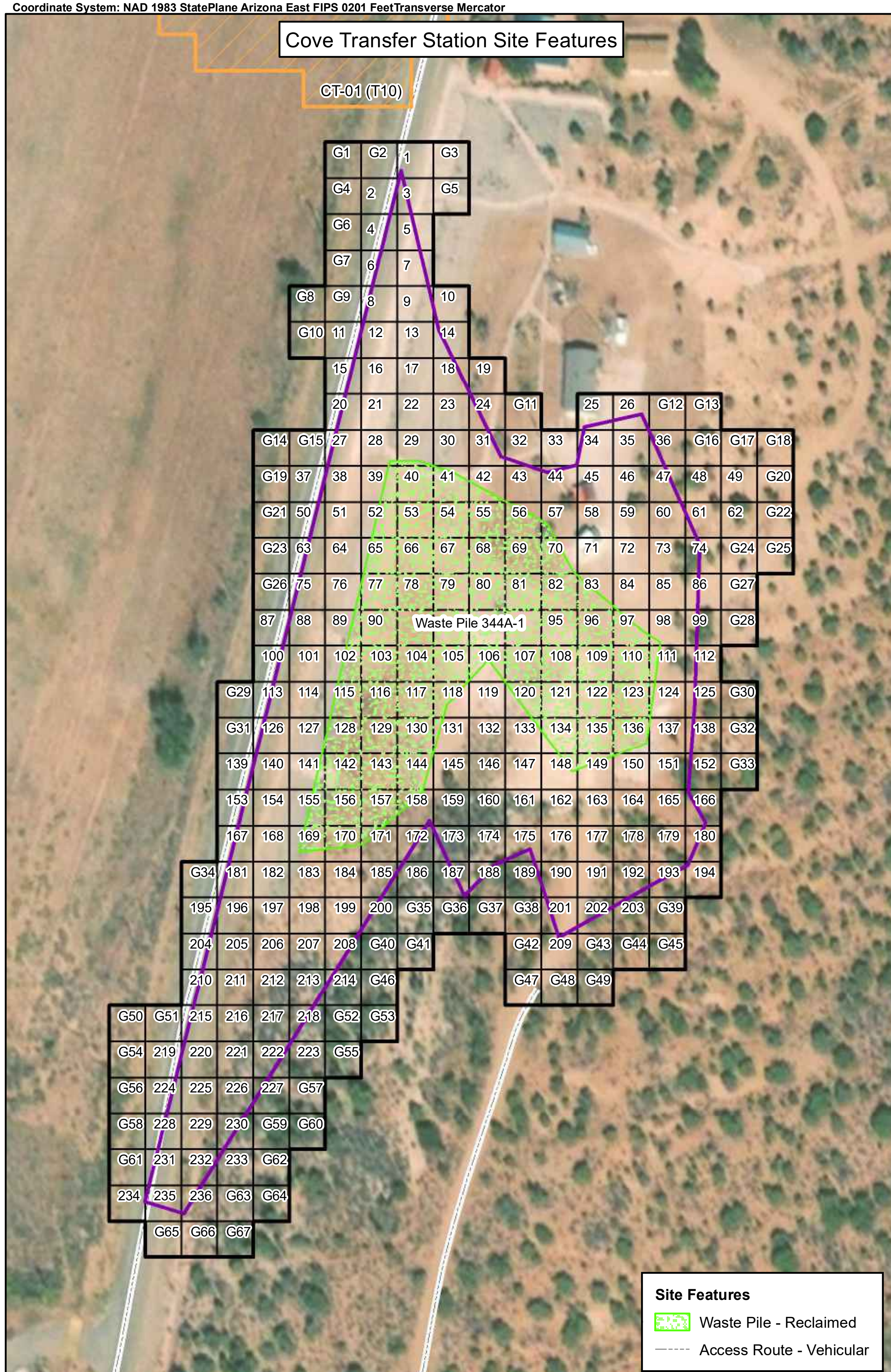
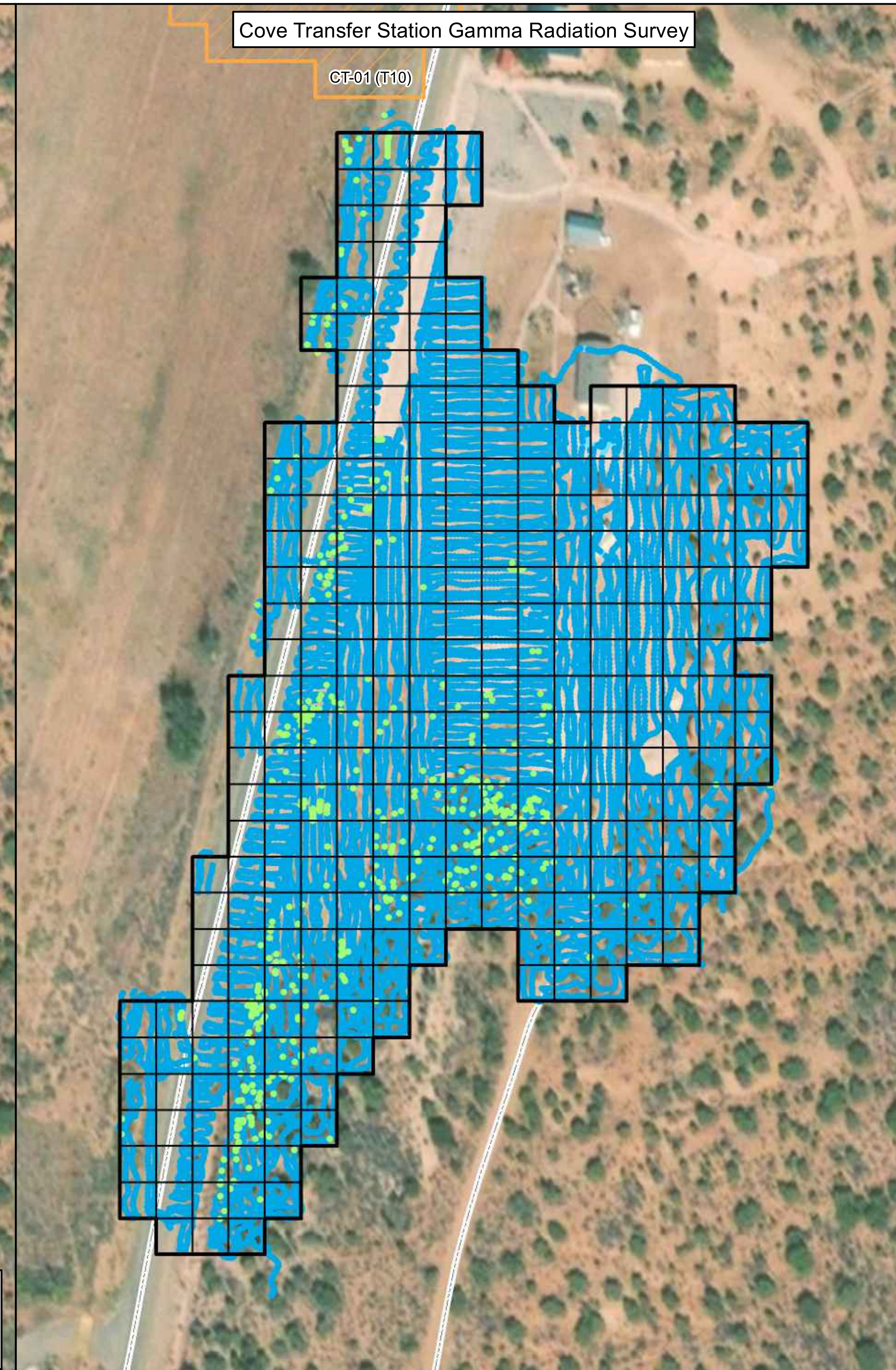
Oakland, CA 94612

NON-AUM TARGET BK-02
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T8
Location: TEEC NOS POS CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Related Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area

1 in = 125 ft

1:1,500

0 62.5 125 250 Feet

N W E S

COVE TRANSFER STATION
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

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1999 Harrison Street, Suite 500
Oakland, CA 94612

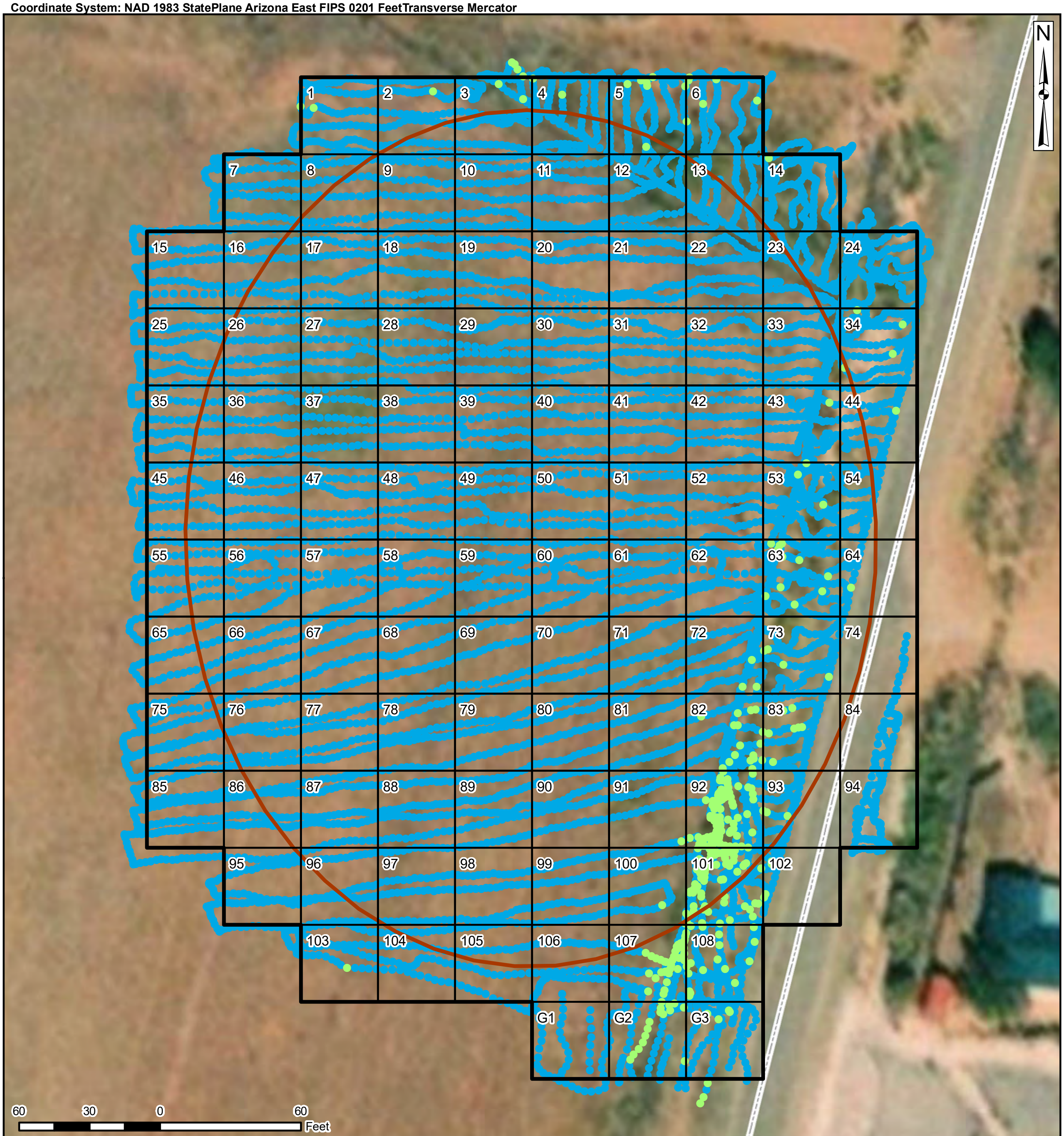
Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019

Notes:

*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Figure No.: T9

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

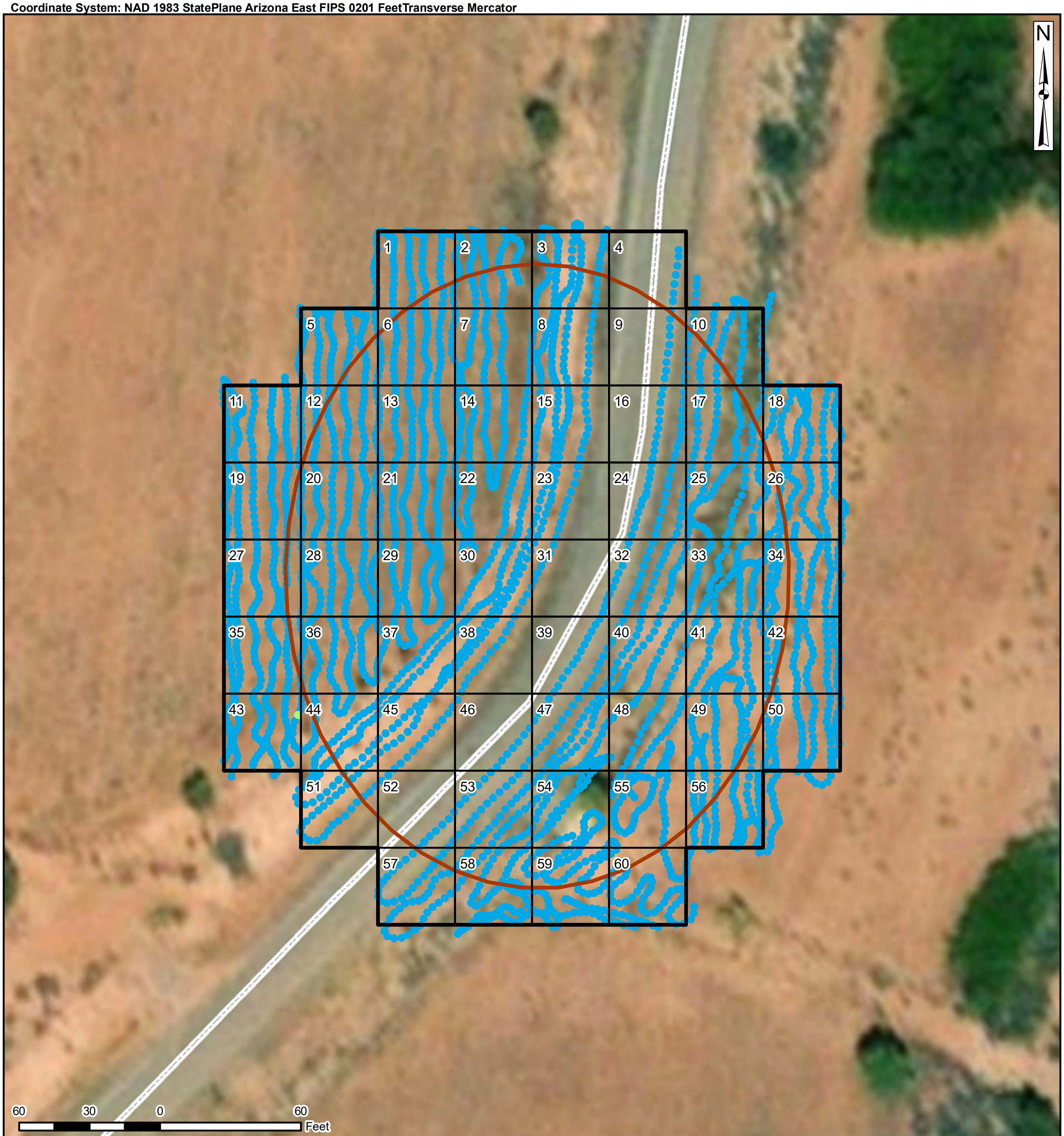
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

NON-AUM TARGET CT-01
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T10
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

Non-AUM Target Site Boundary

Survey Unit (100 m²)

Survey Area Boundary

Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

NON-AUM TARGET CT-02
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T11
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator

Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

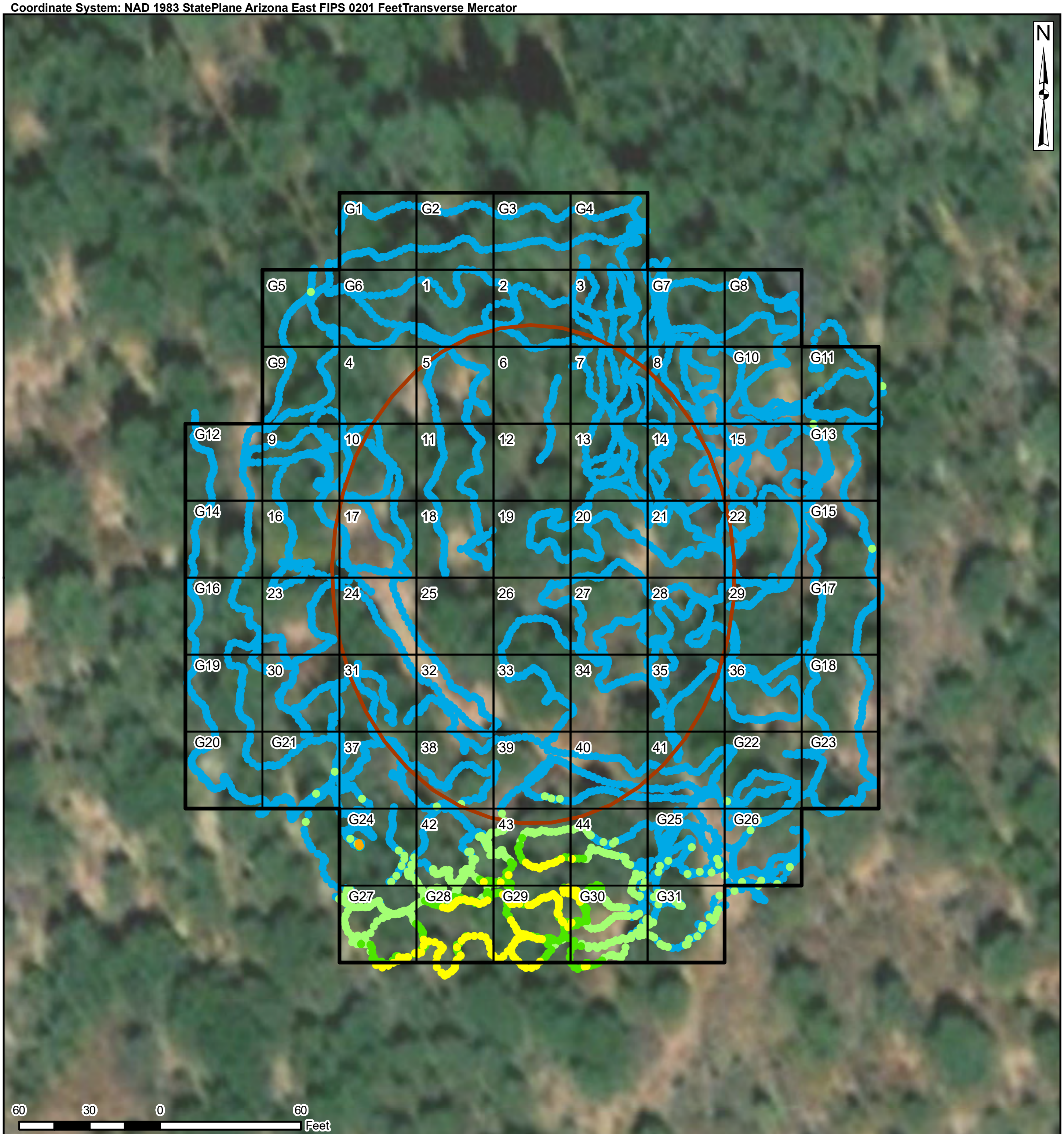
Prepared for: USEPA Region 9

Prepared By: TETRA TECH, 1999 Harrison Street, Suite 500, Oakland, CA 94612

NON-AUM TARGET CT-03
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T12
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

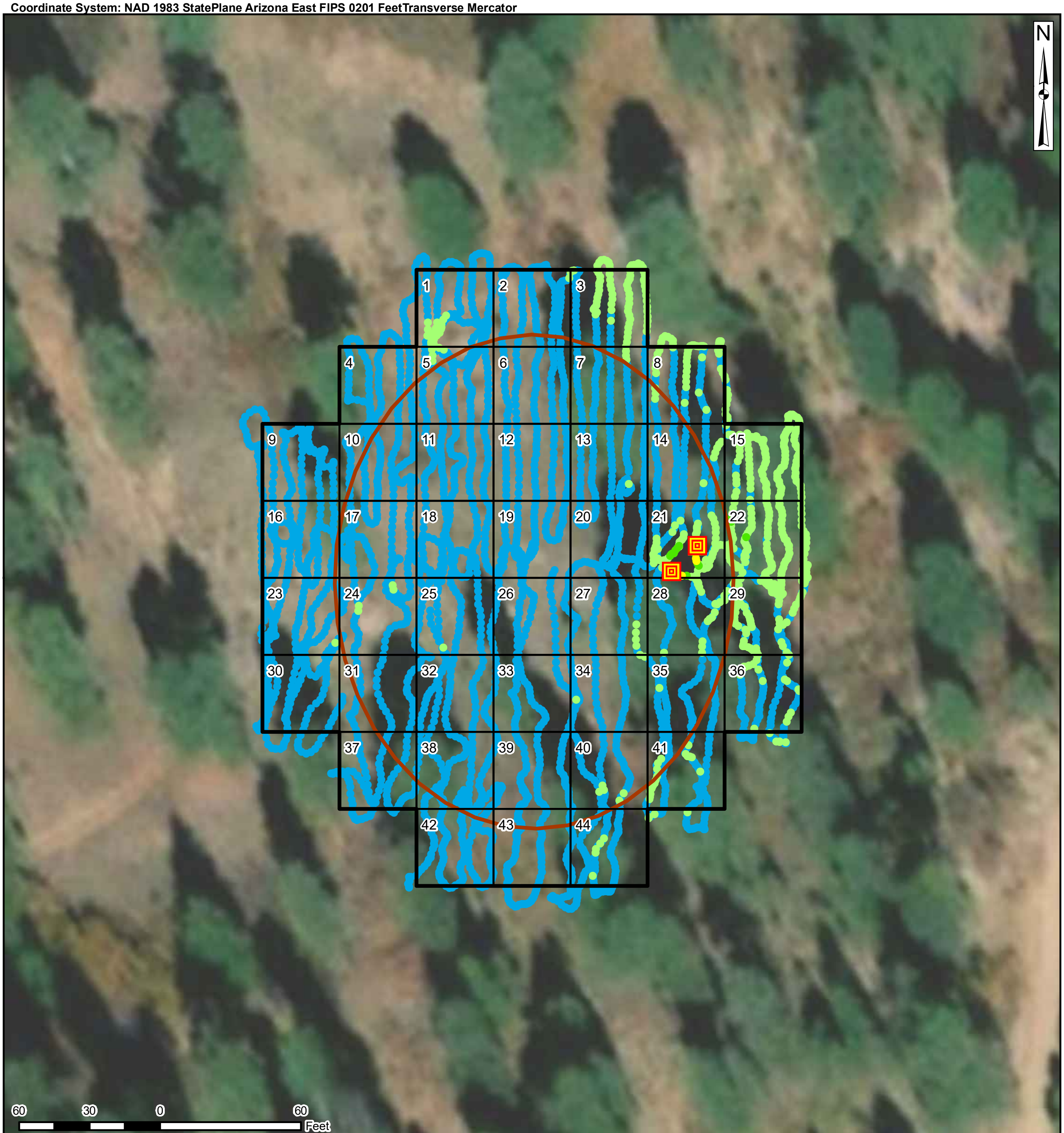
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

NON-AUM TARGET M1-01 GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T13
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- NORM - Field Mapped

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Prepared for: USEPA Region 9

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

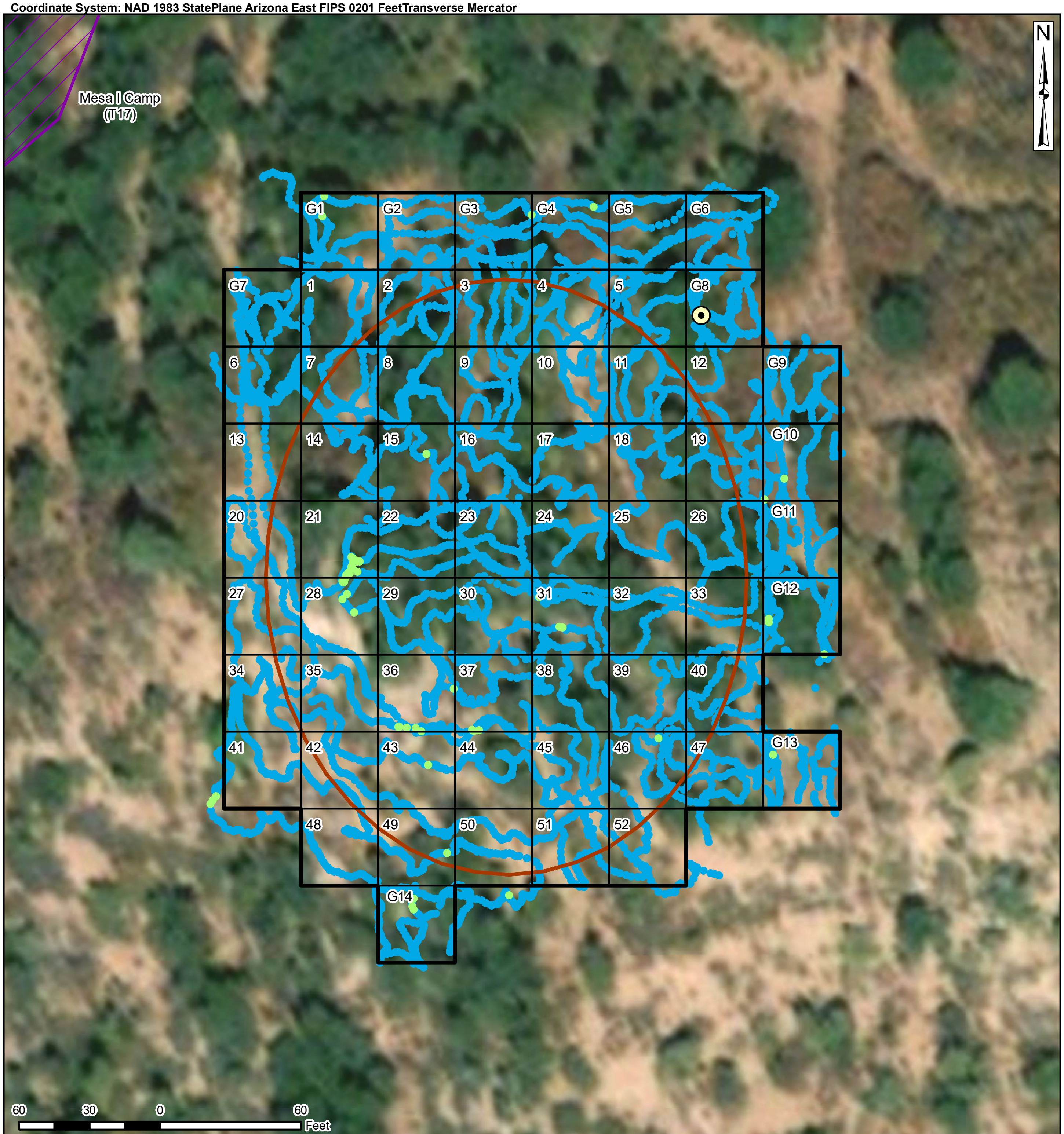
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

NON-AUM TARGET M1-02
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T14
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

Non-AUM Target Site Boundary

Survey Unit (100 m²)

Survey Area Boundary

AUM Related Site Boundary

Pipe - Field Mapped

*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

Prepared By:

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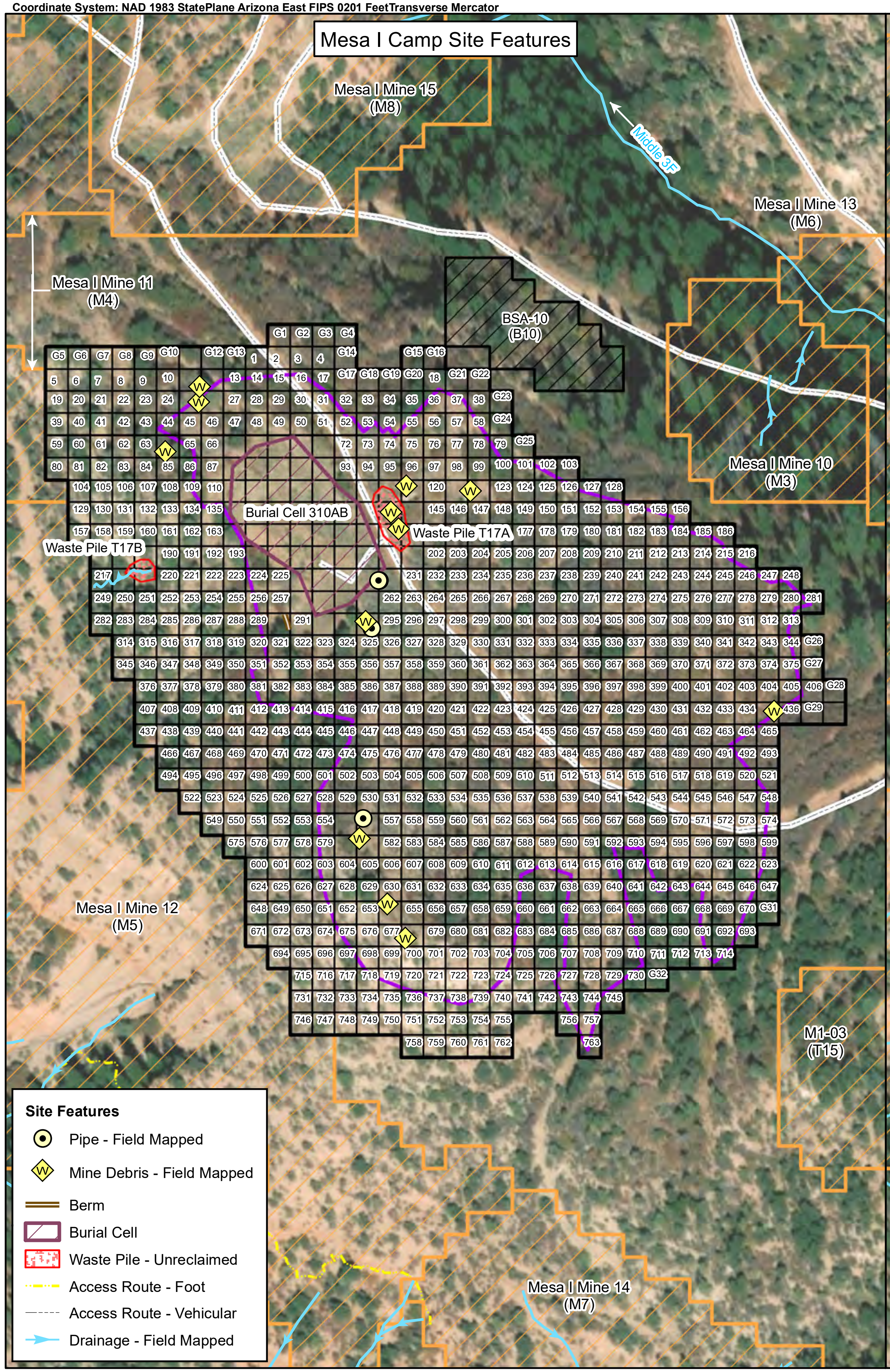
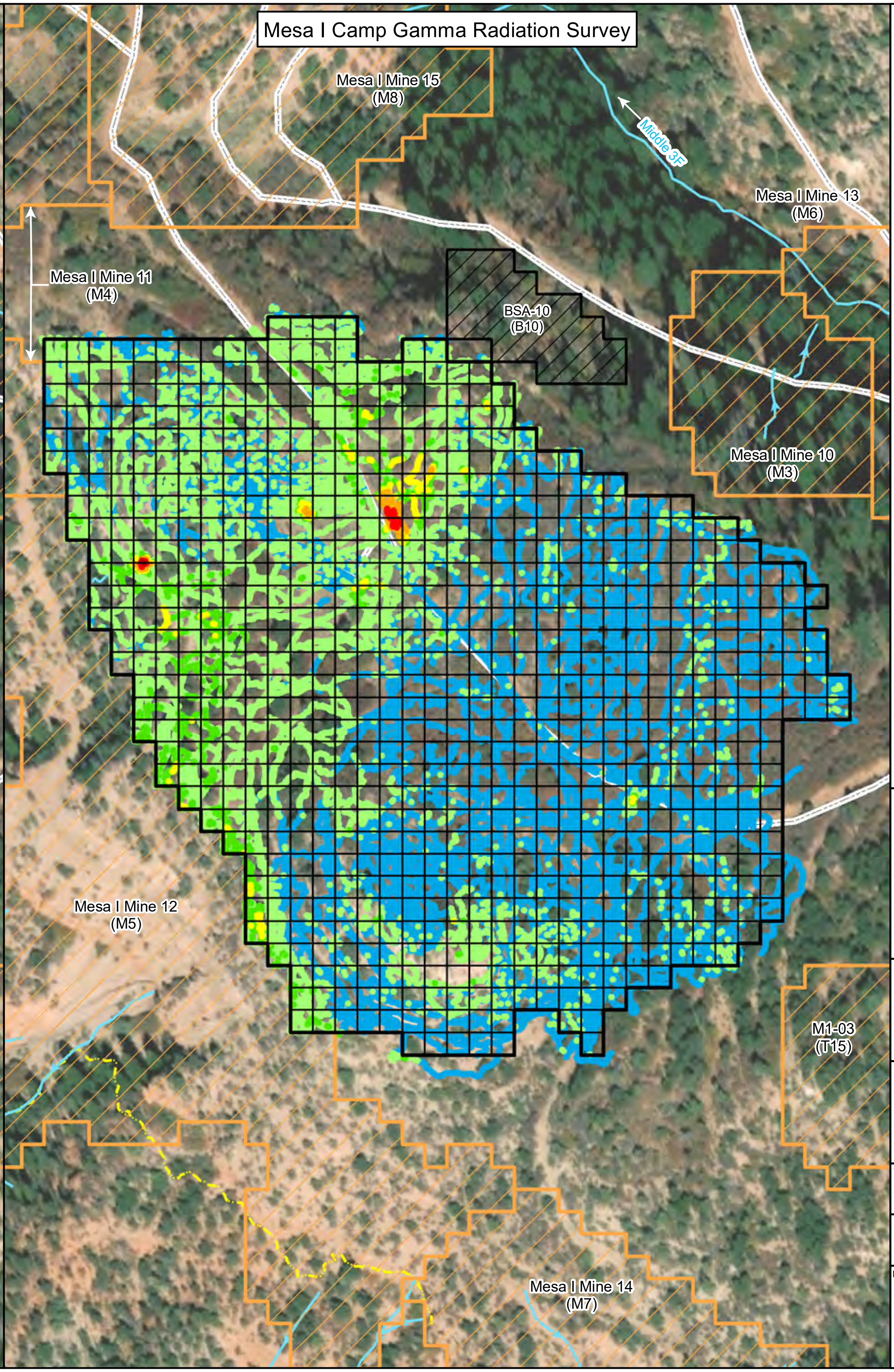
1999 Harrison Street, Suite 500
Oakland, CA 94612

NON-AUM TARGET M1-03 GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T15
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

≤ 12	≤ Avg. BG
12 - 16	Avg. BG - 1 x BTV
16 - 20	1 x BTV - 2 x BTV
20 - 22	2 x BTV - 3 x BTV
22 - 30	3 x BTV - 4 x BTV
30 - 71	4 x BTV - 10 x BTV
71 - 127	≥ 10 x BTV
127 - 350	
≥ 350	

- AUM Related Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Background Location

1 in = 200 ft

1:2,400

0 100 200 400 Feet

N E S W

MESA I CAMP

GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

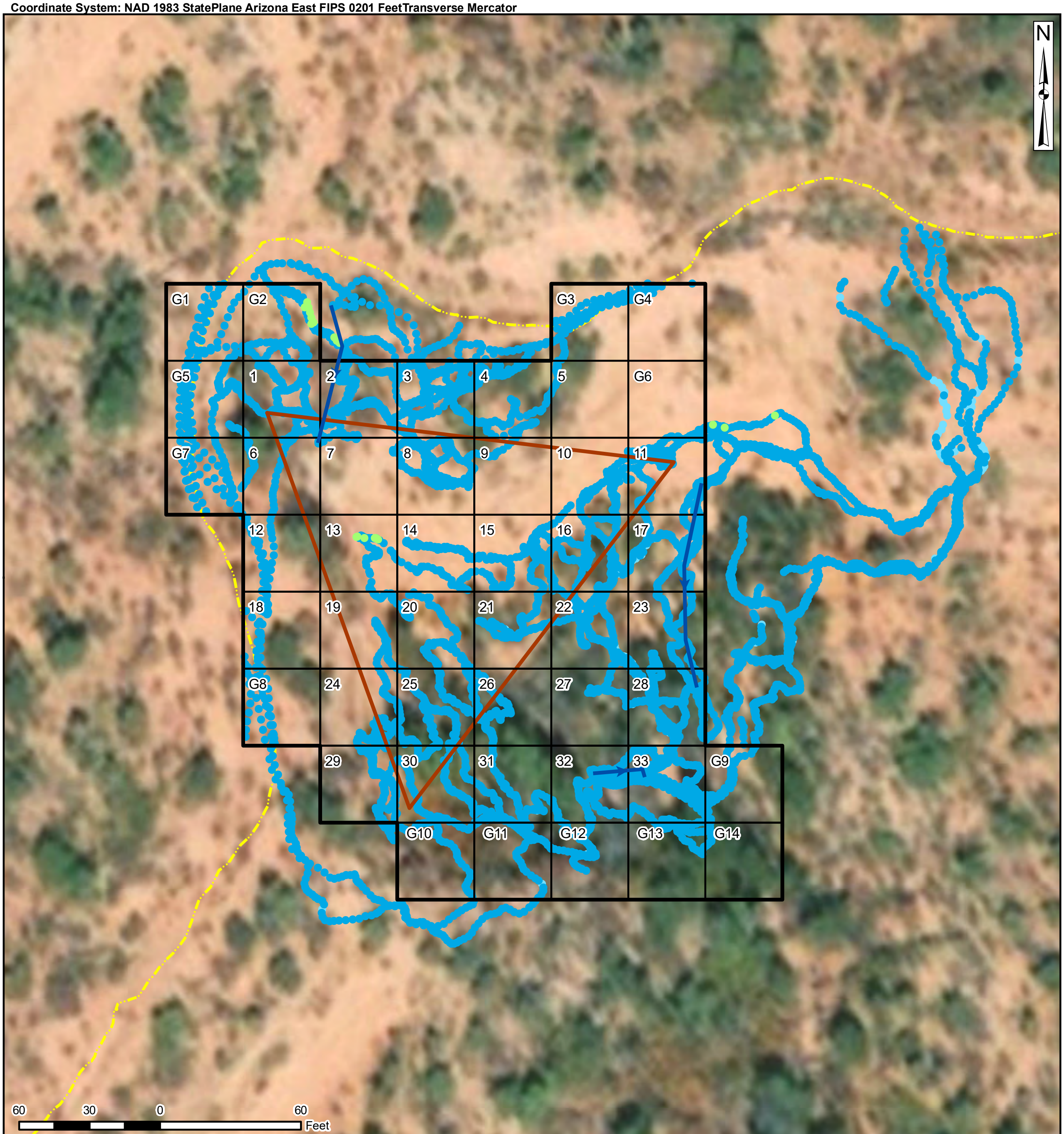
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location:	**Date:**
COVE CHAPTER NAVAJO NATION	7/11/2019

Notes:
*Gross gamma count rate measurements are converted to gamma exposure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: T17

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Foot
- Drainage - Field Mapped

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

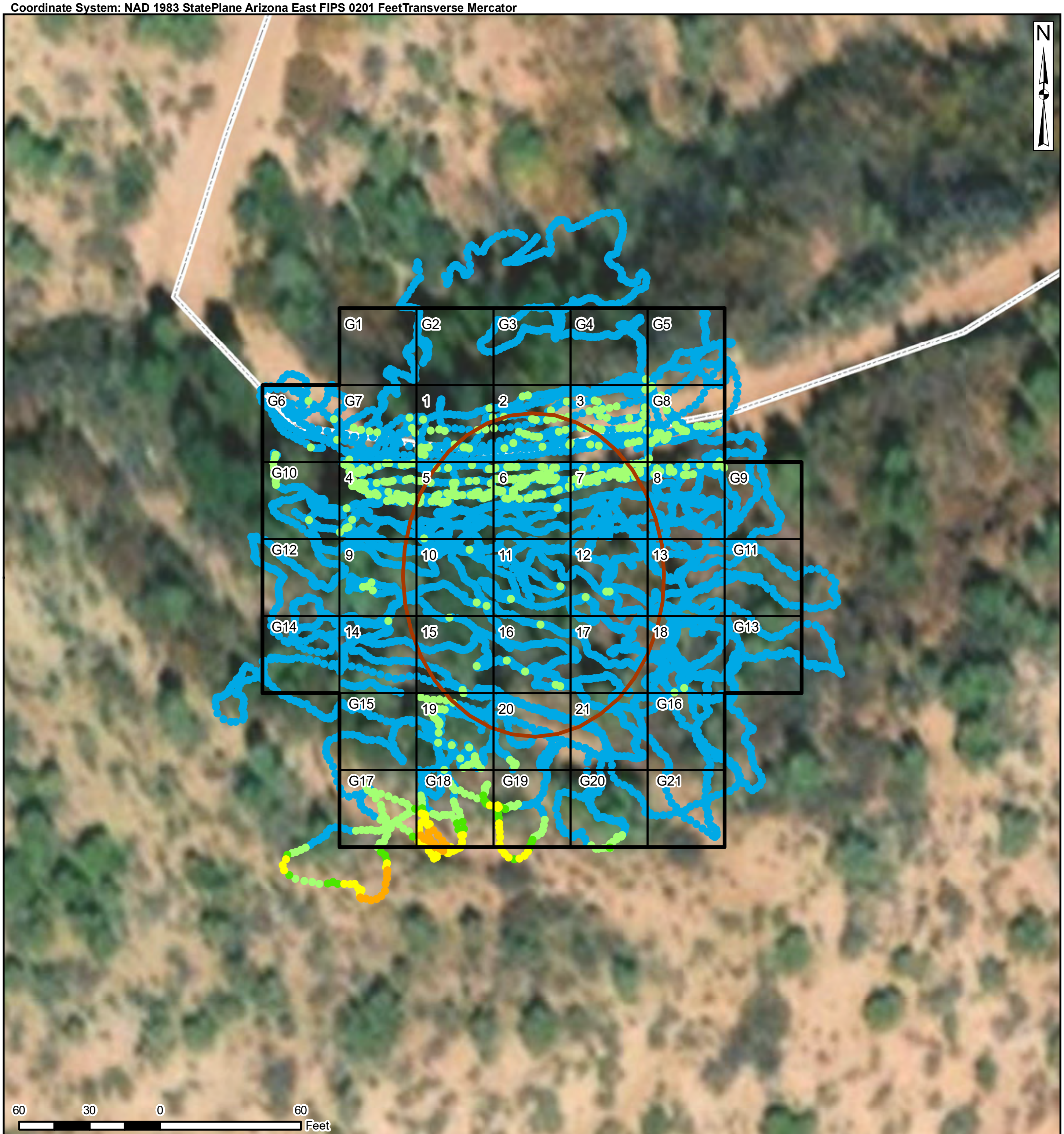
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

NON-AUM TARGET M5-01
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T18
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

Non-AUM Target Site Boundary

Survey Unit (100 m²)

Survey Area Boundary

Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Prepared for: USEPA Region 9

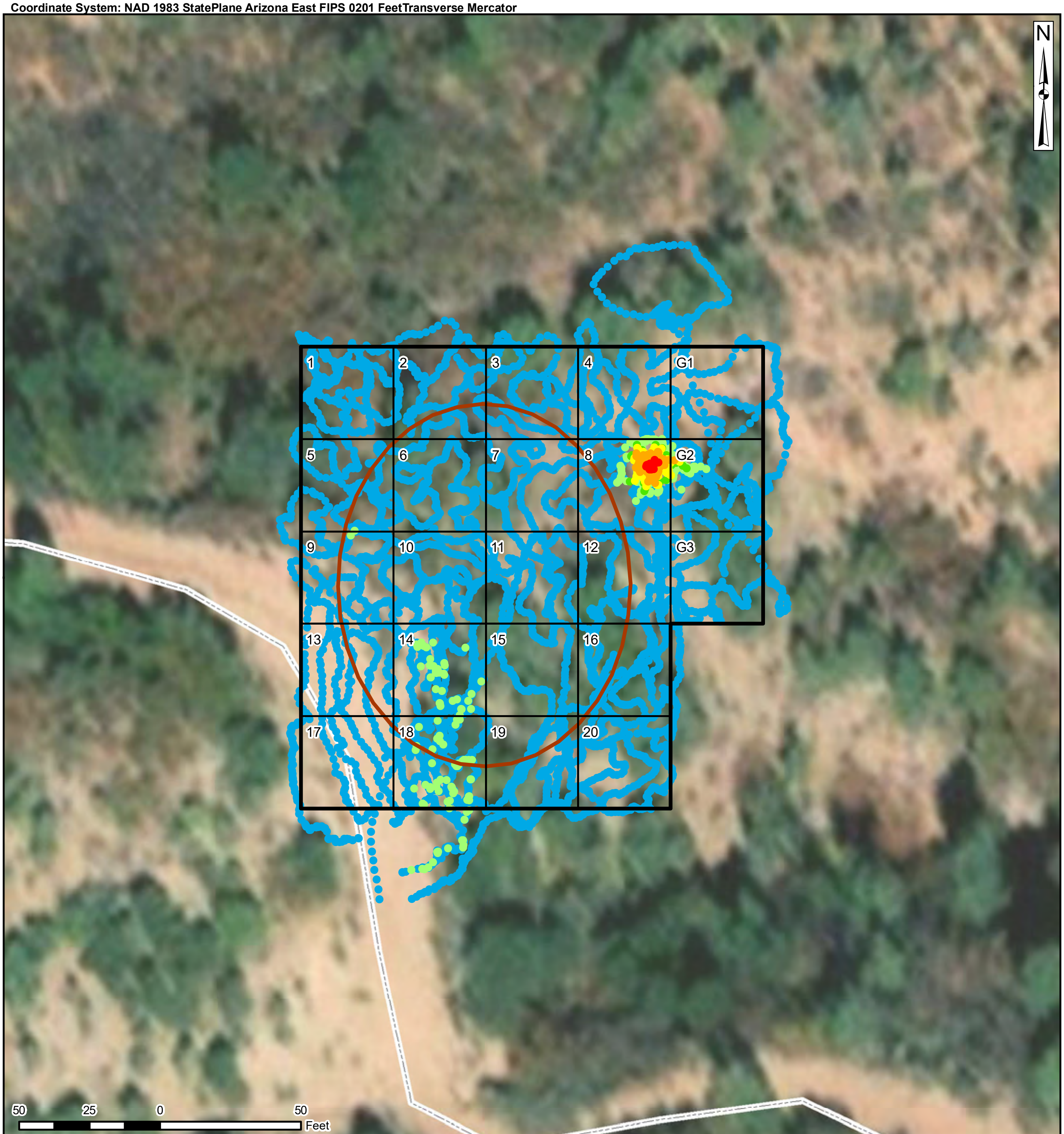
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

NON-AUM TARGET M5-02
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T19
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

Non-AUM Target Site Boundary

Survey Unit (100 m²)

Survey Area Boundary

Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

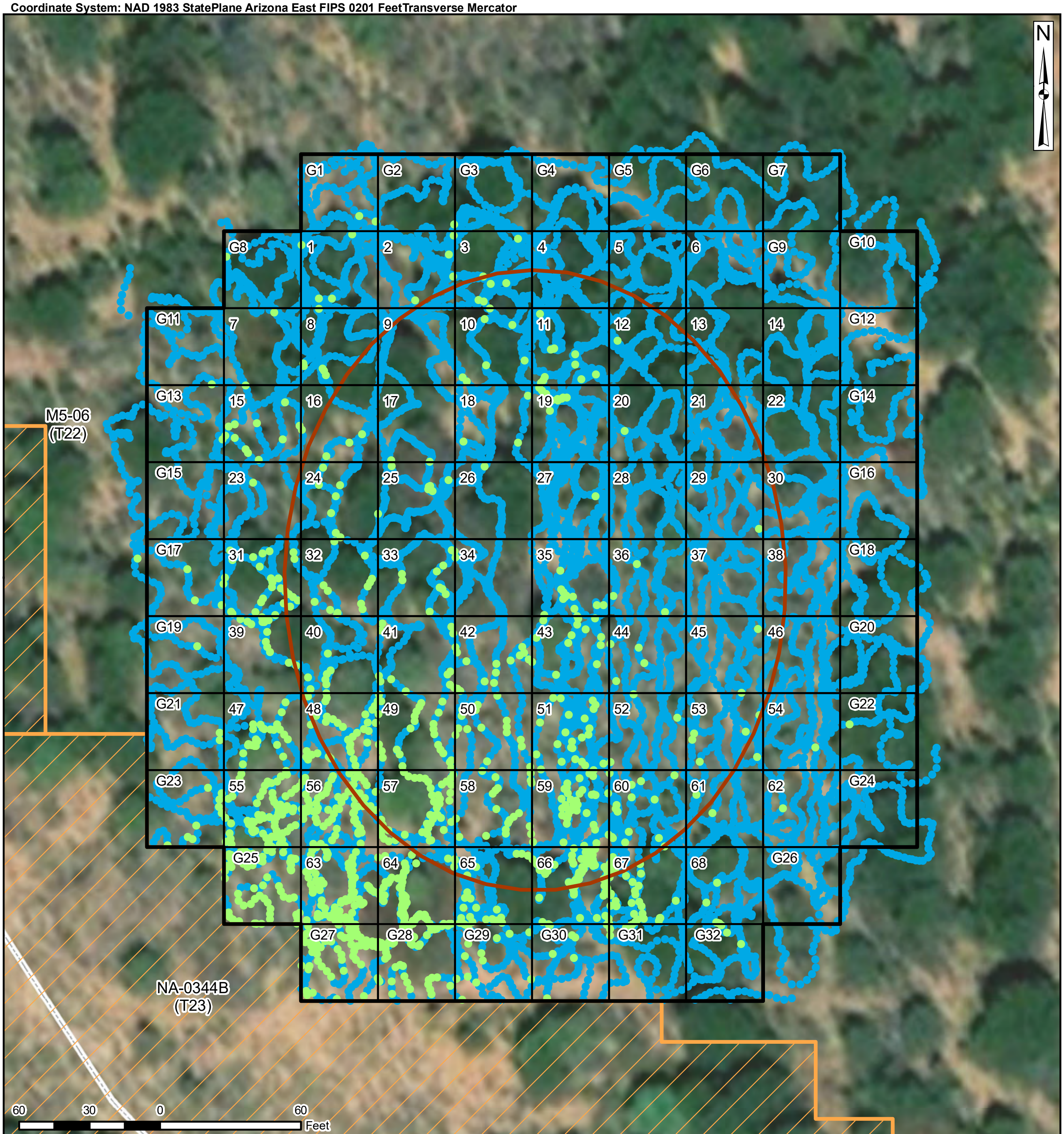
Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

NON-AUM TARGET M5-03
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T20
Location: COVE CHAPTER NAVAJO NATION	**Date:** 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

Prepared By:

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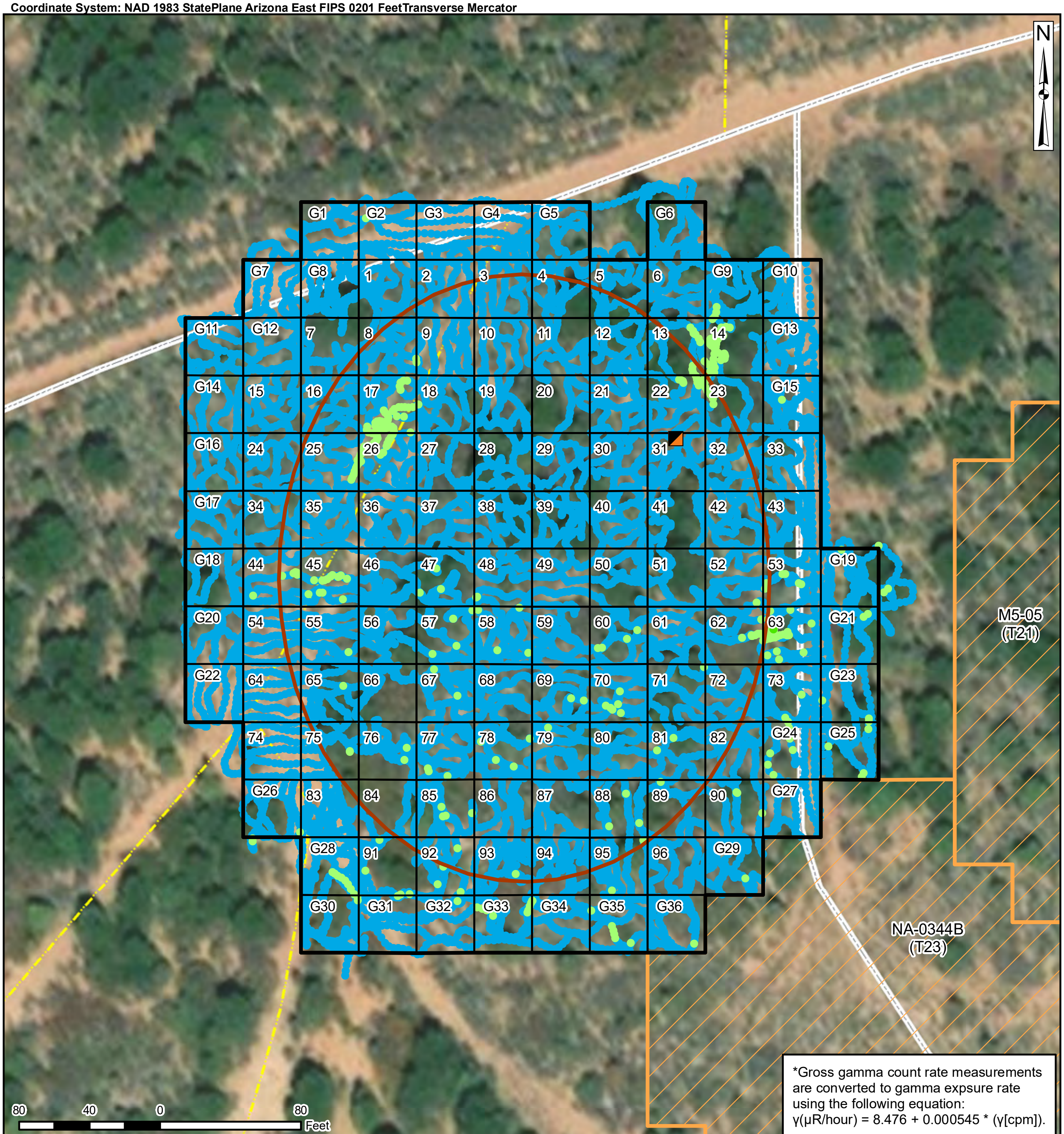
NON-AUM TARGET M5-05
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T21
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Vertical Opening (Field Mapped)
- Access Route - Foot
- Access Route - Vehicular

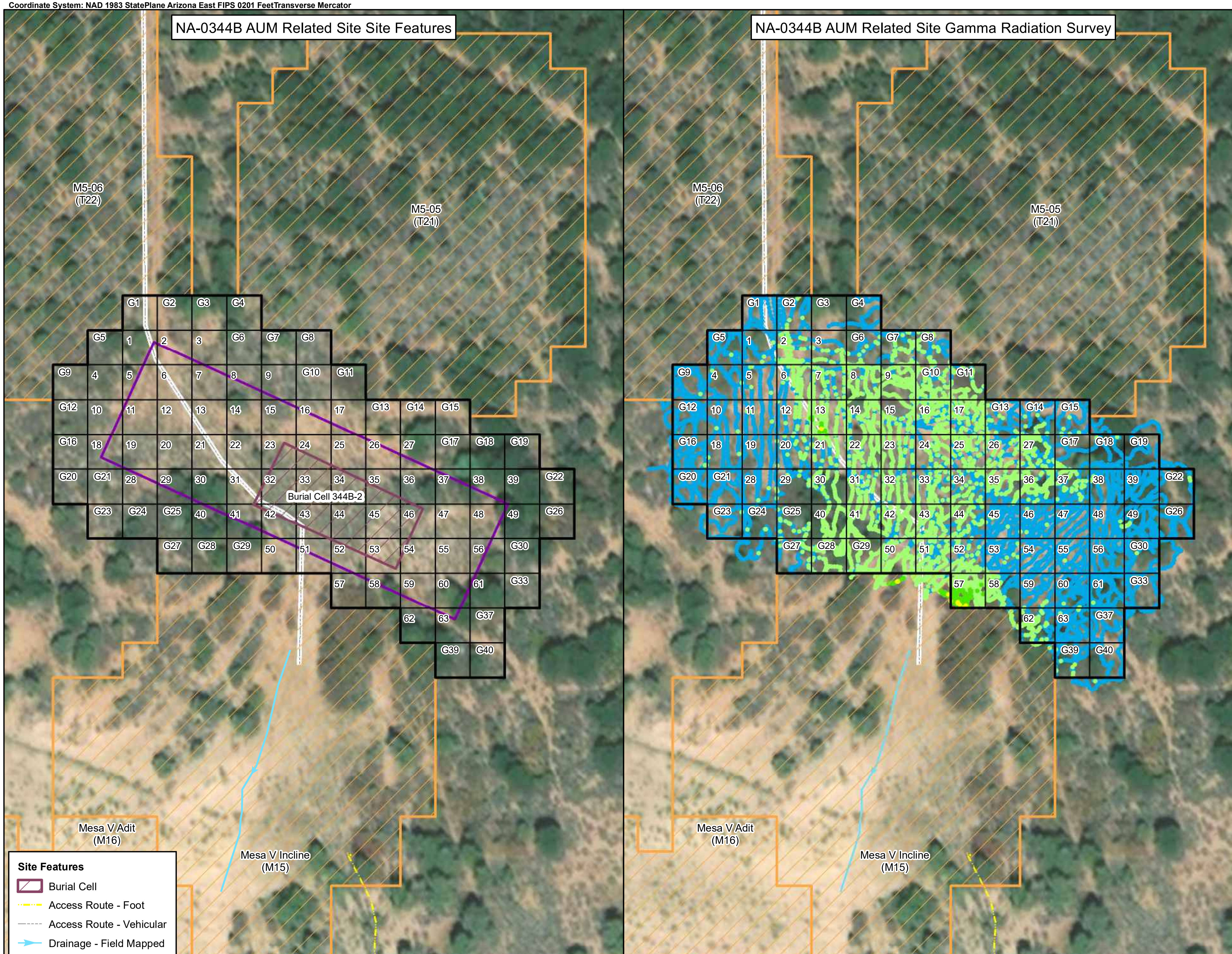
Prepared for: USEPA Region 9

Prepared By: TETRA TECH, 1999 Harrison Street, Suite 500, Oakland, CA 94612

NON-AUM TARGET M5-06
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T22
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350
- AUM Related Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area

1 in = 90 ft

1:1,080

0 45 90 180 Feet

N W E S

NA-0344B AUM RELATED SITE GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

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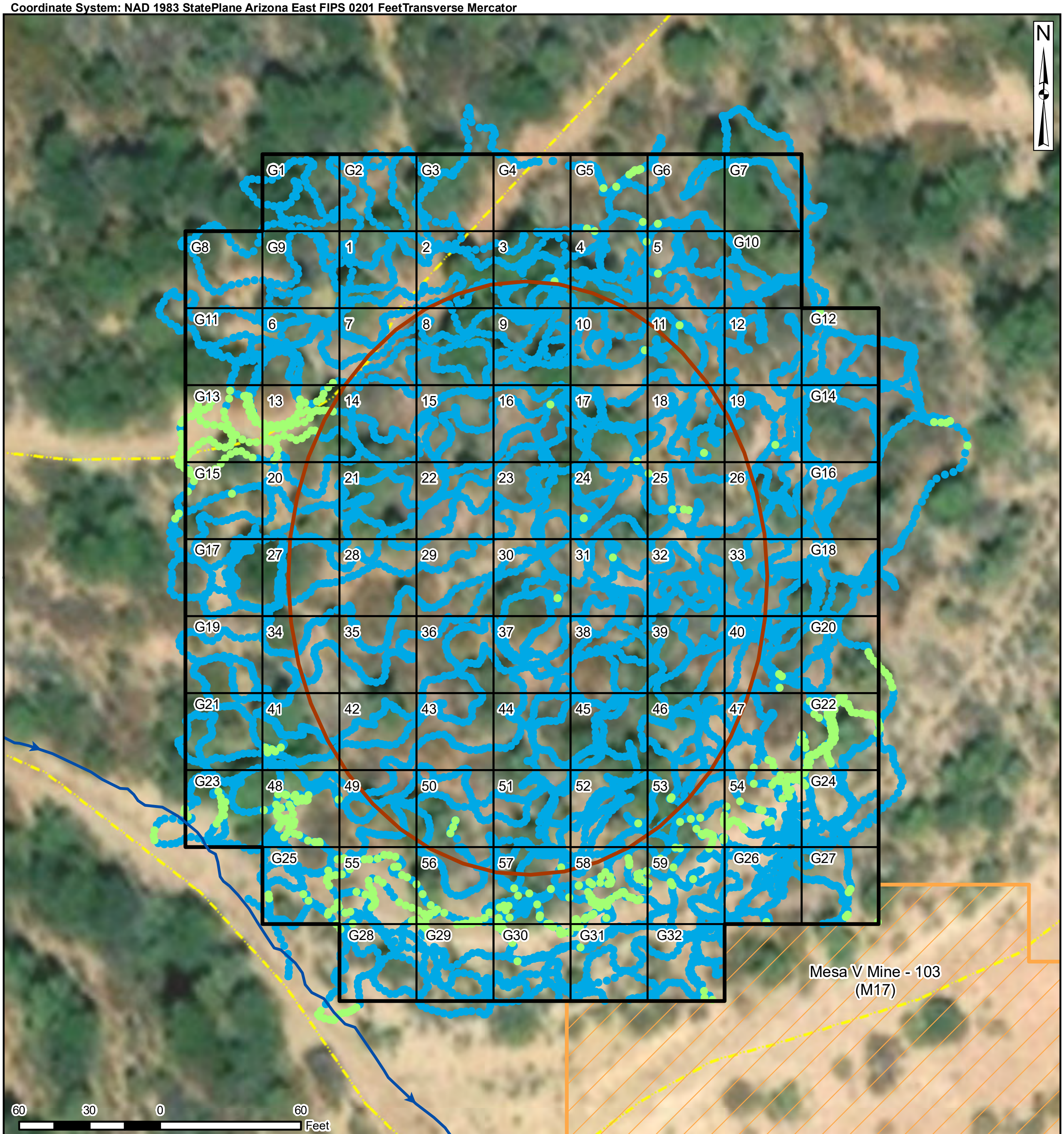
Task Order No.: TO0001	Contract No.: EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019
Notes: *Gross gamma count rate measurements are converted to gamma exposure rate using the following equation: γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).	Figure No.: T23

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Other Survey Area
- Access Route - Foot
- Drainage - Field Mapped

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Prepared for: USEPA Region 9

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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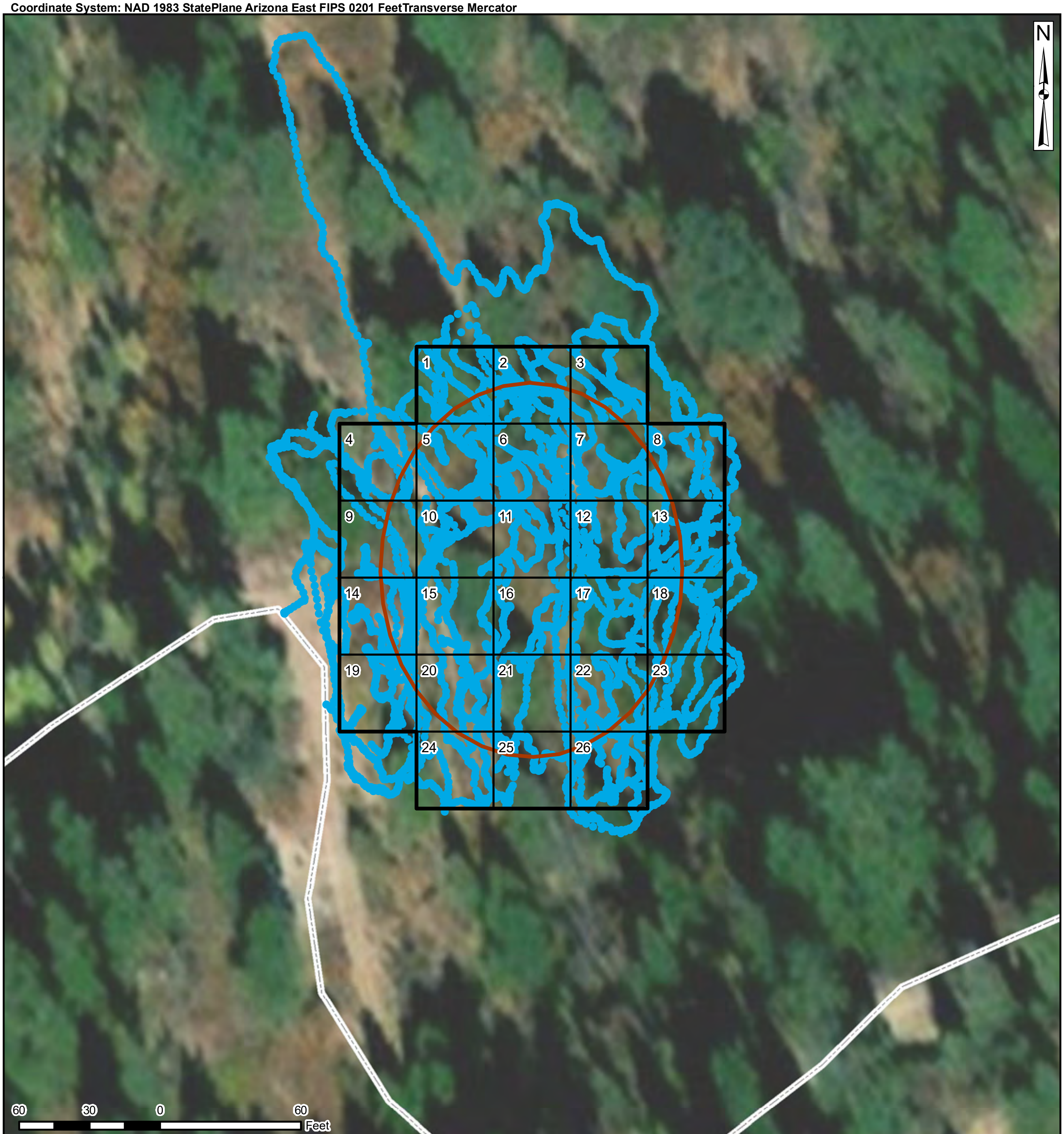
NON-AUM TARGET M5-07
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T24
Location: COVE CHAPTER NAVAJO NATION	**Date:** 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Prepared for: USEPA Region 9

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Prepared By:

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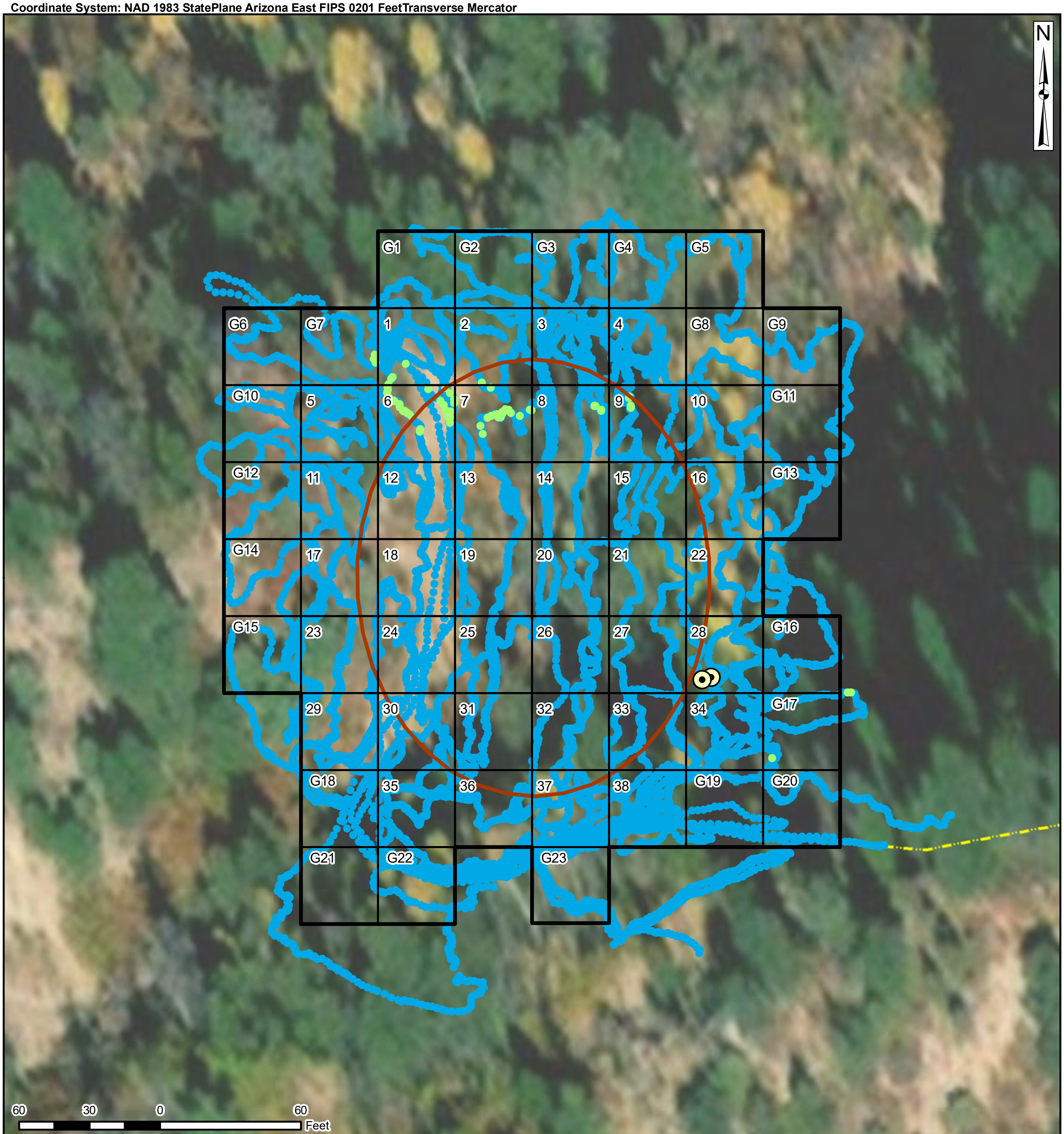
NON-AUM TARGET M5-08 GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T25
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Grid Unit (100 m²)
- Survey Area Boundary
- Pipe (Field Mapped)
- Access Route - Foot

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

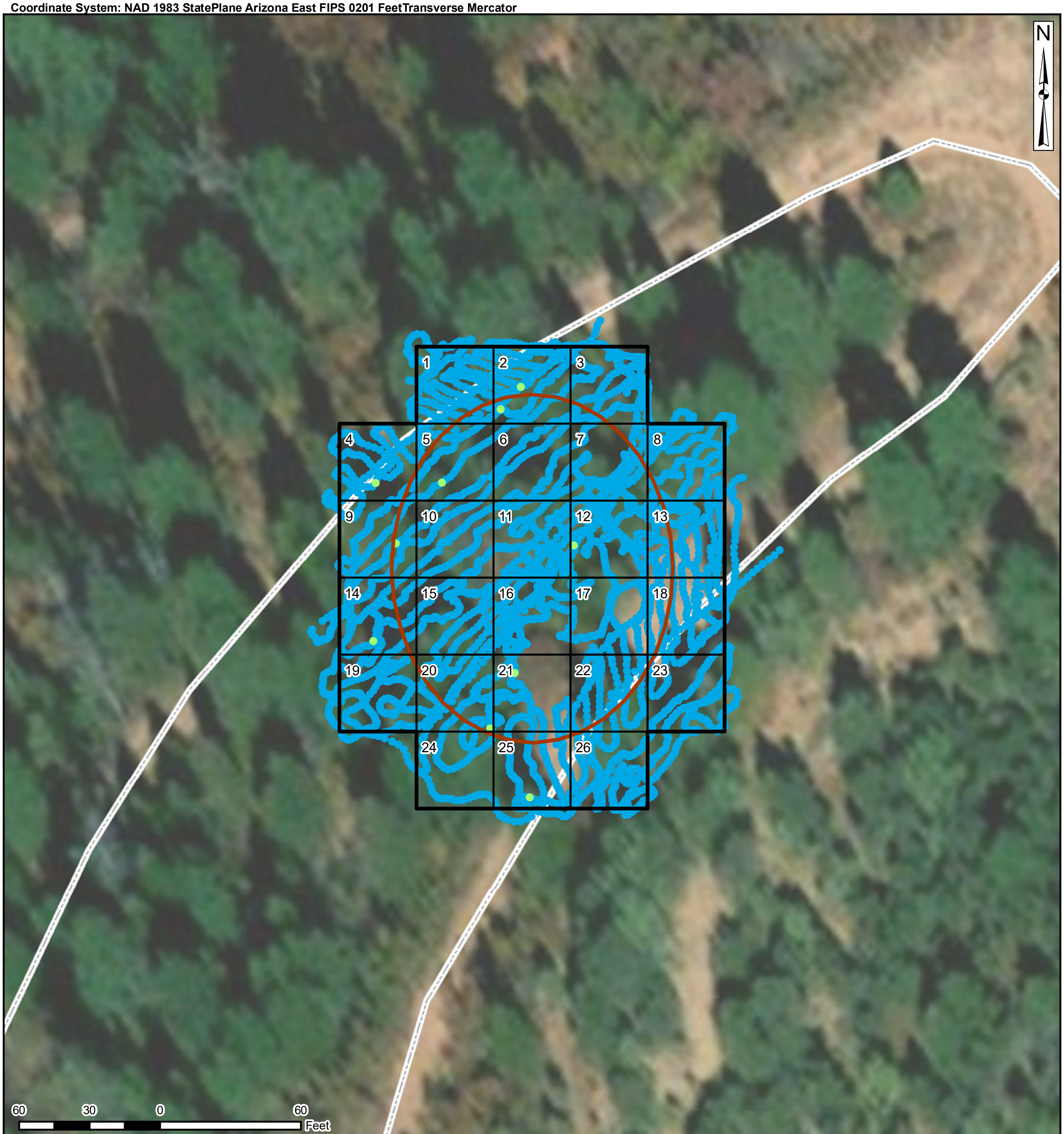
Prepared for: USEPA Region 9

Prepared By: TETRA TECH, 1999 Harrison Street, Suite 500, Oakland, CA 94612

NON-AUM TARGET M5-09
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T26
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (µR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(µR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

Prepared By:

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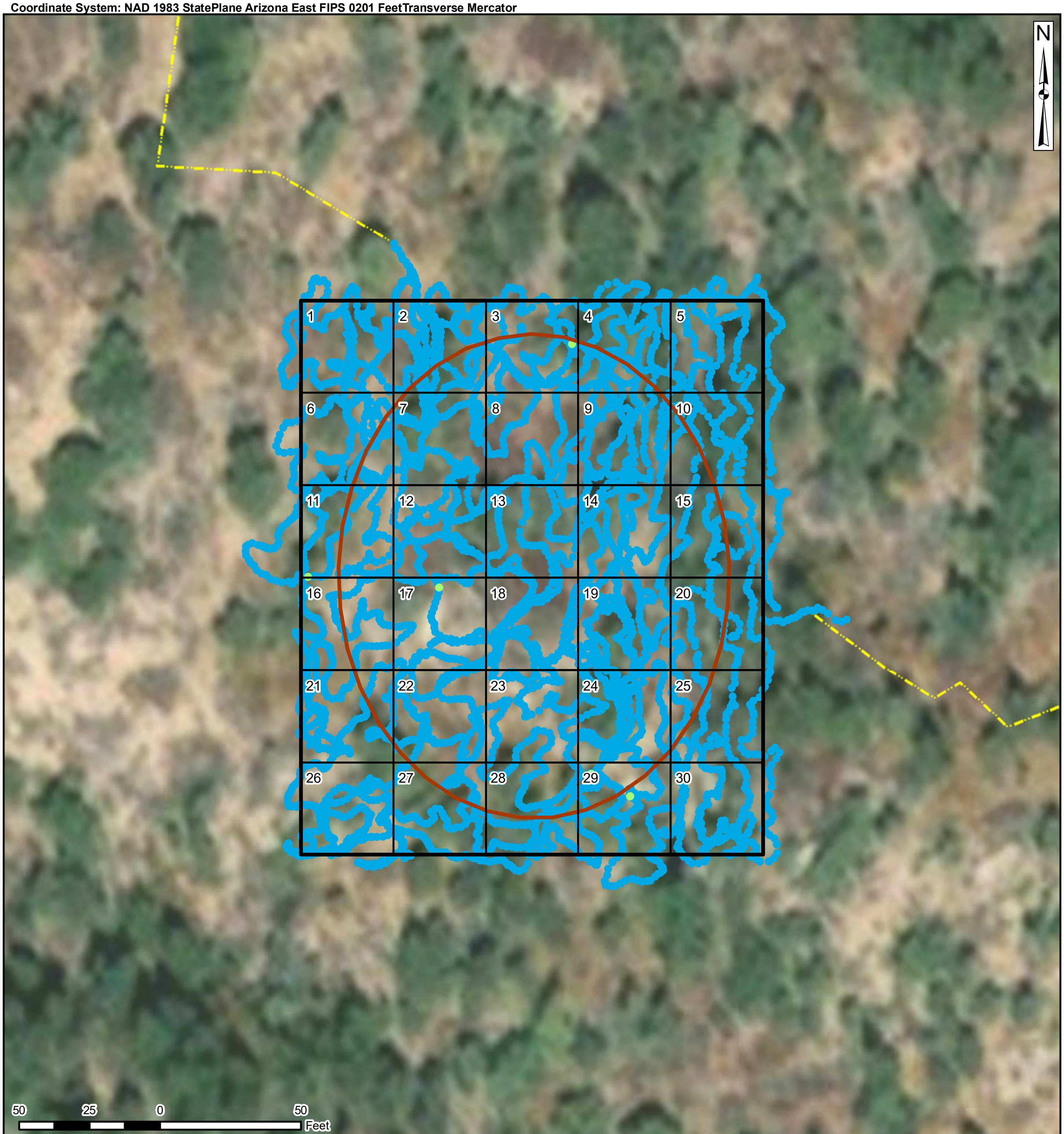
NON-AUM TARGET M4-02
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T27
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Access Route - Foot

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

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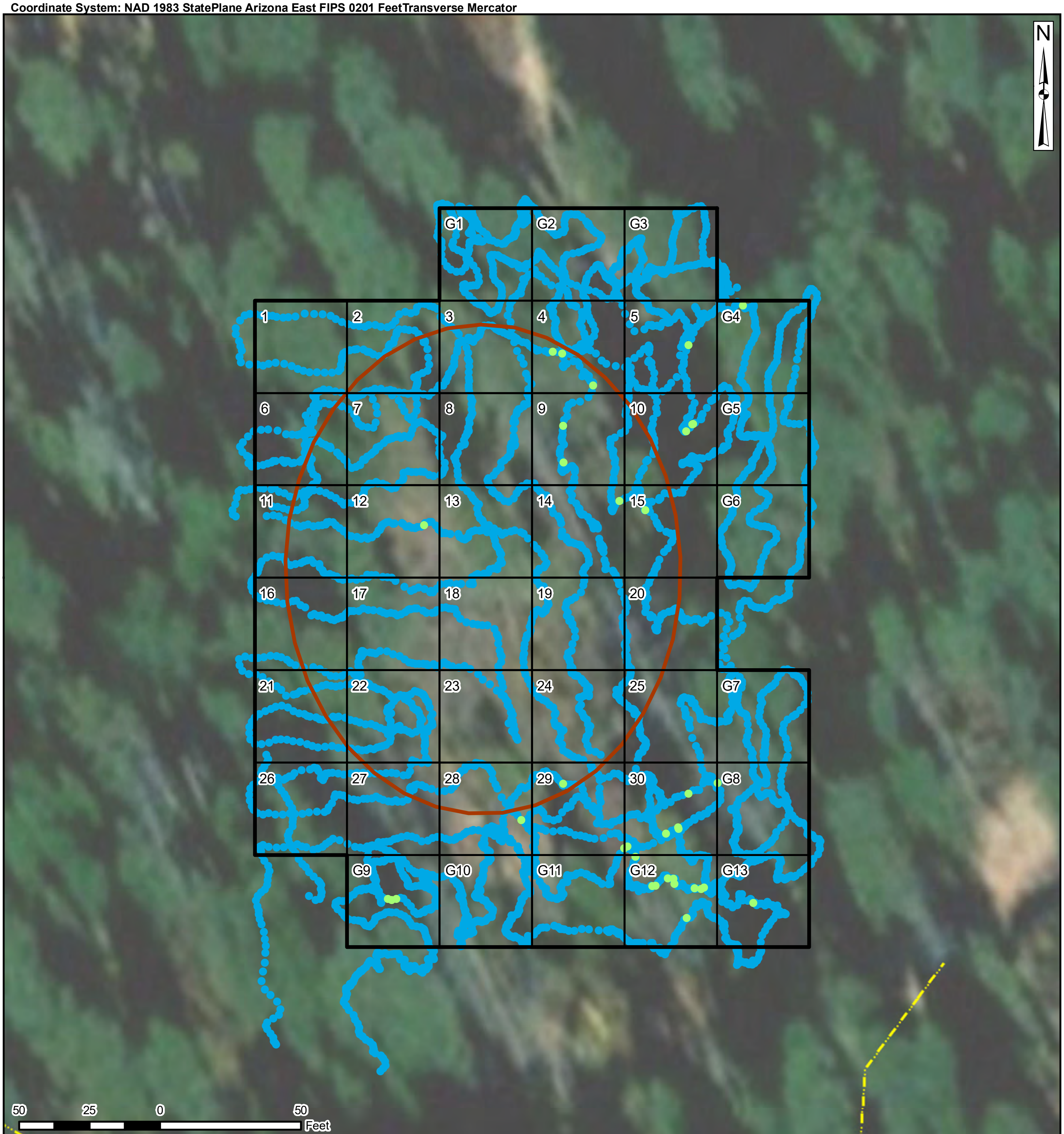
NON-AUM TARGET M1-07
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T30
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

Non-AUM Target Site Boundary

Survey Unit (100 m²)

Survey Area Boundary

Access Route - Foot

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

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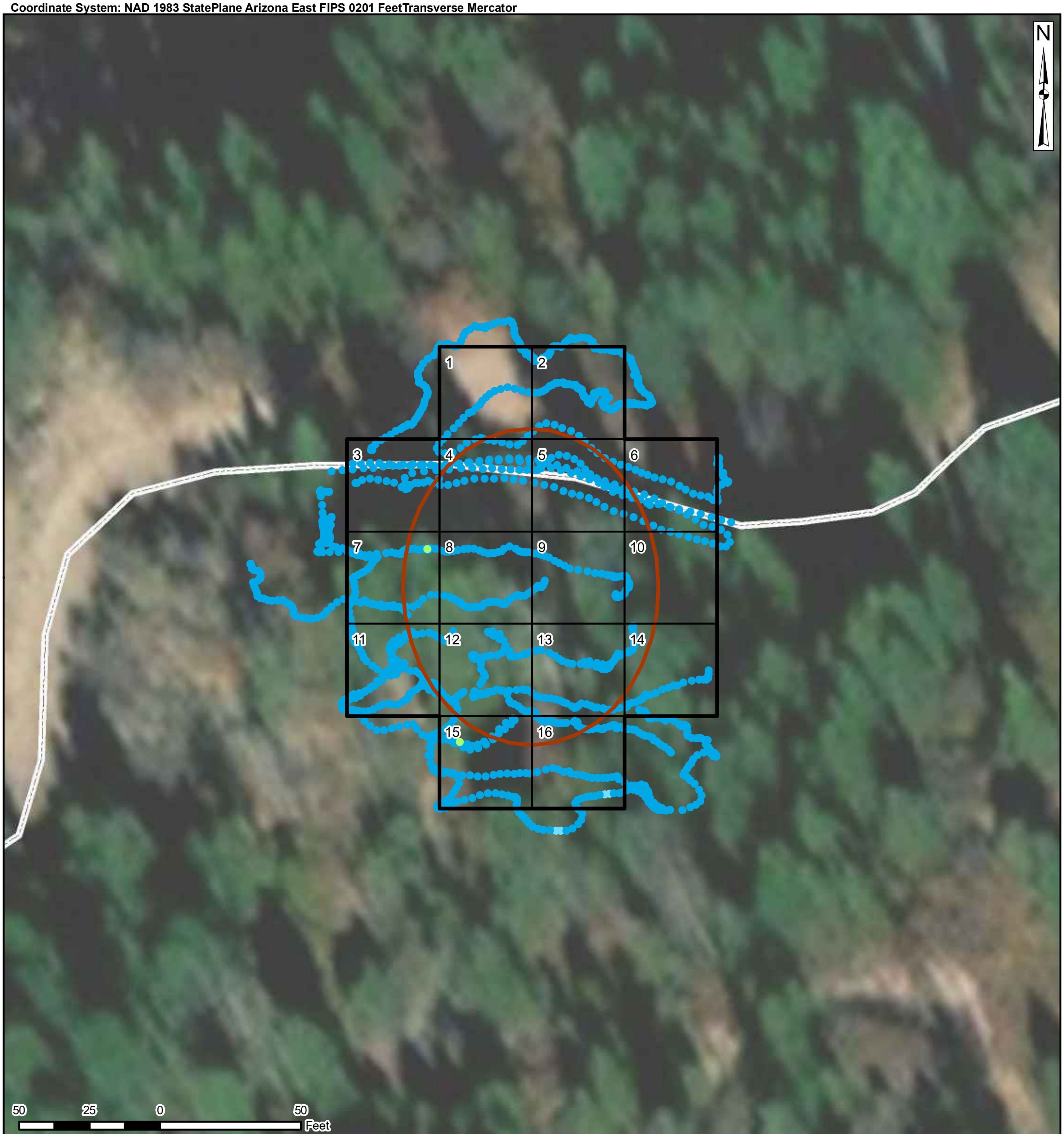
NON-AUM TARGET M1-08
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T31
Location: COVE CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

Non-AUM Target Site Boundary

Survey Unit (100 m²)

Survey Area Boundary

Access Route - Vehicular

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

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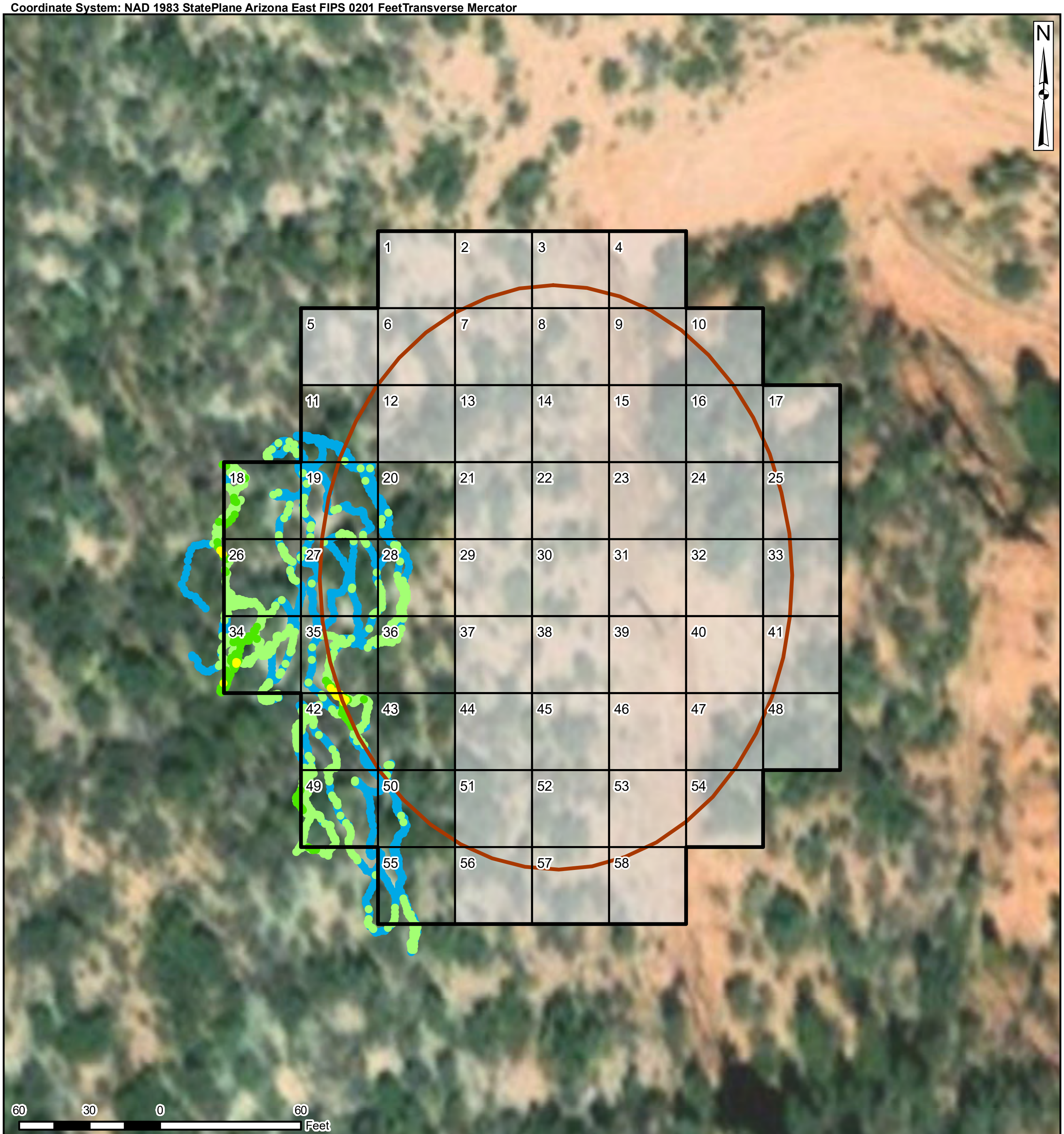
NON-AUM TARGET M2-01
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T32
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator



Gamma Exposure Rate (μR/hr)*

- ≤ 12
- 12 - 16
- 16 - 20
- 20 - 22
- 22 - 30
- 30 - 71
- 71 - 127
- 127 - 350
- ≥ 350

- Non-AUM Target Site Boundary
- Survey Unit (100 m²)
- Survey Area Boundary
- Inaccessible

*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
γ(μR/hour) = 8.476 + 0.000545 * (γ[cpm]).

Prepared for: USEPA Region 9

Prepared By:

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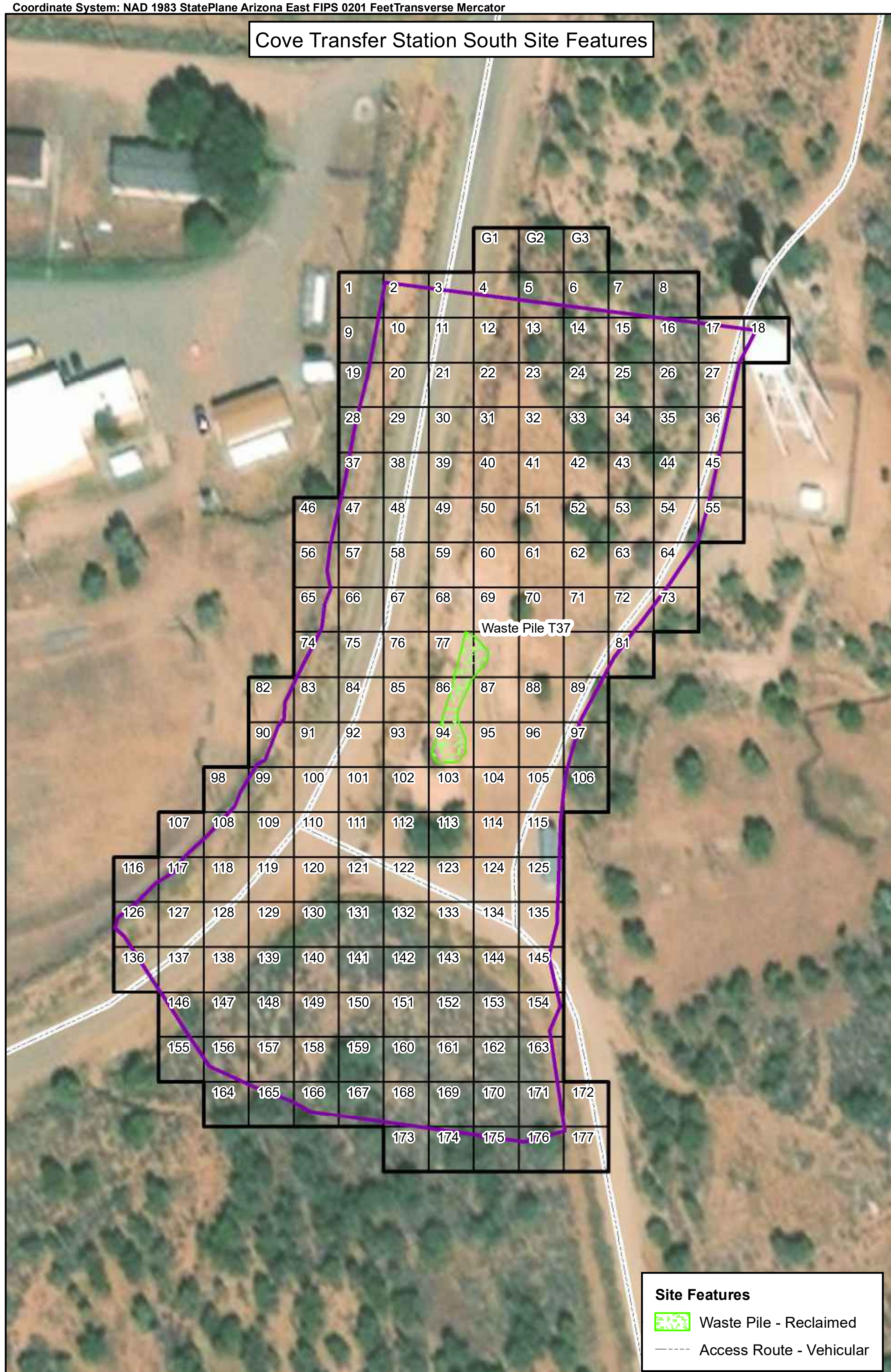
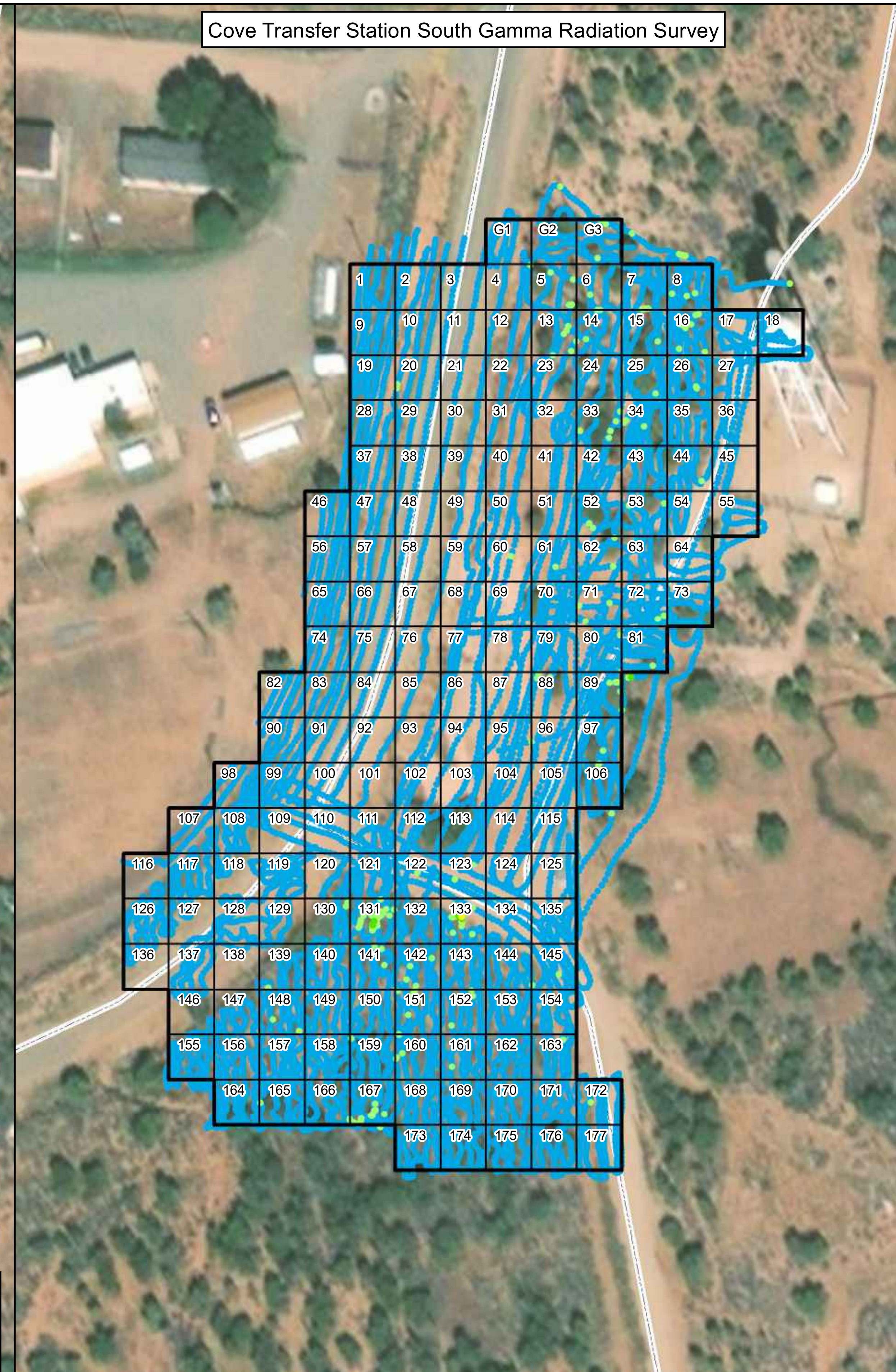
NON-AUM TARGET KE-01
GAMMA EXPOSURE RATE MAP

Task Order No.:	Contract No.:	Figure No.:
TO0001	EP-S9-17-03	T33
Location: LUKACHUKAI CHAPTER NAVAJO NATION	Date: 7/11/2019	

Coordinate System: NAD 1983 StatePlane Arizona East FIPS 0201 FeetTransverse Mercator





Gamma Exposure Rate (μR/hr)*

≤ 12	≤ Avg. BG
12 - 16	Avg. BG - 1 x BTV
16 - 20	1 x BTV - 2 x BTV
20 - 22	2 x BTV - 3 x BTV
22 - 30	3 x BTV - 4 x BTV
30 - 71	4 x BTV - 10 x BTV
71 - 127	≥ 10 x BTV
127 - 350	
≥ 350	

AUM Related Site Boundary

Survey Unit (100 m²)

Survey Area Boundary

1 in = 100 ft

1:1,200

0 50 100 200 Feet

N S E W

COVE TRANSFER STATION SOUTH
GAMMA EXPOSURE RATE MAP

Prepared For:

Prepared By:

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Task Order No.:	Contract No.:
TO0001	EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 7/22/2019

Notes:
*Gross gamma count rate measurements are converted to gamma expsure rate using the following equation:
$\gamma(\mu R/hour) = 8.476 + 0.000545 * (\gamma[cpm])$.

Figure No.: T37