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Investigation Work Plan for Guaje/Barrancas/Rendija Canyons Aggregate Area at Technical Area 00

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Prepared by
Environmental Stewardship–Environmental Remediation and Surveillance Program

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EXECUTIVE SUMMARY

This investigation work plan identifies and describes the activities needed to complete the investigation of solid waste management units (SWMUs) and areas of concern (AOCs) located within the Guaje/Barrancas/Rendija Canyons aggregate area of Technical Area (TA) 00 at Los Alamos National Laboratory. TA-00 is located in the northern portion of the Laboratory, north of Rendija Road and generally north of the Los Alamos townsite. This investigation work plan is required by the March 1, 2005, Compliance Order on Consent (the Consent Order) signed by the New Mexico Environment Department, the Department of Energy, and the University of California.

The Guaje/Barrancas/Rendija Canyons aggregate area consists of the following SWMUs and AOCs:

- SWMU 00-011(a), a mortar impact area
- SWMU 00-011(c), a possible mortar impact area
- SWMU 00-011(d), a bazooka firing area
- SWMU 00-011(e), an ammunition impact area
- AOC 00-015, a firing range (Sportsmen's Club)
- SWMU 00-016, an inactive firing range
- AOC C-00-020, a possible mortar impact area
- AOC 00-024, a cistern
- AOC 00-025, a landfill
- AOC C-0-041, an asphalt and tar remnant site

Although previous investigations have addressed AOCs 00-024, 00-025, and 00-026 together because of their similarities, AOC 00-026 has been assigned to the Bayo Canyon aggregate area and will be addressed in the "Bayo Canyon Aggregate Area Investigation Work Plan" (due to the New Mexico Environment Department on July 30, 2005). SWMU 00-011(d), which is also located in Bayo Canyon, has been included in this plan because the nature of historical activities at this site is very similar to those activities conducted at the munitions impact sites in Rendija Canyon.

This work plan proposes both characterization and remediation activities. The objectives of these activities are to (1) characterize contamination associated with the SWMUs/AOCs that are part of the Guaje/Barrancas/Rendija Canyons aggregate, and (2) reduce or prevent the migration of contamination by removing environmental media with contaminant concentrations exceeding soil screening levels for inorganic and organic chemicals.

The sites have been placed into three categories:

- The first category contains those sites that are administratively complete (i.e., have a no further action determination and, if necessary, have been removed from Module VIII of the Laboratory's Hazardous Waste Facility Permit). This category includes SWMU 00-016, AOC 00-024, and AOC 00-025. This work plan describes their operational history and provides documentation of their completion and removal from the permit.

- The second category contains sites for which characterization is proposed to determine the nature and extent of contamination and the potential need for corrective action. This category includes SWMU 00-011(a), SWMU 00-011(c), SWMU 00-011(d), SWMU 00-011(e), AOC C-00-020, and AOC C-00-041. This work plan describes the operational history of the sites, the results of previous sampling activities and currently available analytical data, and the proposed investigation activities. Munitions and explosives of concern surveys will be completed at these sites to verify similar surveys conducted in the early 1990s. Previous surveys at the two possible mortar impact areas [SWMU 00-011(c) and AOC C-00-020] did not find any evidence of former munitions firing (i.e., munitions debris). If no evidence of munitions and explosives of concern or munitions debris is found during the prescribed surveys, these two sites will not be characterized further. Soil samples will be collected at sites with past and current munitions and explosives of concern and munitions debris recovery to characterize the nature and extent of contamination. The sample results will be evaluated to determine whether nature and extent have been defined and whether any corrective action is warranted.

- The third category contains the one site that is still active, AOC 00-015, the Sportsmen's Club. This work plan describes the operational history of the site but does not present a plan for investigation. Instead, investigation of this site will be deferred until the site is no longer active because ongoing activities at the site affect the ability to perform a representative characterization. Deferring investigation of this site is consistent with the approach described in Section IV.A.5 of the Consent Order for deferring investigation of certain SWMUs and AOCs associated with active firing sites. When the site becomes inactive, an investigation work plan for AOC 00-015 will be submitted to NMED for review and approval. When it becomes inactive, the Department of Energy intends to transfer ownership of the land to the Los Alamos County. At that time, the County will determine the future land use for the site. One objective of the future investigation, therefore, will be to determine whether levels of contamination present at the site will be protective of the intended land use, as required by Section III.Y.1.b of the Consent Order.

Both munitions and explosives of concern and geophysical surveys will be used to identify and remove any remaining mortar, small arms ammunition, or munitions debris from sites that were former impact/firing areas [SWMUs 00-011(a), 00-011(d), and 00-011(e)]. Although previous surveys at SWMU 00-011(c) and AOC C-00-020 did not find any munitions and explosives of concern or munitions debris, new surveys will be conducted for verification.

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1.0 INTRODUCTION

Los Alamos National Laboratory (the Laboratory or LANL) is a multidisciplinary research facility owned by the U.S. Department of Energy (DOE) and managed by the University of California (UC). The Laboratory (Figure 1.0-1) is located in north-central New Mexico, approximately 60 mi northeast of Albuquerque and 20 mi northwest of Santa Fe. The Laboratory site covers 40 mi^2 of the Pajarito Plateau, which consists of a series of finger-like mesas separated by deep canyons containing perennial and intermittent streams running from west to east. Mesa tops range in elevation from approximately 6200 to 7800 ft. The Guaje/Barrancas/Rendija Canyons aggregate area is shown in Figure 1.0-2.

The Laboratory's Environmental Stewardship–Environmental Remediation and Surveillance (ENV-ERS) Program, formerly the Environmental Restoration (ER) Project, is participating in a national effort by DOE to clean up sites and facilities formerly involved in weapons research and development. The goal of the ENV-ERS Program is to ensure that DOE's past operations do not threaten human or environmental health and safety in and around Los Alamos County, New Mexico. To achieve this goal, the ENV-ERS Program investigates sites potentially contaminated by past Laboratory operations.

The sites addressed in this work plan contain hazardous components. Depending on the type of contaminant(s) and the history of a site, the New Mexico Environment Department (NMED) or DOE has administrative authority over work performed by ENV-ERS at each site. The New Mexico Environment Department has authority under the New Mexico Hazardous Waste Act (NMHWA) over cleanup of sites with hazardous waste or certain hazardous constituents, including the hazardous waste portion of mixed waste (i.e., waste contaminated with both radioactive and hazardous constituents). The U.S. Department of Energy has authority over cleanup of sites with radioactive contamination. Radionuclides are regulated under DOE Order 5400.5, "Radiation Protection of the Public and the Environment," and DOE Order 435.1, "Radioactive Waste Management."

Corrective actions at the Laboratory are subject to the Compliance Order on Consent (hereafter, the Consent Order) signed on March 1, 2005, by NMED, DOE, the Regents of the UC, and the State of New Mexico Attorney General. The Consent Order was issued pursuant to the NMHWA, New Mexico Statutes Annotated 1978, § 74-4-10, and the New Mexico Solid Waste Act, New Mexico Statutes Annotated 1978, § 74-9-36(D).

This work plan describes proposed work activities to be completed in accordance with the Consent Order. Appendix A includes a list of acronyms and abbreviations, a glossary, and a metric conversion table. Appendix B provides data from past investigations. Appendix C describes the management of investigation-derived waste (IDW). Appendix D describes site conditions in each of the canyons and watersheds. Appendix E contains the guidance documents referred to in Section 4.

1.1 General Site Information

The Guaje/Barrancas/Rendija Canyons aggregate area consists of the following solid waste management units (SWMUs) and areas of concern (AOCs):

- SWMU 00-011(a), a mortar impact area
- SWMU 00-011(c), a possible mortar impact area
- SWMU 00-011(d), a bazooka firing area
- SWMU 00-011(e), an ammunition impact area
- AOC 00-015, a firing range (Sportsmen's Club)

- SWMU 00-016, an inactive firing range
- AOC C-00-020, a possible mortar impact area
- AOC 00-024, a cistern
- AOC 00-025, a landfill
- AOC C-0-041, an asphalt and tar remnant site

These sites were formerly part of Operable Unit (OU) 1071 within Technical Area (TA) 00. The Laboratory began operations at TA-00 in 1943 and had largely ceased using this area by 1986. Figure 1.0-1 shows the Guaje/Barrancas/Rendija watershed area with respect to Laboratory technical areas and surrounding land holdings. Although previous investigations have addressed AOCs 00-024, 00-025, and 00-026 together because of their similarities, AOC 00-026 has been assigned to the Bayo Canyon aggregate area and will be addressed in the corresponding "Bayo Canyon Aggregate Area Investigation Work Plan." Therefore, this AOC is not discussed further in this work plan. SWMU 00-011(d), which is also located in Bayo Canyon, has been included in this plan because the nature of historical activities at this site is very similar to those activities conducted at the munitions impact sites in Rendija Canyon (SWMUs 00-011 and AOC C-00-020). The SWMU and AOC locations within watershed aggregate areas are shown in Figure 1.0-2.

1.2 Investigation Objectives

The objective of this investigation work plan is to characterize the nature and extent of contamination, if any, associated with the sites. Characterization includes conducting sampling, if necessary, and analysis of sampling results to evaluate the potential need for corrective action.

In order to accomplish the objectives, this plan

- presents historical and background information on the sites;
- describes the rationale for proposed data collection activities; and
- identifies and proposes appropriate methods and protocols for collecting, analyzing, and evaluating data to finalize characterization efforts at these sites.

The sites fall into three categories:

- The first category contains those sites that are administratively complete (i.e., have a no further action [NFA] determination and, if necessary, have been removed from Module VIII of the Laboratory's Hazardous Waste Facility Permit). This category includes SWMUs 00-016, 00-024, and 00-025. This work plan describes their operational history and provides documentation of their completion and removal from the permit.
- The second category contains sites for which characterization is proposed to determine the nature and extent of contamination and the potential need for corrective action. This category includes SWMU 00-011(a), SWMU 00-011(c), SWMU 00-011(d), SWMU 00-011(e), AOC C-00-020, and AOC C-00-041. This work plan describes the operational history of the sites, the results of previous sampling activities and currently available analytical data, and the proposed investigation activities. Munitions and explosives of concern (MEC) surveys will be completed at these sites to verify results from similar surveys conducted in the early 1990s. Previous MEC surveys at the two possible mortar impact areas [SWMUs 00-011(c) and AOC C-00-020] did not result in finding any evidence of former munitions firing (i.e., munitions debris [MD]). If no evidence of MEC/MD is found during the prescribed surveys, these two sites

will not be characterized further. Soil samples will be collected at sites with past and current MEC/MD recovery to characterize the nature and extent of contamination. The sample results will be evaluated to determine whether the nature and extent have been defined and whether any corrective action is warranted.

- The third category contains the one site that is still active, AOC 00-015, the Sportsmen's Club. This work plan describes the operational history of the site but does not present a plan for investigation. Instead, investigation will be deferred until the site is no longer active because ongoing activities at the site affect the ability to perform a representative characterization. Deferring investigation of this site is consistent with the approach described in Section IV.A.5 of the Consent Order for deferring investigation of certain SWMUs and AOCs associated with active firing sites. When the site becomes inactive, an investigation work plan for AOC 00-015 will be submitted to NMED for review and approval. When the site becomes inactive, DOE intends to transfer ownership of the land to the County of Los Alamos. At that time, the County will determine the future land use for the site. One objective of the future investigation, therefore, will be to determine whether levels of contamination present at the site will be protective of the intended land use, as required by Section III.Y.1.b of the Consent Order.

The screening and characterization activities presented in this plan are based on the requirements outlined in the Consent Order as well as the data needs identified for the SWMUs and AOCs.

2.0 BACKGROUND

2.1 Site Description and Operational History

The following sections describe the sites and summarize their operational histories since 1943.

2.1.1 SWMU 00-011(a)

SWMU 00-011(a) is a 28.5-acre former mortar impact area located on General Services Administration (GSA) land about 0.4 mi. east of the Sportsmen's Club firing range (AOC 00-015) in Rendija Canyon (Figures 1.0-2, 2.1-1, and 2.1-2).

- Mid-1940s—Site was used as a mortar impact area. It was the target area for 60-mm and 81-mm rounds.
- Late-1940s—Operations ceased (LANL 1990, 07511).
- Current—This SWMU is not within the area burned by the Cerro Grande fire in 2000. The site is fenced and posted with DOE "no trespassing" signs. However, trails are present within the SWMU boundary on the south side of Rendija Road (Forest Service Road 57).

2.1.2 SWMU 00-011(c)

SWMU 00-011(c) is a possible mortar impact area located on GSA and public land managed by the U.S. Forest Service (USFS) in a tributary of Rendija Canyon north of the Sportsmen's Club (AOC 00-015) (Figures 1.0-2, 2.1-3, and 2.1-4). The area is approximately 10 acres in size.

- 1940s—The site was possibly used as a mortar impact area (LANL 1990, 07511). There is no documentation available providing information on the duration of operations.
- Current—This SWMU is within the area burned by the Cerro Grande fire in 2000. Current site conditions include numerous downed burned trees, very little other vegetation, and several

archaeological sites under investigation. Public hiking trails run through and around the perimeter of the site.

2.1.3 SWMU 00-011(d)

SWMU 00-011(d) is a bazooka firing area largely on Los Alamos County land except for a small section on private property. The area is in a small north-trending tributary of Bayo Canyon northeast of the intersection of San Ildefonso Road and Diamond Drive (Figures 1.0-2, 2.1-5, and 2.1-6). The area is approximately 5 acres in size.

- Mid-1940s—The site was used as a target area for 2.36-in. bazooka rounds.
- Late-1940s—Operations ceased (LANL 1990, 07511).
- Current—This SWMU is not within the area that was burned by the Cerro Grande fire in 2000. The site is open to the public.

2.1.4 SWMU 00-011(e)

SWMU 00-011(e) is a former ammunition impact area located on GSA and USFS land in a tributary of Rendija Canyon north-northeast of the Sportsmen's Club (AOC 00-015). The area extends north along the tributary to the top of the cliff face (Figures 1.0-2, 2.1-7, and 2.1-8). The area is roughly rectangular and is approximately 14 acres in size.

- Mid-1940s—Site was used as an impact area. It was the target area for 20-mm and 37-mm rounds.
- Late-1940s—Operations ceased (LANL 1990, 07511).
- Current—This SWMU is not within the area burned by the Cerro Grande fire in 2000. Access to the site is limited. Active rifle firing areas at the Sportsmen's Club are in direct alignment with the site.

2.1.5 AOC 00-015

AOC 00-015 is the Sportsmen's Club small-arms firing range (SAFR), an active range located on GSA land in Rendija Canyon (Figures 1.0-2, 2.1-9, and 2.1-10). The Club is leased to a nonprofit group from DOE. The area is approximately 30 acres in size.

- 1966 to present—Operations started in 1966 and consist of several SAFRs built and operated by the Sportsmen's Club. Several different firing ranges are currently in operation, including pistol ranges, a skeet range, two trap ranges, and a rifle range. Each range also contains one or more earthen primary impact berms and lateral or side berms. The rifle range contains primary impact berms at 100-, 200-, and 300-yd distances (Figure 2.1-10). There are shattered clay targets present on the skeet and trap ranges and lead within the earthen berms and on the range surfaces.
- Current—This SWMU is not within the area burned by the Cerro Grande fire in 2000. The site is used as an outdoor SAFR and includes skeet, trap, pistol, rifle, and indoor firing ranges used by members of the nonprofit Sportsmen's Club.

2.1.6 SWMU 00-016

SWMU 00-016 is a former SAFR located on public land managed by the USFS in Rendija Canyon (Figure 1.0-2). The area is approximately 4 acres in size.

- 1947 to early 1960s—Atomic Energy Commission (AEC) security personnel used the site as a SAFR.
- Early 1960s to 1992—Public used the site for recreational shooting.
- 1990s—The Laboratory implemented voluntary corrective action (VCA) activities at the site during the period 1993 through 1997 to remove lead and lead-contaminated soil.
- 1999—The VCA Report and NFA recommendation were approved by NMED (NMED 1999, 64564).
- 2001—The site was removed from Module VIII by NMED (NMED 2001, 71256). Therefore, this SWMU is not discussed further in this work plan.

2.1.7 AOC C-00-020

AOC C-00-020 is a 30-acre possible mortar impact area located along the north valley wall of Rendija Canyon on USFS land (Figures 1.0-2, 2.1-11, and 2.1-12). The site also includes a northern tributary of Rendija Canyon. Most of the site lies within the Santa Fe National Forest except for a small area on the southeastern edge that is private property. This site was suspected to be a former mortar impact area because of a "U.S. Property—No Trespassing" sign and nearly illegible, bilingual signs posted along the southern edge of the area. The "No Trespassing" signs are not currently posted and were only posted for a short time in the early 1940s (LANL 1992, 07667, p. 5-26).

- Early 1940s—The site was possibly used as a mortar impact area.
- Current—This AOC is within an area burned by the Cerro Grande fire in 2000. The stream channel that runs through the center of the site has been widened by flooding. There are burned and live trees on the steep slopes adjacent to the stream.

2.1.8 AOC 00-024

AOC 00-024 was a cistern located on private property on Barranca Mesa. It was an unlined hole in the Bandelier Tuff with a wood cover (Figure 1.0-2).

- Pre-1965—The cistern was used as a disposal site for expended munitions and gun components (LANL 1992, 07667, p. 6-3).
- 1965—The entire contents of the cistern were removed (LANL 1992, 07667, p. 6-3).
- 1992—AOC 00-024 was recommended for NFA in the OU 1071 Resource Conservation and Recovery Act (RCRA) field investigation (RFI) work plan (LANL 1992, 07667).
- 1993—The work plan and NFA recommendation were approved by the Environmental Protection Agency (EPA) (EPA 1993, 15110).
- 2005—The NFA determination was later confirmed by EPA in a letter to NMED (EPA 2005, 88464). Therefore, this AOC is not discussed further in this work plan.

2.1.9 AOC 00-025

AOC 00-025 was the Tank Mesa "landfill," a possible waste disposal area. Tank Mesa, currently named Otowi Mesa, is located between Barrancas and Bayo Canyons at the east end of Barranca Mesa (Figure 1.0-2). The landfill was never located (LANL 1992, 07667, p. 6-4). Documentation providing the approximate years of operation is not available.

- 1992—AOC 00-025 was recommended for NFA in the OU 1071 RFI work plan (LANL 1992, 07667).
- 1993—The work plan and NFA recommendation were approved by EPA (EPA 1993, 15110).
- 2005—The NFA determination was confirmed by EPA in a letter to NMED (EPA 2005, 88464). Therefore, this AOC is not discussed further in this work plan.

2.1.10 AOC C-00-041

AOC C-00-041 was the site of a former asphalt batch plant in a 50- by 600-ft portion of a side slope and drainage channel that flows into Rendija Canyon on USFS land (Figures 1.0-2, 2.1-13, and 2.1-14).

- Late 1940s to 1958—Aerial photographs show evidence of asphalt plant operations (LANL 1996, 54925, p. 1).
- 1969—Land was transferred from the AEC to the USFS to manage as public land after the plant had been removed (LANL 1996, 54925, p.1).
- Current—The site is currently undeveloped public land.

2.2 Land Use

Current use of the sites is recreational. The only site being used consistently and almost daily is the Sportsmen's Club (AOC 00-015), a SAFR open to members of a nonprofit group. In the future, proposed land transfer may result in changes in land use, possibly to commercial or residential.

2.3 Conceptual Site Model

The sampling proposed in this plan uses a conceptual site model to predict areas of potential contamination and allow for adequate characterization of these areas. A conceptual site model describes potential contaminant sources, transport mechanisms, and receptors.

2.3.1 Potential Contaminant Sources

Releases at the sites occurred as a result of asphalt plant operations, mortar rounds, small arms rounds, and general ordnance (both exploded and unexploded) used at the impact sites and firing ranges. Those sites that have been sampled indicate high explosives (HE) are not present in surface samples collected from portions of drainage channels, but further sampling is necessary to determine inorganic chemical, HE, semivolatile organic compounds (SVOCs), and possible perchlorate extent.

2.3.2 Potential Contaminant Transport Mechanisms

Current potential transport mechanisms that may lead to exposure of potential receptors include

- dissolution and/or particulate transport of surface contaminants during precipitation and runoff events,
- airborne transport of contaminated surface soils,
- continued dissolution and advective/dispersive transport of chemical contaminants contained in subsurface soil and bedrock as a result of past asphalt plant operations or ordnance and ammunition use, and
- disturbance and uptake of contaminants in shallow soil by plants and animals.

2.3.3 Current and Future Potential Contaminant Receptors

Potential receptors of possible contaminants at all sites include

- residents,
- users of the Sportsmen's Club,
- trail users in the canyons and on the mesas, and
- plants and animals both on-site and in areas immediately surrounding the sites.

2.4 Previous Site Investigations

2.4.1 SWMU 00-011(a)

In 1993, RFI activities included identifying and removing unexploded ordnance (UXO) and MD, performing a geophysical survey to complete a quality assurance/quality control (QA/QC) check of the UXO/MD removal activities, mapping the geomorphology, and collecting surface soil and quaternary alluvium (QAL) samples. The SWMU boundary was determined by adding new areas (lanes) to search until no UXO/MD were found in the outermost lane, and no additional UXO/MD were found within 50 ft in all directions of the outermost MD fragments. If no UXO/MD were found, the innermost edge of the lane was considered the final boundary. If UXO/MD were found during the UXO sweep or geophysical survey, the entire lane would be reswept and the boundaries adjusted as necessary (LANL 1994, 59427, p. 8). Two live HE mortar rounds (60-mm and 81-mm) were found and destroyed without incident. After the detonations, the resulting MD was recovered (LANL 1994, 59427, p. 8). Other materials recovered during the ordnance sweep included almost 2400 pieces of ordnance fragments and three times as many pieces of scrap material (Figure 2.1-2). The locations of recovered fragments indicated that there was more than one firing point and that these firing points were located on the south side of the canyon floor (LANL 1994, 59427, p. 8). Two burial pits containing mostly tires and UXO/MD were excavated and cleaned out (EHSI 1994, 59057, p. 1).

Geomorphic mapping included mapping all drainage channels that drained the area enclosed within the boundaries of the site and the areas with high concentrations of ordnance fragments. Sampling locations were selected from sediment catchment areas within the drainage channels that drained the areas of high fragment concentration. Soil and QAL samples were collected from 18 locations (locations 00-01201 through 00-1218) and field screened for radioactivity (Figure 2.1-2). These samples were analyzed for inorganic chemicals on-site by the Chemical Sciences and Technology (CST) Division of the Laboratory. High explosives analyses were completed at an off-site fixed laboratory. Sampling results are presented in Section 2.5.1. The RFI report requested NFA and approval of the site for future residential use (LANL 1994, 59427, p. 8-10). The RFI report was approved by EPA in 1994 (EPA 1994, 62098). The Laboratory submitted a Class III permit modification request to NMED in June 2001 to remove SWMU 00-011(a) from Module VIII (LANL 2001, 71096).

2.4.2 SWMU 00-011(c)

In 1993, RFI activities included conducting an ordnance sweep followed by a geophysical QA/QC sweep. Ordnance surveys at the site found scrap metal such as bailing wire and tin cans. Because there was a complete absence of MD, it was assumed that the site was never used as an ordnance impact area. The RFI report requested NFA (LANL 1994, 59427, p. 13 and 14). The RFI report was approved by EPA in 1994 (EPA 1994, 62098).

2.4.3 SWMU 00-011(d)

In 1992 and 1993, RFI activities included identifying and removing UXO and MD, performing a geophysical survey to complete a QA/QC check of the UXO/MD removal activities, mapping the geomorphology, and collecting soil and sediment samples. The MD recovered was 2.36-in. bazooka round fragments, including fin assemblies, motors, bullets, and miscellaneous pieces as well as one partly intact round (LANL 1994, 59427, p. 15).

Geomorphic mapping of the impact area included mapping the surficial, unconsolidated sediment at the site and mapping the drainage channels that would likely be pathways for the surficial transport of contaminants. Sediment catchment areas along both the drainage channels on the hillslope below the cliff and along the axial drainage channels were selected for sampling because they were the areas with the highest probability of contaminant transport from the impact zone by surface water runoff (LANL 1994, 59427, p. 15). Soil and sediment samples were collected from seven locations (locations 00-01050 through 00-01056) and were field screened for radioactivity (Figure 2.1-6). These samples were analyzed for inorganic chemicals on-site by CST. The results of HE analyses were not usable because of exceedance of holding times. Therefore, 13 additional soil and sediment samples were collected later in 1993 from the same locations and from two additional locations, 00-01057 and 00-01058. These samples were analyzed for lead at CST on-site and for HE at an off-site fixed laboratory. Sampling results are presented in Section 2.5.2. The RFI report requested NFA and recommended that Los Alamos County remove the fence from the site boundary and open the area to the public (LANL 1994, 59427, pp. 15–18). The RFI Report was approved by EPA in 1994 (EPA 1994, 62098). The site remains open today.

2.4.4 SWMU 00-011(e)

In 1993, RFI activities included identifying and removing UXO and MD, performing a geophysical survey to complete a QA/QC check of the UXO/MD removal activities, mapping the geomorphology, and collecting shallow surface soil and sediment samples. The SWMU boundary was determined by adding new areas (lanes) to search until no UXO/MD were found in the outermost lane, and no additional UXO/MD were found within 50 ft in all directions of the outermost MD fragments. If no UXO/MD were found, the innermost edge of the lane was considered the final boundary. If UXO/MD were found during the UXO sweep or geophysical survey, the entire lane was reswept and boundaries adjusted as necessary (LANL 1994, 59427, p. 8). During the ordnance sweep, the materials recovered were primarily 37-mm rounds and fragments. The recovered MD included two 20-mm rounds, 102 armor piercing rounds, and fragments of an indeterminate number of 37-mm HE rounds (Figure 2.1-8). Recovered rounds were detonated within the main ordnance impact area of the site. After each of the detonations, the resulting MD was recovered (LANL 1994, 59427, p. 24).

Geomorphic mapping included mapping all of the drainage channels that drained the area within the boundaries of the site and areas that contained high concentrations of ordnance fragments. Sediment catchment areas along the drainage channels of the hillslope below the cliff and within and directly below the main impact zone were selected for sampling because they were areas with the highest probability of contaminant transport from the SWMU by surface water runoff (LANL 1994, 59427, p. 24). Samples were collected from eight locations from surface soils and selected sediment traps (locations 00-01219 through 00-01226) and field screened for radioactivity (Figure 2.1-8). These samples were analyzed for inorganic chemicals on-site by CST. High explosives analyses were completed at an off-site fixed laboratory. Sampling results are presented in Section 2.5.3. The RFI report requested NFA and approval for residential use (LANL 1994, 59427, pp. 22–27). The RFI report was approved by EPA in 1994 (EPA 1994, 62098). The Laboratory submitted a Class III permit modification request to NMED in June 2001 to remove SWMU 00-011(e) from Module VIII (LANL 2001, 71096).

2.4.5 AOC 00-015

In 1992, the OU 1071 RFI work plan recommended that no action be taken at this site until the firing range ceased operation and the land use changed (LANL 1992, 07667, p. 6-3). This work plan was subsequently approved by EPA (EPA 1993, 15110). No sample collection or remedial actions have been conducted at the site.

2.4.6 AOC-C-00-020

- 1991—An ordnance team from Fort Bliss, Texas, inspected the area and concluded that it was not a former impact area. However, because the arrangement of the "no trespassing" signs and the canyon geometry was similar to that found at SWMUs 00-011(c) and 00-011(d), the area was retained as an AOC (LANL 1992, 07667, p. 5-26).
- 1993—RFI activities included conducting an ordnance sweep followed by a geophysical QA/QC sweep. No ordnance, MD, or UXO were located. The geophysical survey found anomalies that turned out to be rocks and some pieces of tin. The RFI phase report recommended the site be designated for NFA and requested approval for residential land use (LANL 1994, 59427, pp. 28 and 29).

2.4.7 AOC C-00-041

- 1995—The USFS requested that DOE remediate the site per USFS regulations. Additionally, the NMED Surface Water Bureau considered the asphalt to be refuse in a watercourse and recommended its removal (LANL 1996, 54925, p.1). A VCA was conducted that included collecting samples to characterize the site before remediation activities were performed. Water, soil, and/or tar were sampled for site characterization at five locations (locations 00-03745 through 00-03749), and analyzed for RCRA metals, volatile organic compounds (VOCs), SVOCs, total petroleum hydrocarbons (TPH), polychlorinated biphenyls (PCBs), and pesticides (LANL 1996, 54925, p. 1). One tar sample was analyzed for RCRA metals and for waste characterization using the toxicity characteristic leaching procedure (TCLP). Asphalt was generally confined to the stream channel. A horizontal layer of asphalt, varying in thickness from 0.5 to 8 in., was found at a depth of 3 to 4 ft. Excavation removed most of this layer. However, excavation stopped when the remaining asphalt had thinned to a layer 1/16 to 1/4 in. thick by 3 ft wide at a depth of 4 ft beneath a cover of soil and vegetation and could not be excavated further with the backhoe (LANL 1996, 54925, p. 2). Approximately 300 yd^3 of material were excavated and taken to the Los Alamos County landfill for disposal. Robert Remillard of the USFS Los Alamos Area Office declared that the USFS was satisfied with the work at the site (LANL 1996, 54925, p. 2). Completion concurrence is currently pending with the DOE.
- 1999—After public users of the area complained about tar and asphalt remaining on-site, a field inspection was conducted in the area. As a result, a small amount of visible tar/asphalt was removed from the drainage channel, a standpipe drain was installed downstream of the Ponderosa Estates subdivision to control storm event runoff into the drainage channel, and rock-check dams were installed in the drainage channel. The standpipe drain was designed to use the natural drainage basin downstream of the subdivision as a storm water retention area and to dissipate flow from large runoff events into the drainage channel where this AOC was located (Veenis 1999, 69722).
- May 2005—The Laboratory constructed additional rock-check dams and other erosional control measures along the watercourse.

2.5 Data Evaluation

In 1993 and 1994, soil, sediment, and/or QAL samples were collected at SWMUs 00-011(a), 00-011(d), and 00-011(e) and analyzed for inorganic chemicals on-site by CST. The samples were analyzed for HE by an off-site laboratory. The QA/QC data for validation of the CST data are incomplete. Therefore, inorganic chemical data cannot be used to quantitatively determine the nature and extent of contamination at the SWMUs, but this extent can be qualitatively summarized. High explosives were analyzed at an off-site laboratory and have adequate QA/QC data. No HE was detected. Because HE was not detected and the inorganic chemical data cannot be used for decision making because of incomplete QA/QC data, these data are not presented in tables or figures in this report. High explosives data are included in Appendix B. At AOC C-00-041, three soil samples were collected from locations where soil and tar have been subsequently removed. Therefore, these soil sample analytical results are not indicative of current conditions and are not used to determine nature and extent. Sampling has not been conducted at SWMU 00-011(c), AOC 00-015, or AOC C-00-020; therefore, there are no sample results to discuss.

2.5.1 SWMU 00-011(a)

Site soil and QAL samples were collected at SWMU 00-011(a) and analyzed for HE and inorganic chemicals (Figure 2.1-2). High explosives were analyzed at an off-site fixed laboratory but were not detected in any sample. Screening-level evaluation of inorganic chemical data analyzed by CST indicates that the majority of the inorganic chemicals detected were collected in QAL samples (Figure 2.1-2, locations 00-01202 and 00-01203). However, no background data are available for comparison. Cobalt and lead were detected at concentrations greater than the soil background value (BV) (LANL 1998, 59730) in 2 out of 18 samples (Figure 2.1-2, locations 00-01208 and 00-01209). The cobalt concentration was within the range of background levels, while lead slightly exceeded the background level range (the site concentration was 29 mg/kg; the background level maximum is 28 mg/kg [LANL 1998, 59730]). Although sampling locations were selected from sediment storage locations within the drainage channels that drained the areas of high fragment concentration, samples were not collected from areas where ordnance fragments were previously removed (Figure 2.1-2). Additionally, the inorganic chemical analyses were performed on-site by CST and do not have adequate QA/QC information available for validation. Therefore, nature and extent have not been defined at this SWMU.

2.5.2 SWMU 00-011(d)

Site soil and sediment samples were collected at SWMU 00-011(d) and analyzed for HE and inorganic chemicals. High explosives were analyzed at an off-site fixed laboratory but were not detected in any sample. Evaluation of screening-level inorganic chemical data analyzed by CST indicates that 22 out of 26 inorganic chemicals analyzed were detected at concentrations greater than the soil and/or sediment BVs (LANL 1998, 59730). Twelve of the inorganic chemicals exceeded the maximum range of the soil and/or sediment background level data set (LANL 1998, 59730): aluminum, arsenic, barium, chromium, cobalt, copper, iron, lead, potassium, sodium, vanadium, and zinc. Some of these chemicals are found at the farthest downslope location (Figure 2.1-6, location 00-01056). Additionally, the inorganic chemical analyses were performed on-site by CST and do not have adequate QA/QC information available for validation. Therefore, nature and extent have not been defined for inorganic chemicals at this SWMU.

2.5.3 SWMU 00-011(e)

Site soil and sediment samples were collected at SWMU 00-011(e) and analyzed for HE and inorganic chemicals. High explosives were analyzed at an off-site fixed laboratory but were not detected in any sample. Screening-level evaluation of inorganic chemical data analyzed by CST indicates that only zinc was detected at concentrations greater than the soil BV (LANL 1998, 59730) in one out of eight samples (Figure 2.1-8, location 00-01219). Although sampling locations were selected from sediment storage locations within the drainage channels that drained the areas of high fragment concentration, samples were not collected from areas where ordnance fragments were removed previously (Figure 2.1-8). Additionally, the inorganic chemical analyses were performed on-site by CST and do not have adequate QA/QC information available for validation. Therefore, nature and extent have not been defined at this SWMU.

3.0 SITE CONDITIONS

Site conditions for Guaje, Bayo, Barrancas, and Rendija Canyons (the North Canyons) are reported in the North Canyons work plan (LANL 2001, 72714) and are presented in detail in Appendix D. This appendix

- describes the environmental settings of Guaje, Bayo, Barrancas, and Rendija Canyons;
- summarizes existing information relevant to the characterization of the northern canyons systems;
- identifies additional information needed to expand the conceptual understanding of the environmental processes that occur within the systems and to assess the magnitude and importance of potential exposure pathways within the canyon systems; and
- provides the technical basis for the conceptual model, described in Chapter 4 of the North Canyons work plan.

The following sections summarize the current surface features and the existing subsurface geologic characteristics beneath the sites in Guaje, Bayo, Barrancas, and Rendija Canyons. Known surface and subsurface traits and their potential effects on the occurrence and concentration of contaminants include

- canyon-mesa terrain, which affects meteorological conditions and ecological habitats at the surface;
- a semiarid climate with low precipitation and a high evapotranspiration rate, which limits the extent of subsurface moisture percolation and limits the amount of moisture available to leach radionuclides or other hazardous waste constituents; and
- a thick, relatively dry unsaturated (vadose) zone, which greatly restricts or prevents downward migration of contaminants in the liquid phase through the vadose zone to the regional aquifer.

These, and other elements of the environmental setting, are useful in evaluating site investigation data with respect to the potential impacts of contamination from historical site activities.

3.1 Surface Conditions

3.1.1 Current Site Topography and Topographic Drainages

Guaje Canyon

Guaje Canyon is the northernmost canyon discussed in this work plan. The watershed drainage is approximately 16.9 mi^2. The watershed heads on the flanks of the Sierra de los Valles at an elevation of 10,497 ft. The Guaje Canyon channel extends east-southeast for approximately 16.4 mi to its confluence with Los Alamos Canyon at an elevation of approximately 5660 ft (LANL 1997, 62316, p. 3-2). The Guaje Canyon channel traverses predominately USFS land except for the lower 2.3 mi, which are within *San Ildefonso Pueblo*. The Guaje Canyon watershed primarily drains USFS land.

Three named tributaries are present in upper Guaje Canyon on the flanks of the Sierra de los Valles; each canyon trends northwest to southeast. Aqua Piedra Canyon is approximately 3.0 mi long and has a watershed area of 1.61 mi^2. Aqua Piedra Spring is located in the middle part of Aqua Piedra Canyon. Caballos Canyon is approximately 2.9 mi in length and contains another tributary canyon called Vallecitos Canyon, which is the westernmost tributary to Guaje Canyon, and extends for approximately 1.7 mi to the confluence with Caballos Canyon. Vallecitos and Caballos Canyons contain ephemeral streams, receiving snowmelt and storm water runoff from watershed areas of 1.2 and 1.5 mi^2, respectively.

In addition to the named tributaries, two unnamed tributaries of significance to Guaje Canyon are present in the middle and lower sections of its watershed. The "south fork" of Guaje Canyon extends for approximately 1.3 mi on the north side of Guaje Ridge and enters Guaje Canyon from the southwest. The "north fork" of Guaje Canyon extends for about 2.3 mi parallel to Guaje Canyon on the north and enters Guaje Canyon from the north-northeast. These tributaries contain ephemeral streams and occasionally contribute flow to Guaje Canyon. The lower reaches of Guaje Canyon also receive runoff from Rendija and Barrancas Canyons.

Barrancas Canyon

Barrancas Canyon has a relatively small drainage area of 4.9 mi^2 that heads on the northern Pajarito Plateau east of Barranca Mesa at an elevation of 7278 ft (LANL 1997, 62316, p. 3-2). The canyon extends east-southeast approximately 5.5 mi to its confluence with Guaje Canyon at an elevation of 5860 ft (LANL 1997, 62316, p. 3-2).

The main Barrancas Canyon channel crosses approximately 1.6 mi of Los Alamos County land, 0.4 mi of USFS land, 2.7 mi of Laboratory property, and 0.7 mi of San Ildefonso Pueblo land. The Barrancas Canyon watershed contains three unnamed tributaries. The southernmost tributary (the "south fork") intersects the Barrancas Canyon channel about 0.66 mi west of the Guaje Canyon confluence and is about 1 mi long. The south fork is located predominately on Laboratory property within TA-74. Two longer tributaries north of the main Barrancas Canyon channel extend east from Deer Trap Mesa approximately 2.7 mi (middle fork) and 2.9 mi (north fork) before merging and continuing an additional 1.9 mi to the main Barrancas Canyon channel. These northern tributaries are mostly within USFS land but the headland areas are within Los Alamos County land.

Bayo Canyon

Bayo Canyon has a relatively small drainage area of 4.0 mi^2 and heads on the Pajarito Plateau in a residential area of Los Alamos at an elevation of approximately 7400 ft (LANL 1997, 62316, p. 3-2). The canyon extends east-southeast between North Mesa on the south and Barranca and Otowi Mesas on the north for a distance of approximately 8.2 mi to its confluence with Los Alamos Canyon. The elevation at the confluence is approximately 5790 ft (LANL 1997, 62316, p. 3-2).

Bayo Canyon contains an ephemeral stream. Most surface water flow occurs after heavy summer rains and is generally short in duration (less than 2 hr). There are currently no effluent discharges in Bayo Canyon (Purtymun 1995, 45344, p. 43). The channel traverses approximately 3.47 mi of Los Alamos County land, 3.12 mi of Laboratory property (TA-74), and 1.66 mi of San Ildefonso Pueblo land on its way to its confluence with Los Alamos Canyon (LANL 1997, 62316, p. 3-2). The watershed has an unnamed tributary (the "south fork of Bayo Canyon") on Laboratory property approximately 1.9 mi from the confluence with Los Alamos Canyon. Another unnamed tributary in the western part of the watershed between Camino Encantada and Barranca Mesa is called the "north fork of Bayo Canyon."

Rendija Canyon

Rendija Canyon is located immediately north of the Los Alamos townsite. The watershed has a drainage area of 9.5 mi^2. The canyon heads on the flanks of the Sierra de los Valle just west of the townsite at an elevation of 9826 ft. The canyon contains an ephemeral stream channel that extends approximately 9 mi east to its confluence with Guaje Canyon. The lowest elevation of the watershed is approximately 6300 ft (LANL, 1997, 62316, p. 3-2).

Rendija Canyon primarily crosses USFS land except for approximately 1.6 mi of the middle portion of the canyon that crosses GSA land. Parcels of private land and Los Alamos County land, such as the Guaje Pines Cemetery, are located in Rendija Canyon along the north side of the Los Alamos townsite. One named tributary, Cabra Canyon, enters the Rendija Canyon channel from the north in the central portion of the watershed. Cabra Canyon trends northwest-southeast, is approximately 2 mi long, has a watershed area of 1.2 mi^2, and is on USFS and GSA land. Three unnamed tributaries to Rendija Canyon are located west of Cabra Canyon and drain south-southeast into the main Rendija Canyon channel. These tributaries are approximately 1.5, 2.0, and 1.2 mi long.

3.1.2 Features and Structures

Man-Made Drainages

Man-made alterations to the Bayo, Rendija, and Guaje Canyon watersheds likely have changed the channel and drainage pathways in these canyons. Anthropogenic impact to the canyon floors and drainage has occurred from the installation of the roads serving these canyons, construction of sewers and water-supply pipelines for the Los Alamos townsite, and from Laboratory activities conducted within some of the watersheds. Within Guaje Canyon, additional changes have resulted from the installation of Guaje Reservoir and municipal water supply wells and pumping stations.

Vegetation

Vegetation generally includes a ponderosa pine-mixed conifer series in the higher, western portions of the watersheds and a piñon-juniper series in the lower, eastern portions of the watersheds (Biggs 1993, 48979).

Bayo Canyon is characteristic of the lower, eastern portions of the other three watersheds. The steep-sided and narrow upper part of Bayo Canyon is relatively moist and cool and supports a pine-fir forest. As the canyon widens, the pine-fir overstory thins and is restricted to the north-facing slope of Kwage Mesa. The canyon bottom supports many ponderosa pine trees, except in the vicinity of the old firing sites, where all vegetation was removed during the period of active site operation. Ponderosa pine woodland gives way to a piñon-juniper woodland on the drier south-facing slope of Otowi Mesa (Ferenbaugh et al. 1982, 06293).

Erosional Features and Sediment Transport

Recent sedimentation and degradation rates vary within each watershed and have not been fully identified. Localized aggradation and degradation processes may occur to raise or incise a specific interval of the streambed. In Bayo Canyon, sediments deposited since the 1950s range from 0.5 to 2 ft and include fragments of Laboratory debris. Sediments appear to cycle through Bayo Canyon every 100 to 1000 years. Tributary drainages exhibit additional cycles of erosion and deposition occurring on a time scale of tens to hundreds of years (Drake and Inoue 1993, 53456, pp. 1, 6, and 27).

The upper portions of the Guaje Canyon and Rendija Canyon watersheds burned extensively during the Cerro Grande fire in May 2000 (BAER 2000, 68662). Hydrologic changes caused by the fire have increased sediment load, peak flood discharges, and runoff volumes in these canyons. Postfire floods have already contributed to significant channel erosion in some places and sediment aggradation in others, and additional channel changes are likely in the next several years.

Barrancas Canyon and its tributaries have not been significantly impacted by Laboratory operations or other historic activities, with the exception of grazing and logging, and the canyon may be in a relatively natural state.

Basins

There are several structural basins located within the watersheds. These basins are discussed in detail in Appendix D, p. 3-45.

3.1.3 Current Site Usage and Operations

Current site usage and operations are described in Section 2.1 of this work plan.

3.1.4 Influential Features in Surrounding Sites

Sediment Transport and Surface Water Runoff

The water flowing through the North Canyons is used by plants, may be used by wildlife, and potentially may be used by humans; therefore, surface water constitutes a potential contaminant transport pathway to receptors. Surface water flow also provides one of the primary mechanisms for redistributing contaminants that may be present in the North Canyons. Normal precipitation and runoff in the watershed preclude a transport mechanism for contaminant migration to the top of the Puye Formation (Mayfield et al. 1979, 11717, pp. 50 and 58).

3.2 Subsurface Conditions

3.2.1 Subsurface Investigations

Subsurface investigations conducted to a limited extent in middle Bayo Canyon at former TA-10 site and in a small area in middle Guaje Canyon provide information on potential alluvial groundwater. The results of past investigations (see Appendix D, Section 3.4.4) provide the background of conditions needed to assess the importance of contaminant transport pathways. In 1961, four test holes were drilled in middle Bayo Canyon to determine if shallow groundwater was present at the former TA-10, Bayo site. Three test holes were drilled into the top of the Puye Formation to a maximum depth of 88.9 ft. Alluvium was reported to be 5 to 16 ft thick above the tuff in these holes. There was no indication of perched water or excessive moisture in the tuff above the Puye Formation. No contaminant analyses were performed on these samples. Subsurface investigations have not been conducted in Barrancas or Rendija Canyons.

3.2.2 Relevant Soil Horizons

Bayo Canyon is the smallest (in area) of the four northern canyons. The canyon heads in unit Qbt 3 of the Tshirege Member of the Bandelier Tuff, where the channel gradient is about 6.7%. As the canyon cuts through the Cerro Toledo interval and into the more erodible Otowi Member approximately 2 mi downstream, the gradient decreases to about 3%. Approximately 1.9 mi further downstream the channel incises the Puye Formation fanglomerates, and the gradient increases again to about 5%. Bayo Canyon is incised into the upper Santa Fe Group for a short distance upstream of the confluence with Los Alamos Canyon.

Barrancas Canyon is the shortest of the four northern canyons discussed in this work plan. The total change in elevation from the head of Barrancas Canyon to its confluence with Guaje Canyon is about 1370 ft. The canyon heads in the Tshirege Member of the Bandelier Tuff. The relatively steep and narrow upper portion of the canyon cuts through Tshirege units Qbt 2 through Qbt 1v, and the gradient in the upper portion is about 5%. The channel then cuts through the Cerro Toledo interval and into the Otowi Member, where the gradient decreases slightly to about 4%. About 1.3 mi further downstream, the channel is incised into Tertiary sediments of the Puye Formation, and from that point to Guaje Canyon the gradient averages about 3.3%.

The upper reach (~0.6 mi) of Rendija Canyon is cut into lava flows and associated rocks of the Tschicoma Formation on the flanks of the Sierra de los Valles. Beginning about 13.5 km upstream from the confluence with Guaje Canyon, the channel cuts into the Bandelier Tuff, including tephras and volcaniclastic sediments of the Cerro Toledo interval. The channel is incised into the Puye Formation about 3 mi upstream from Guaje Canyon (Reneau and McDonald 1996, 55538, Figure 2-18). Exposures of the relatively erodible Otowi Member of the Bandelier Tuff and Cerro Toledo interval pumice deposits, for example, have led to extensive lateral stream erosion and development of relatively broad stream terraces. Where the Puye Formation is exposed, the gradient increases, the channel becomes more incised, and terraces are narrower (Reneau and McDonald 1996, 55538). The total change in elevation from the head of Rendija Canyon to its confluence with Guaje Canyon is 3530 ft, and the average gradient is 7.4%. The gradient varies significantly, largely in response to changes in lithology along the length of the canyon. In the upper reach where the Tschicoma Formation is exposed, the gradient is about 15%, and the canyon is narrow and steep-sided. Where the canyon floor consists of the Tshirege Member of the Bandelier Tuff, the gradient is more moderate, ranging from about 8% to 5%. In the Otowi Member and the Cerro Toledo interval, the gradient decreases to about 2%, and the canyon is broader. As the canyon cuts into the Puye Formation downstream of the Sportsmen's Club, the gradient increases again to about 4%.

Guaje Canyon is the longest of the four canyons addressed in this work plan. The total change in elevation from the head of Guaje Canyon to its confluence with Los Alamos Canyon is about 4840 ft (LANL 1997, 62316, p. 3-2), and the average gradient is about 5.6%. The gradient changes along the length of the canyon largely in response to changes in bedrock lithology. For about its first 3 mi, the canyon cuts into the Tschicoma Formation and is steep and narrow with a gradient of about 7%. The canyon is incised into the Puye Formation down to the basal axial facies west of the Guaje Mountain fault zone (GMFZ), at which point the Tschicoma Formation is again exposed for less than 1 mi. The gradient over the conglomerates of the Puye Formation west of the fault zone is about 4%. East of the GMFZ the canyon again is incised into Puye Formation rocks, including the axial facies but primarily the upper fanglomerate deposits, and is mantled with late Quaternary alluvial channel and terrace deposits. The gradient in the Puye Formation east of the fault zone averages about 3.5% but decreases gradually to about 1% or less in the lower reach immediately upstream of Los Alamos Canyon.

3.2.3 Anticipated Stratigraphic Units

The generalized stratigraphy of the Pajarito Plateau, where the sites in this work plan are located, is shown in Appendix D, Figure 3.3-1. The stratigraphy consists of Bandelier Tuff (Qbt) overlain by a thin layer of alluvium and soil. The alluvium is of Pleistocene and Holocene age and rests unconformably on the Bandelier Tuff and deeper units in some parts of all four canyons. The alluvium in the canyons generally consists of reworked Bandelier Tuff and older bedrock units. The alluvium may also contain a minor eolian component. The Bandelier Tuff unit is subdivided into two members, in ascending order: the

Otowi Member and the Tshirege Member. The sites described in this work plan are situated on top of the alluvium or within the Tshirege Member. The Otowi and Tshirege Members are separated at about 300 ft below ground surface (bgs) by the Cerro Toledo (Qct) interval, a 30-ft-thick sequence of volcaniclastic sediments deposited in braided stream systems. The Bandelier Tuff and deposits of the Cerro Toledo interval are derived primarily from explosive volcanic eruptions in the Valles Caldera approximately 1.2 million years ago (Broxton and Eller 1995, 58207, p. 7).

Sampling at the sites described in this work plan is not expected to exceed a depth of about 3 ft. Therefore, anticipated stratigraphic units include surficial soils and sediments, alluvium, and the uppermost portions of the Bandelier Tuff.

3.2.4 Presence of Groundwater

Observations of perched intermediate groundwater in Laboratory wells are rare on the Pajarito Plateau. Perched waters are thought to form mainly at horizons where medium properties change dramatically, such as at paleosol horizons with clay or caliche found in basalt and volcanic sediment sequences. The Cerro Toledo interval, Guaje Pumice Bed, and Puye Formation are local examples.

In 1961 four test holes were drilled at former TA-10 to determine if groundwater served as a migration pathway for contaminants from former firing sites in Bayo Canyon. The boreholes penetrated the alluvium into the underlying Puye Formation. Alluvial groundwater and significant moisture were not encountered (Mayfield et al. 1979, 11717, pp. 50 and 51). Additional information on the test holes is found in Appendix D, Section 3.4.2.

Several subsurface investigations designed to determine the nature and extent of contaminants at former TA-10 in Bayo Canyon have not encountered groundwater in the alluvium or the underlying formations. These investigations have included drilling approximately 14 boreholes in 1973 and 1974. Results of the investigations did not indicate the presence of groundwater or significant amounts of moisture in subsurface sediments. Borehole depths ranged from 8 ft to 40 ft. Most boreholes were located within 250 ft of the Bayo Canyon channel (Mayfield et al. 1979, 11717, pp. 47–59). Seven additional test holes were drilled in Bayo Canyon on November 12 and 13, 1980, to depths from 12 to 37 ft. The soil/tuff contact generally was encountered at depths of 6 to 27 ft. The bedrock beneath the streambed (Otowi Member of the Bandelier Tuff) was usually weathered, and some boreholes encountered pumice. No indications of moisture or groundwater were noted (Purtymun 1994, 58233, pp. 97-1 and 97-2).

A total of 93 boreholes were drilled and sampled during the RFI at former TA-10 in Bayo Canyon from May to November 1994. The investigation was conducted to characterize the nature and extent of potential subsurface contaminants. Each borehole was drilled to a minimum depth of 50 ft. The alluvium in middle Bayo Canyon was approximately 20 to 40 ft thick. Groundwater was not encountered in any of the boreholes. Damp alluvium and Bandelier Tuff were noted (LANL 1996, 54332, p. 9-13). These intermediate-depth boreholes are discussed in Appendix D, Section 3.4.2.

In fall 1966, two shallow test holes were drilled in Guaje Canyon between the Rendija Canyon fault and the Guaje Mountain fault. The boreholes were located approximately 3 mi downstream of the Guaje Reservoir. The test holes were drilled to depths of 17 and 23 ft. The screened intervals of the wells are not known. Saturation in the boreholes was reported from the approximate level of the Guaje Canyon stream channel to total depth (Purtymun 1995, 45344, p. 299). Groundwater samples were not collected, and the wells have not been routinely monitored.

In 1946, test wells were installed in lower Los Alamos and Guaje Canyons to determine if a water supply could be developed for Los Alamos. GT-4 was drilled in the lower reaches of Guaje Canyon at its confluence with Los Alamos Canyon at an elevation of 5675 ft. The total depth of the well was 315 ft. Alluvium was encountered from the surface to a depth of 54 ft, and the Santa Fe Group was encountered from this depth to the total depth of the test hole. Specific references to saturation within the alluvium were not noted. However, it was determined that the alluvium was too thin to support a municipal water supply (Purtymun 1995, 45344, pp. 245 and 246).

Based on information from these investigations, shallow alluvial groundwater likely is present in the upper and middle reaches of Guaje Canyon, supported by infiltration from spring-fed surface water. Streamflow losses from evapotranspiration, infiltration, and possibly faults reduce the volume of surface water downstream. The saturated thickness of alluvial groundwater likely decreases downstream in the middle part of the canyon.

The regional aquifer in the Los Alamos area rises westward from the Rio Grande within the Santa Fe Group into the Puye Formation beneath the central and western portion of the Pajarito Plateau. Depth of the aquifer decreases from about 1200 ft bgs along the western margin of the plateau to about 600 ft bgs along the eastern margin. The water in the regional aquifer is separated from alluvial and perched water in the volcanics by 350 to 620 ft of tuff and volcanic sediments.

4.0 SCOPE OF ACTIVITIES

The scope of activities is dependent on the current knowledge of operational history and the degree of prior screening and characterization of each site. A phased approach will be used to determine the activities for each site, including site reconnaissance, screening, characterization, excavation, confirmation sampling, and evaluation of survey screening and sample data. This approach will allow for the acquisition of confirmation data and review of the results prior to demobilization. In turn, this information will ensure that the investigation objectives are met in an efficient and timely manner. The phased approach, and proposed screening, characterization, and remediation activities are discussed in the following sections. The characterization activities are based on the requirements outlined in the Consent Order, as well as the data needs identified for each site.

4.1 MEC Site Surveys

Although SWMUs 00-011(a), 00-011(c), 00-011(d), and 00-011(e) and AOC C-00-020 have been previously surveyed for MEC, additional surface MEC and/or MD may exist. The sites in Rendija Canyon have been subjected to recent floods as a result of the Cerro Grande fire, possibly leading to migration and unearthing of MEC and MD. Recent review of the floodplains/wetlands assessment for Rendija Canyon resulted in NMED comments requiring the DOE to investigate and remediate the mortar impact areas (i.e., remove any MEC) prior to any transfer or conveyance of land (NMED 2004, 87287). The New Mexico Environment Department indicated that the techniques and standards used when the sites were initially investigated are not adequate today (NMED 2004, 87287).

At these SMWUs and the AOC, surface surveys will be conducted to identify and remove surface metallic debris/MEC that could mask subsurface anomalies (defined as any identified subsurface mass that may be geologic in origin, MEC, or some other man-made material) and to aid in focusing the digital geophysical mapping (DGM) efforts to identify subsurface MEC. The surface survey will cover all areas within the SWMU/AOC boundaries.

SWMU 00-011(c) and AOC C-00-020 do not lend themselves to effective geophysical surveys and, therefore, will not be included in the DGM surveys. SWMU 00-011(c) has many burned and downed trees resulting from the Cerro Grande fire, and AOC C-00-020 has very irregular topography, both of which will hinder the survey attempts.

Digital geophysical mapping surveys, which will be completed at SWMUs 00-011(a), 00-011(d), and 00-011(e), apply magnetic and electromagnetic methods to identify the locations of subsurface MEC/MD. The priority for DGM surveys will be completed at the highest impact areas, as defined by the subdivisions where the highest amounts of MEC and MD were previously recovered. Applicable guidance is presented in Appendix E (USACE 2003, 88477; USACE 2003, 88478; ITRC 2004, 88479). The areas selected for DGM surveys will be mapped, and a list of anomalies will be generated. Applicable guidance is provided in Appendix E (USACE Data Item Description 005-05, "Geophysical Investigation Plan" [USACE 2003, 88477]).

The anomalies identified and reacquired in the field will be excavated and categorized as one of the following: MEC, MD, other identified scrap, false positive (e.g., no contact), or any other applicable designation. Anomaly identification logs will be maintained in accordance with applicable guidance provided in Attachment C of U.S. Army Corps of Engineers [USACE] Data Item Description 005-05, "Geophysical Investigation Plan" (USACE 2003, 88477) (see Appendix E). The locations of the removed MEC and MD will be recorded by a global positioning system (GPS) unit to serve as sampling locations for the grid samples described in Section 4.2 of this work plan.

All disposal operations will be conducted in accordance with Laboratory requirements and Bureau of Alcohol, Tobacco, and Firearms and USACE guidance (USACE 2003, 88711; USACE 2004, 88718). If possible, recovered MEC will be disposed of by detonation. After sympathetic detonation of the MEC (i.e., detonation of a charge by exploding another charge adjacent to it), a sweep of the demolition area will be conducted to ensure no MEC remains and all MD generated has been recovered. Only qualified UXO technicians will conduct demolition operations. All MD recovered from both the investigation and disposal operations will be certified as explosive-free by the UXO quality/safety officer and the senior UXO supervisor on the project.

4.2 Surface and Shallow Subsurface Sampling Activities

Characterization of potentially explosives-contaminated sites is difficult because of the very heterogeneous distribution of contamination in the environment and within samples (EPA 1996, 55840, p. 1). Approximately 70% to 90% of soil samples analyzed during an explosives site investigation do not contain detectable levels of explosives (EPA 1996, 55840, p. 1). Because sampling error (i.e., variability) is typically much greater than analytical error, especially for explosive residues, overall error is more effectively reduced by increasing the number of field-screening samples as opposed to the number of samples sent for off-site fixed laboratory analyses (EPA 1996 55840, p. 20).

For impact ranges such as SWMUs 00-011(a), 00-011(d), and 00-011(e), the most commonly found explosive constituents are 2,4,6-trinitrotoluene (TNT) and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) (EPA 2002, 88480, p. 3-13). Therefore, all locations (Figures 4.2-1, 4.2-4, and 4.2-5) will be sampled and field screened for TNT and RDX using, at a minimum, D TECH, an on-site analytical method for detecting explosives in soil. D TECH Immunoassay Test Kits (EPA SW846 Methods 4050 and 4051) employ immunoassay methods for detection of TNT and RDX with detection limits of 0.5 mg/kg. The results are presented as concentration ranges and correlate well with off-site fixed laboratory results of SW846 Method 8330 (EPA 2002, 88480, p. 7-39). The integrated use of both on-site field methods and laboratory analytical methods for explosive compounds detection will provide a comprehensive tool for determining the lateral and vertical extent of contamination (EPA 2002, 88480, p. 7-38).

The sampling activities have been tailored to each site as described in the following sections.

4.2.1 SWMU 00-011(a)

The proposed sample locations at SWMU 00-011(a) are shown in Figure 4.2-1 (explosive compounds field-screening locations) and Figure 4.2-2 (target analyte list [TAL] metal and perchlorate sampling locations). Table 4.2-1 provides a summary of the proposed sample locations, depths, and analytical suites.

To improve site characterization and reduce sampling error, a statistical approach has been used to determine the spacing and number of screening sampling locations required to obtain confidence in finding an area of contamination, if one exists. The statistical method summarized below involves sampling along a grid and is more fully explained in *Statistical Methods for Environmental Pollution Monitoring* (Gilbert 1987, 56179, Section 10.1).

To determine the grid spacing, the statistical method requires the suspected size and shape of contamination (S), as well as an acceptable level of error (β) that meets project goals (Gilbert 1987, 56179, Section 10.1). If present, contamination would most likely be concentrated within those areas affected by the detonation of a round. Therefore, S is estimated from the lethal bursting diameters presented in the Army Field Manual Number 7-90, *Tactical Employment of Mortars* (Dept. of U.S. Army 1992, 88481, Figure B-5). At this site the majority of contamination resulting from detonation is assumed to be circular. In the calculation below, S is estimated from the average lethal bursting diameters for 60-mm and 81-mm mortar rounds recovered at this SWMU during previous remediation activities. According to Army Field Manual Number 7-90, lethal bursting diameters are 65.6 ft (20 m) and 111.5 ft (34 m) for the 60-mm and 81-mm mortar rounds, respectively. The average radius from both circles is 44.3 ft (13.5 m), calculated as (65.6 ft + 111.5 ft)/4.

The suspected size and shape of contamination (S) is calculated in the following manner:

$$S = \frac{\text{length of the short axis of the expected shape of contamination}}{\text{length of the long axis of the expected shape of contamination}}$$

For a circle, all axes are the same length and, as a result:

$$S = 1$$

To maximize the likelihood of detection of contamination, the acceptable risk of not finding elevated levels of contamination, or of committing a beta error (β), is set to 5% (Gilbert 1987, 56179, p. 121), resulting in a 95% confidence level of finding a localized area of contamination.

The following equation determines the spacing of sample locations required to obtain a 95% confidence level of placing a sample location within the average lethal bursting diameter for 60-mm and 81-mm mortar rounds:

$$L/G,$$

where

L= contamination radius or 44.3 ft (13.5 m), and
G= the spacing between sampling grid lines.

Figure 4.2-3 shows the statistical curves relating L/G to β for different circular target shapes when sampling on a square grid pattern (Gilbert 1987, 56179, Figure 10.3). Figure 4.2-3 shows that using the curve corresponding to the expected shape (S) of contamination, in this case 1, L/G can be found on the horizontal axis that corresponds to the predetermined acceptable probability of β, or 0.05 (shown on vertical axis of Figure 4.2-3). As shown on Figure 4.2-3, for a 0.05 value of β, the ratio of L/G is approximately 0.60.

Solving for G:

L/G = 0.60

L= 44.3 ft (13.5 m)

0.60 = 44.3 ft (13.5 m)/G

G = 73.8 ft (22.5 m)

Therefore, in order to have a 95% confidence level that samples have been placed to coincide with the average lethal bursting diameter of the mortar rounds found at the site, a portion of samples will be collected on a grid with spacing of approximately 74 ft. For TAL metals and perchlorate, the area of potential contamination is assumed to be larger than for explosive compounds because the fragments of the mortar rounds expand beyond the lethal bursting diameter and likely overlap. Therefore, the grid sampling locations for TAL metals and perchlorate is set at 148 ft (2 x 74 ft), based conservatively upon twice the lethal bursting size, which is approximately equivalent to the explosion size needed to suppress or hit a target 90% of the time (Dept. of U.S. Army 1992, 88481, Figure B-10). Using the same 95% confidence level as for the explosive compounds field-screening sample locations, this grid spacing is calculated as two times the contamination radius (44.3 x 2) divided by the ratio of L/G (0.60), or (44.3 ft x 2)/0.60 = 148 ft.

To determine if contaminant migration has occurred, samples will also be collected approximately every 100 ft along active drainage areas in locations determined by a geomorphologist to be made up of post-1943 sediments (Figures 4.2-1 and 4.2-2, proposed biased samplinglocations). Any obvious active drainage/sediment catchment areas located within 10 ft of a grid location will replace those grid locations. Cliff areas will be sampled from one depth because of their nearly vertical surface topography.

SWMU 00-011(a) was previously subdivided during UXO/MD surveys/removal activities in 1993 and fragment recoveries were tallied for each subdivision (Figure 2.1-2). To focus sampling efforts within a site area of approximately 30 acres, these subdivisions were placed into "higher" or "lower" fragment recovery areas by calculating average fragment recoveries. Subdivisions with fragment recoveries greater than the average fragment recovery per subdivision at the site were designated as higher, and those equal to or less than the average were designated as lower. The average number of fragments recovered at the site per subdivision is 62 (Figure 2.1-2, recovery fractions, calculated as 2426 fragments/39 subdivisions = 62). Therefore, subdivisions with more than 62 fragments recovered were designated as the higher recovery areas. Contamination would more likely be present in the higher recovery areas compared to the lower recovery areas. Focusing sampling in the higher recovery areas increases the likelihood of finding contamination, if it exists.

Higher recovery areas will have grid spacing set approximately 74 ft apart (G, calculated above) with explosive compounds field screening, explosive compounds laboratory analyses, and TAL metal and perchlorate samples collected at varying grid intersections described below (Figures 4.2-1 and 4.2-2). Alternatively, lower recovery areas will be field screened for explosive compounds and sampled for TAL metals and perchlorate analyses less frequently, with samples collected approximately every 296 ft along the grid (every fourth sample location) (Figures 4.2-1 and 4.2-2). As indicated above, the 95% confidence level grid sampling interval of 74 ft will only apply to the higher recovery areas, where contamination, if it exists, is most likely to be present. However, if laboratory results indicate explosive compounds are present or if TAL metals or perchlorate concentrations are above background in more than 20% of the samples, sampling in lower recovery areas will be changed to follow the same grid spacing as that for the higher recovery areas.

Explosive Compounds Sampling

In higher and lower recovery areas, samples will be collected from the 0- to 0.5-ft and 2.0- to 3.0-ft depth intervals and field screened for explosive compounds using D TECH (Figure 4.2-1). At each drainage sediment sample location, two depth intervals determined by the sediment depth will be field screened for explosive compounds (Figure 4.2-1). Cliff locations will have samples collected from one depth interval. If mortar rounds (fragments, parts, etc.) are found during the prescribed MEC and geophysical sweeps, these locations also will be field screened for explosive compounds. These sample locations will be labeled "biased locations" and will replace the closest grid location. If multiple fragments are found and removed from a localized area, one sample location will be established every 5 ft^2 of area in which the multiple fragments were found. The initial sample depth may change depending on the depth at which the ordnance is found. Samples collected from areas of removed ordnance will start at the depth just below the depth of the ordnance. That is, if a fragment is found 3 ft bgs, then the 0- to 0.5-ft interval will be 3.0 to 3.5 ft bgs.

Normally, at least 10% to 20% of field-screening samples with positive results are sent to an off-site fixed laboratory for explosive compounds analyses, and a smaller fraction of the nondetect samples also may be verified (EPA 1996, 55840, p. 20). In some cases, field-screening methods are used to identify samples containing explosive residues and these samples are sent for laboratory analyses (EPA 1996, 55840, p. 20). At SWMU 00-011(a), a minimum of 20% of the total locations field screened for explosive compounds, regardless of result, will be sent for off-site fixed laboratory explosive compounds analyses. If all field-screening results are negative, samples for off-site fixed laboratory explosive compounds analyses will be representative of the entire site (e.g., every fifth screening location will be sent to the laboratory). Any depth interval with a positive field-screening result will be sent for off-site fixed laboratory explosive compounds analyses. If explosive compounds are detected in the deepest interval at a sampling location, then deeper 1-ft intervals will be sampled until explosive compounds field-screening results are negative. The next depth interval with a negative field-screening result will be sent for off-site fixed laboratory explosive compounds analyses.

TAL Metals and Perchlorate Sampling

TAL metal and perchlorate sample locations overlap with all other explosive compounds field-screening locations; therefore, samples will be collected concurrently for these analyses. Screening locations with positive explosive compounds field-screening results not already identified as sampling locations for TAL metals and perchlorate will have soil or sediment collected concurrently for analyses of explosive compounds, TAL metals, and perchlorate at an off-site fixed laboratory.

In the higher recovery areas, locations approximately every 148 ft along the grid (every second grid point) will be sampled from the 0- to 0.5-ft and 2.0- to 3.0-ft intervals (Figure 4.2-2, locations 1 though 24). In the lower recovery areas, locations approximately every 296 ft along the grid will be sampled from the 0- to 0.5-ft and 2.0- to 3.0-ft intervals. Samples will be collected from two depth intervals as determined by the sediment depth approximately every 100 ft along active drainages (Figure 4.2-2, locations 25 through 56). All of these samples will be analyzed for TAL metals and perchlorate at an off-site fixed laboratory.

If mortar rounds (fragments, parts, etc.) are found during the prescribed MEC and geophysical sweeps, these locations also will be sampled for TAL metals and perchlorate. These sample locations will be labeled "biased locations" and will replace the closest grid location. If multiple fragments are found and removed from a localized area, one sample location will be established every 5 ft^2 of area in which the multiple fragments were found. The initial sample depth may change depending on the depth at which the ordnance is found. Samples collected from areas of removed ordnance will start at the depth just below the depth of the ordnance. That is, if a fragment is found 3 ft bgs, then the 0- to 0.5-ft interval will be 3.0 to 3.5 ft bgs.

4.2.2 SWMU 00-011(c)

Previous removal efforts in the early 1990s did not find any MEC or MD at this site, indicating it was never used as a munitions impact area. Recent floods resulting from the Cerro Grande fire, may have led to migration and unearthing of MEC and MD. If MEC or MD are not found during the prescribed MEC survey, it will further support the conclusion that SWMU 00-011(c) was never used as an impact area. As a result of not finding any MEC or MD, characterization sampling will not be conducted. However, if MEC and/or MD are found, higher recovery areas (as determined by areas with more than the average number of recovered items found at this site) will be sampled using a grid system as described for SWMUs 00-011(a). The grid sizing and number of samples collected will depend on the type and locations of munitions recovered. If the type of munitions recovered is different from those discussed for SWMUs 00-011(a) and 00-011(e), the size of explosions will be estimated to determine grid sizing.

If warranted by the survey results, samples will be collected approximately every 100 ft along active drainages in locations determined by a geomorphologist to be post-1943 sediments. Any obvious active drainage/sediment catchment areas located within 10 ft of a grid location will replace those grid locations.

At each soil sample location, the 0- to 0.5-ft and 2.0- to 3.0-ft depth intervals will be field screened for explosive compounds using D TECH. At each drainage sediment sample location, two depth intervals determined by the sediment depth will be field screened for explosive compounds. A minimum of 20% of the total locations field screened for explosive compounds, regardless of result, will be sent for off-site fixed laboratory explosive compounds analyses. If all field-screening results are negative, samples for off-site fixed laboratory explosive compounds analyses will be representative of the entire site (e.g., every fifth screening location will be sent to the laboratory). Any depth interval with a positive field-screening result will be sent for off-site fixed laboratory explosive compounds analyses. If explosive compounds are detected in the deepest interval at a sampling location, then deeper 1-ft intervals will be sampled until explosive compounds field-screening results are negative. The next depth interval with a negative field-screening result will be sent for off-site fixed laboratory explosive compounds analyses. All TAL metal and perchlorate sample locations overlap with explosive compounds field-screening locations; therefore, samples will be collected concurrently for these analyses. Screening locations with positive explosive compounds field-screening results not already identified as sampling locations for TAL metals and perchlorate will have soil or sediment collected concurrently for analyses of explosive compounds, TAL metals, and perchlorate at an off-site fixed laboratory.

In higher and lower recovery areas, locations along the grid will be sampled from the 0- to 0.5-ft and 2.0- to 3.0-ft intervals and analyzed for TAL metals and perchlorate at an off-site fixed laboratory.

If rounds (fragments, parts, etc.) are found during the prescribed MEC sweeps, these locations will also be field screened for explosive compounds and samples will be collected for TAL metals and perchlorate off-site fixed laboratory analyses. These sample locations will be labeled "biased locations" and will replace the closest grid location. If multiple fragments are found and removed from a localized area, one sample location will be established every 5 ft^2 of area in which the multiple fragments were found. The initial sample depth may change depending on the depth at which the ordnance is found. Samples collected from areas of removed ordnance will start at the depth just below the depth of the ordnance. That is, if a fragment is found 3 ft bgs, then the 0- to 0.5-ft interval will be 3.0 to 3.5 ft bgs.

4.2.3 SWMU 00-011(d)

The proposed sample locations at SWMU 00-011(d) are shown in Figure 4.2-4. Table 4.2-2 provides a summary of the proposed sample locations, depths, and analytical suites.

According to the 1992 field investigation, the majority of bazooka rounds were fired into one main area along the southwest-facing side of the cliff (Figure 4.2-4, bazooka impact area). Therefore, samples will be collected in a biased manner from the impact area and along the downslope active drainages present at the site. If bazooka rounds (fragments, parts, etc.) are found during the prescribed MEC and geophysical sweeps, these locations will also be field screened for explosive compounds using D TECH and samples will be collected for TAL metal and perchlorate off-site fixed laboratory analyses. These sample locations will replace the closest prescribed location. If multiple fragments are found and removed from a localized area, one sample location will be established every 5 ft^2 of area in which the multiple fragments were found. The initial sample depth may change depending on the depth at which the ordnance is found. Samples collected from areas of removed ordnance will start at the depth just below the depth of the ordnance. That is, if a fragment is found 3 ft bgs, then the 0- to 0.5-ft interval will be 3.0 to 3.5 ft bgs.

Samples will be collected approximately every 100 ft along the drainage channel below the cliff from two depth intervals at locations determined by a geomorphologist to be post-1943 sediments (Figure 4.2-4, Locations 1 through 9). The former bazooka impact area will be sampled from three locations at one sample depth because of the nearly vertical surface topography (Figure 4.2-4, locations 10 through 12). The cliff area has multiple drainage channels along the face that will be sampled from two depth intervals at locations determined by a geomorphologist to be post-1943 sediments (Figure 4.2-4, locations 13 through 15). A total of six locations will be sampled west of the drainage channel at the bottom of the cliff to define lateral extent from the 0- to 0.5-ft and 2.0- to 3.0-ft depth intervals (Figure 4.2-4, locations 16 through 21). Samples will be screened for explosive compounds in the field and analyzed for TAL metals and perchlorate at an off-site fixed laboratory.

A minimum of 20% of the total locations field screened for explosive compounds, regardless of result, will be sent for off-site fixed laboratory explosive compound analyses. If all field-screening results are negative, samples for off-site fixed laboratory explosive compound analyses will be representative of the entire site (e.g., every fifth screening location will be sent to the laboratory). Any depth interval with a positive field-screening result will be sent for off-site fixed laboratory explosive compound analyses. If explosive compounds are detected in the deepest interval at a sampling location, then deeper 1-ft intervals will be sampled until explosive compounds field-screening results are negative. The next depth interval with a negative field-screening result will be sent for off-site fixed laboratory explosive compound analyses.

4.2.4 SWMU 00-011(e)

The proposed sample locations at SWMU 00-011(e) are shown in Figures 4.2-5 (explosive compounds field-screening locations) and 4.2-6 (TAL metal and perchlorate sampling locations). Table 4.2-3 provides a summary of the proposed sample locations, depths, and analytical suites.

This site will be sampled using the same statistical approach used for SWMU 00-011(a) to determine the spacing and number of sample locations required to obtain a 95% confidence level of finding a localized area of contamination if one exists. At this SWMU, L is assumed to be the average lethal bursting diameter for 20-mm and 37-mm rounds which were recovered at this SWMU. Although these specific rounds are not discussed in the Army Field Manual Number 7-90, *Tactical Employment of Mortars* (Dept. of U.S. Army 1992, 88481, Figure B-5), the lethal bursting diameters may be inferred to have a similar relationship to the round size as those diameters calculated for the 60- and 81-mm mortar rounds. Because the majority of the rounds and MD recovered at this site were 37-mm in size, the average size round at this SWMU could conservatively be assumed to be 30-mm. Estimating from the 60-mm mortar round lethal bursting diameter, the value for a 30-mm round would be approximately half of 65.6 ft (20 m), or 32.8 ft (10 m). Assuming a circular shape, the average value of L (contamination radius based on the 30-mm round) is 16.4 ft (5 m).

Solving for G:

L/G = 0.60

L = 16.4 ft (5 m)

0.60 = 16.4 ft (5 m)/G

G = 27.3 ft (8.3 m)

Therefore, to have a 95% confidence level that samples have been placed to coincide with the average lethal bursting diameter of the rounds found at the site, a portion of samples will be collected on a grid with spacing of approximately 27 ft. For TAL metals and perchlorate, the area of potential contamination is assumed to be larger than that for explosive compounds because the fragments of the rounds expand beyond the lethal bursting diameter. Therefore, the grid sampling locations for TAL metals and perchlorate will be set at 54 ft (2 x 27 ft), based conservatively upon twice the lethal bursting size, which is approximately equivalent to the explosion size needed to suppress or hit a target 90% of the time (Dept. of U.S. Army 1992, 88481, Figure B-10). Using the same 95% confidence level as for the explosive compounds field-screening sample locations, this grid spacing is calculated as two times the contamination radius (16.4 x 2) divided by the ratio of L/G (0.60), or (16.4 ft x 2)/0.60 = 54 ft.

The site was previously subdivided during UXO/MD surveys and removal activities in 1993, and MD recoveries were tallied for each subdivision (Figure 2.1-8). Portions of the cliff with previous MD recovery at this SWMU are too steep to allow grid sampling or a large number of locations to be sampled (Figure 2.1-8, subdivisions with 1/6, 0/2, and 0/6 MD recoveries). Additionally, the majority of subdivisions previously surveyed did not result in finding any MD (Figure 2.1-8, 0/0 recoveries). Therefore, portions of these areas will be sampled from biased locations. To determine if contaminant migration has occurred, areas without fragment or round recovery will have samples collected every 100 ft along active drainage areas in locations determined by a geomorphologist to be post-1943 sediments (Figure 4.2-5, proposed biased screening locations). The steep cliff area with previous recovery will have three biased locations sampled from one depth in areas of suspected contamination (high-impact area, sediment-catchment area, etc.). Additionally, grid locations will be replaced by sampling any obvious active drainage/sediment catchment areas located within 10 ft of a grid location.

To focus sampling efforts within the remaining subdivisions with MD recovery, these areas were placed into higher or lower MD recovery areas by calculating average MD recoveries. Subdivisions with MD recoveries greater than the average fragment recovery per subdivision at the site were designated as higher, and those equal to or less than the average were designated as lower. The average number of rounds recovered per subdivision with recovery is 9 rounds (Figure 2.1-8, recovery fractions, calculated as 92 rounds/10 subdivisions = 9 rounds). The average number of fragments/bullets recovered per subdivision with recovery is 21 fragments/bullets (Figure 2.1-8, recovery fractions, calculated as 205 fragments and/or bullets/10 subdivisions = 21 fragments and/or bullets). Therefore, recovery areas with more than 9 rounds and 21 fragments/bullets recovered were designated as the higher recovery areas. Contamination would more likely be present in the higher recovery areas compared to the lower recovery areas. Focusing sampling in the higher recovery areas increases the likelihood of finding contamination, if it exists.

Higher recovery areas will have grid spacing set approximately 27 ft apart (G, as calculated above) with explosive compounds field screening, explosive compounds laboratory analyses, and TAL metal and perchlorate samples collected at the grid intersections (Figures 4.2-5 and 4.2-6). Alternatively, lower recovery areas will be field screened for explosive compounds and sampled for TAL metals and perchlorate analyses less frequently, with samples collected approximately every 108 ft along the grid (every fourth sample location) (Figures 4.2-5 and 4.2-6). As indicated, the 95% confidence level grid sampling interval of 27 ft will only apply to the higher recovery areas, where contamination, if it exists, is most likely to be present. However, if laboratory results indicate explosive compounds are present or if TAL metals or perchlorate concentrations are above background levels in more than 20% of the samples, sampling in lower recovery areas will be changed to follow the same grid spacing as for the higher recovery areas.

Explosive Compounds Sampling

In higher and lower recovery areas, samples will be collected from the 0- to 0.5-ft and 2.0- to 3.0-ft depth intervals and field screened for explosive compounds using D TECH (Figure 4.2-5). At each drainage sediment sample location, two depth intervals determined by the sediment depth will be field screened for explosive compounds (Figure 4.2-5). The steep cliff area with previous recovery will have three biased locations sampled from one depth interval in areas of suspected contamination (high impact area, sediment catchment area, etc., Figure 4.2-5). If rounds (fragments, parts, etc.) are found during the prescribed MEC and geophysical sweeps, these locations will also be field screened for explosive compounds. These sample locations will be labeled "biased locations" and will replace the closest grid location. If multiple fragments are found and removed from a localized area, one sample location will be established every 5 ft^2 of area in which the multiple fragments were found. The initial sample depth may change depending on the depth at which the ordnance is found. Samples collected from areas of removed ordnance will start at the depth just below the depth of the ordnance. That is, if a fragment is found 3 ft bgs, then the 0- to 0.5-ft interval will be 3.0 to 3.5 ft bgs.

A minimum of 20% of the total locations field screened for explosive compounds, regardless of result, will be sent for off-site fixed laboratory explosive compounds analyses. If all field-screening results are negative, samples for off-site fixed laboratory explosive compounds analyses will be representative of the entire site (e.g., every fifth screening location will be sent to the laboratory). Any depth interval with a positive field-screening result will be sent for off-site fixed laboratory explosive compounds analyses. If explosive compounds are detected in the deepest interval at a sampling location, then deeper 1-ft intervals will be sampled until explosive compounds field-screening results are negative. The next depth interval with a negative field-screening result will be sent for off-site fixed laboratory explosive compounds analyses.

TAL Metals and Perchlorate Sampling

TAL metal and perchlorate sample locations overlap with every other explosive compounds field-screening location; therefore, samples will be collected concurrently for these analyses. Screening locations with positive explosive compounds field-screening results not already identified as sampling locations for TAL metals and perchlorate will have soil or sediment collected concurrently for analyses of explosive compounds, TAL metals, and perchlorate at an off-site fixed laboratory.

In the higher recovery areas, locations approximately every 54 ft along the grid (every second grid point) will be sampled from the 0- to 0.5-ft and 2.0- to 3.0-ft intervals (Figure 4.2-6, locations 1 through 38). In the lower recovery areas, locations approximately every 108 ft along the grid will be sampled from the 0- to 0.5-ft and 2.0- to 3.0-ft intervals (locations 39 through 50). Areas without previous ordnance recovery will have only samples collected at two depth intervals approximately every 100 ft along active drainage areas (locations 51 through 60). The cliff area with previously recovered ordnance will have samples collected from one depth interval in the same biased locations screened for explosive compounds (Figure 4.2-6, locations 61 through 63). All of these samples will be analyzed for TAL metals and perchlorate at an off-site fixed laboratory.

If rounds (fragments, parts, etc.) are found during the prescribed MEC and geophysical sweeps, these locations also will be sampled for TAL metals and perchlorate. These sample locations will be labeled "biased locations" and will replace the closest grid location. If multiple fragments are found and removed from a localized area, one sample location will be established every 5 ft^2 of area in which the multiple fragments were found. The initial sample depth may change depending on the depth at which the ordnance is found. Samples collected from areas of removed ordnance will start at the depth just below the depth of the ordnance. That is, if a fragment is found 3 ft bgs, then the 0- to 0.5-ft interval will be 3.0 to 3.5 ft bgs.

4.2.5 AOC C-00-020

Previous removal efforts in the early 1990s did not find any MEC or MD at this site, indicating that it may have never been used as a munitions impact area. Recent floods resulting from the Cerro Grande fire may have led to migration and unearthing of MEC and MD. If MEC or MD are not found during the prescribed MEC survey, this will further support the conclusion that AOC C-00-020 was never used as an impact area. As a result of not finding any MEC or MD, characterization sampling will not be conducted. However, if MEC and/or MD are found, higher recovery areas (as determined by areas with more than the average number of recovered items at this site) will be sampled using a grid system as described for SWMU 00-011(a). The grid sizing and number of samples collected will depend on the type and locations of munitions recovered. If the type of munitions recovered are different from those discussed for SWMUs 00-011(a) and 00-011(e), the size of explosions will be estimated to determine grid sizing.

If warranted by the survey results, samples will be collected approximately every 100 ft along active drainages in locations determined by a geomorphologist to be post-1943 sediments. Any obvious active drainage/sediment catchment areas located within 10 ft of a grid location will replace those grid locations.

At each soil sample location, the 0- to 0.5-ft and 2.0- to 3.0-ft depth intervals will be field screened for explosive compounds using D TECH. At each drainage sediment sample location, two depth intervals determined by the sediment depth will be field screened for explosive compounds. A minimum of 20% of the total locations field screened for explosive compounds, regardless of result, will be sent for off-site fixed laboratory explosive compounds analyses. If all field-screening results are negative, samples for off-site fixed laboratory explosive compounds analyses will be representative of the entire site (e.g., every fifth screening location will be sent to the laboratory). Any depth interval with a positive field-screening result will be sent for off-site fixed laboratory explosive compounds analyses. If explosive compounds are detected in the deepest interval at a sampling location, then deeper one foot intervals will be sampled until explosive compounds field-screening results are negative. The next depth interval with a negative field-screening result will be sent for off-site fixed laboratory explosive compounds analyses. All TAL metal and perchlorate sample locations overlap with explosive compounds field-screening locations; therefore, samples will be collected concurrently for these analyses. Screening locations with positive explosive compounds field-screening results not already identified as sampling locations for TAL metals and perchlorate will have soil or sediment collected concurrently for analyses of explosive compounds, TAL metals, and perchlorate at an off-site fixed laboratory.

In higher and lower recovery areas, locations along the grid will be sampled from the 0- to 0.5-ft and 2.0- to 3.0-ft intervals and analyzed for TAL metals and perchlorate at an off-site fixed laboratory.

If rounds (fragments, parts, etc.) are found during the prescribed MEC sweeps, these locations will also be field screened for explosive compounds and samples collected for TAL metals and perchlorate off-site fixed laboratory analyses. These sample locations will be labeled "biased locations" and will replace the closest grid location. If multiple fragments are found and removed from a localized area, one sample location will be established per every 5 ft^2 of area in which the multiple fragments were found. The initial sample depth may change depending on the depth at which the ordnance is found. Samples collected from areas of removed ordnance will start at the depth just below the depth of the ordnance. That is, if a fragment is found 3 ft bgs, then the 0- to 0.5-ft interval will be 3.0 to 3.5 ft bgs.

4.2.6 AOC-C-00-041

The proposed sample locations at AOC C-00-041 are shown in Figure 4.2-7. Table 4.2-4 provides a summary of the proposed sample locations, depths, and analytical suites.

Any remaining asphalt and tar are assumed to be restricted largely to the site itself, with the majority of tar residues to be found between the former location of the batch plant and the bottom of the watercourse. The potential contaminants at AOC C-00-041 are TAL metals, VOCs, SVOCs, and TPH. A walkover of the site will be conducted to look for remnants of tar and asphalt that may have been missed during the VCA or exposed subsequent to the VCA. If tar or asphalt is encountered, the coordinates will be identified by plotting a point on the site map using a GPS unit and the area will be marked by a pin flag and the material removed.

Biased samples will be collected at 100-ft intervals down the center of the AOC near the present watercourse (Figure 4.2-7, locations 1 through 12). Sample locations will be biased toward sediment pockets and former locations of asphalt and tar. Two biased sample locations will be established in the footprint of the former batch plant (Figure 4.2-7, locations 13 and 14). Three additional biased sample locations will be established downslope from the former batch plant location (Figure 4.2-7, locations 15 through 17). Samples will be collected at 0- to 0.5-ft and 2.0- to 3.0-ft depth intervals and analyzed for TAL metals, VOCs, SVOCs, and TPH.

4.3 Health and Safety Requirements

A site-specific health and safety plan and integrated work document will be written prior to conducting any field activities.

5.0 INVESTIGATION METHODS

All work will be performed in accordance with all applicable standard operating procedures (SOPs), quality procedures (QPs), and the ENV-ERS Quality Management Program. Applicable investigation methods are presented in Table 5.0-1.

5.1 Sample Point and Structure Location Surveying

Site attributes (i.e., soil sample locations, sediment sample locations, ordnance locations, as well as staked out sampling grids) will be located by using GPS. Horizontal locations will be measured to the nearest 0.5 ft. The survey results will be presented as part of the investigation report. Sample coordinates will be uploaded into the Environmental Restoration Database.

5.2 Collecting Soil and Rock Samples

The most common method for surface and shallow subsurface sampling is the spade-and-scoop method, described in Environmental Stewardship–Environmental Characterization and Remediation (ENV-ECR)

SOP-6.09. Stainless-steel shovels, spades, scoops, and bowls will be used because of their ease of decontamination. Disposable tools made of polystyrene or Teflon may also be used. In some cases, hand-augering tools may be used to collect shallow subsurface samples if geologic material conditions permit. The use of tools and their applicability is described in ENV-ECR SOP-6.10. If a surface sample location is in bedrock, an axe or hammer and chisel may be used to collect samples. Sites that may have explosive compounds will be sampled according to ENV-ECR SOP-01.07, Operational Guidelines for Taking Soil and Water Samples in Explosive Areas.

All samples (surface and subsurface) will be shipped through the Sample Management Office (SMO) to off-site fixed laboratories for analysis. Samples will be sent to laboratories on the ENV-ERS-approved suppliers list. All samples will be collected and handled according to ENV-ECR SOP-15.09, Chain of Custody for Analytical Data Record Packages. The analytical suites for each sample location are described in the sections pertaining to the individual site and listed in Tables 4.2-1 through 4.2-4.

Quality assurance/quality control samples will include field duplicate samples collected in accordance with ENV-ECR SOP-1.05. Field duplicate samples will be collected as directed by ENV-ECR SOP-01.05 at a frequency of at least 1 for every 10 regular samples per the Consent Order. Rinsate blanks will also be collected to confirm decontamination of sampling equipment.

5.3 Field Screening

Visual examination will be used at all of the sites to help aid in finding sampling locations. Explosive compounds field screening will be performed at all of the sites except AOC 00-041. Headspace vapor screening for VOCs will be performed only at AOC C-00-041. Explosive compounds field screening will be performed using D TECH Immunoassay Test Kits for TNT and RDX (EPA SW846 Methods 4050 and 4051). The results are presented as concentration ranges and correlate well with SW846 Method 8330 (EPA 2002, 88480, p. 7-39).

5.4 Equipment Decontamination

Following investigation activities, project personnel will decontaminate all equipment. Residual material adhering to equipment will be removed using dry decontamination methods (ENV-ECR SOP-01.08). If the equipment cannot be free-released following dry decontamination, a high-pressure sprayer, along with long-handled brushes and rods, will be used to remove contaminated material more effectively. Pressure-washing of equipment will be performed on a temporary wash pad with a high-density polyethylene liner. Cleaning solutions and wash water will be collected and contained for proper disposal. Decontamination solutions will be sampled to determine final disposition. All parts of the equipment will be thoroughly cleaned. Equipment air filters will be considered contaminated and will be removed and replaced before the equipment leaves the site.

5.5 Waste Management

Materials identified as waste will be segregated into specific waste types for appropriate disposal. Investigation activities will minimize the waste generated by following the ENV-ERS 2004 Pollution Prevention Roadmap (LANL 2004, 88465). Methods for managing investigation-derived waste, including soil, tuff, concrete and other structural material, protective personal equipment, and other miscellaneous materials, and the assumptions used to estimate waste volumes are described in Appendix C.

5.6 Excavation Backfilling and Cover Replacement

Excavations will be backfilled and compacted, and clean cover material will be placed over the affected area. The clean fill material will be procured from off-site. All affected surfaces will be restored to original grade, reseeded with a native seed mix, and straw mulch will be applied to help stabilize the surface. To prevent future subsidence, the replaced material will be compacted to the extent practical and will be mounded slightly in anticipation of settling.

6.0 MONITORING AND SAMPLING PROGRAM

No monitoring is currently performed at any of the sites. It is anticipated that no further sampling or monitoring will be required at any of the sites after these work plan activities are completed.

7.0 SCHEDULE

Following approval of this work plan by NMED, readiness review and site preparation activities can begin. Preparation activities, implementation of the fieldwork, and demobilization are anticipated to require 4 to 6 months. Sample submittals to the SMO will be completed by this time. Receipt of analytical data is anticipated prior to demobilization so an evaluation can be made regarding the need for additional remediation. An investigation report will then be written and submitted to NMED, as required in the Consent Order.

8.0 REFERENCES

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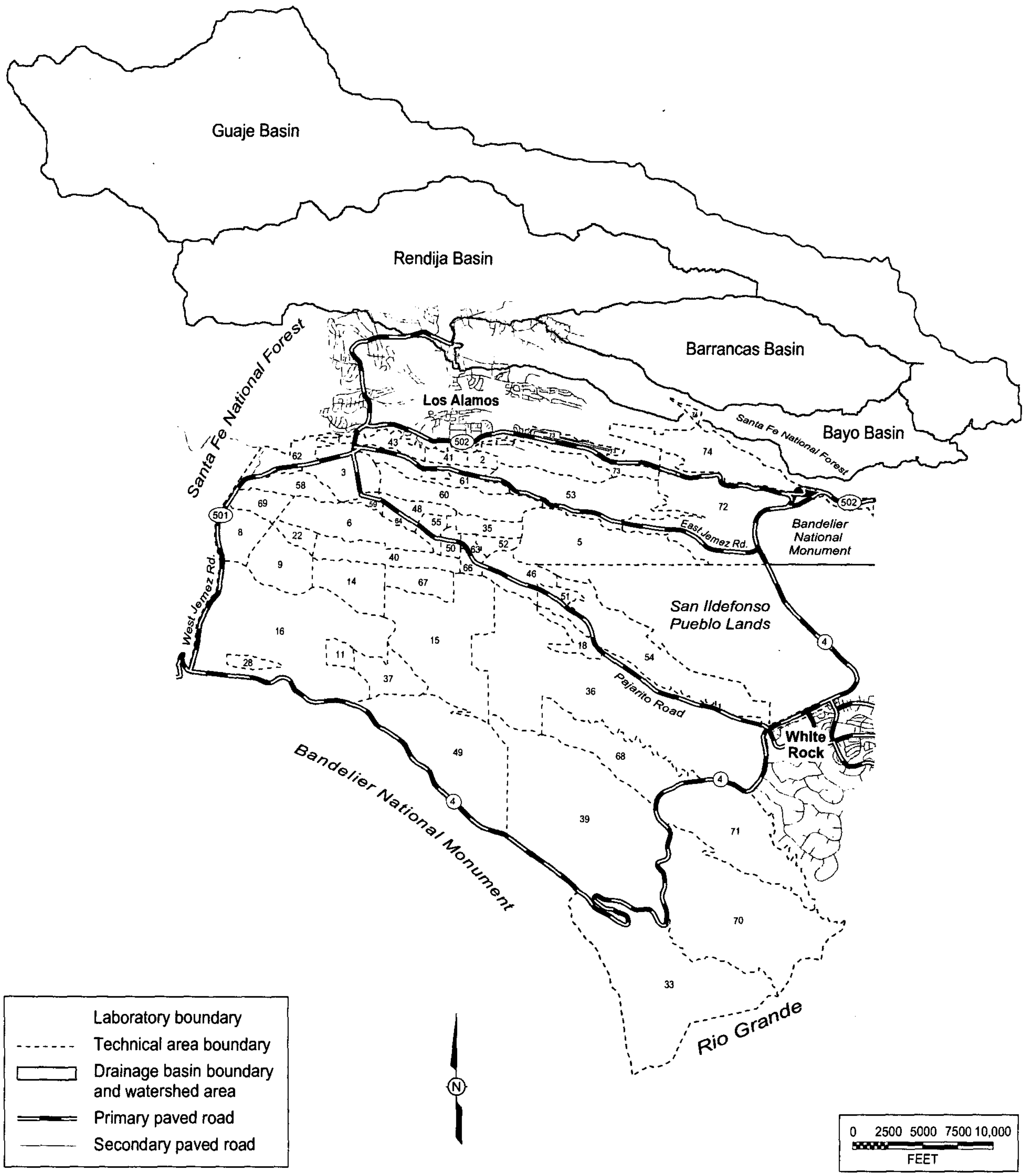

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Figure 1.0-1. Location of Guaje, Barrancas, Rendija, and Bayo watersheds with respect to Laboratory technical areas and surrounding land holdings

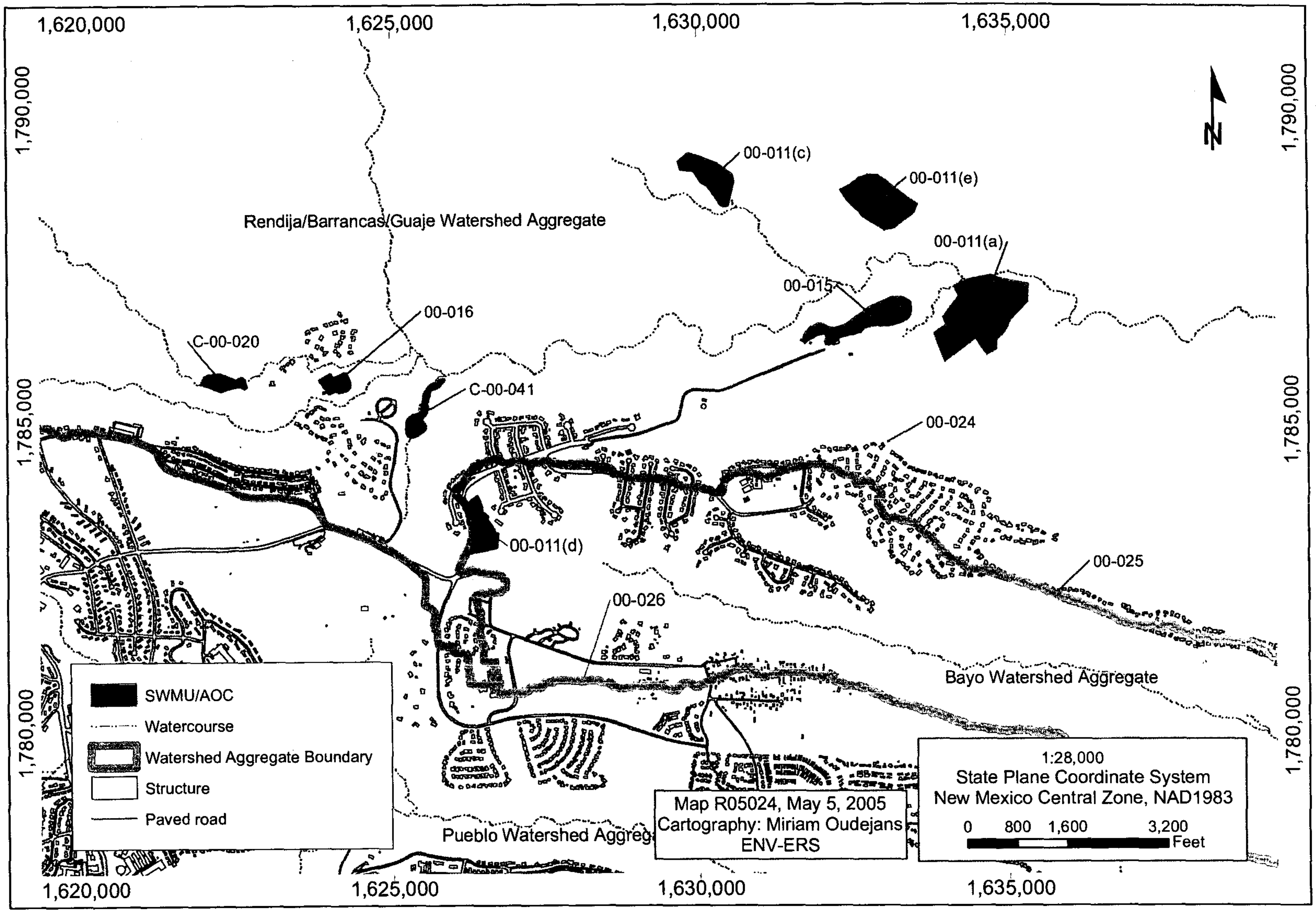
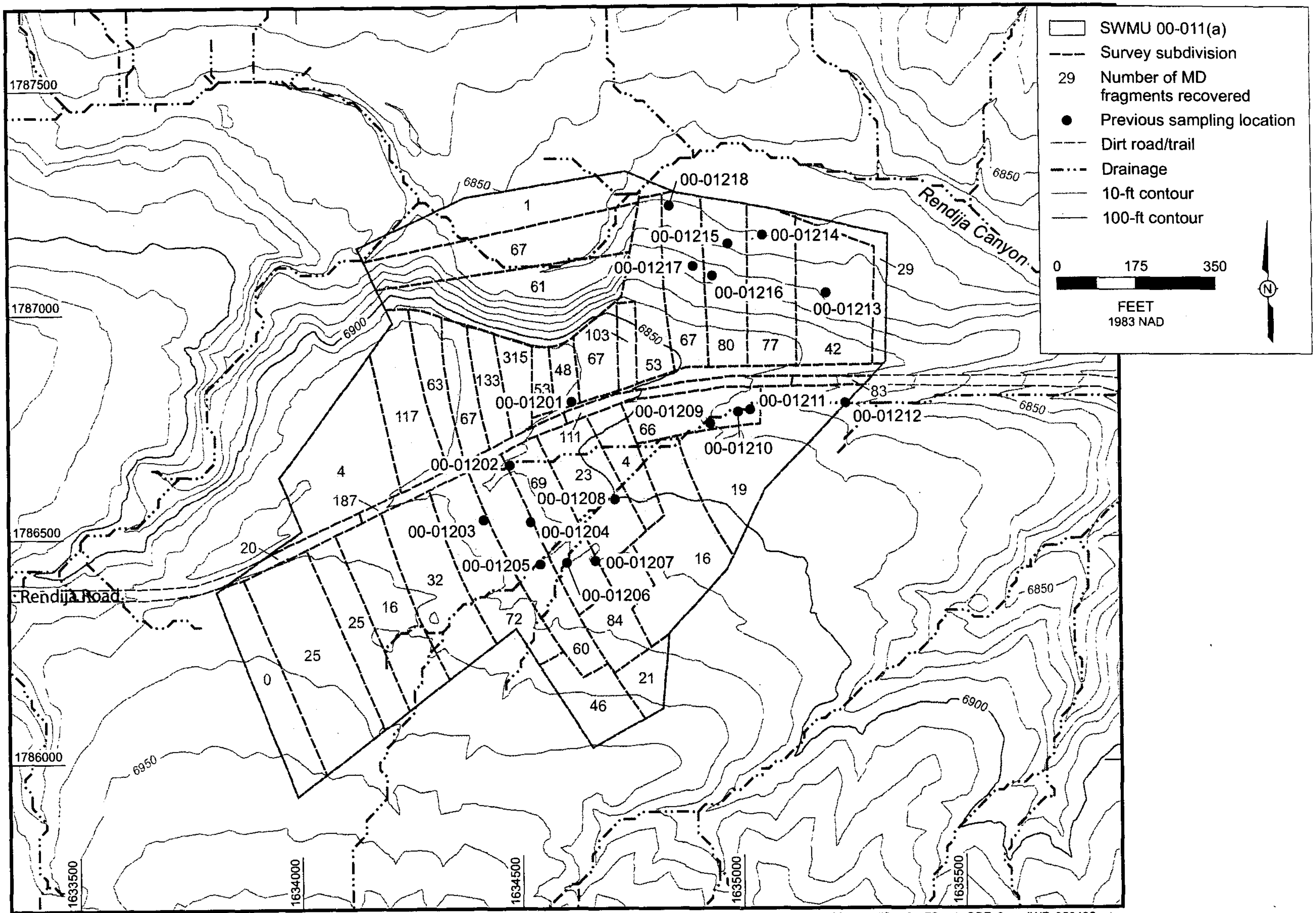


Figure 1.0-2. SWMU and AOC locations within the Bayo and Rendija/Barrancas/Guaje watershed aggregates

Figure 2.1-1. Aerial photograph of SWMU 00-011(a)



Source: D. Walther, GISLab m201434, 031005; modified for F2.4-1, GBR Cyns IWP, 050405, ptm

Figure 2.1-2. SWMU 00-011(a) areas of removed MD fragments, mortar rounds, and previous sampling locations

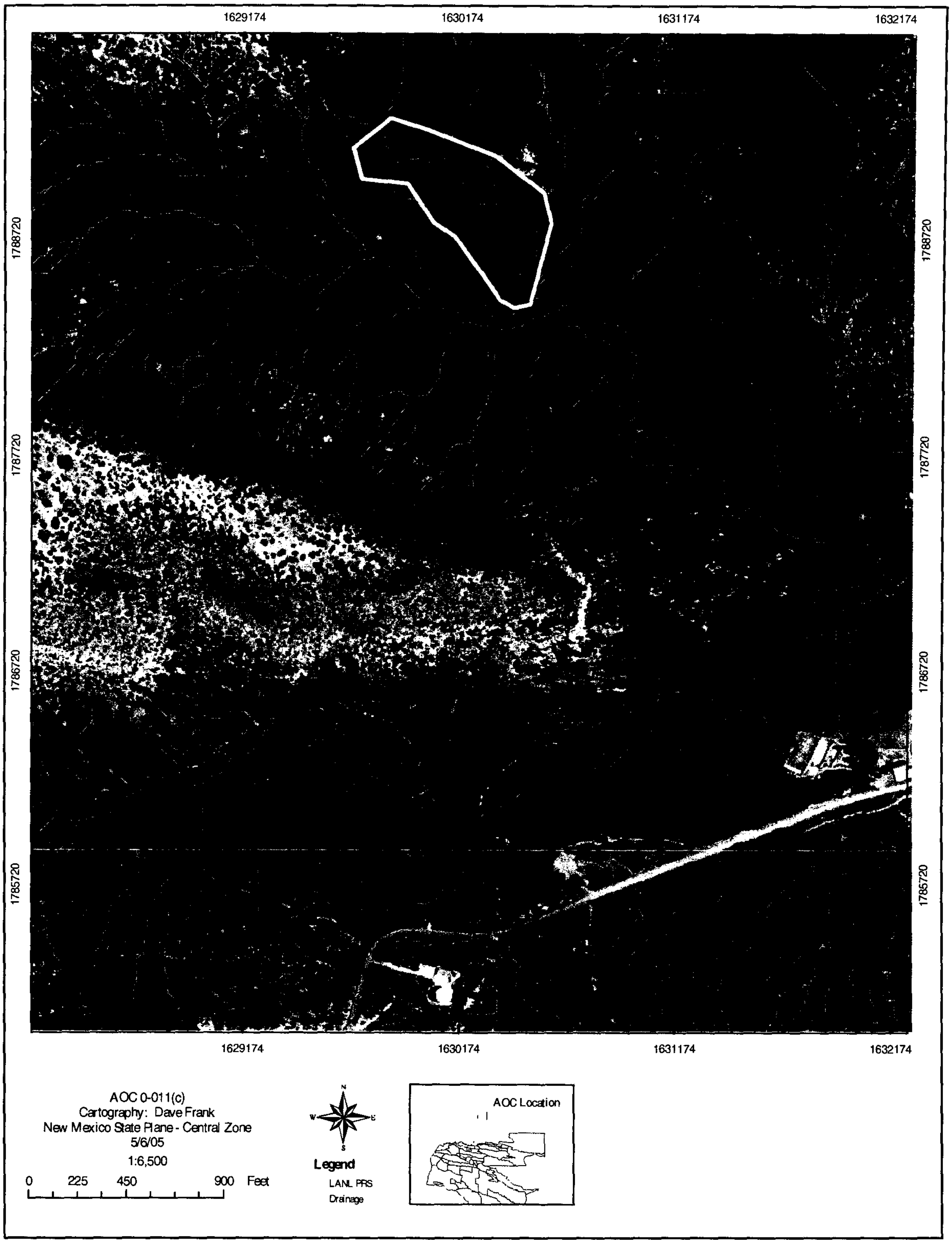
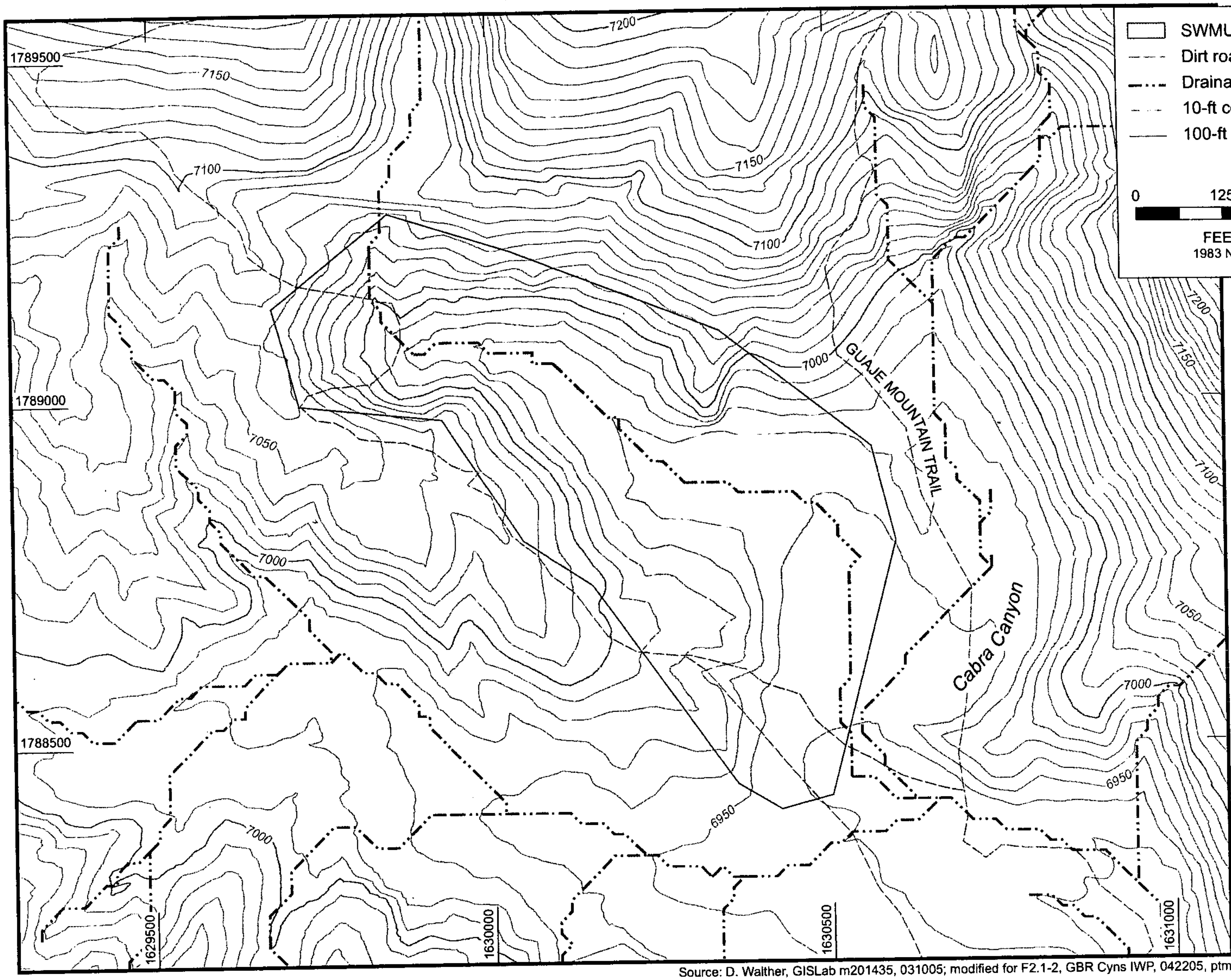


Figure 2.1-3. Aerial photograph of SWMU 00-011(c)



Source: D. Walther, GISLab m201435, 031005; modified for F2.1-2, GBR Cyns IWP, 042205, ptm

Figure 2.1-4. SWMU 00-011(c) site map

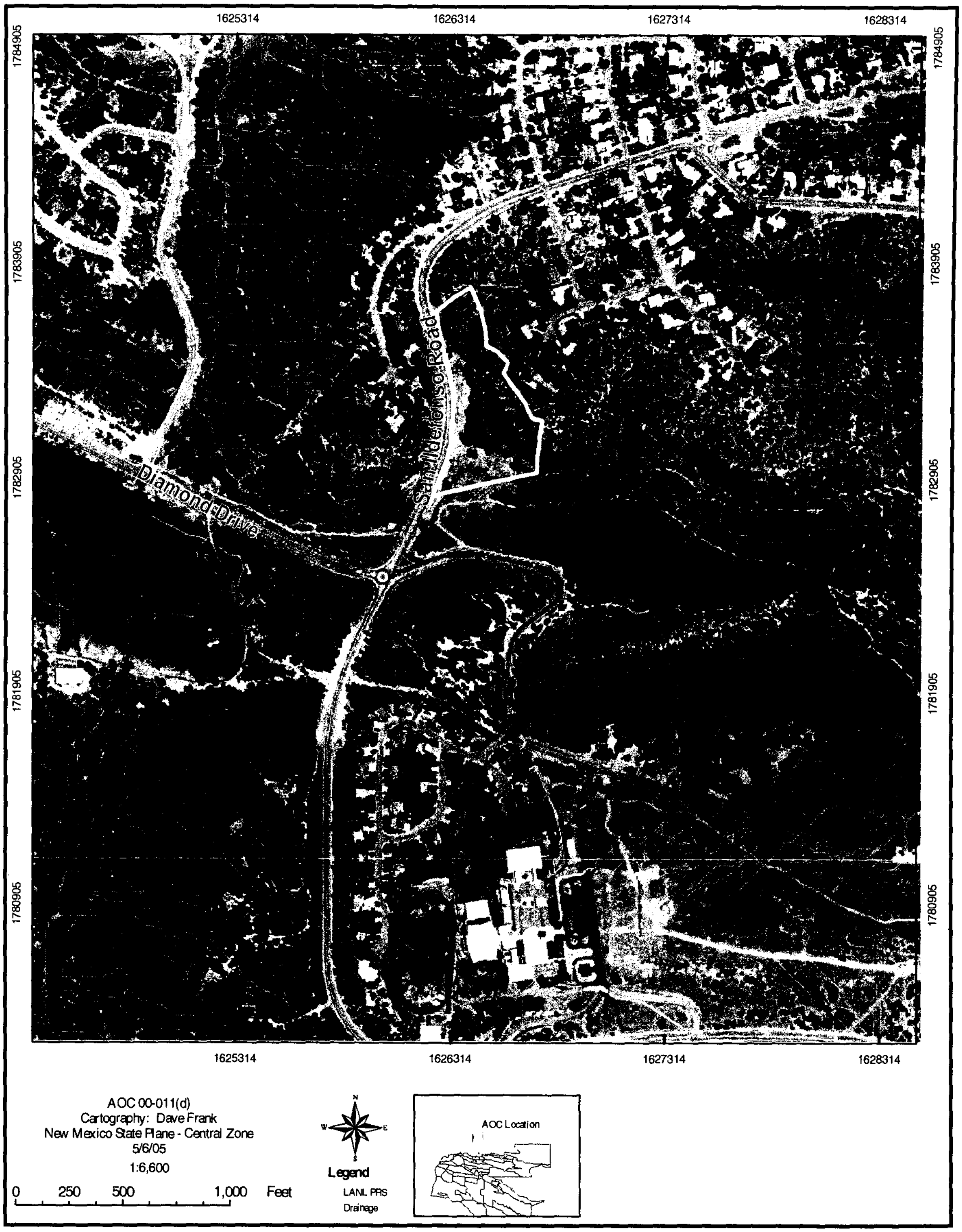
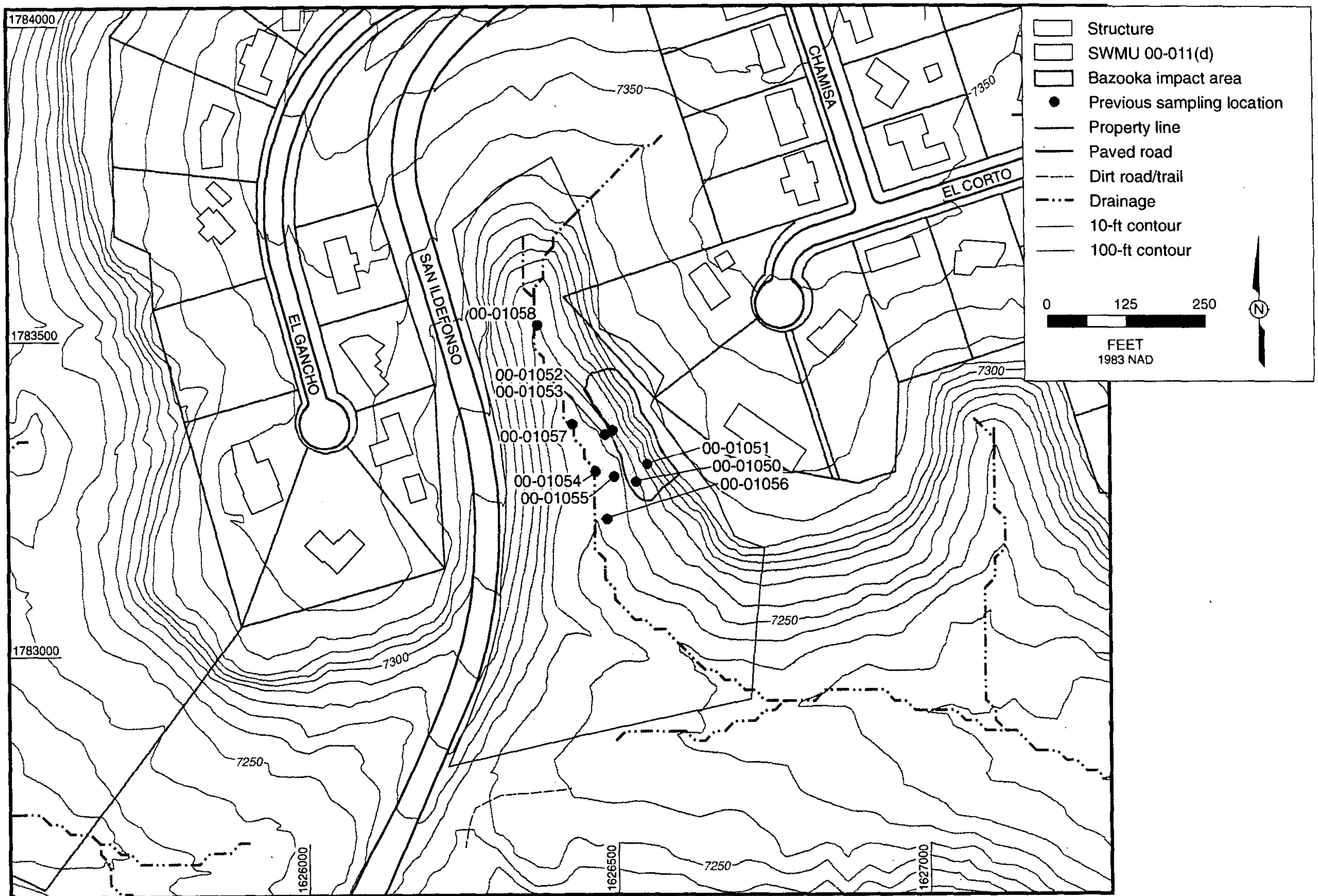


Figure 2.1-5. Aerial photograph of SWMU 00-011(d)



Source: D. Walther, GISLab m201436, 031005; modified for F2.4-3, GBR Cyns IWP, 050305, ptm

Figure 2.1-6. SWMU 00-011(d) bazooka impact area and previous sampling locations

Figure 2.1-7. Aerial photograph of SWMU 00-011(e)

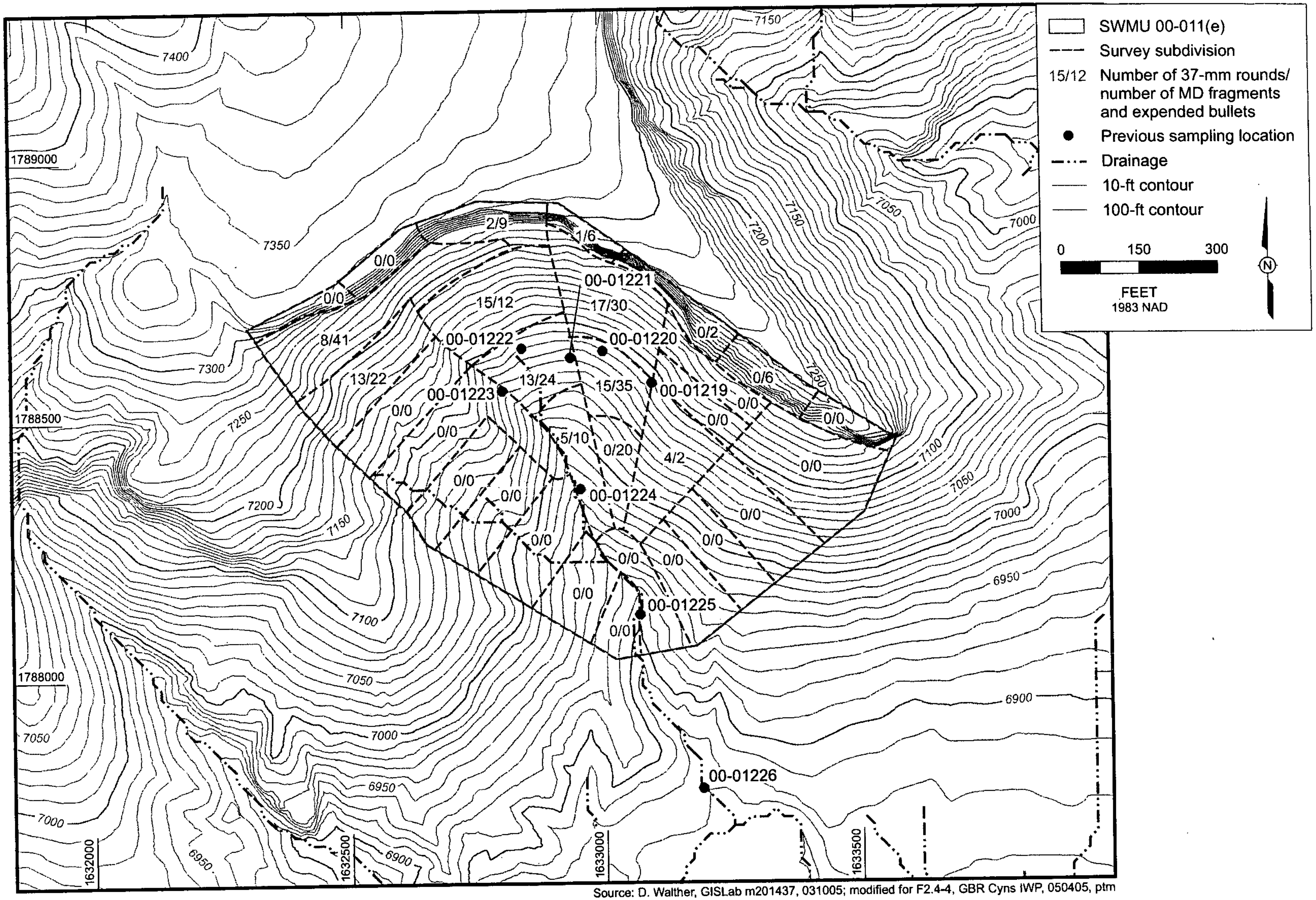


Figure 2.1-8. **SWMU 00-011(e) areas of removed 37-mm rounds, MD fragments, expended bullets, and previous sampling locations**

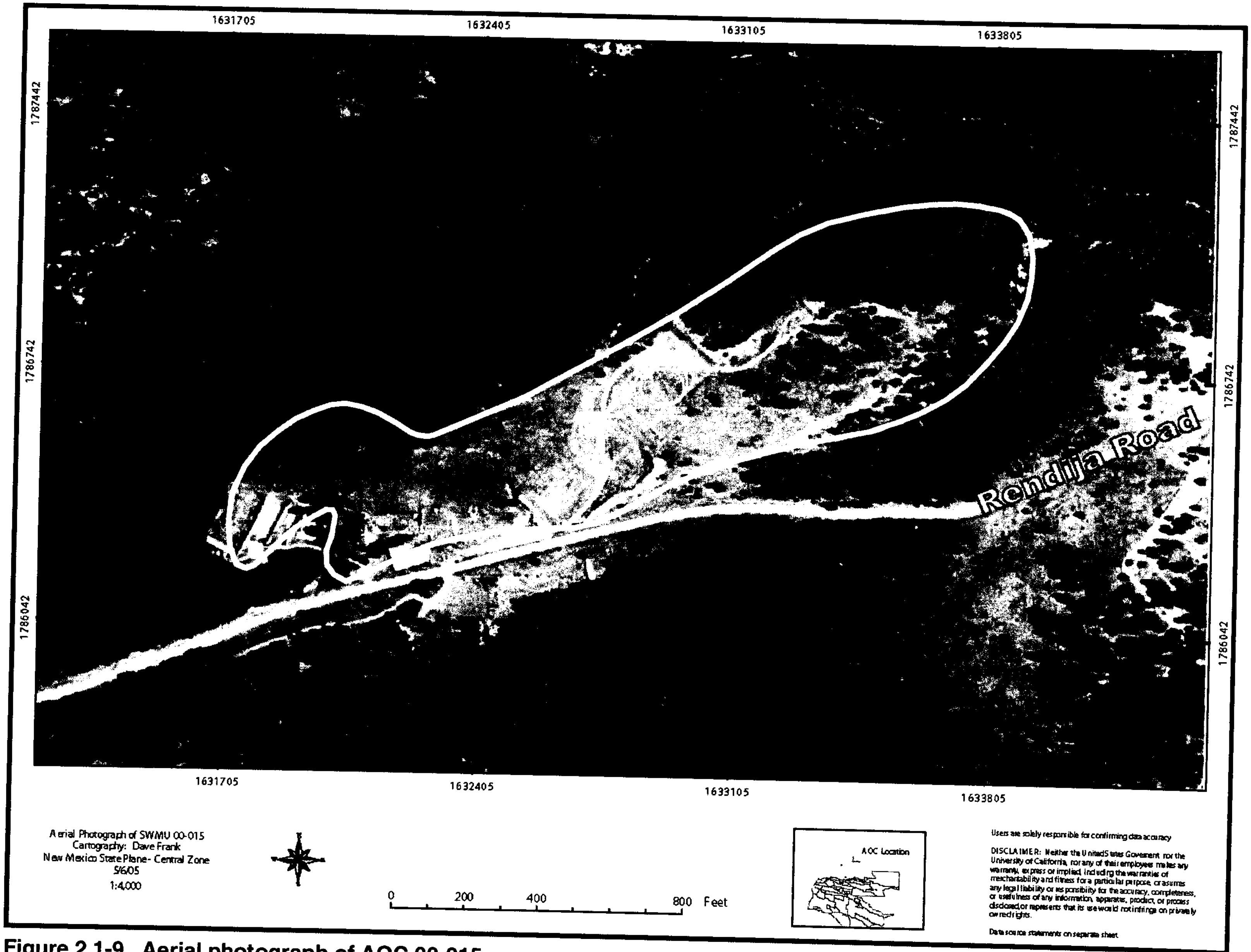
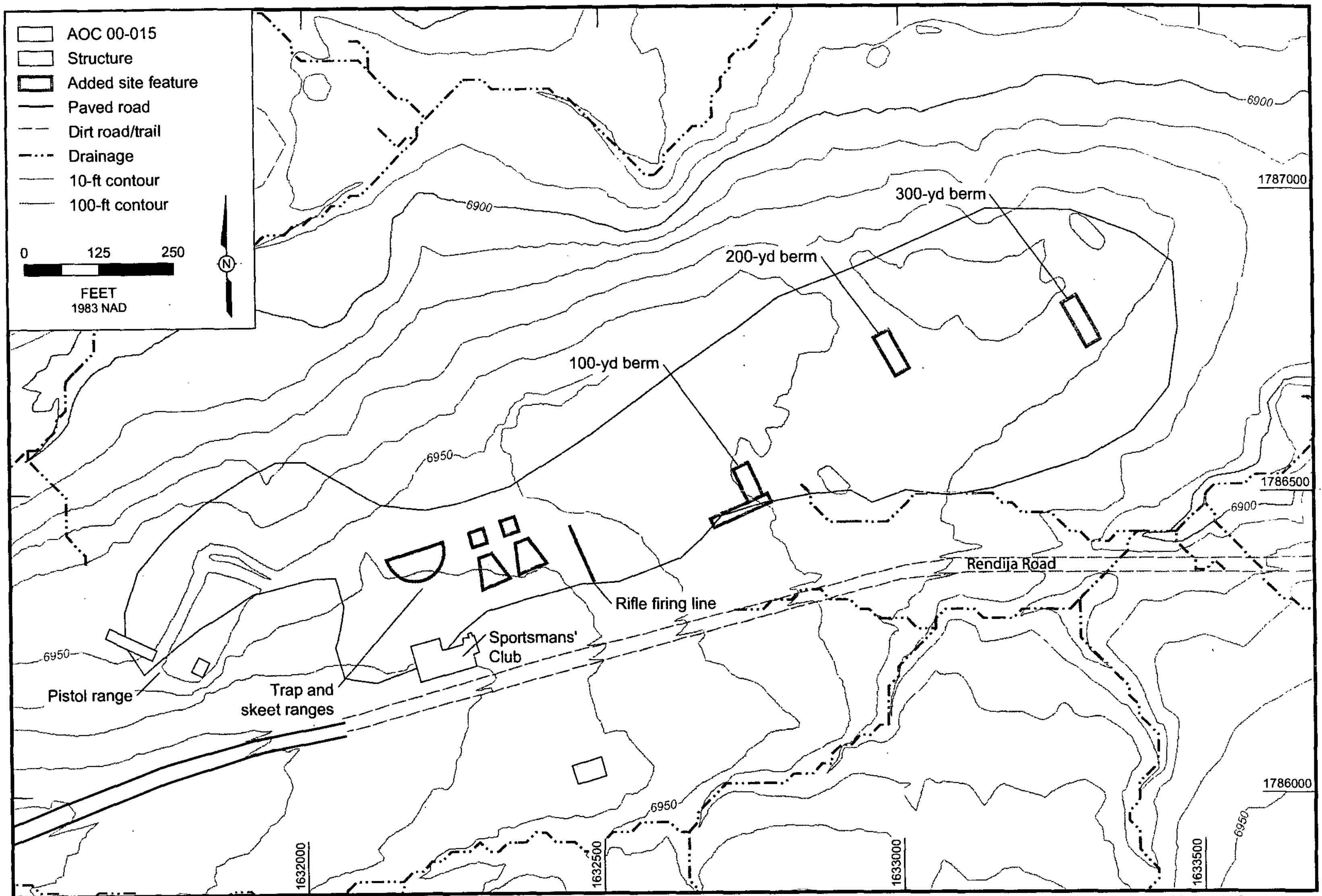


Figure 2.1-9. Aerial photograph of AOC 00-015



Source: D. Walther, GISLab m201438, 031005; modified for F2.1-5, GBR Cyns IWP, 042505, ptm

Figure 2.1-10. AOC 00-015 site map

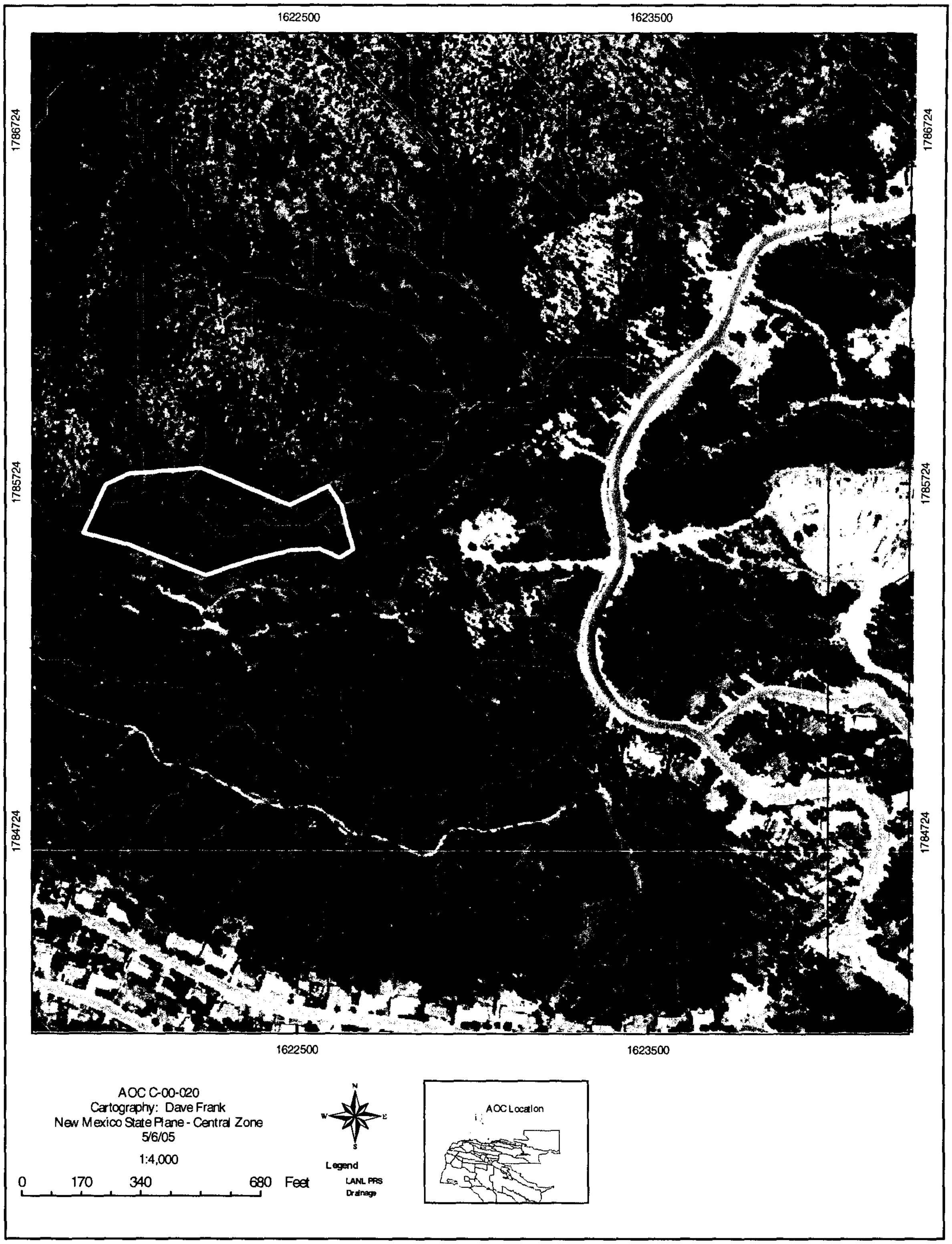
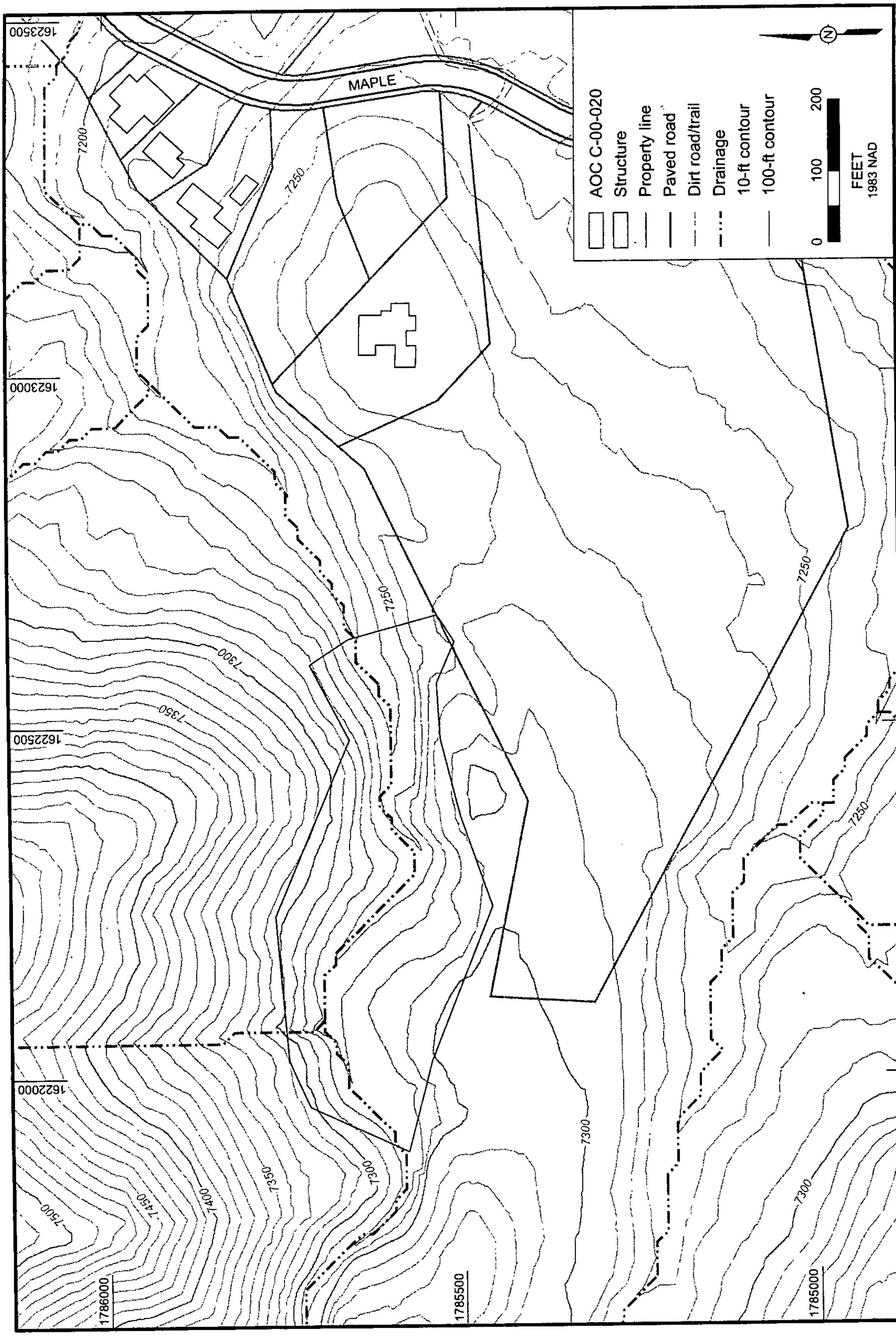


Figure 2.1-11. Aerial photograph of AOC C-00-020



Source: D. Walther, GISLab m201439, 031005; modified for F2.1-7, GBR Cyns IWP, 042505, ptm

Figure 2.1-12. AOC C-00-020 site map

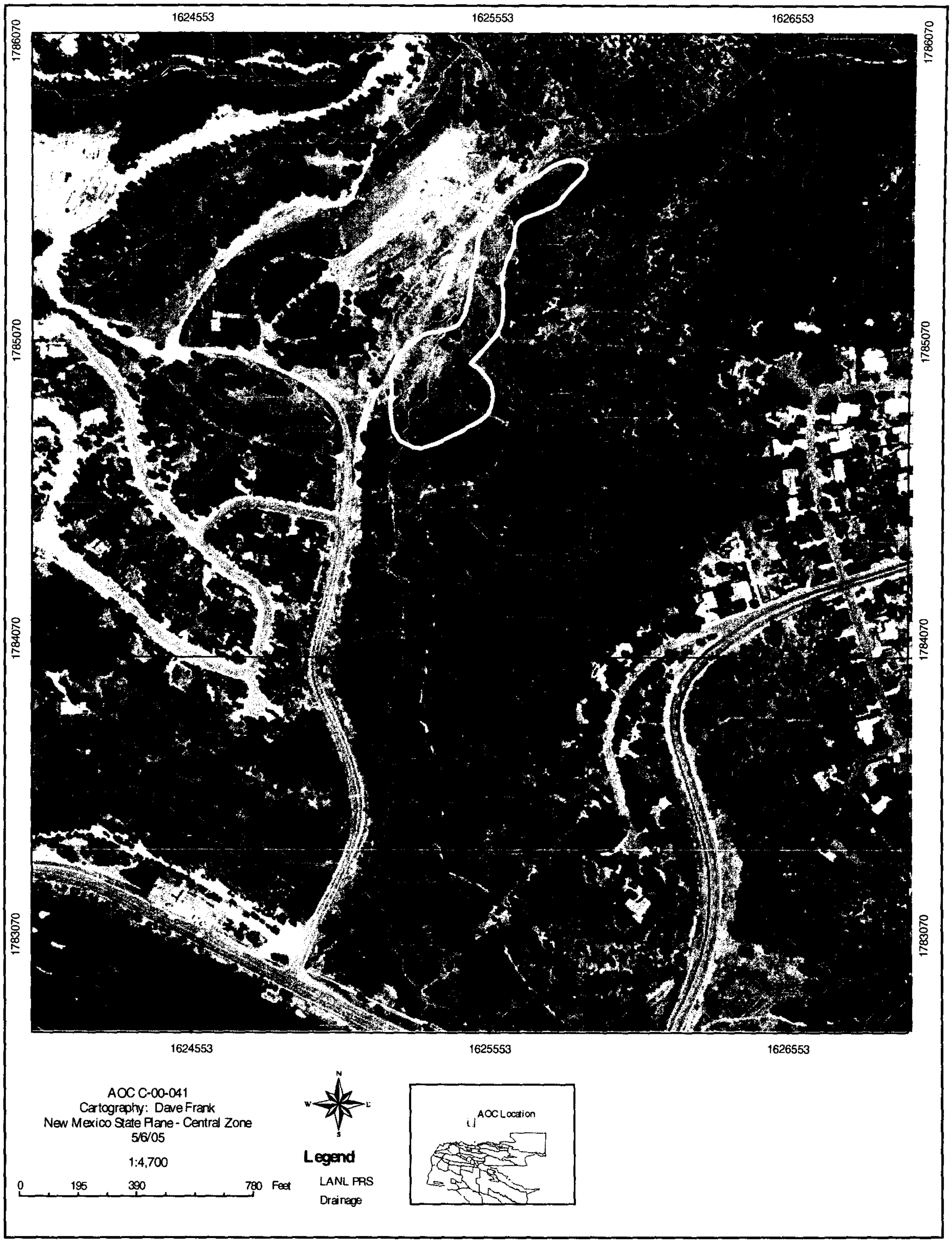
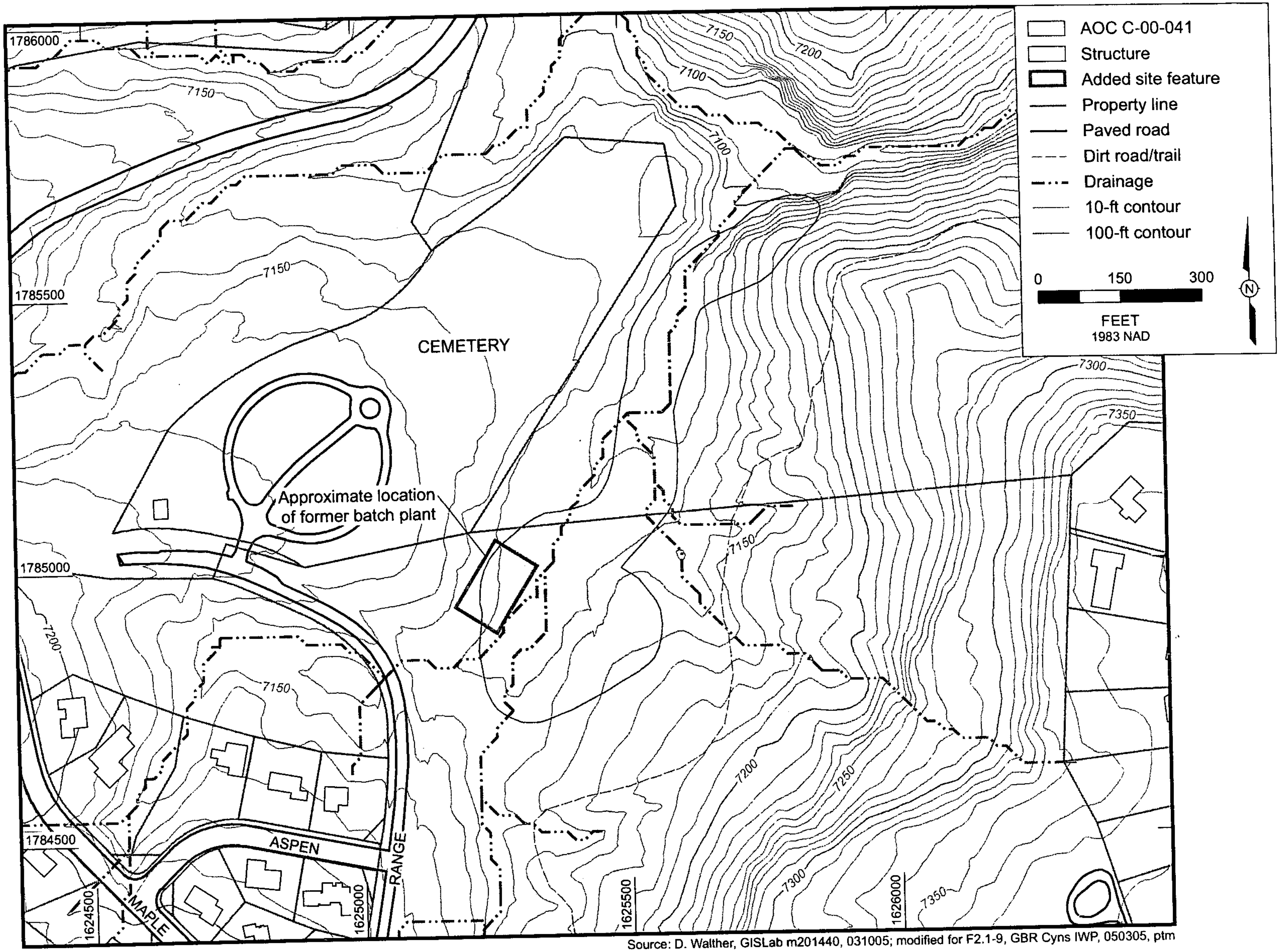
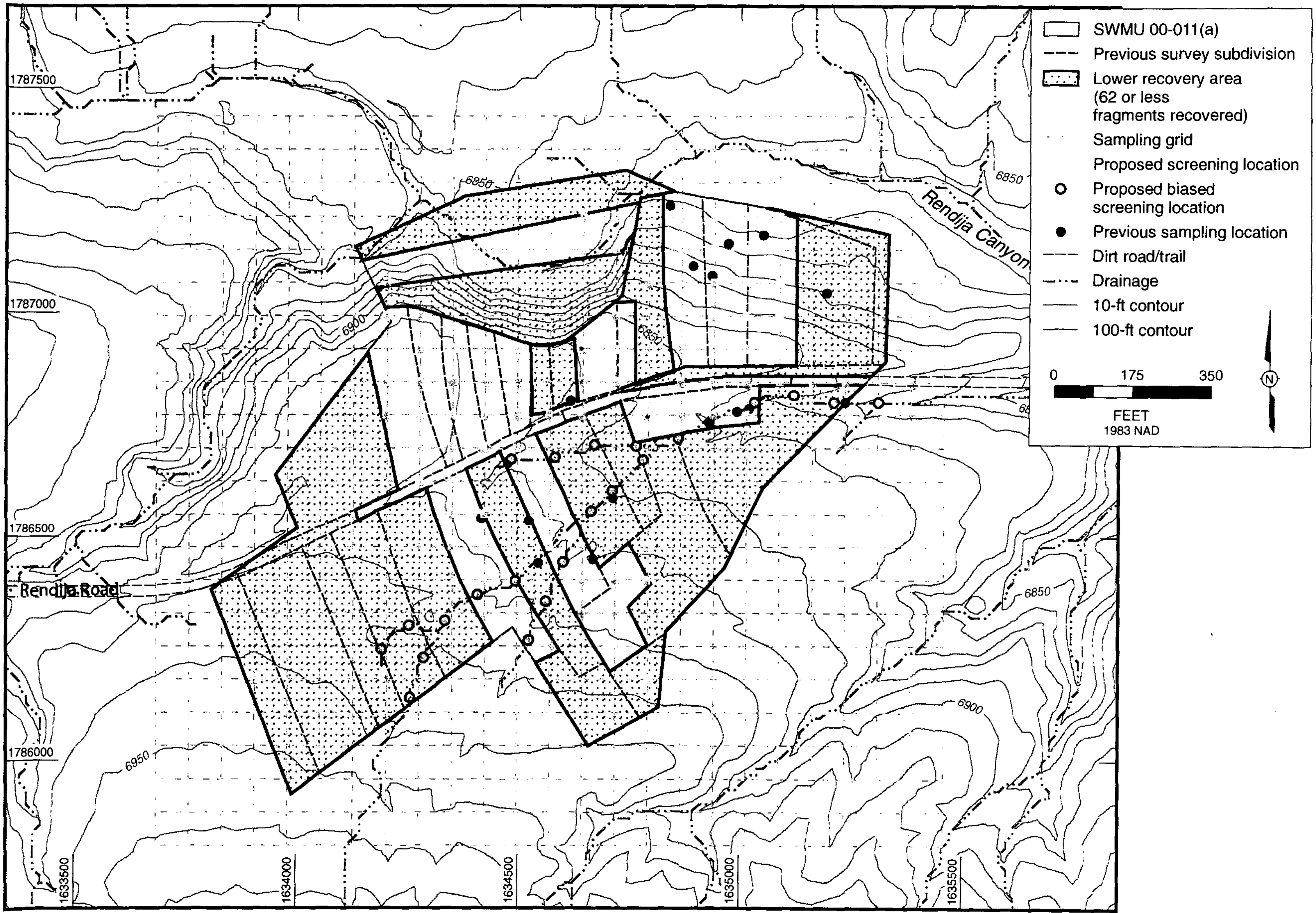


Figure 2.1-13. Aerial photograph of AOC C-00-041



Source: D. Walther, GISLab m201440, 031005; modified for F2.1-9, GBR Cyns IWP, 050305, ptm

Figure 2.1-14. AOC C-00-041 site map



Source: D. Walther, GISLab m201434, 031005; modified for F2.4-1, GBR Cyns IWP, 050405, ptm

Figure 4.2-1. SWMU 00-011(a) proposed explosive compounds screening locations

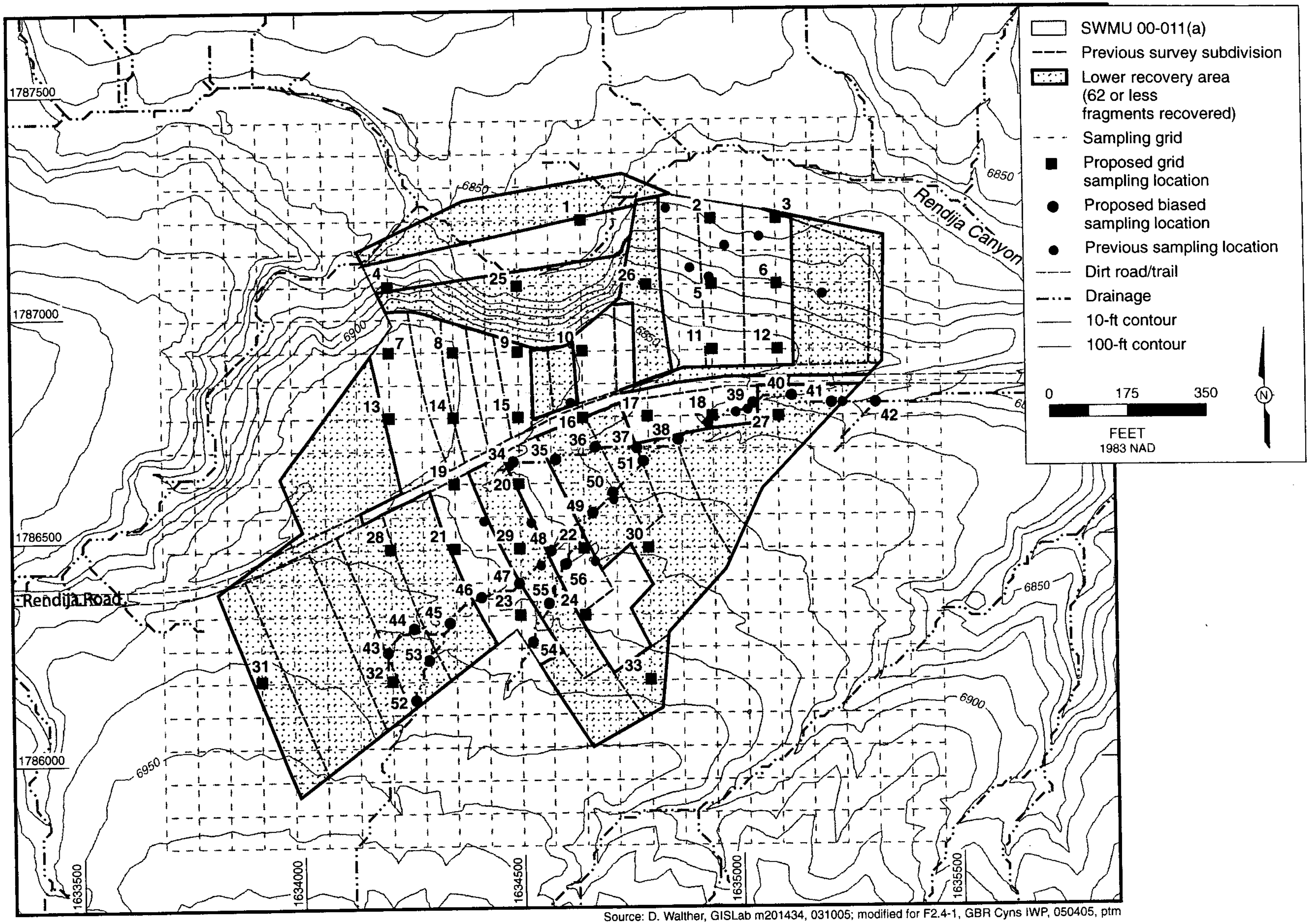


Figure 4.2-2. SWMU 00-011(a) proposed sampling locations for TAL metal and perchlorate analyses

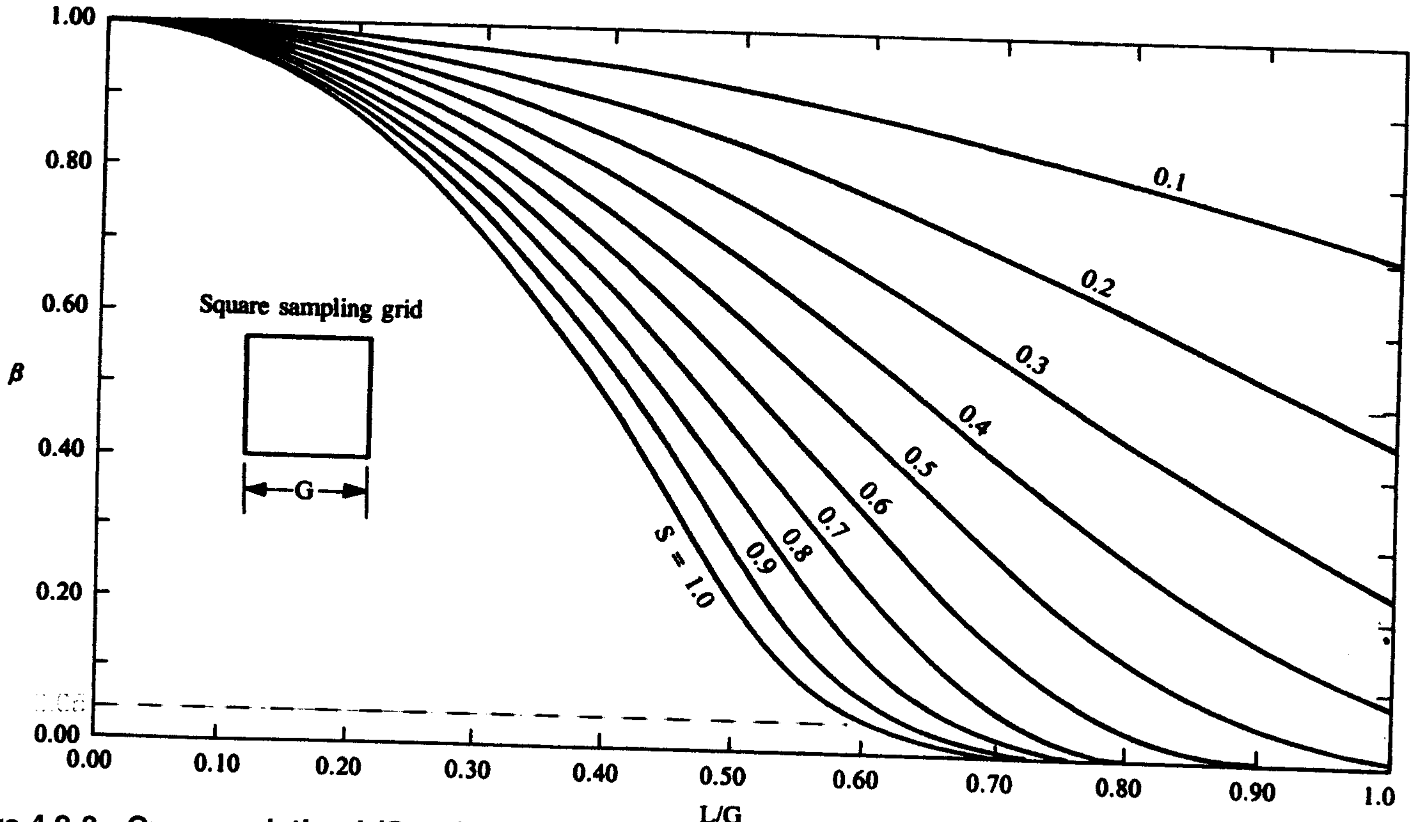
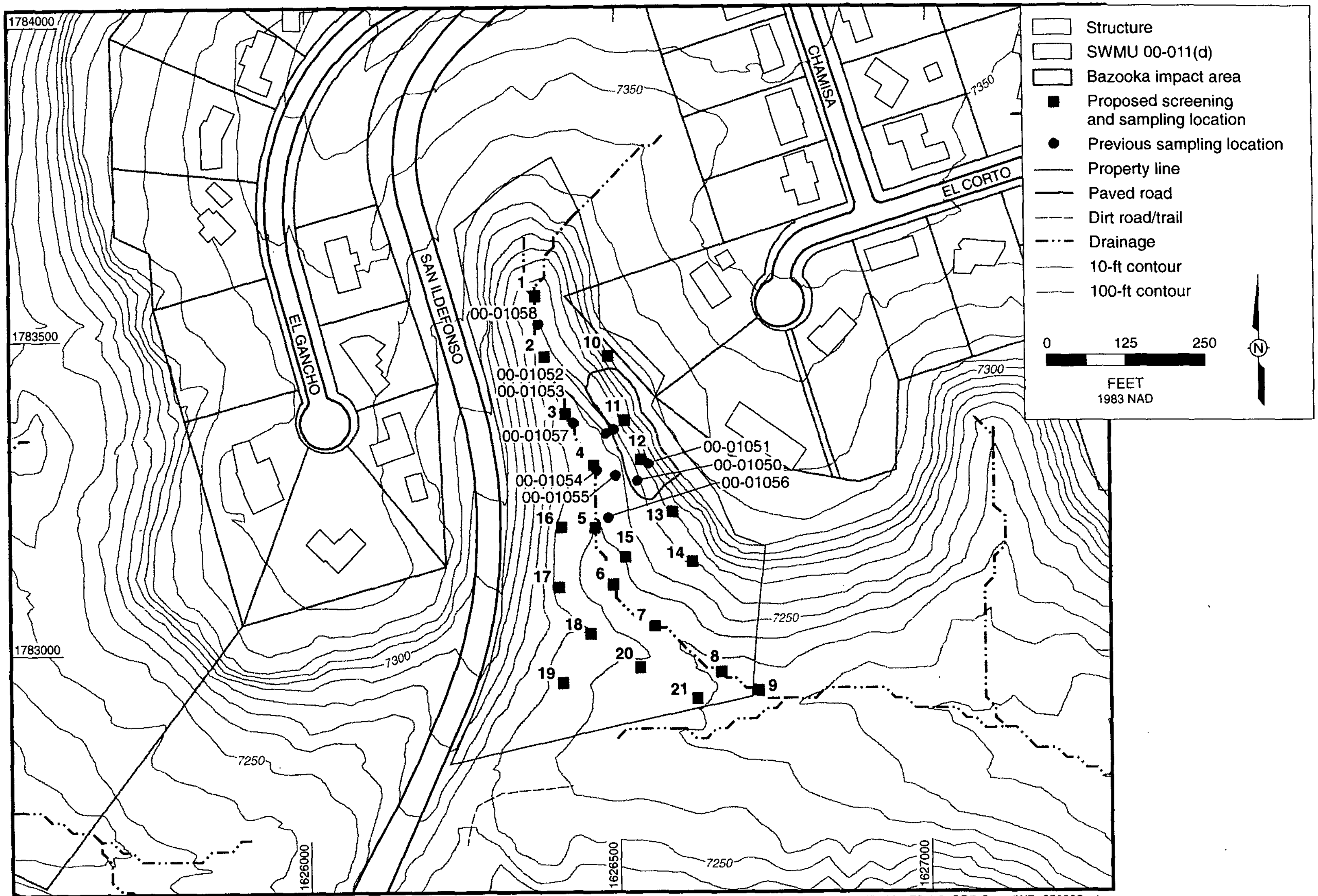
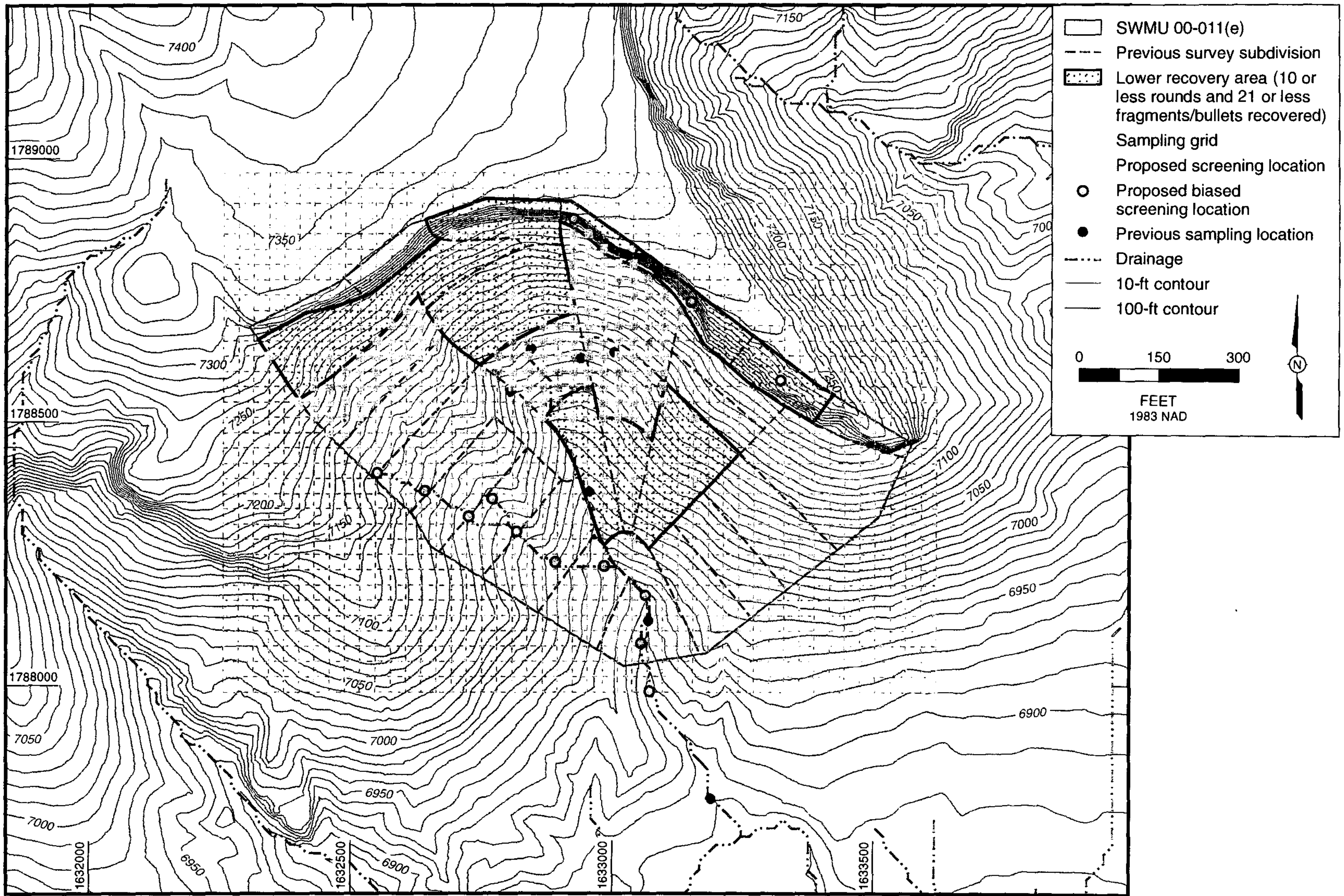


Figure 4.2-3. Curves relating L/G to β for different hotspot shapes when sampling is on a square grid pattern



Source: D. Walther, GISLab m201436, 031005; modified for F2.4-3, GBR Cyns IWP, 050305, ptm

Figure 4.2-4. SWMU 00-011(d) proposed sampling locations



Source: D. Walther, GISLab m201437, 031005; modified for F2.4-4, GBR Cyns IWP, 050405, ptm

Figure 4.2-5. SWMU 00-011(e) proposed explosive compounds screening locations

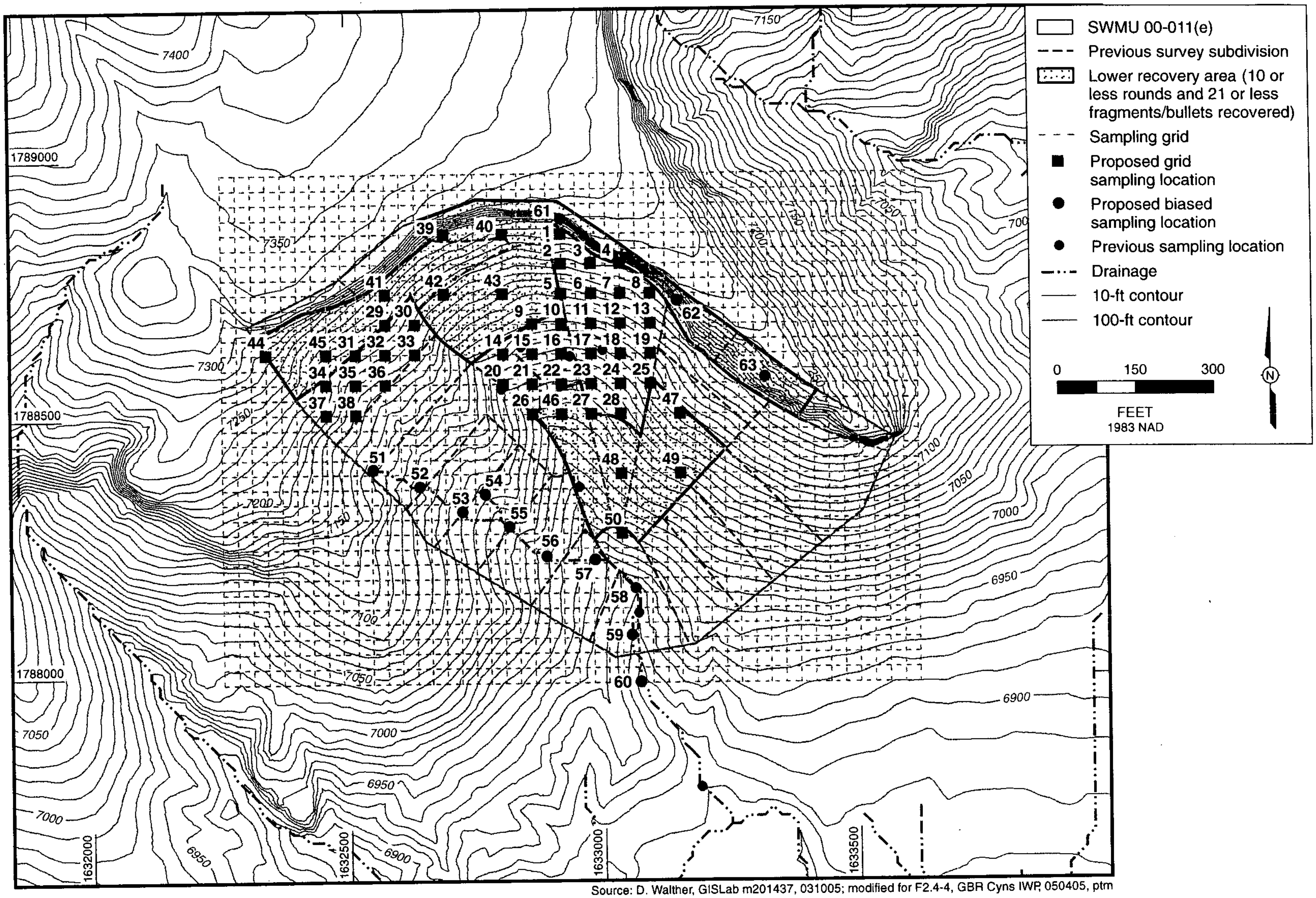
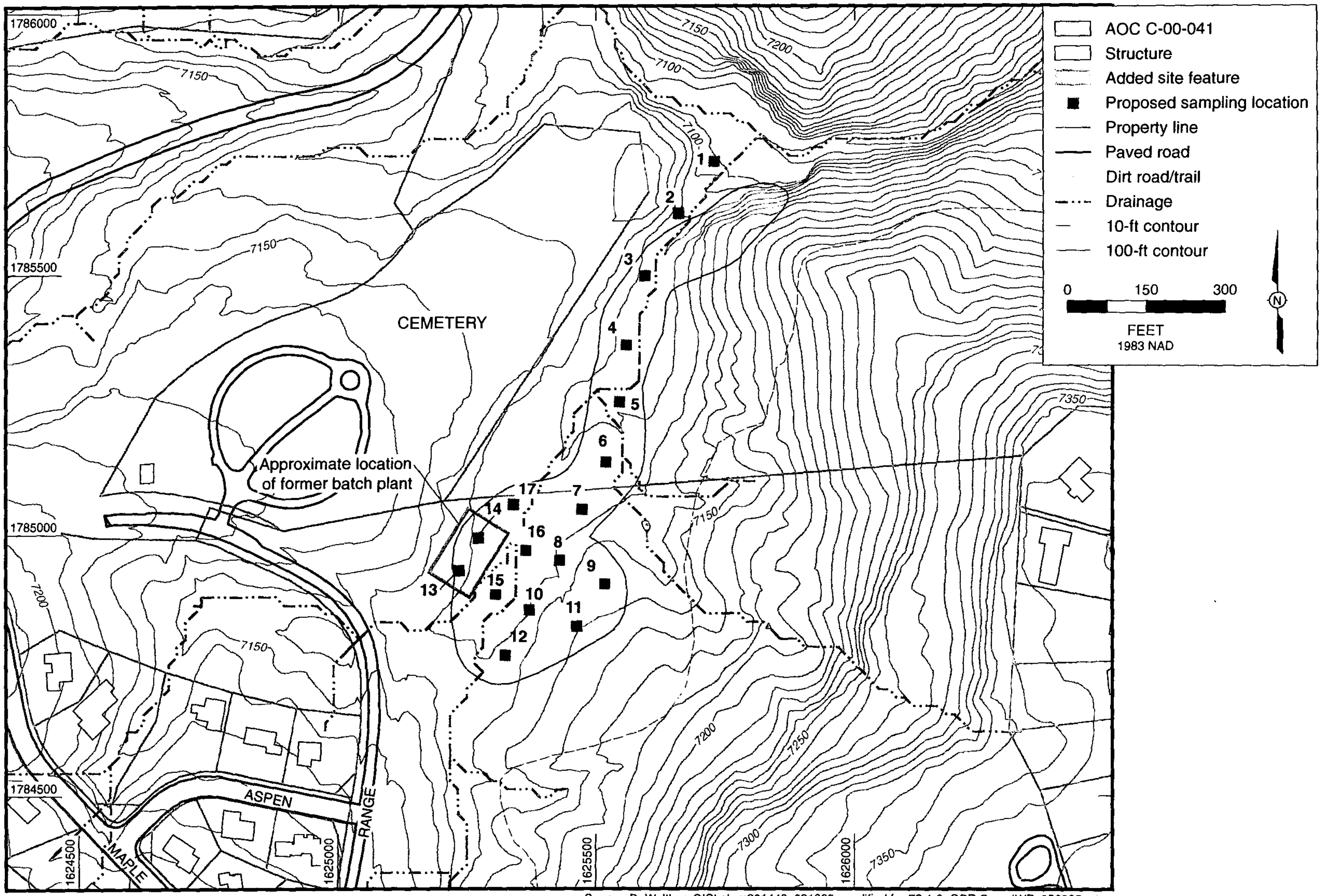


Figure 4.2-6. SWMU 00-011(e) proposed sampling locations for TAL metal and perchlorate analyses



Source: D. Walther, GISLab m201440, 031005; modified for F2.1-9, GBR Cyns IWP, 050305, ptm

Figure 4.2-7. AOC C-00-041 proposed sampling locations

Table 4.2-1
Summary of Proposed Soil Sampling at SWMU 00-011(a)

Location Number	Location	Sample Depth (ft)	TAL Metals	Perchlorate	Explosive Compounds Screening[1]
Grid Samples					
1–24	148-ft grid sample	0 to 0.5 2 to 3	X X	X X	X X
25–33	296-ft grid sample	0 to 0.5 2 to 3	X X	X X	X X
Active Drainages					
34–56	Biased sample	To be determined (TBD)[b]	X X	X X	X X
Entire Site					
~120 total	Biased samples and 74-ft and 296-ft grid samples	0 to 0.5 2 to 3 (TBD in drainages)			X X

[a] The two sample depths will be screened for explosive compounds in the field using D TECH. A minimum of 20% of the samples screened will be sent to an off-site fixed laboratory for confirmation.

b Locations and sampling depths will be determined in the field by a geomorphologist. The depth of sediment will determine sample depths collected.

Table 4.2-2
Summary of Proposed Soil Sampling at SWMU 00-011(d)

Location Number	Location	Sample Depth (ft)	TAL Metals	Perchlorate	Explosive Compounds Screening[a]
Drainage channel below cliff					
1	Northern end of drainage channel	To be determined (TBD)[b]	X X	X X	X X
2	100 ft south of location 1 in the drainage channel	TBD	X X	X X	X X
3	100 ft south of location 2 in the drainage channel	TBD	X X	X X	X X
4	100 ft south of location 3 in the drainage channel	TBD	X X	X X	X X
5	100 ft south of location 4 in the drainage channel	TBD	X X	X X	X X
6	100 ft south of location 5 in the drainage channel	TBD	X X	X X	X X
7	100 ft south of location 6 in the drainage channel	TBD	X X	X X	X X
8	100 ft south of location 7 in the drainage channel	TBD	X X	X X	X X
9	100 ft south of location 8 in the drainage channel	TBD	X X	X X	X X
Bazooka impact area					
10	North of bazooka impact area	TBD	X	X	
11	Within impact area, east of former location 00-01052	TBD	X	X	X
12	Within impact area near former location 00-01051	TBD	X	X	X
Cliff drainage area					
13	Start of drainage	TBD	X X	X X	X X
14	Middle of drainage	TBD	X X	X X	X X
15	South end of additional drainage area	TBD	X X	X X	X X
Area west of drainages					
16	West of location 5, along the hill base	0 to 0.5 2 to 3	X X	X X	X X
17	West of location 6, along the hill base	0 to 0.5 2 to 3	X X	X X	X X
18	100 ft west of drainage channel, west of location 7	0 to 0.5 2 to 3	X X	X X	X X
19	West of location 20, along the hill base	0 to 0.5 2 to 3	X X	X X	X X

Table 4.2-2
Summary of Proposed Soil Sampling at SWMU 00-011(d) (continued)

Location Number	Location	Sample Depth (ft)	TAL Metals	Perchlorate	Explosive Compounds Screening[a]
20	100 ft west of drainage channel, west of location 8	0 to 0.5 2 to 3	X X	X X	X X
21	100 ft west of location 9	0 to 0.5 2 to 3	X X	X X	X X

[a] The two sample depths will be screened for explosive compounds in the field using D TECH. A minimum of 20% of the samples screened will be sent to an off-site fixed laboratory for confirmation.

[b] Locations and sampling depths will be determined in the field by a geomorphologist. The depth of sediment will determine sample depths collected.

Table 4.2-3
Summary of Proposed Soil Sampling at SWMU 00-011(e)

Location Number	Location	Sample Depth (ft)	TAL Metals	Perchlorate	Explosive Compounds Screening[a]
Grid Samples					
1–38	54 ft grid sample	0 to 0.5 2 to 3	X X	X X	X X
39–50	108 ft grid sample	0 to 0.5 2 to 3	X X	X X	X X
Active Drainages					
51–60	Biased sample	To be determined (TBD)[b]	X X	X X	X X
Cliff Area					
61–63	Biased sample	TBD	X	X	X
Entire Site					
~160 total	Biased samples and 27 ft and 108 ft grid samples for field screening using D TECH	0 to 0.5 2 to 3 (TBD in drainages)			X X

[a] The two sample depths will be screened for explosive compounds in the field using D TECH. A minimum of 20% of the samples screened will be sent to an off-site fixed laboratory for confirmation.

[b] Locations and sampling depths will be determined in the field by a geomorphologist. The depth of sediment will determine sample depths collected.

Table 4.2-4
Summary of Proposed Soil Sampling at AOC C-00-041

Location Number	Location	Sample Depth (ft)	TAL Metals	VOCs	SVOCs	TPH
1	North end of drainage area along western edge of drainage	0 to 0.5 2 to 3	X X	X X	X X	X X
2	100 ft south of location 1 along western side of drainage	0 to 0.5 2 to 3	X X	X X	X X	X X
3	100 ft south of location 2 along western side of drainage	0 to 0.5 2 to 3	X X	X X	X X	X X
4	100 ft south of location 3 along center of SWMU area	0 to 0.5 2 to 3	X X	X X	X X	X X
5	100 ft south of location 4 along center of SWMU area	0 to 0.5 2 to 3	X X	X X	X X	X X
6	100 ft south of location 5 along center of SWMU area	0 to 0.5 2 to 3	X X	X X	X X	X X
7	100 ft south of location 6 along center of SWMU area	0 to 0.5 2 to 3	X X	X X	X X	X X
8	100 ft south of location 7 along center of SWMU area	0 to 0.5 2 to 3	X X	X X	X X	X X
9	100 ft southeast of location 8	0 to 0.5 2 to 3	X X	X X	X X	X X
10	100 ft southwest of location 8	0 to 0.5 2 to 3	X X	X X	X X	X X
11	100 ft southeast of location 10	0 to 0.5 2 to 3	X X	X X	X X	X X
12	100 ft southwest of location 10	0 to 0.5 2 to 3	X X	X X	X X	X X
13–14	Inside former batch plant boundary	0 to 0.5 2 to 3	X X	X X	X X	X X
15–17	Downslope of former batch plant boundary	0 to 0.5 2 to 3	X X	X X	X X	X X

Table 5.0-1
Summary of Investigation Methods

Method	Summary
Spade and Scoop Collection of Soil Samples	This method is typically used for collection of shallow (i.e., approximately 0–12 in.) soil or sediment samples. The "spade-and-scoop" method involves digging a hole to the desired depth, as prescribed in the sampling and analysis plan, and collecting a discrete grab sample. The sample is typically placed in a clean stainless steel bowl for transfer into various sample containers.
Hand Auger Sampling	This method is typically used for sampling soil or sediment at depths of less than 10–15 ft, but may in some cases be used for collecting samples of weathered or nonwelded tuff. The method involves hand-turning a stainless-steel bucket auger (typically with a 3–4 in. inner diameter), creating a vertical hole which can be advanced to the desired sample depth. When the desired depth is reached, the auger is decontaminated before advancing the hole through the sample depth. The sample material is transferred from the auger bucket to a stainless-steel sampling bowl before filling the various required sample containers.
Split-Spoon Core-Barrel Sampling	In this method, a stainless steel core barrel (typically with a 4-in. inner diameter and 2.5 ft long) is advanced using a powered drilling rig. The core barrel extracts a continuous length of soil and/or rock which can be examined as a unit. The split-spoon core barrel is a cylindrical barrel split length-wise so that the two halves can be separated to expose the core sample. Once extracted, the section of core is typically screened for radioactivity and organic vapors, photographed, and described in a geologic log. A portion of the core may then be collected as a discrete sample from the desired depth.
Headspace Vapor Screening	Individual soil, rock, or sediment samples may be field-screened for volatile organic compounds by placing a portion of the sample in a plastic sample bag or in a glass container with a foil-sealed cover. The container is sealed and gently shaken, and allowed to equilibrate for 5 min. The sample is then screened by inserting a photoionization detector probe into the container and measuring and recording any detected vapors.
Portable XRF Field Screening	A portable x-ray fluorescence analyzer may be used to measure metals content in soils while in the field to provide screening data and guide collection of samples for determination of extent of metals contamination. The instrument includes sealed radioactive sources and can identify and quantify 26 elements. The instrument must be properly warmed up and calibrated according to manufacturer's directions before use. Soil samples should be homogenized and have large rocks, vegetation, and any foreign objects removed (samples may be sieved). The sample surface should be flattened or smoothed with a trowel or similar tool. For quantitative work, reference standard materials should be analyzed and the precision of the instrument determined at least once per day or once for every 20 samples. Precision may be determined by performing multiple analyses of certified reference standard materials.

Table 5.0-1 (continued)

Method	Summary
Handling, Packaging, and Shipping of Samples	Field team members seal and label samples before packing, and ensure that the sample containers and the containers used for transport are free of external contamination. Field team members package all samples so as to minimize the possibility of breakage during transportation. After all environmental samples are collected, packaged, and preserved, a field team member transports them to either the Sample Management Office (SMO) or an SMO-approved radiation screening laboratory under chain-of-custody. The SMO arranges for shipping of samples to analytical laboratories. The field team member must inform the SMO and/or the radiation screening laboratory coordinator when levels of radioactivity are in the action-level or limited-quantity ranges.
Sample Control and Field Documentation	The collection, screening, and transport of samples is documented on standard forms generated by the SMO. These include sample collection logs, chain-of-custody forms, and sample container labels. Collection logs are completed at the time of sample collection, and are signed by the sampler and a reviewer who verifies the logs for completeness and accuracy. Corresponding labels are initialed and applied to each sample container, and custody seals are placed around container lids or openings. Chain-of-custody forms are completed and assigned to verify that the samples are not left unattended.
Field Quality Control Samples	Field quality control samples are collected as directed in the March 1, 2005, Compliance Order on Consent as follows: Field Duplicate: At a frequency 10%; collected at the same time as a regular sample and submitted for the same analyses. Equipment Rinsate Blank: At a frequency of 10%; collected by rinsing sampling equipment with deionized water, which is collected in a sample container and submitted for laboratory analysis. Trip Blanks: Required for all field events that include the collection of samples for volatile organic compound analysis. Trip blank containers of certified clean sand that are opened and kept with the other sample containers during the sampling process.
Field Decontamination of Drilling and Sampling Equipment	Dry decontamination is the preferred method to minimize the generation of liquid waste. Dry decontamination may include the use of a wire brush or other tool for removal of soil or other material adhering to the sampling equipment, followed by use of a commercial cleaning agent (nonacidic, waxless cleaners) and paper wipes. Dry decontamination may be followed by wet decontamination if necessary. Wet decontamination may include washing with a non-phosphate detergent and water, followed by a water rinse and a second rinse with deionized water. Alternatively, steam cleaning may be used.
Containers and preservation of samples	Specific requirements/processes for sample containers, preservation techniques, and holding times are based on EPA guidance for environmental sampling, preservation, and quality assurance. Specific requirements for each sample are printed on the sample collection logs provided by the SMO (size and type of container, i.e. glass, amber glass, polyethylene, preservative, etc.). All samples are preserved by placing in insulated containers with ice to maintain a temperature of 4°C. Other requirements such as nitric acid or other preservatives may apply to different media or analytical requests.

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Appendix A

Acronyms and Abbreviations, Glossary, and Metric Conversion Table

A-1.0 ACRONYMS AND ABBREVIATIONS

AEC	Atomic Energy Commission
AOC	area of concern
bgs	below ground surface
BV	background value
CST	Chemical Sciences and Technology
DGM	digital geophysical mapping
DOE	U.S. Department of Energy
DOT	Department of Transportation
ECR	Environmental Characterization and Remediation Group
ENV	Environmental Stewardship Division
EOD	explosive ordnance disposal
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration (as in *former ER Project*)
ERS	Environmental Remediation and Surveillance Program
GPS	global positioning system
GSA	General Services Administration
HE	high explosives
IDW	investigation-derived waste
LANL	Los Alamos National Laboratory
MD	munitions debris
MEC	munitions and explosives of concern
NFA	no further action
NMED	New Mexico Environment Department
NMHWA	New Mexico Hazardous Waste Act
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PPE	personal protective equipment
QA/QC	quality assurance/quality control
QAL	quaternary alluvium
S	suspected size and shape of contamination
SAFR	small-arms firing range
SMO	Sample Management Office
SOP	standard operating procedure

SSL	soil screening level
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TA	technical area
TAL	target analyte list
TBD	to be determined
TCLP	toxicity characteristic leaching procedure
UC	University of California
USACE	U.S. Army Corps of Engineers
USFS	U.S. Forest Service
UXO	unexploded ordnance
VCA	voluntary corrective action
VOC	volatile organic compound
WCSF	waste characterization strategy form
WPF	waste profile forms

A-2.0 GLOSSARY

administrative authority—For Los Alamos National Laboratory, one or more regulatory agencies, such as the New Mexico Environment Department, the U.S. Environmental Protection Agency, or the U.S. Department of Energy, as appropriate.

aggregate—At the Los Alamos National Laboratory, an area within a *watershed* containing solid waste management units (SWMUs) and/or areas of concern, and the media affected or potentially affected by releases from those SWMUs and/or areas of concern. Aggregates are designated to promote efficient and effective corrective action activities.

area of concern—(1) A release that may warrant investigation or remediation and is not a specific solid waste management unit (SWMU). (2) An area at Los Alamos National Laboratory that may have had a release of a hazardous waste or a hazardous constituent but is not a SWMU.

background level—(1) The concentration of a substance in an environmental medium (air, water, or soil) that occurs naturally or is not the result of human activities. (2) In exposure assessment, the concentration of a substance in a defined control area over a fixed period of time before, during, or after a data-gathering operation.

barrier—Any material or structure that prevents, or substantially delays, the movement of solid-, liquid-, or gaseous-phase chemicals in environmental media.

chemical—Any naturally occurring or human-made substance characterized by a definite molecular composition.

cleanup—A series of actions taken to deal with the release, or threat of a release, of a hazardous substance that could affect humans and/or the environment. The term cleanup is sometimes used interchangeably with the terms remedial action, removal action, or corrective action.

cleanup levels—Media-specific contaminant concentration levels that must be met by a selected corrective action. Cleanup levels are established by using criteria such as the protection of human health and the environment; compliance with regulatory requirements; reduction of toxicity, mobility, or volume through treatment; long- and short-term effectiveness; implementability; and cost.

constituent — Any compound or element present in environmental media, including both naturally occurring and man-made elements.

contaminant—(1) Chemical and radionuclides present in environmental media or on debris above background levels. (2) According to the New Mexico Environment Department (NMED) Consent Order, any hazardous waste listed or identified as characteristic in 40 Code of Federal Regulations (CFR) 261 (incorporated by 20.4.1.200 New Mexico Administrative Code [NMAC]); any hazardous constituent listed in 40 CFR 261 Appendix VIII (incorporated by 20.4.1.200 NMAC) or 40 CFR 264 Appendix IX (incorporated by 20.4.1.500 NMAC); any groundwater contaminant listed in the Water Quality Control Commission (WQCC) Regulations at 20.6.3.3103 NMAC; any toxic pollutant listed in the WQCC Regulations at 20.6.2.7 NMAC; explosive compounds; nitrate; and perchlorate. (Note: Under the NMED Consent Order, the term "contaminant" does not include radionuclides or the radioactive portion of mixed waste.)

contamination — Substances introduced into the environment as a result of people's activities, regardless of whether the concentration is a threat to health (see pollution).

corrective action—(1) In the Resource Conservation and Recovery Act, an action taken to rectify conditions potentially adverse to human health or the environment. (2) In the quality assurance field, the process of rectifying and preventing nonconformances.

corrective action process — One or more of a series of activities (initial site assessment, site characterization, interim actions, evaluation of remedial alternatives, and implementation of selected remedy); also refers to RCRA facility assessments, RFIs, corrective measures studies, and corrective measures implementations.

detection limit—The minimum concentration that can be determined by a single measurement of an instrument. A detection limit implies a specified statistical confidence that the analytical concentration is greater than zero.

discharge—The accidental or intentional spilling, leaking, pumping, pouring, emitting, emptying, or dumping of hazardous waste into, or on, any land or water. (Resource Conservation and Recovery Act, 40 Code of Federal Regulations [CFR] 260.10)

disposal—The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into, or on, any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwaters. (40 Code of Federal Regulations [CFR] 260.10)

effluent—Wastewater (treated or untreated) that flows out of a treatment plant, sewer, or industrial outfall. Generally refers to wastes discharged into surface waters.

environmental surveillance—The collection and analysis of samples from air, water, soil, foodstuffs, biota, and other media to determine the environmental quality of an industry or community. Environmental surveillance is performed commonly at sites that contain nuclear facilities.

exposure pathway—Any path from the sources of contaminants to humans and other species or settings through soil, water, or food.

groundwater—Interstitial water that occurs in saturated earth material and is capable of entering a well in sufficient amounts to be used as a water supply.

hazardous waste—(1) Solid waste (as defined in 40 Code of Federal Regulations [CFR] 261.2) that is a listed as hazardous waste (as provided in 40 CFR Subpart D), or as a waste that exhibits any of the characteristics of hazardous waste (i.e., ignitability, corrosivity, reactivity, or toxicity, as provided in 40 CFR, Subpart C). (2) According to the New Mexico Environment Department's Consent Order, any solid waste or combination of solid wastes that, because of its quantity, concentration, or physical, chemical, or infectious characteristics, meets the description set forth in New Mexico Statutes Annotated 1978, § 74-4-3(K) and is listed as a hazardous waste or exhibits a hazardous waste characteristic under 40 CFR 261 (incorporated by 20.4.1.200 New Mexico Administrative Code).

Hazardous and Solid Waste Amendments (HSWA)—Public Law No. 98-616, 98 Stat. 3221, enacted in 1984, which amended the Resource Conservation and Recovery Act of 1976 (42 United States Code § 6901 et seq).

Hazardous and Solid Waste Amendments (HSWA) Module — Module VIII of the Laboratory's RCRA Hazardous Waste Facility Permit. The permit allows the Laboratory to operate as a treatment, storage, and disposal facility. Module VIII regulates the cleanup of inactive sites and the activities of the ER Project for those PRSs listed on the permit.

high-explosives (HE) — The three most common high explosive substances found at the Laboratory are RDX (Royal Demolition eXplosive), TNT (2,4,6-initrotoluene), and HMX (High Melting eXplosive). These highly explosive materials do not occur naturally in the environment and are all used in making military shells, bombs, and grenades. Exposures to these materials are rare because they are generally used in controlled areas. People can be exposed to these chemicals by breathing dust contaminated with the materials, getting it on their skin, or drinking contaminated water.

- RDX can cause seizures, nausea, and vomiting. It may be a human carcinogen.
- TNT may cause anemia and abnormal liver function, spleen enlargement, and harmful effects on the immune system. It is a possible human carcinogen.
- HMX has no known harmful health effects. The EPA has not determined whether it is a human carcinogen.

inactive site — Waste disposal sites that are no longer being operated.

inorganic chemical — Compounds of elements other than carbon such as hexavalent chromium (the form of chromium in a valence state of +6).

interim measure—An action that can be implemented to minimize or prevent the migration of contaminants and to minimize or prevent actual or potential human or ecological exposure to contaminants, while long-term final corrective action remedies are evaluated and, if necessary, implemented.

in situ stabilization — A cleanup strategy that leaves the contaminants in place but unable to migrate or be released into the environment.

institutional controls—Controls that prohibit or limit access to contaminated media. Institutional controls may include use restrictions, permitting requirements, standard operating procedures, laboratory implementation requirements, laboratory implementation guidance, and laboratory performance requirements.

long-term surveillance and monitoring — Collecting periodic measurements over time to assess status and trends.

long-term maintenance — Maintaining the conditions and assumptions under which risk-based decisions were made.

medium (environmental)—Any material capable of absorbing or transporting constituents. Examples of media include tuffs, soils and sediments derived from these tuffs, surface water, soil water, groundwater, air, structural surfaces, and debris.

nature and extent of contamination — The "nature" of contamination is the chemicals (naturally occurring or man-made) present in or that have been released to the environment and are determined by detection of a chemical in one or more environmental samples. In the case of naturally occurring or widespread man-made chemicals, detection is determined by comparison to background levels. The "extent" of contamination means how much of a given chemical is present in the environment and is determined by comparison to site baseline values, if applicable, and/or analysis of trends in the data.

no further action—Under the Resource Conservation and Recovery Act, a corrective-action determination whereby, based on evidence or risk assessment, no further investigation or remediation is warranted.

notice of deficiency (NOD)—A written notification from the administrative authority to a facility owner/operator following the review of a permit application or other permit-related plan or report. The NOD requests additional information before a decision can be made regarding the original plan or report.

organic chemical — Compound of elements that contains carbon such as carbon dioxide.

permit modification—A change to a condition in a facility's Hazardous Waste Facility Permit, initiated by either a request from the permittee or by the administrative authority's action.

pollutant — Any substance, produced and released into the environment as a result of human activity, that has damaging effects on humans or ecological receptors.

polychlorinated biphenyls (PCBs)—Any chemical substance that is limited to the biphenyl molecule that has been chlorinated to varying degrees, or any combination that contains such substances. PCBs are colorless, odorless compounds that are chemically, electrically, and thermally stable and have proven to be toxic to both humans and other animals.

potential release site (PRS)—A potentially contaminated site at Los Alamos National Laboratory. PRSs include both solid waste management units and areas of contamination.

radiation—A stream of particles or electromagnetic waves emitted by atoms and molecules of a radioactive substance as a result of nuclear decay. The particles or waves emitted can consist of neutrons, positrons, alpha particles, beta particles, or gamma radiation.

receptor—A person, other animal, plant, or geographical location that is exposed to a chemical or physical agent released to the environment by human activities.

release—Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing of hazardous waste or hazardous constituents into the environment.

remediation—(1) The process of reducing the concentration of a contaminant (or contaminants) in air, water, or soil media to a level that poses an acceptable risk to human health and the environment. (2) The act of restoring a contaminated area to a usable condition based on specified standards.

remedy or remedial action — Those actions consistent with permanent remedy instead of or in addition to removal actions in the event of a release or threatened release of a hazardous substance into the environment. Those actions used to prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health or welfare of the environment.

Resource Conservation and Recovery Act (RCRA)—The Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act of 1976. (Public Law [PL] 94-580, as amended by PL 95-609 and PL 96-482, United States Code 6901 et seq.)

RCRA Hazardous Waste Facility Permit — EPA or an authorized state issues RCRA permits to regulate the storage, treatment, and disposal of hazardous waste and the hazardous component of radioactive mixed waste. See also HSWA Module.

runoff—The portion of the precipitation on a drainage area that is discharged from the area either by sheet flow or adjacent stream channels.

run-on—Surface water that flows onto an area as a result of runoff occurring higher up on a slope.

sediment—(1) A mass of fragmented inorganic solid that comes from the weathering of rock and is carried or dropped by air, water, gravity, or ice. (2) A mass that is accumulated by any other natural agent and that forms in layers on the Earth's surface (e.g., sand, gravel, silt, mud, fill, or loess). (3) A solid material that is not in solution and is either distributed through the liquid or has settled out of the liquid.

site characterization—Defining the pathways and methods of migration of hazardous waste or constituents, including the media affected; the extent, direction and speed of the contaminants; complicating factors influencing movement; or concentration profiles. (U.S. Environmental Protection Agency, May 1994. Publication EPA-520/R-94/004)

site conceptual model—A qualitative or quantitative description of sources of contamination, environmental transport pathways for contamination, and receptors that may be impacted by contamination and whose relationships describe qualitatively or quantitatively the release of contamination from the sources, the movement of contamination along the pathways to the exposure points, and the uptake of contaminants by the receptors.

soil erosion — The removal and thinning of the soil layer due to climatic and physical process such as high rainfall that is greatly accelerated by certain activities such as deforestation as after a fire.

solid waste—Any garbage, refuse, or sludge from a waste treatment plant, water-supply treatment plant, or air-pollution control facility, and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations and from community activities. Solid waste does not include solid or dissolved materials in domestic sewage; solid or dissolved materials in irrigation return flows; industrial discharges that are point sources subject to permits under section 402 of the Federal Water Pollution Control Act, as amended; or source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954, as amended.

solid waste management unit (SWMU)—(1) Any discernible site at which solid wastes have been placed at any time, whether or not the site use was intended to be the management of solid or hazardous waste. SWMUs include any site at a facility at which solid wastes have been routinely and systematically released. This definition includes regulated sites (i.e., landfills, surface impoundments, waste piles, and land treatment sites), but does not include passive leakage or one-time spills from production areas and sites in which wastes have not been managed (e.g., product storage areas). (2) According to the New Mexico Environment Department (NMED) Consent Order, any discernible site at which solid waste has been placed at any time, and from which NMED determines there may be a risk of a release of hazardous waste or hazardous waste constituents (hazardous constituents), whether or not the site use was intended to be the management of solid or hazardous waste. Such sites include any area in Los Alamos National Laboratory at which solid wastes have been routinely and systematically released; they do not include one-time spills.

surface water — No perennial surface water flows extend completely across the Laboratory in any canyon. Periodic natural surface runoff occurs in two modes:

- Spring snowmelt runoff that occurs over days to weeks at a low discharge rate and sediment load, and
- Summer runoff from thunderstorms that occurs over hours at a high discharge rate and sediment load.

The surface water within the Laboratory is not a source of municipal, industrial, or irrigation water, though wildlife does use the waters.

technical area (TA)—At Los Alamos National Laboratory, an administrative unit of operational organization (e.g., TA-21).

topography—The physical or natural features of an object or entity and their structural relationships.

tuff—Consolidated volcanic ash, composed largely of fragments produced by volcanic eruptions.

watershed—A region or basin drained by, or contributing waters to, a river, stream, lake, or other body of water and separated from adjacent drainage areas by a divide, such as a mesa, ridge, or other geologic feature.

A-3.0 METRIC CONVERSION TABLE

Metric to US Customary Unit Conversions

Multiply SI (Metric) Unit	by	To Obtain US Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (µm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram (µg/g)	1	parts per million (ppm)
liters (L)	0.26	gallons (gal.)
milligrams per liter (mg/L)	1	parts per million (ppm)
degrees Celsius (°C)	9/5 + 32	degrees Fahrenheit (°F)

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Appendix B

Guaje/Barrancas/Rendija Canyons Aggregate Area
Analytical Data
(CD included with this report)

Appendix C

Management Plan for Investigation-Derived Waste

C-1.0 MANAGEMENT OF INVESTIGATION-DERIVED WASTE

This appendix to the work plan describes how investigation-derived waste (IDW) generated during the investigation of the Guaje/Barrancas/Rendija Canyons aggregate area sites will be managed.

Investigation-derived waste generated during the investigations and corrective actions at these sites will be managed in a way that is protective of human health and the environment, compliant with applicable regulatory requirements, and consistent with the waste-minimization goals of Los Alamos National Laboratory (the Laboratory or LANL).

Applicable Laboratory standard operating procedures (SOPs) incorporate the requirements of all applicable U.S. Environmental Protection Agency and New Mexico Environment Department regulations, Department of Energy Orders, and Laboratory Implementation Requirements. Environmental Stewardship–Environmental Characterization and Remediation (ENV-ECR) SOPs applicable to the characterization and management of IDW are

- ENV-ECR SOP-01.06, Management of Environmental Restoration Project Waste, and
- ENV-ECR SOP-01.10, Waste Characterization.

These SOPs are available at the following internet address: http://erproject.lanl.gov/documents/procedures.html.

Waste minimization is accomplished by implementing the requirements of the 2004 Pollution Prevention Roadmap (LANL 2004, 88465). The Roadmap is updated annually as a requirement of Module VIII of the Laboratory's Permit (EPA 1990, 01585; EPA 1994, 44146).

A Waste Characterization Strategy Form (WCSF) will be prepared and approved by Laboratory personnel per requirements of ENV-ECR SOP-01.10 prior to the start of field investigation activities. Existing Waste Profile Forms (WPFs) will be used or referenced for new WPFs needed for implementation of the work plan. The WCSF will provide detailed information on IDW characterization, management, containerization, and potential volume generation. Investigation-derived waste characterization will be achieved through existing data and/or documentation and through direct sampling of the IDW, or sampling of the media being investigated (i.e., surface soil, subsurface soil, sediment, etc.). If waste characterization sampling is necessary, it will be described in the WCSF.

The selection of waste containers will be based on the appropriate Department of Transportation (DOT) requirements and the type and amount of IDW that is planned to be generated. Each waste container will be individually labeled as to the waste classification, item identification number, radioactivity (if applicable), and date of generation, immediately following containerization. Waste containers will be managed in clearly marked and appropriately constructed waste accumulation areas. Waste accumulation area postings, regulated storage duration, and inspection requirements will be based on IDW type and classification. Container and storage requirements will be described in the WCSF, based on requirements outlined in the most recent versions of the Laboratory Waste Management Facilities Waste Acceptance Criteria and Laboratory Implementation Requirements: 404-00-03, Hazardous and Mixed Waste Requirements; 404-00-04, Managing Solid Waste; 404-00-05, Managing Radioactive Waste; and 405-10-01, Packaging and Transportation. Prior to waste generation, the WCSF will be approved by Laboratory Environmental and Surveillance Program personnel and by the process detailed in ENV-SOP 01.10, Waste Characterization.

Transportation and disposal requirements will be detailed in the WCSF and approved prior to the generation of waste. Disposal of solid IDW will take place at an approved off-site disposal facility. Liquid

IDW may be processed at the Technical Area (TA) 46 Sanitary Wastewater Systems Plant. Hazardous and/or mixed waste may be transported and stored at TA-54, Area L, prior to off-site disposal, or will be shipped directly to an off-site disposal facility. Transportation of IDW will comply with appropriate DOT requirements.

The anticipated waste streams that will be generated and managed during work plan implementation at the Guaje/Barrancas/Rendija Canyons aggregate area sites include the following:

- Wood and concrete (targets, sheds, firing areas)
- Tar and/or asphalt
- Munitions and explosives of concern (MEC) (live and/or expended, including high explosives)
- Metal debris (mortar/round fragments munitions debris [MD])
- Mixed vegetation debris (tree stumps, slash, and wood debris)
- Personal protective equipment (PPE), plastic, and other IDW
- Decontamination fluids

Live rounds will be shipped to an approved facility for subsequent destruction or to the LANL Explosive Ordinance Disposal (EOD) group for ultimate disposition (ITRC 2003, p. 44). All MEC disposal operations will be conducted in accordance with Laboratory requirements and Bureau of Alcohol, Tobacco, and Firearms and U.S. Army Corps of Engineers guidance (USACE 2003, 88211; USACE 2004, 88718). After disposition of the MEC, a sweep of the demolition area will be conducted to ensure no MEC remains and all MD generated are recovered. All MD recovered (from both the investigation and disposal operations) will be certified as explosive-free by the unexploded ordnance (UXO) quality/safety officer and the senior UXO supervisor on the project.

Table C-1
Waste Streams from Implementation of the Corrective Actions at the Sportsmen's Club

Waste Stream	Waste Type	Estimated Maximum Volume	Disposal Destination
Wood and concrete	Solid	10 yd^3	LANL, TA-54 *
Metal debris	Solid	10 yd^3	LANL, TA-54 *
Rock and gravel	Solid	400 yd^3	To be determined by site conditions
Vegetation	Solid	10 yd^3	LANL, TA-54 *
PPE, plastic, and other IDW	Solid	5 yd^3	LANL, TA-54*
Decontamination fluids	Liquid	100 gal.	LANL, TA-46 Sanitary Wastewater Systems Plant

* Unless the waste is low-level waste, TA-54 is used as a storage site prior to disposal at an appropriate off-site facility.

REFERENCES

EPA (U.S. Environmental Protection Agency), April 1990. U.S. Environmental Protection Agency, Region 6 Hazardous Waste Permit (Hazardous and Solid Waste Amendments). (EPA 1990, 01585)

EPA (U.S. Environmental Protection Agency), April 1994. "Module VIII, Special Conditions Pursuant to the 1984 Hazardous and Solid Waste Amendments to RCRA for Los Alamos National Laboratory, EPA ID NM0890010515 38817," module of EPA Hazardous Waste Facility Permit issued to Los Alamos National Laboratory, Dallas, Texas. (EPA 1994, 44146)

LANL (Los Alamos National Laboratory), December 2004. "2004 Pollution Prevention Roadmap December 2004," Los Alamos National Laboratory document LA-UR-04-8973, Los Alamos, New Mexico. (LANL 2004, 88465)

USACE (U.S. Army Corps of Engineers), November 2003. "Safety and Health Requirements," Manual No. 385-1-1, Department of the Army, Washington, D.C. (USACE 2003, 88711)

USACE (U.S. Army Corps of Engineers), August 2004. "Basic Safety Concepts and Considerations for Munitions and Explosives of Concern Response Action Operations," Manual No. EP 385-1-95a, Department of the Army, Washington, D.C. (USACE 2004, 88718)

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Appendix D

Site Conditions:
Chapter 3 of North Canyons Work Plan

3.0 ENVIRONMENTAL SETTING

This chapter has four major functions: it

- describes the environmental settings of Bayo, Barrancas, Rendija, and Guaje Canyons (the "north canyons systems");
- summarizes existing information relevant to the characterization of the northern canyons systems;
- identifies additional information needed to expand the conceptual understanding of the environmental processes that occur within the systems and to assess the magnitude and importance of potential exposure pathways within the canyon systems; and
- provides the technical basis for the conceptual model, which is described in Chapter 4 of this work plan.

The regional environmental setting of Los Alamos National Laboratory (the "Laboratory") is presented in Chapter 3 of "Core Document for Canyons Investigations" (the "core document") (LANL 1997, 62316) and in Chapter 2 of the "Installation Work Plan for Environmental Restoration Project" (IWP) (LANL 2000, 66802).

Nomenclature used in this Document

Since circa 1961, boreholes drilled in the north canyons have been advanced for their intended purpose, completed, left open and uncompleted, or plugged and abandoned. These boreholes and completions are designated by letters and numbers. Generally, the first two or three letters or numbers designate the canyon or technical area (TA). For example, BC = Bayo Canyon, GC = Guaje Canyon, 10- = boreholes at TA-10. The last letter or letters designate borehole function. Historic drilling efforts have often used additional notations. Municipal water well locations often are designated by a single letter to identify the canyon.

BCO- observation well in Bayo Canyon; completed with screen or perforated casing to monitor groundwater

BCM- moisture access hole in Bayo Canyon; borehole cased with 2-in. (5.08-cm)-diameter aluminum pipe, plugged at the bottom to keep water out of the pipe; intended for logging in situ moisture measurements with a neutron moisture/density probe

Well G- Guaje Canyon municipal water supply well

GR- Guaje Canyon municipal water supply replacement wells; completed to replace aging municipal wells in Guaje Canyon

GT- Guaje test wells

LA- Los Alamos Canyon municipal water supply wells

TH- test hole

Each letter typically is followed by a number, which normally indicates the sequence of well installation. In some canyons the number designation increased down-canyon. However, due to the paucity of wells in the north canyons, no numbering system has been implemented. The Guaje Canyon municipal supply wells generally are numbered in the order of installation, which was from the lower canyon upward.

Some boreholes, originally designated "TH" for test hole, were drilled as exploration test holes in various canyons on the Pajarito Plateau. For clarification in this work plan, a two-letter abbreviation that designates the specific canyon has been added to "TH" (such as GCTH, for Guaje Canyon test hole) to provide a specific symbol relating to each borehole's location.

Within this work plan, "well" refers to a completed borehole with the capability to contain water, specifically the water supply, test, observation, and water-balance wells. Uncompleted core holes are referred to as "boreholes," whereas the "moisture access holes" are referred to as such. A comprehensive compilation and description of boreholes and completions installed by the Laboratory before circa 1993 are provided by Purtymun (1995, 45344).

Environmental surveillance sediment sampling locations are designated as "Bayo at SR 502," and "Guaje at SR 502," which indicate a location near a major highway.

The New Mexico Environment Department (NMED) Oversight Bureau describes collection sites by various nomenclatures. Springs are identified by local name as "Indian Springs" or by the canyon abbreviation preceding the spring number (e.g., "Guaje Canyon Spring 1"). Surface water locations are identified by the canyon name abbreviation and the distance in miles as measured upstream from the Rio Grande. For example, surface water has been collected at station Guaje Canyon Spring 5.7, which is located in Guaje Canyon 5.7 mi (9.17 km) from the confluence with the Rio Grande. It should be noted that the abbreviation "GC" also has been used to designate samples collected in Garcia Canyon. Groundwater sampling locations are identified by the Laboratory well nomenclature.

3.1 Location, Topography, and Surface Drainage

3.1.1 Bayo Canyon

Bayo Canyon has a relatively small drainage area of 4.0 mi^2 (10.4 km^2) that heads on the Pajarito Plateau in a residential area of Los Alamos at an elevation of approximately 7400 ft (2256 m) (LANL 1997, 62316, p. 3-2). The location of the canyon and watershed area is shown in Appendix A, Figure A-1 *(this figure is now attached to the end of this text [Appendix D]).* The canyon extends east/southeast between North Mesa on the south and Barranca and Otowi Mesas on the north, for a distance of approximately 8.2 mi (13.2 km) to the confluence with Los Alamos Canyon. The elevation at the confluence is approximately 5790 ft (1765 m) (LANL 1997, 62316, p. 3-2).

Bayo Canyon contains an ephemeral stream. Most surface water flow occurs after heavy summer rains and is generally short in duration (less than 2 hr). There are currently no effluent discharges in Bayo Canyon (Purtymun, 1995, 45344, p. 43). The channel length is approximately 3.47 mi (5.58 km) on Los Alamos County property, 3.12 mi (5.0 km) on Laboratory property (TA-74), and approximately 1.66 mi (2.66 km) on San Ildefonso Pueblo land to the confluence with Los Alamos Canyon (LANL 1997, 62316, p. 3-2). The watershed has an unnamed tributary (the "south fork of Bayo Canyon") on Laboratory property approximately 1.9 mi (3.1 km) from the confluence with Los Alamos Canyon." Another unnamed tributary in the western part of the watershed between Camino Encantada and Barranca Mesa is called the "north fork of Bayo Canyon" (Figure A-1).

Bayo Canyon transects the northern section of the Laboratory and encompasses former TA–10 and portions of TA-74. The canyon drains a portion of the Barranca Mesa residential area, some potential release sites (PRSs) within TA-0, former TA-10, and the central portion of TA-74 (Figure A-1).

3.1.2 Barrancas Canyon

Barrancas Canyon has a relatively small drainage area of 4.9 mi^2 (12.7 km^2) that heads on the northern Pajarito Plateau east of Barranca Mesa at an elevation of 7278 ft (2219 m) (LANL 1997, 62316, p. 3-2). The canyon extends east-southeast approximately 5.5 mi (8.9 km) to its confluence with Guaje Canyon at an elevation of 5860 ft (1786 m) (LANL 1997, 62316, p. 3-2) (Figure A-1).

The main Barrancas Canyon channel crosses approximately 1.6 mi (2.6 km) of Los Alamos County land, approximately 0.4 mi (0.6 km) on US Forest Service (USFS) land, 2.7 mi (4.3 km) on Laboratory property, and 0.7 mi (1.1 km) on San Ildefonso Pueblo land. The Barrancas Canyon watershed contains three unnamed tributaries. The southernmost tributary (south fork) intersects the Barrancas Canyon channel about 0.66 mi (1 km) west of the Guaje Canyon confluence and is about 1 m (1.6 km) long. The south fork is located predominately on Laboratory property within TA-74. Two longer tributaries north of the main Barrancas Canyon channel extend east from Deer Trap Mesa approximately 2.7 mi (4.3 km) (middle fork) and 2.9 mi (4.6 km) (north fork) before merging and continuing an additional 1.9 mi (3.1 km) to the main Barrancas Canyon channel. These northern tributaries are mostly within USFS land but the headland areas are within Los Alamos County land (Figure A-1).

Barrancas Canyon and tributaries contain ephemeral streams that receive intermittent flow from snowmelt and storm water runoff. The Barrancas Canyon watershed drains a portion of the Los Alamos town site, Laboratory property at TA-74, and USFS land. There are no effluent discharges in the watershed (Figure A-1).

3.1.3 Rendija Canyon

Rendija Canyon is located immediately north of the Los Alamos town site. The watershed has a drainage area of 9.5 mi^2 (24.6 km^2). The canyon heads on the flanks of the Sierra de los Valle just west of the town site at an elevation of 9826 ft (2311 m). The canyon contains an ephemeral stream channel that extends approximately 9 mi (14.5 km) east to the confluence with Guaje Canyon. The minimum elevation of the watershed is approximately 6300 ft (1920 m) (LANL, 1997, 62316, p. 3-2).

Rendija Canyon primarily crosses USFS land except for approximately 1.6 mi (2.6 km) of the middle portion of the canyon that crosses General Services Administration (GSA) land. Parcels of private land and Los Alamos County land, such as the Guaje Pines Cemetery, are located in Rendija Canyon along the north side of Los Alamos. One named tributary, Cabra Canyon, enters the Rendija Canyon channel from the north in the central portion of the watershed. Cabra Canyon trends northwest to southeast, is approximately 2 mi (3.2 km) long, and has a watershed area of 1.2 mi^2 (3.1 km^2) on USFS and GSA land (Figure A-1). Three unnamed tributaries to Rendija Canyon are located west of Cabra Canyon and drain south-southeast into the main Rendija Canyon channel. These tributaries are approximately 1.5, 2, and 1.2 mi (2.4, 3.2, and 1.9 km) long.

Rendija Canyon and its tributaries contain ephemeral streams. There are no effluent discharges in the Canyon. The watershed drains portions of Los Alamos town site, GSA land, and USFS land (Figure A-1).

3.1.4 Guaje Canyon

Guaje Canyon is the northernmost canyon discussed in this work plan. The watershed drainage is approximately 16.9 mi^2 (43.8 km^2). The watershed heads on the flanks of the Sierra de los Valles at an elevation of 10,497 ft (3199 m). The Guaje Canyon channel extends east-southeast for approximately 16.4 mi (26.4 km) to the confluence with Los Alamos Canyon at an elevation of approximately 5660 ft (1725 m) (LANL, 1997, 62316, p. 3-2). The Guaje Canyon channel transverses predominately USFS land except for the lower 2.3 mi (3.7 km), which are within San Ildefonso Pueblo land. The Guaje Canyon watershed primarily drains USFS land.

Three named tributaries are present in upper Guaje Canyon on the flanks of the Sierra de los Valles; each canyon trends northwest to southeast. Aqua Piedra Canyon is approximately 3.0 mi (4.8 km) long and has a watershed area of 1.61 mi^2 (4.1 km^2). Aqua Piedra Spring is located in the middle part of Aqua Piedra Canyon. Caballos Canyon is approximately 2.9 mi (4.6 km) in length and contains another tributary canyon called Vallecitos Canyon, which is the westernmost tributary to Guaje Canyon, and extends for approximately 1.7 mi (2.7 km) to the confluence with Caballos Canyon. Vallecitos Canyon and Caballos Canyon contain ephemeral streams, receiving snowmelt and storm water runoff from watershed areas of 1.2 and 1.5 mi^2 (3.1 and 3.9 km^2), respectively.

In addition to the named tributaries, two unnamed tributaries of significance to Guaje Canyon are present in the middle and lower sections of the Guaje Canyon watershed. The south fork of Guaje Canyon extends for approximately 1.3 mi (2.1 km) on the north side of Guaje Ridge and enters Guaje Canyon from the southwest. The north fork of Guaje Canyon extends for about 2.3 mi (3.7 km) parallel to Guaje Canyon on the north and enters Guaje Canyon from the north-northeast. These tributaries contain ephemeral streams and occasionally contribute flow to Guaje Canyon. The lower reaches of Guaje Canyon also receive runoff from Rendija Canyon and Barrancas Canyon (Figure A-1).

Guaje Canyon is informally divided into three sections for discussion purposes. The upper part of Guaje Canyon refers to the portion upstream and up-channel of the confluence with the south fork of Guaje Canyon. The middle part of Guaje Canyon extends from the confluence with the south fork to the confluence with Rendija Canyon. The lower part of Guaje Canyon extends from the confluence with Rendija Canyon to Los Alamos Canyon.

Two springs at an elevation of approximately 8850 ft (2700 m) support a perennial reach in upper Guaje Canyon. Guaje Reservoir, a small concrete structure, is located in upper Guaje Canyon at an elevation of 8020 ft (2445 m), approximately 3 mi (4.8 km) upstream from the confluence with the south fork. The reservoir is about 25 ft long and 11 ft high with a capacity of 250,000 gal.; it receives flow from the springs and from the watershed area of 6 mi^2 (15.4 km^2) above the reservoir. The reservoir was constructed and equipped with a pipeline system to divert water to Los Alamos (Purtymun 1975, 11787, pp. 276–282). The reservoir served as a municipal water supply from 1947 to 1959 with annual production ranging from approximately 24×10^6 to 213×10^6 gal. From 1972 to 1992, water diverted from the reservoir was used for irrigation purposes by Los Alamos County. During this period, annual production ranged from 2.2×10^6 to 9.7×10^6 gal. (McLin et al. 1998, 63506, p. 13).

The Guaje well field is located in the lower and middle parts of the canyon. The Guaje well field provides a significant portion of the municipal water supply for the Los Alamos area (Figure A-1).

3.2 Climate

Los Alamos County has a semiarid, temperate, mountain climate, which is summarized in the core document (LANL 1997, 62316, p. 3-1) and Chapter 2 of the IWP (LANL 2000, 66802). Detailed data compilations and extensive statistical summaries, including projected probabilities of meteorological occurrences, are provided by Bowen (1990, 6899).

Historical site-specific meteorological data for the north canyons are not available. The monitoring locations closest to the canyons are tower stations at TA-53 (mesa top) and TA-41 (canyon site) and precipitation gages at TA-74 and the North Community of Los Alamos (see Figure A-1). Annual climate summaries are presented in the annual environmental surveillance reports (ESP 2000, 68661).

In 2000 after the Cerro Grande fire, several remote automated weather stations (RAWS) were installed north of Los Alamos. The Guaje Canyon and the Garcia Canyon RAWS are located in or near the north canyons watersheds. Two RAWS are located within the north canyons watershed area. One, the "Garcia Canyon" station, is located at the northern boundary of Aqua Piedra Canyon, which is a tributary to Guaje Canyon, and another, the "Guaje Canyon" station, is located on Guaje Ridge between Rendija Canyon and Guaje Canyon (BAER, 2000, 68662, p. 199; Figure A-1 of this document). These stations monitor meteorological parameters including precipitation and are used to provide a flash flood warning in areas of risk. A flash flood warning is issued when a RAWS records a sustained rainfall at a rate of 1 in./hr. RAWS data are available at the Desert Research Institute web site at http://www.wrcc.dri.edu/losalamos/.

3.3 Geology

Discussions of the regional geologic setting of the Pajarito Plateau are presented in Griggs (1964, 65649), the IWP (LANL 2000, 66802), the hydrogeologic work plan (LANL 1998, 59599), and most recently in the core document (LANL 1997, 62316, p. 3-6). The following discussion uses the core document as the technical basis for the geologic setting and provides detail that is specific to Guaje, Rendija, Bayo, and Barrancas Canyons. Unless otherwise noted, locations of wells and boreholes discussed in this document are shown on Figure A-1. Some locations are beyond the extent of Figure A-1; these wells and boreholes can be found on maps and figures in the core document (LANL 1997, 62316) and/or the hydrogeologic work plan (LANL 1998, 59599).

The surface distribution of bedrock geologic units is shown on geologic maps prepared by Griggs (1964, 65649), Smith et al. (1970, 9752), and Rogers (1995, 54419). Structure is discussed in Wachs et al. (1988, 6690).

3.3.1 Stratigraphy

The principal bedrock units in the Guaje-Rendija-Bayo-Barrancas Canyons area consist of the following, in ascending order:

- Santa Fe Group: 4 to 21 Ma (Manley 1979, 11714);
- Puye Formation: 1.7 to 4 Ma (Turbeville et al. 1989, 21587; Spell et al. 1990, 21586) and interstratified volcanic rocks including the Tschicoma Formation on the west (2.53 to 6.7 Ma) and basalts of the Cerros del Rio volcanic field on the east (2 to 3 Ma) (Gardner and Goff 1984, 44021; WoldeGabriel et al. 1996, 54427);
- Otowi Member of the Bandelier Tuff: ca 1.61 Ma (Izett and Obradovich 1994, 48817);
- tephras and volcaniclastic sediments of the Cerro Toledo interval (Broxton and Reneau 1995, 49726, p. 11); and
- Tshirege Member of the Bandelier Tuff: ca 1.22 Ma (Izett and Obradovich 1994, 48817; Spell et al. 1990, 21586).

The bedrock stratigraphy in the Pajarito Plateau area is illustrated in Figure 3.3-1. The stratigraphy is based on the sitewide three-dimensional stratigraphic model, which contains detailed stratigraphic mapping for the sedimentary deposits and has been supplemented by additional detail on the volcanic units (Carey et al., 66782). Stratigraphic information for pertinent wells in the Guaje Canyon and Bayo Canyon areas is discussed in Section 3.4.2.

Group/Formation	Member/Unit	Subunit	Description
Bandelier Tuff	Tshirege Member	Qbt 4	Ash-flow units
		Qbt 3	
		Qbt 2	
		Qbt 1v	
		Qbt 1g	
		Tsankawi Pumice Bed	
Cerro Toledo interval			Volcaniclastic sediments and ash-falls
Bandelier Tuff	Otowi Member		Ash-flow units
			Guaje Pumice Bed
Puye Formation and intercalated volcanic rocks	Fanglomerate		Fanglomerate facies includes sand, gravel, conglomerate, and tuffaceous sediments
	Volcanic rocks		Cerros del Rio basalts intercalated within the Puye Formation, includes up to four interlayered basaltic flows. Andesites of the Tschicoma Formation present in western part of plateau
	Fanglomerate		Fanglomerate facies includes sand, gravel, conglomerate, and tuffaceous sediments; includes "old alluvium"
	Axial facies deposits of the ancestral Rio Grande		Totavi Lentil
Santa Fe Group	Coarse sediments		Coarse-grained upper facies (called the "Chaquehui Formation" by Purtymun 1995, 45344)
	Basalt		
	Coarse sediments		
	Basalt		
	Coarse sediments		
	Basalt		
	Coarse sediments		
	Basalt		
	Coarse sediments		
	Arkosic clastic sedimentary deposits		Undivided Santa Fe Group (includes Chamita[?] and Tesuque Formations)

Source: Baltz et al. 1963, 8402; Purtymun 1995, 45344; LANL 1998, 59599; Broxton and Reneau 1995, 49726.

Figure 3.3-1. Generalized stratigraphy of bedrock geologic units of the Pajarito Plateau

Alluvium of Pleistocene and Holocene age rests unconformably on the Bandelier Tuff and deeper units in some parts of all four canyons. The alluvium in the canyons generally consists of reworked Bandelier Tuff and older bedrock units. The alluvium may also contain a minor eolian component.

3.3.2 Geomorphology

3.3.2.1 Bayo Canyon

Bayo Canyon is the smallest (in area) of the four northern canyons. The total change in elevation is 1610 ft (491 m); and the average gradient over its entire length is 0.037 m/m (3.7%, 2.1 degrees) (LANL 1997, 62316, p. 3-2). The channel gradient changes in response to bedrock lithologic changes over the length of the canyon.

The canyon heads in unit Qbt 3 of the Tshirege Member of the Bandelier Tuff, where the channel gradient is about 0.067 m/m (6.7%, 3.8 degrees). As the canyon cuts through the Cerro Toledo interval and into the more erodible Otowi Member approximately 2 mi (3.2 km) downstream, the gradient decreases to about 0.03 m/m (3%, 1.9 degrees). Approximately 1.9 mi (3.1 km) further downstream the channel incises the Puye Formation fanglomerates, and the gradient increases again to about 0.05 m/m (5%, 2.9 degrees). Bayo Canyon is incised into the upper Santa Fe Group for a short distance upstream of the confluence with Los Alamos Canyon.

A veneer of late Quaternary alluvium forms the floor of much of Bayo Canyon, ranging in thickness from 0 to 26 ft (0 to 7.9 m) as measured in several test holes drilled in the canyon. The alluvium near the axis of the canyon is typically greater than 13 ft (4 m) thick (Cogbill 1994, 46146, p. 2). Bayo Canyon at former TA-10 is asymmetric, with the active channel shifted to the north side of the canyon and flanked by one or more stepped terraces (Drake and Inoue 1993, 53456, p. 18).

A series of Quaternary terraces has been identified in Bayo Canyon at former TA-10. Quaternary alluvial deposits have been subdivided into three units, the youngest of which (Qal 3) contains historic artifacts from TA-10 and probably dates from the period 1944 to 1963 (Drake and Inoue 1993, 53456, p. 6). These units are 0.5 to 3.5 ft (0.15 to 1.1 m) thick at former TA-10 and downstream. The alluvial deposits consist of terraces along the main channel and tributary channels, fan deposits associated with side drainages, and colluvial deposits at the base of steep valley side slopes. The Q3 surface of Drake and Inoue is defined as the top of the Qal 3 sediment deposits. The Q3 terrace surfaces have a maximum width of about 250 ft (76 m), but generally occur as laterally restricted terraces 30 to 80 ft (9 to 24 m) across. They are 0.5 to 2 ft (0.15 to 0.6 m) above local base level along the main channel, but can be up to 3.7 ft (1.1 m) above local base level along tributary channels.

The Qal 1 and Qal 2 sediments as characterized by Drake and Inoue lie beneath the Q1 and Q2 surfaces, do not contain historic artifacts, and are considered older than 50 yr. The older Qal 1 sediments consist primarily of fan deposits near the valley floor and colluvium underlying valley side slopes, and are typically about 6 ft (1.8 m) thick. The younger Qal 2 sediments consist of terrace and fan deposits at or near the canyon floor, and are typically greater than 2.5 ft (0.76 m) thick. Q1 surfaces comprise most of the canyon floor on the south side of the active channel, and Q2 surfaces comprise most of the remainder of the narrow inner canyon (Drake and Inoue 1993, 53456, pp. 17–18).

The late Quaternary terraces and soils in Bayo Canyon appear to reflect at least two cycles of incision and aggradation, followed by a third period of incision during the late Holocene. Preliminary interpretations suggest that sediment is cycled through some parts of the canyon on a time scale of 10^2 to 10^3 yr. Up to 3.5 ft (1.1 m) of historic sediment has been deposited along the main channel on the south side of the canyon below the former TA-10 since about 1944 (Drake and Inoue 1993, 53456, pp. 1–26).

3.3.2.2 Barrancas Canyon

Barrancas Canyon is the shortest of the four northern canyons discussed in this work plan. Barrancas Canyon contains an ephemeral stream with no perennial reaches, springs, or wetlands. Stream loss caused by infiltration and evaporation generally prevents runoff from reaching Guaje Canyon (LANL 1998, 59599, p. 4-86).

The total change in elevation from the head of Barrancas Canyon to its confluence with Guaje Canyon is about 1370 ft (417 m). The canyon heads in the Tshirege Member of the Bandelier Tuff. The relatively steep and narrow upper portion of the canyon cuts through Tshirege units Qbt 2 through Qbt 1v and the gradient in the upper portion is about 0.05 m/m (5%, 2.9 degrees). The channel then cuts through the Cerro Toledo interval and into the Otowi Member, where the gradient decreases slightly to about 0.04 m/m (4%, 2.3 degrees). About 1.3 mi (2.1 km) further downstream, the channel is incised into Tertiary sediments of the Puye Formation, and from that point to Guaje Canyon the gradient averages about 0.033 m/m (3.3%, 1.9 degrees).

3.3.2.3 Rendija Canyon

Rendija Canyon contains an ephemeral stream with no springs, perennial reaches, or wetlands (LANL 1998, 59599, p. 4-85). The upper reach (~1 km, 0.6 mi) of Rendija Canyon is cut into the lava flows and associated rocks of the Tschicoma Formation on the flanks of the Sierra de los Valles. Beginning about 13.5 km (8.4 mi) upstream from the confluence with Guaje Canyon, the channel is cut into the Bandelier Tuff, including tephras and volcaniclastic sediments of the Cerro Toledo interval. The channel is incised into the Puye Formation at about 5 km (3 mi) upstream from Guaje Canyon (Reneau and McDonald 1996, 55538, Figure 2-18). Changes in bedrock lithology along the length of the canyon result in some changes in the morphology of the channel and associated deposits. Exposures of the relatively erodible Otowi Member of the Bandelier Tuff and Cerro Toledo interval pumice deposits, for example, have led to extensive lateral stream erosion and development of relatively broad stream terraces. Where the Puye Formation is exposed, the gradient increases, the channel becomes more incised, and terraces are narrower (Reneau and McDonald 1996, 55538).

The total change in elevation from the head of Rendija Canyon to its confluence with Guaje Canyon is 3530 ft (1076 m), and the average gradient is 7.4%. The gradient varies significantly, largely in response to changes in lithology along the length of the canyon. In the upper reach where the Tschicoma Formation is exposed, the gradient is about 0.15 m/m (15%, 8.5 degrees), and the canyon is narrow and steep-sided. Where the canyon floor consists of the Tshirege Member of the Bandelier Tuff, the gradient is more moderate, ranging from about 0.08 m/m (8%, 4.6 degrees) to 0.05 m/m (5%, 2.9 degrees). In the Otowi Member and the Cerro Toledo interval, the gradient decreases to about 0.02 m/m (2%, 1.1 degree), and the canyon is broader. As the canyon cuts into the Puye Formation downstream of the Sportsman's Club, the gradient increases again to about 0.04 m/m (4%, 2.3 degrees).

Rendija Canyon contains at least five Pleistocene and four Holocene stream terraces that are perhaps the best-preserved flight of terraces on the Pajarito Plateau. They range in age from about 0.5 to greater than 160 ka, as determined by carbon-14 dating and soil chronofunctions (Reneau and McDonald 1996, 55538). In the reaches downstream of the Sportsman's Club, the Rendija Canyon channel is incised into fanglomerates of the Puye Formation, with a significant increase in stream gradient and narrowing of the Holocene terraces.

3.3.2.4 Guaje Canyon

Guaje Canyon is the longest of the four canyons addressed in this work plan, and it contains an interrupted stream. A perennial reach extends from a series of springs located upstream of Guaje Reservoir to some distance downstream of the reservoir. The stream is ephemeral downstream from that point to its confluence with Los Alamos Canyon (LANL 1997, 62316, p. 3-26).

The total change in elevation from the head of Guaje Canyon to its confluence with Los Alamos Canyon is about 4840 ft (1476 m) (LANL 1997, 62316, p. 3-2), and the average gradient is about 0.056 m/m (5.6%, 3.2 degrees). The gradient changes along the length of the canyon largely in response to changes in bedrock lithology. For about the first 3 mi (4.8 km), the canyon is cut into Tschicoma Formation, and is steep and narrow, with a gradient of about 0.07 m/m (7%, 4 degrees). The canyon is incised into the Puye Formation down to the basal axial facies west of the Guaje Mountain fault zone (GMFZ), at which point the Tschicoma Formation is again exposed for less than 1 mi (1.6 km). The gradient over the conglomerates of the Puye Formation west of the fault zone is about 0.04 m/m (4%, 2.3 degrees). East of the GMFZ the canyon again is incised into Puye Formation rocks, including the axial facies but primarily the upper fanglomerate deposits, and is mantled with late Quaternary alluvial channel and terrace deposits. The gradient in the Puye Formation east of the fault zone averages about 0.035 m/m (3.5%, 2 degrees), but decreases gradually to about 1% or less in the lower reach immediately upstream of Los Alamos Canyon.

3.4 Environmental Setting

3.4.1 Surface Sediments

3.4.1.1 Background Conditions

Background data on concentrations of inorganic chemicals and radionuclides in sediments are available from several areas on the Pajarito Plateau that are unaffected by Laboratory operations (Ryti et al. 1998, 59730). These data include samples from Guaje Canyon and from other canyons that are geologically similar to the north canyons. The term "background value" (BV) indicates an estimate of the upper range of the background concentrations, and is either the 95% upper tolerance limit (UTL) value for an analyte or detection limits for infrequently detected analytes (Ryti et al. 1998, 59730).

Portions of the north canyons receive runoff from urban areas at Los Alamos. Therefore, sediments may contain concentrations of metals and other constituents that may be more representative of urban "baseline" conditions rather than developed BV conditions (e.g., Reneau et al. 1998, 59160, p. 1-7).

In May 2000, the Cerro Grande fire burned large parts of upper Rendija Canyon and Guaje Canyon. Thus, fire-related chemicals and combustion products are present in these watersheds. Postfire sampling has shown that concentrations of metals and radionuclides in ash and muck (sediment that is dominated by reworked ash) are greater than previously determined sediment BVs (LANL 2000, 69054). Changes in sediment chemistry as a result of the Cerro Grande fire will be considered in the assessment of media sampled in Rendija and Guaje Canyons.

3.4.1.2 Historic Channel Changes

Changes are known to have occurred in the north canyons' channels since the beginning of Laboratory operations. An understanding of recent sedimentation and erosion patterns may identify potential contaminant transport mechanisms and horizontal and vertical distribution of possible contaminants in the alluvium. Sedimentation and erosion patterns have not been well defined in the north canyons.

Man-made alterations to the Bayo, Rendija, and Guaje Canyon watersheds likely have altered the channel and drainage pathways in these canyons. Anthropogenic impact to the canyon floors and drainage has occurred from the installation of the roads serving these canyons, construction of sewers and water-supply pipelines for Los Alamos town site, and from Laboratory activities conducted within some of the watersheds. Within Guaje Canyon, additional changes have resulted from the installation of Guaje Reservoir and municipal water supply wells and pump stations.

Recent sedimentation and degradation rates vary within each watershed and have not been fully identified. Localized aggradation and degradation processes may occur to raise or incise a specific interval of the streambed. In Bayo Canyon, sediments deposited since the 1950s near former TA-10 range from 0.5 to 2 ft (0.15 to 0.6 m) and include fragments of laboratory debris. Sediment deposits associated with activities at former TA-10 are up to 3.5 ft (1 m) (Drake and Inoue 1993, 53456, pp. 1, 26, 27). Sediments appear to cycle through Bayo Canyon every 100 to 1000 yr. Tributary drainages exhibit additional cycles of erosion and deposition occurring on a time scale of tens to hundreds of years (Drake and Inoue 1993, 53456, pp. 1, 6, 27).

The upper portions of the Guaje Canyon and Rendija Canyon watersheds burned extensively during the Cerro Grande fire in May 2000 (BAER 2000, 68662). Hydrologic changes caused by the fire have increased sediment load, peak flood discharges, and runoff volumes in these canyons. Postfire floods have already contributed to significant channel erosion in some places and sediment aggradation in others, and additional channel changes are likely in the next several years.

Barrancas Canyon and its tributaries have not been significantly impacted by Laboratory operations or other historic activities, with the exception of grazing and logging, and may be in a relatively natural state.

3.4.1.3 Historic Sediment Investigations

3.4.1.3.1 Plutonium Investigations in North Canyons

In 1965 and 1970, investigations were conducted across the Los Alamos area to assess the concentration and movement of soil-bound plutonium and radioactivity in stream channels. As part of the investigation, sediments were collected from each of the north canyons. Sediments from Bayo and Barrancas Canyons were sampled and analyzed for gross activity in 1965, and, in 1970, for gross activity and plutonium. Sampling locations in Bayo Canyon were approximately 1 mi downstream of former TA-10 and above the confluence with Los Alamos Canyon. Barrancas Canyon was sampled above the confluence with Guaje Canyon. Three sediment stations were established in Rendija Canyon and sampled for plutonium-238 and plutonium-239 in 1970. These stations were located near Guaje Pines Cemetery, downstream of the Sportsman's Club, and above the confluence with Guaje Canyon (Mayfield et al. 1979, 11717, pp. 50, 56; Purtymun 1970, 4795; Purtymun 1975, 11787, pp. 23–30).

In 1970, sediment stations were also established in Guaje Canyon and samples were collected for the analyses of plutonium isotopes. The three Guaje Canyon sediment stations were located above the confluence with Rendija Canyon, Barrancas Canyon, and Los Alamos Canyon. Sediments were collected from active channels (less than 1-in. [2.5-cm] depth) in each of the north canyons. Particle-sized distribution of the sediments was determined on material less than 4 mm to assess the percentage of clay- and silt-sized particles. Generally, the sediments were composed of 3% to 7.5% (by weight) of silt- and clay-sized material. Analyses for plutonium-238 and plutonium-239 were conducted by concentration and purification using ion exchange chemistry followed by an alpha spectrometer assay. Results of the analyses indicated activity within the range attributed to worldwide fallout (Mayfield et al. 1979, 11717, pp. 50, 56; Purtymun 1970, 4795; Purtymun 1975, 11787, pp. 23–30).

3.4.1.3.2 Former TA-10 Site in Bayo Canyon

Historic activities at former TA-10, Bayo site, are the primary Laboratory activities that affect Bayo Canyon. Bayo site was active from 1949 to 1963. An estimated 1.4 Ci of "natural uranium," 1.2 Ci of depleted uranium, and from 30 to 40 Ci of strontium-90 were dispersed to the surface environment in Bayo Canyon and beyond by the explosives testing. An additional 85 to 120 Ci of strontium-90 were deposited in the waste handling facilities (Mayfield et al. 1979, 11717, p. 4). In 1964 buildings and structures were decommissioned and decontaminated and in 1967 the property was transferred to Los Alamos County (see Section 2.3.2.2 of this document).

In 1973, four sediment sampling stations were established along Bayo Canyon including

- Station A - approximately 6500 ft (2000 m) upstream from Bayo site;
- Station B - within Bayo site;
- Station C - approximately 6500 ft (2000 m) downstream of Bayo site; and
- Station D – approximately 15,000 ft (4600 m) downstream of Bayo site.

Each station included five sampling locations, a center location, and locations 65 ft (20 m) and 650 ft (200 m) east and west of the center. Samples were collected from the bed sediments or stream bank. Stations A and B (upstream and within Bayo site) were analyzed for gross alpha and beta activity, and plutonium-238 and plutonium-239. Stations C and D (downstream of Bayo site) were analyzed only for plutonium-238 and plutonium-239. Analytical results from Stations A and B (upstream of Bayo site and within Bayo site) showed that gross alpha activity and plutonium concentrations were approximately background levels while gross beta concentrations were approximately twice background levels. Soil samples were collected from Stations A and B at points 20 and 200 m (65 ft and 650 ft) north and south of the center sediment sampling location. Analytical results showed that gross alpha and plutonium isotope concentrations were within background levels for the area. Gross beta activity was about 2 to 3 times background levels. The investigation concluded that elevated gross beta activity seen at Stations A and B appears attributable to the presence of strontium-90 (Mayfield et al. 1979, 11717, p. 50).

The Formerly Utilized Sites Remedial Action Program (FUSRAP) investigation included the collection of samples from approximately 27 random and nonrandom sampling locations in natural drainage pathways and the active stream channel at the former TA-10 site. The purpose of the sampling was to assess the redistribution or deposition of residual contaminants by surface water runoff (Mayfield et al. 1979, 11717, pp. 25, 26, 30). The sample depths were approximately 0 to 30 cm (0 to 12 in.) and included core samples (composite) and profile samples (discrete intervals). Results of the analyses showed that total uranium concentrations in sediment samples ranged from 1.6 to 7.6 μg/g, with highest concentrations from shallow depths (0 to 5 cm [0 to 2 in.]) at the former TA-10 site (Mayfield et al. 1979, 11717, p. 35). Concentrations of strontium-90 ranged from 0 to 8.2 pCi/g with the highest concentrations from the 0- to 5-cm (0- to 2-in.) interval. (Mayfield et al. 1979, 11717, p. 34). The background concentration of strontium-90 attributable to worldwide fallout at the time was estimated to be 0.4 pCi/g (Mayfield et al., 1979, 11717, p. 32).

3.4.1.3.3 Routine Environmental Surveillance of Active Channel Sediments

Since 1973, the Laboratory Environmental Surveillance Program has collected active channel sediment samples from locations in Bayo Canyon and Guaje Canyon. Table 3.4-1 summarizes the sediment sampling locations and dates. The sampling locations are shown on Figure A-1.

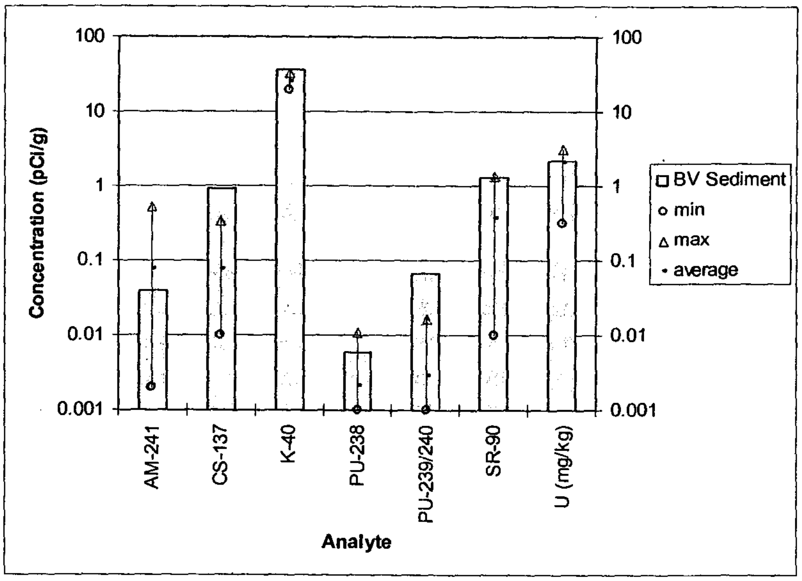
Table 3.4-1
Environmental Surveillance Sediment Sampling Locations

Location	Comment
Bayo Canyon at SR 502	Active channel sediment site at SR* 502, 1978 to 1999
Guaje Canyon at SR 502	Active channel sediment site at SR 502, 1977 to 1999
Guaje Canyon near G-4	Active sediment site near municipal well G-4, 1973 to 1980
Guaje Reservoir	Sediment collected from Guaje Reservoir, 1999

Source: Environmental Surveillance Reports, 1973–1999.
*SR = state road.

Bayo Canyon

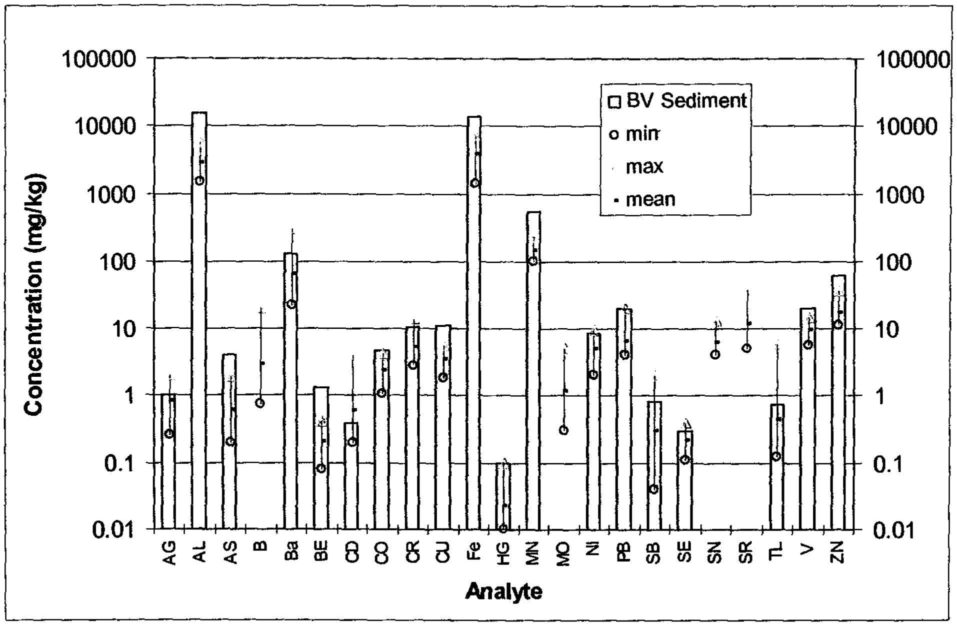
Active channel sediment samples have been collected in Bayo Canyon above the confluence with Los Alamos Canyon at State Road (SR) 502 annually since 1978. The samples are routinely analyzed for radionuclides. In some years since 1990 the samples were analyzed for metals. A summary of the results for radionuclides is shown in Figure 3.4-1. The radionuclide concentrations have generally been found to be within sediment BVs. However, americium-241 has been measured in concentrations above the sediment BV in 1992, 1998, and 1999, at concentrations of 0.106, 0.17, and 0.55 pCi/g, respectively (Environmental Surveillance Reports, 1978–1999). All americium-241 concentrations observed above BV were analyzed by gamma spectroscopy; results of alpha spectrometry for americium-241 have all been below BV.



Source: Environmental Surveillance Reports, 1978—1999.

Figure 3.4-1. Summary of radionuclides in Bayo Canyon sediments at SR 502

The summary of the results of analyses of sediments for metals is shown in Figure 3.4-2. Most metals have been observed in concentrations below the BV for sediments. Metals found in concentrations above the sediment BV include barium, cadmium, and thallium. In 1996 the sediment samples from Bayo Canyon were also analyzed for high explosive (HE) compounds, which were found to be below detection limits for HE compounds.

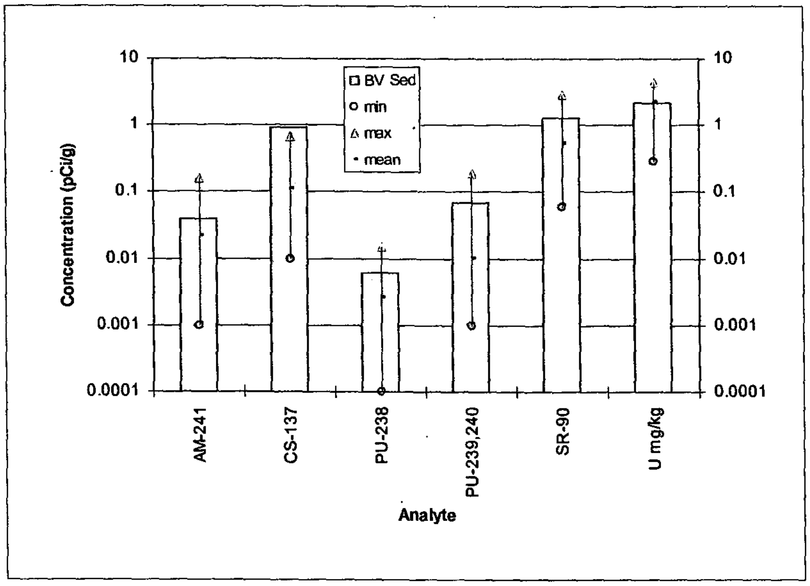


Source: Environmental Surveillance reports, 1990–1999.

Figure 3.4-2. Summary of metals in Bayo Canyon sediments at SR 502

Guaje Canyon

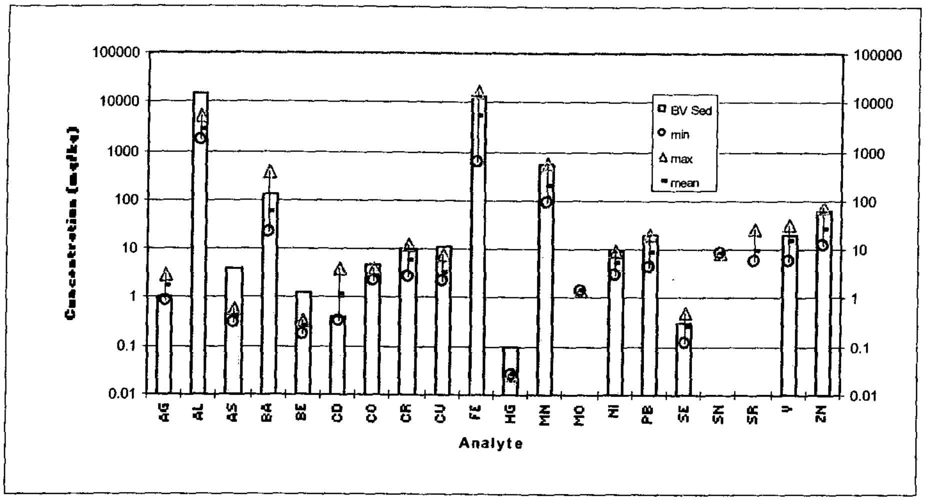
Active channel sediment samples have been collected annually in lower Guaje Canyon at SR 502 above the confluence with Los Alamos Canyon since 1977. The samples are routinely analyzed for radionuclides; since 1990, the samples also have been analyzed for metals. A summary of radionuclide analyses is shown in Figure 3.4-3. Maximum values for americium-241, plutonium-238, plutonium-239,240, strontium-90, and uranium have been above the BV for sediments. All results of americium-241 that have been observed above the BV have been from gamma spectroscopy measurements; all measurements of americium-241 using alpha spectrometry have been below the BV.



Source: Environmental Surveillance Reports, 1977–1999.

Figure 3.4-3. Summary of radionuclides in Guaje Canyon sediments at SR 502

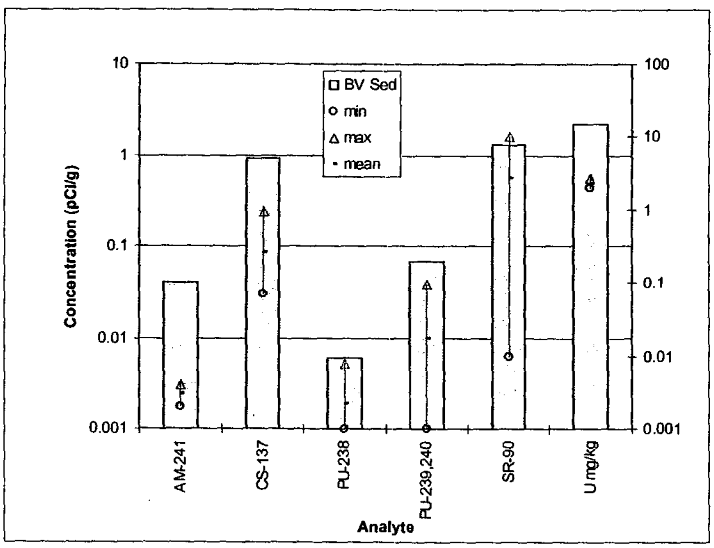
A summary of metals analyses obtained since 1990 for sediment samples collected in Guaje Canyon at SR 502 is shown in Figure 3.4-4. Most metals showed concentrations below the BV for sediments; however, maximum values of silver, barium, and cadmium have been above the BV.



Source: Environmental Surveillance Reports, 1990–1999.

Figure 3.4-4. Summary of metals in sediments collected at Guaje Canyon at SR 502

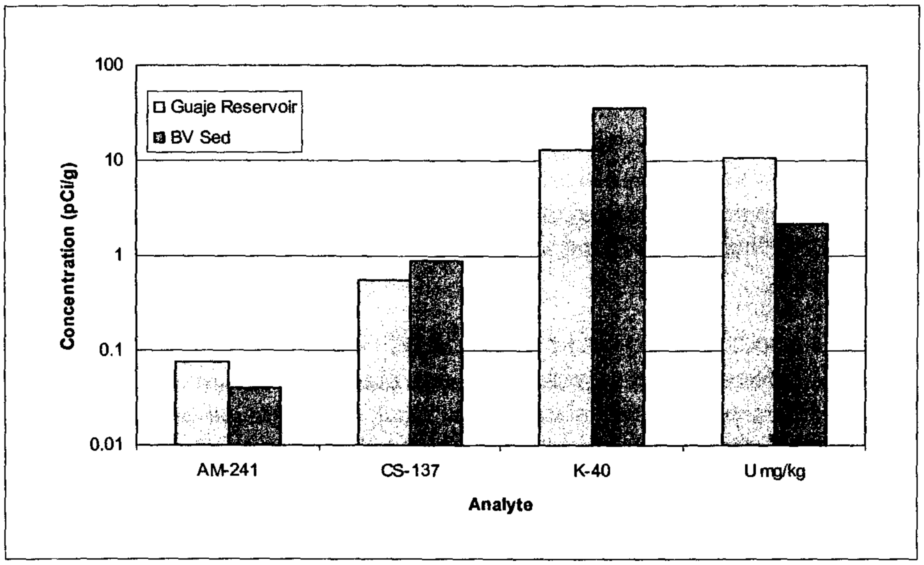
From 1973 through 1980, six sediment samples were collected in Guaje Canyon near well G-4 and the samples were analyzed for radionuclides. A summary of the results is shown in Figure 3.4-5. Gross gamma and strontium-90 were measured in concentrations above the BV for sediments. Three of four samples collected in Guaje Canyon contained strontium-90 in concentrations above the BV. The maximum concentration of strontium-90 was 10.4 pCi/g, which was collected in October 1976 (Environmental Surveillance Reports, 1973–1980).



Source: Environmental Surveillance Reports, 1973–1980.

Figure 3.4-5. Summary of radionuclides in Guaje Canyon sediment near well G-4, 1973 through 1980

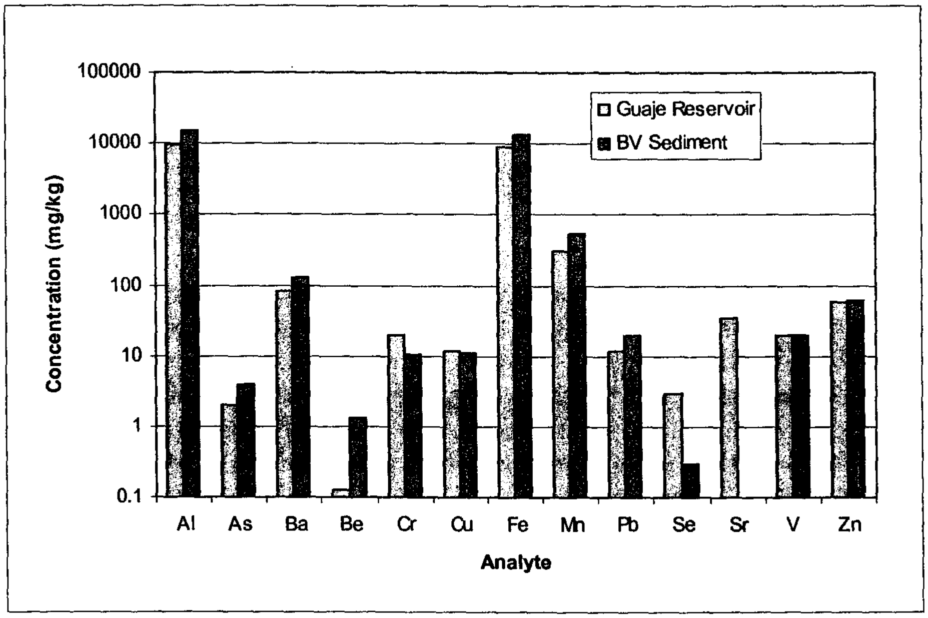
In 1999 a sediment sample was collected from Guaje Reservoir in Guaje Canyon and analyzed for metals and radionuclides (ESP 2000, 68661, p. 170). A summary of the radionuclide analyses is shown in Figure 3.4-6. Americium-241 (gamma spectroscopy), gross alpha, gross beta, and uranium were measured in concentrations above the BV for sediments (ESP 2000, 68661, pp. 225 et seq.).



Source: ESP 2000, 68661, pp. 170, 225.

Figure 3.4-6. Summary of radionuclides in Guaje Reservoir sediment, 1999

A summary of the metals analyses from samples collected from Guaje Reservoir in 1999 is shown in Figure 3.4-7. Metals measured in concentrations above the BV for sediments included copper and selenium (ESP 2000, 68661, pp. 245 et seq.).



Source: ESP 2000, 68661, pp. 170, 245, 251.

Figure 3.4-7. Summary of metals in Guaje Reservoir sediment, 1999

3.4.1.3.4 Recent Environmental Surveillance Sediment and Soil Sampling

In 1999, the US Environmental Protection Agency (EPA) collected four sediment samples from Bayo Canyon approximately 1 mi (1.6 km) east of former TA-10. Sediment collection depths were as follows: Bayo-1, 0-14 cm; Bayo-2, 14 to 27 cm; Bayo-3, 10 to 22 cm; and Bayo-4, 4 to 11 cm. Split samples were collected by the Laboratory Water Quality and Hydrology Group (ESH-18). The samples collected by ESH-18 were analyzed for radionuclides and metals.

Figure 3.4-8 summarizes the radionuclide analyses and Figure 3.4-9 summarizes the metals analyses obtained by ESH-18. All radionuclides were found in concentrations below the BV for sediment except for one sample that contained americium-241 in a concentration of 0.129 pCi/g using gamma spectroscopy; however, the same sample analyzed using alpha spectrometry contained 0.0037 pCi/g americium-241, below the sediment BV. All metals were found in concentrations below the BV for sediments (ESP 2000, 68661, pp. 170, 223, 297).

From June 1 to 19, 2000, after the Cerro Grande fire in May, surface soil samples were collected from locations on Laboratory property, at perimeter stations, and at background stations to assess potential contaminants from fallout ash, smoke and Laboratory air stack emissions, and fugitive dust (e.g., the resuspended dust from contaminated areas at Laboratory facilities). One perimeter station was located in Rendija Canyon near the Sportsman's Club. Analysis of samples from that location indicated the average concentrations of radionuclides and trace elements were similar to results obtained from soils collected in 1999 (Fresquez 2000, 68663, pp. 3, 5, 8).

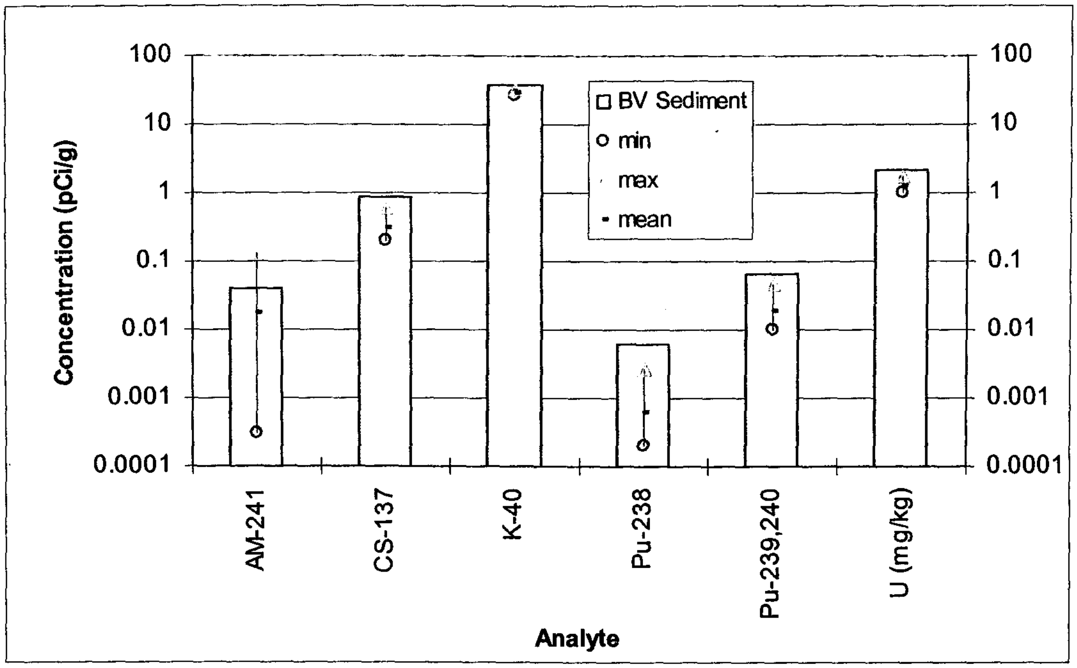
3.4.1.3.5 RFI Sediment and Soil Sampling

The Laboratory ER Project has conducted field investigations and sampling activities at PRSs within TA-0 in Rendija Canyon and upper Bayo Canyon, and at PRSs at former TA-10 in Bayo Canyon and Barrancas Canyon. Resource Conservation Recovery Act facility investigation (RFI) soil sampling has been conducted at the Guaje well field G-1 site in Guaje Canyon. The results of the investigation were reported in the RFI reports for former TA-10 in Operable Unit (OU) 1079 (LANL 1995, 49974; LANL 1996, 54332), the supplemental RFI report (LANL 1996, 54617), and RFI reports for PRSs at TA-0 in OU 1071 (LANL 1994, 59427; LANL 1996, 54837; LANL 1998, 59996). Results of the investigations are summarized below.

3.4.1.3.5.1 Summary of Soil and Sediment Sampling at TA-0

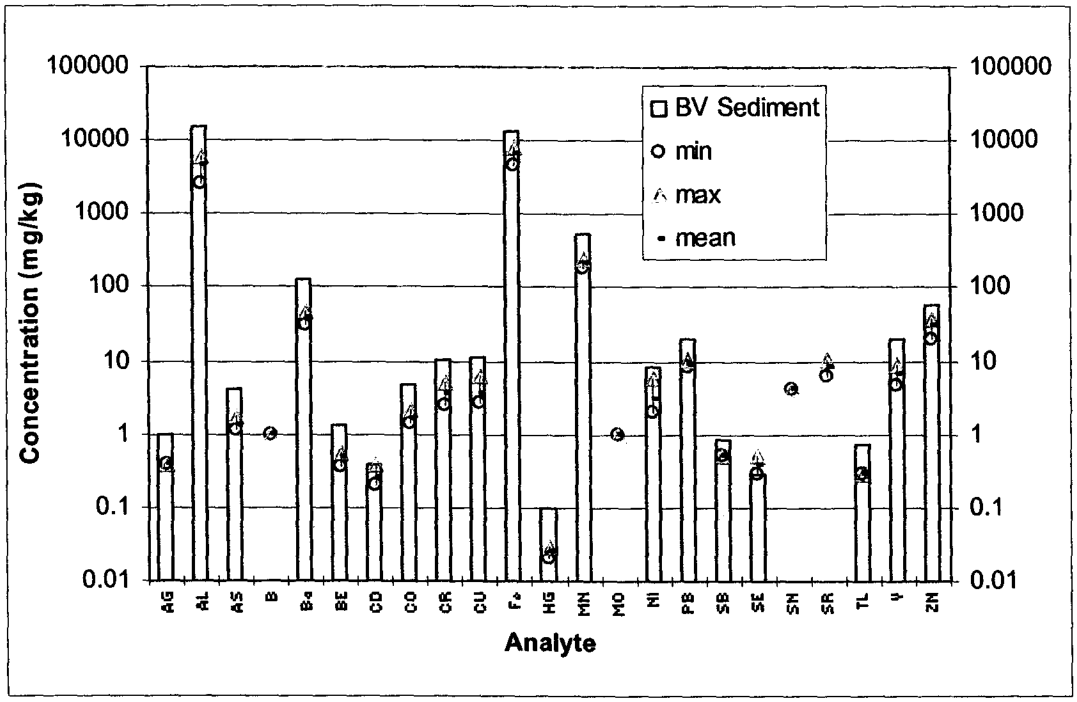
Rendija Canyon

In 1993, 1994, 1996, and 1997 sediment samples were collected from 78 locations in side drainages in Rendija Canyon as part of the RFI for PRSs 0-011(a), 0-011(e), and 0-016 in the canyon. Most were surface samples (less than 1-ft [0.3-m] depth), with a few samples collected from depths up to 1.17 ft (0.36 m). The samples were analyzed for inorganic constituents and HE compounds (LANL 1998, 59996; LANL 1994, 59427). Figure 3.4-10 shows the aggregated results of the sample analyses. Metals measured in concentrations above BVs include cobalt, lead, and selenium, of which lead was measured most often above BV. A total of 70 samples were analyzed for lead and 24 (34%) contained concentrations above the BV. Of 26 samples analyzed for cobalt and selenium, 14 samples (54%) contained cobalt above the BV and 13 samples (50%) contained selenium above the BV.



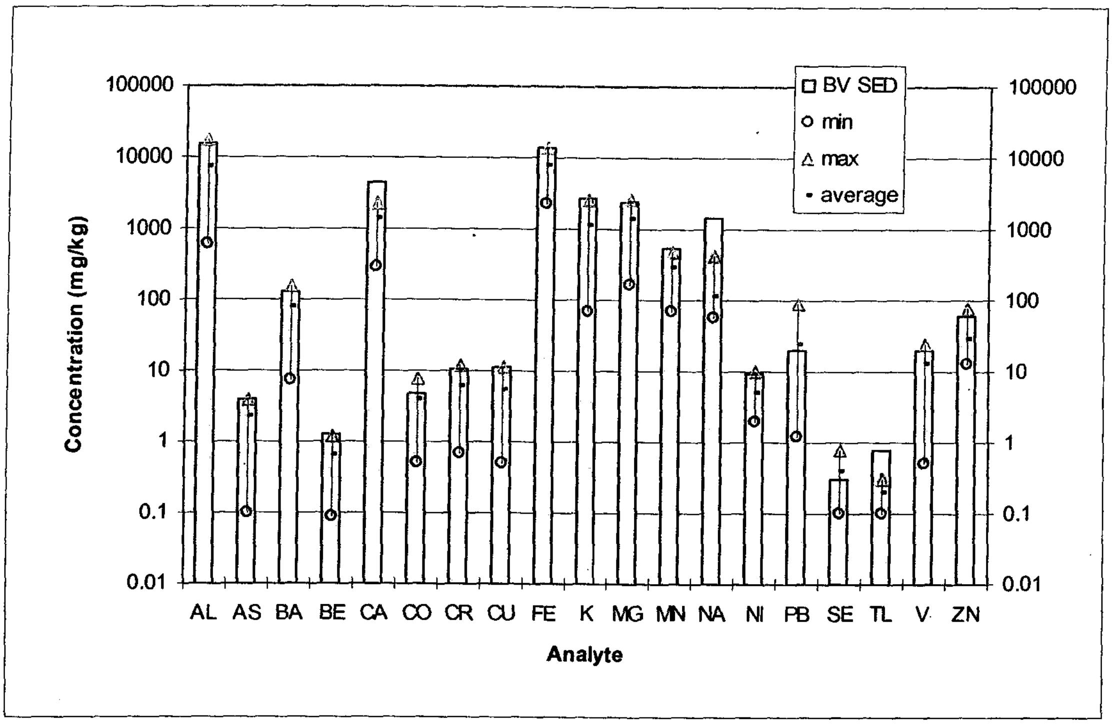
Source: Environmental Surveillance Report, 1999.

Figure 3.4-8. Summary of radionuclides in Bayo Canyon sediment, December 1999



Source: Environmental Surveillance Report, 1999.

Figure 3.4-9. Summary of metals in Bayo Canyon sediments, December 1999



Source: LANL 1998,59996; LANL 1994, 59427.

Figure 3.4-10. Summary of detects of inorganic constituents in Rendija Canyon surface sediment samples

At PRS 00-016, the maximum lead concentration remaining after the voluntary corrective action (VCA) was performed was 85.6 mg/kg in the main cleanup area. The maximum concentration remaining in the side drainage channel area north of the main cleanup site was 70.6 mg/kg. Of 41 samples in the main cleanup areas, 15 were above the soil BV of 22.3 mg/kg, and 3 of 3 first-order-drainage samples were above the BV (LANL 1998, 59996, pp. 48–53; LANL 2000, 67472, p. 2-6).

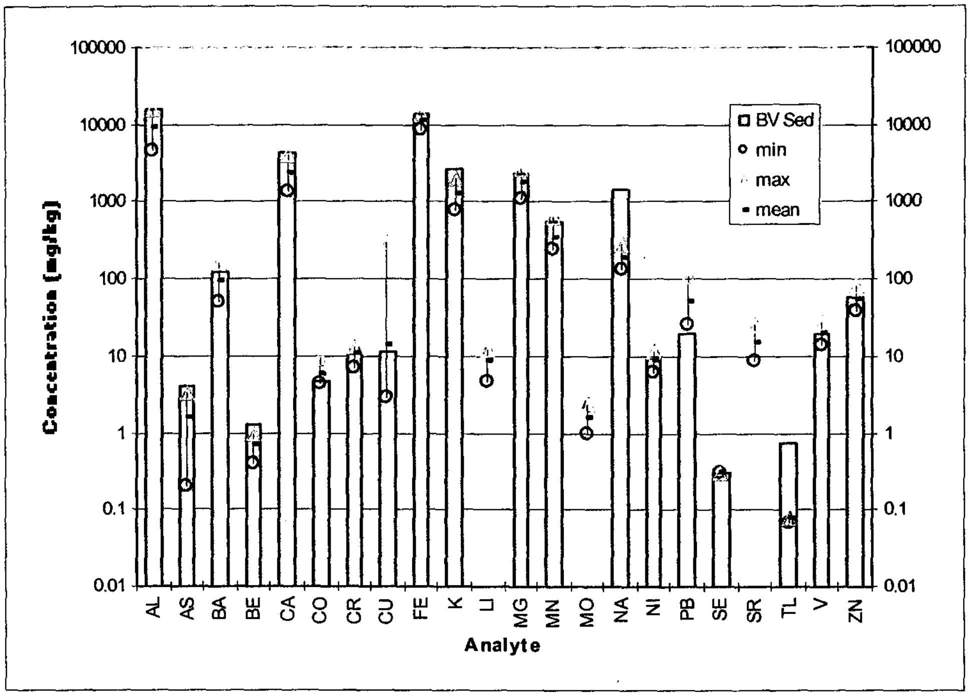
At PRS 00-011(a), 1 sample of 17 was above the BV for lead; the maximum lead concentration in drainages was 29 mg/kg. Selenium was above the BV (0.3 mg/kg) in 13 of 17 samples collected at PRS 00-011(a) and the highest selenium concentration was 0.8 mg/kg (LANL 1994, 59427, pp. 11, 12).

At PRS 0-011(e), no samples were above the BV for lead or other inorganic constituents (LANL 1994, 59427, p. 26).

Organic HE compounds were not detected in samples from the mortar impact sites.

Upper Bayo Canyon

In October 1992 surface sediment samples were collected from seven side-drainage locations at PRS 00-011(d), a bazooka impact area in upper Bayo Canyon. The samples were analyzed for metals (using hydrofluoric acid-leach procedure) and HE compounds (LANL 1994, 59427, p. 16). The results showed that three samples contained lead above the BV but below the screening action level (SAL) value. Additionally, the surface samples contained detectable amounts of the HE compound ethyl-4-nitrobenzene. However, the holding time for HE analysis had been exceeded, so in June 1993 nine additional samples were collected and analyzed for HE compounds and some samples were analyzed for metals using the nitric-acid leach procedure. The summary of the results of the metals analyses is shown in Figure 3.4-11. Metals measured in concentrations above sediment BVs included copper (one sample contained 300 mg/kg copper) and lead, which was measured above the sediment BV in all samples. Lead concentrations ranged from 31 to 156 mg/kg. HE compounds were not detected in concentrations above the method detection limits in any of the samples (LANL 1994, 59427, p. 18).



Source: LANL 1994, 59427.

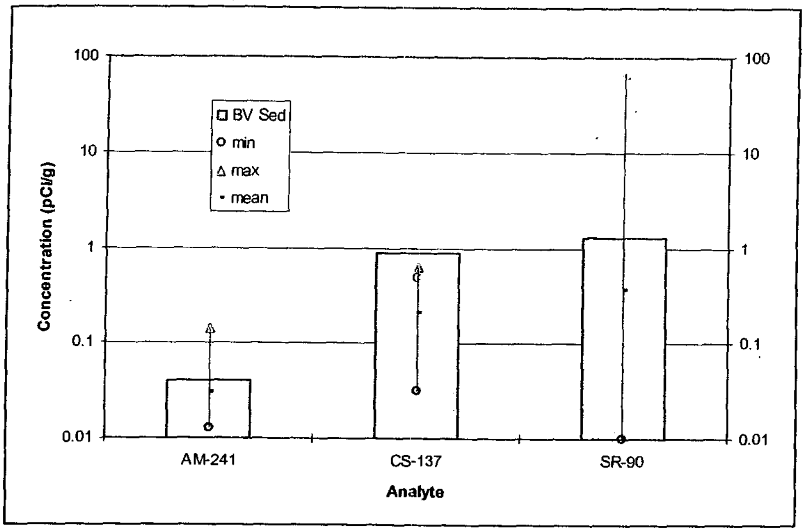
Figure 3.4-11. Summary of metals analyses at PRS 00-011(d) in upper Bayo Canyon

3.4.1.3.5.2 Summary of RFI Sampling at Former TA-10

Middle Bayo Canyon

The RFI for PRSs at former TA-10 in Bayo Canyon was performed from 1994 through 1996. Surface samples were analyzed for semivolatile organic compounds (SVOCs), metals, total uranium, and strontium-90; about 50% of the samples were analyzed for HE compounds. The results of the investigation were reported in the RFI reports for former TA-10 in OU 1071 (LANL 1995, 49974; LANL 1996, 54332) and the supplemental RFI report (LANL 1996, 54617). These samples were collected in a grid that covered much of the canyon floor in the area within and surrounding former TA-10. Some sampling locations were within post-1942 sediment along the channel in Bayo Canyon, but most were located throughout the rest of the valley floor to characterize contamination associated with shot dispersal from the former firing sites.

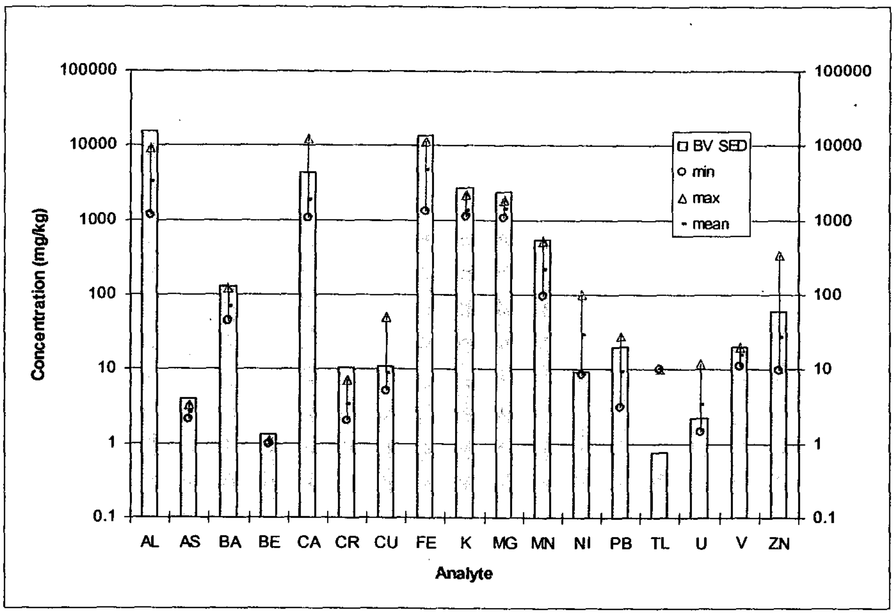
Figure 3.4-12 shows the results of radionuclide analyses of 103 surface samples (less than 1 ft [0.3 m] deep). The radionuclide detected most often was strontium-90; 7 samples contained strontium-90 above the sediment BV. The highest concentration of strontium-90 observed in the surface samples was 67 pCi/g. Americium-241 was detected in 2 samples above the BV, with a maximum concentration of 0.144 pCi/g using gamma spectroscopy (LANL 1996, 54617).



Source: LANL 1996, 54617.

Figure 3.4-12. Summary of radionuclides in surface samples in middle Bayo Canyon

The summary of inorganic constituents in surface sediments from Bayo Canyon is shown in Figure 3.4-13. Inorganic constituents measured in concentrations greater than sediment BVs include calcium, copper, nickel, lead, uranium, and zinc (LANL 1995, 49974; LANL 1996, 54332). Metals found in concentrations greater than the sediment BV include copper (3 of 98 samples above the BV), nickel (1 of 98 samples above the BV), and uranium, which was measured in 78 of 98 (80%) samples at concentrations greater than the sediment BV. The sediment BV for uranium is 2.22 mg/kg whereas the Qbt 1v BV is 6.22 mg/kg. Many of the samples may have been collected from material associated with units of the Tshirege Member of the Bandelier Tuff, which outcrops in the area where the samples were collected, and for which sediment BVs are not an appropriate comparison.



Source: LANL 1996, 54332.

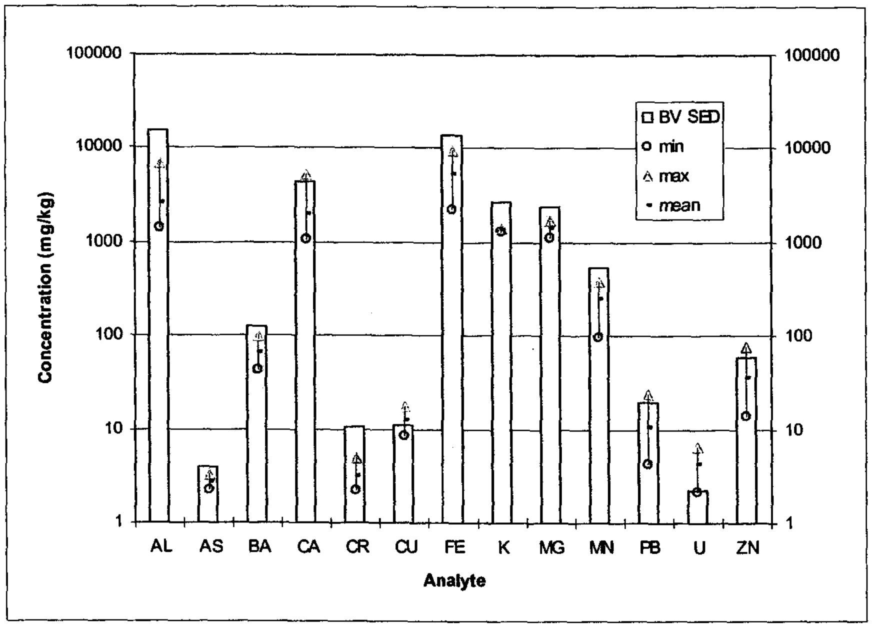
Figure 3.4-13. Summary of inorganic constituents in surface sediments at former TA-10 in Bayo Canyon

HE compounds detected in Bayo Canyon surface samples include nitrobenzene, nitrotoluene, and dinitrotoluene (LANL 1995, 49974; LANL 1996, 54332).

In 1996, surface samples were collected from an area about 200 ft (61 m) long and 160 ft (49 m) wide at former TA-10 in Bayo Canyon (LANL 1996, 55698). The samples were collected from beneath vegetation and from a grid spaced at 20-ft (6-m) centers. Field screening measurements for beta/gamma activity were obtained for sediment samples that were used to estimate the strontium-90 concentration. Strontium-90 concentrations in surface and near-surface soil samples ranged from 2 to 146 pCi/g with a mean of 21.9 pCi/g and a median value of 13 pCi/g (LANL 1997, 56358, Table 1, pp. 6–9). Of 98 surface sample sites collected in the grid pattern for analyses at off-site laboratories, 25 sites (25%) contained strontium-90 in concentrations above the sediment BV of 1.3 pCi/g (LANL 1997, 56358, p. 5).

Barrancas Canyon

Sediment samples were collected in the Barrancas Canyon watershed in 1994 and 1995 during the RFI investigation of former TA-10 in Bayo Canyon. Surface sediment samples were collected from 12 locations in small drainages on mesa-tops and side-canyons and analyzed for inorganic constituents, HE, and strontium-90. The results of analyses for inorganic constituents that were detected in the samples are shown in Figure 3.4-14. Copper was detected in two samples, one of which contained 17.7 mg/kg, above the BV of 11.2 mg/kg. Uranium was detected in all 12 samples analyzed and 11 samples contained uranium above the sediment BV of 2.22 mg/kg. The highest uranium concentration measured was 6.4 mg/kg (LANL 1995, 49974, pp. 24–27, Table A-4). The samples collected in Barrancas Canyon may have been collected from material derived from unit Qbt 1v, which outcrops in the area where the samples were collected. Qbt 1v has a uranium BV of 6.22 mg/kg, about 3 times the BV of other units in the Tshirege Member of the Bandelier Tuff and of stream sediment BVs at the Laboratory (Ryti et al. 1998, 59730, Table 6-1). Other inorganic constituents generally were measured in concentrations below sediment BVs.



Source: LANL 1995, 49974.

Figure 3.4-14. Summary of inorganic constituents detected in surface sediment samples from Barrancas Canyon

Two samples collected from small drainages on the side of a mesa within the Barrancas Canyon watershed detected strontium-90 but in concentrations below the sediment BV. One sample contained high melting explosive (HMX) in a concentration of 1.56 mg/kg and nitrobenzene in a concentration of 0.154 mg/kg (LANL 1995, 49974, p. 25, Table A-6, p. A-33). The presence of these HE compounds in the Barrancas Canyon watershed probably resulted from the experimental detonations conducted in Bayo Canyon during the 1940s and 1950s (see Section 2.3.2).

3.4.1.4 Summary of Surface Sediment Data

Significant information about surface sediments provided in Section 3.4.1.3 is summarized below.

- Surface sediments in upper Bayo Canyon near PRS 00-011(d) contained lead in concentrations of 31 to 156 mg/kg (above the sediment BV) and one sample contained 300 mg/kg copper.
- Surface sediments in middle Bayo Canyon near former TA-10 contained calcium, copper, nickel, uranium, and zinc in concentrations above sediment BV; copper, nickel, and uranium were above the sediment BV. Strontium-90 was present in surface sediments in concentrations up to 67 pCi/g. HE compounds detected in Bayo Canyon surface sediment samples included nitrobenzene, nitrotoluene, and dinitrotoluene.
- Surface sediments from small side drainages to Barrancas Canyon were found to contain copper and uranium above BVs. The HE compounds HMX and nitrobenzene were also detected in the surface sediments.
- Routine environmental surveillance sampling for stream sediments in the active channel was conducted at Bayo Canyon at SR 502 and Guaje Canyon at SR 502, but no sampling of floodplain sediments has occurred.
- Active channel samples collected in lower Bayo Canyon at SR 502 generally contained radionuclide concentrations within sediment BVs. Barium, cadmium, and thallium also were found in concentrations above the sediment BV.
- In Rendija Canyon, metals measured in concentrations above BVs include cobalt, lead, and selenium; lead was measured most often (in 34% of samples) above BV. The maximum lead concentration at PRS 00-016 after the VCA was performed was 85.6 mg/kg. The maximum lead concentration at PRS 0-011(a) was 29 mg/kg and selenium was above the BV in 13 samples. Lead concentrations at PRS 0-011(e) were below the BV. Organic HE compounds were not detected in samples from the mortar impact sites in Rendija Canyon.
- Sediment samples collected from Guaje reservoir in 1999 contained americium-241, gross alpha, gross beta, and uranium in concentrations above the sediment BV.
- Sediment samples collected in Guaje Canyon near well G-4 contained gross gamma and strontium-90 in concentrations above BVs.
- Active channel sediment samples collected in lower Guaje Canyon at SR 502 showed average values for all radionuclides within the BVs for sediments, although maximum values for plutonium-238, plutonium-239,240, strontium-90, and uranium were above the sediment BVs. Silver, barium, and cadmium concentrations have been measured above the sediment BVs.

3.4.2 Previous Subsurface Investigations

Subsurface investigations conducted to a limited extent in middle Bayo Canyon at former TA-10 and in a small area in middle Guaje Canyon provide information on potential alluvial groundwater. Subsurface investigations have not been conducted in Barrancas Canyon or Rendija Canyon.

3.4.2.1 Bayo Canyon

In 1961 four test holes, TH-1 through TH -4, were drilled at TA-10 in middle Bayo Canyon. Borehole locations are shown in Figure A-1. For clarification in nomenclature, the boreholes currently are identified as BCTH-1 through BCTH-4. The test holes were drilled to determine if shallow groundwater was present at the former TA-10, Bayo site. Three test holes were drilled into the top of the Puye Formation to maximum depth of 88.9 ft (27.1 m). Alluvium was reported to be 5 to 16 ft (1.5 to 4.9 m) thick above the tuff in these holes. There was no indication of perched water or excessive moisture in the tuff above the Puye Formation. The small volumes of water hauled in and used for previous site operations and normal precipitation and runoff in the watershed precluded a transport mechanism for contaminant migration to the top of the Puye Formation (Mayfield et al. 1979, 11717, pp. 50, 58). No contaminant analyses were performed on these samples.

In 1973 and 1974, additional test holes (the M-series) were drilled in the vicinity of the former liquid waste disposal area at TA-10 to collect samples for contaminant analysis. These holes were drilled from 8 to 39 ft (2.4 to 11.9 m) deep. No groundwater was encountered in the test holes. Cuttings from some holes contained strontium-90 in concentrations greater than the BV. The area was further investigated by drilling 10 additional boreholes. These test holes (the E and W series) were advanced from 6 to 35 ft (1.8 to 10.7 m). No groundwater was reported. The results of sample analyses showed that gross alpha activity was near background levels with the exception of one borehole where 4 to 10 times the background levels was detected. Gross beta activity generally was detected above background levels at all locations. The maximum gross beta value was 24,000 pCi/g (Mayfield et al. 1979, 11717, pp. 47–59).

During the 1974 FUSRAP investigation, subsurface samples were collected from the firing sites, former structures, and the canyon floor in middle Bayo Canyon. About 380 subsurface soil samples were collected and analyzed for gross alpha and beta activity. Laboratory analyses for selected radionuclides were performed on selected and random samples, and strontium-90 analyses were conducted on 68 of the subsurface samples. Twelve of the subsurface samples contained strontium-90 in concentrations greater than 20 pCi/g and eight samples exceeded 100 pCi/g; the maximum strontium-90 concentration was 4310 pCi/g. No groundwater or excessive moisture was reported from the sampling effort (Mayfield et al. 1979, 11717, pp. 4, 25, 26, 30, 51, 88).

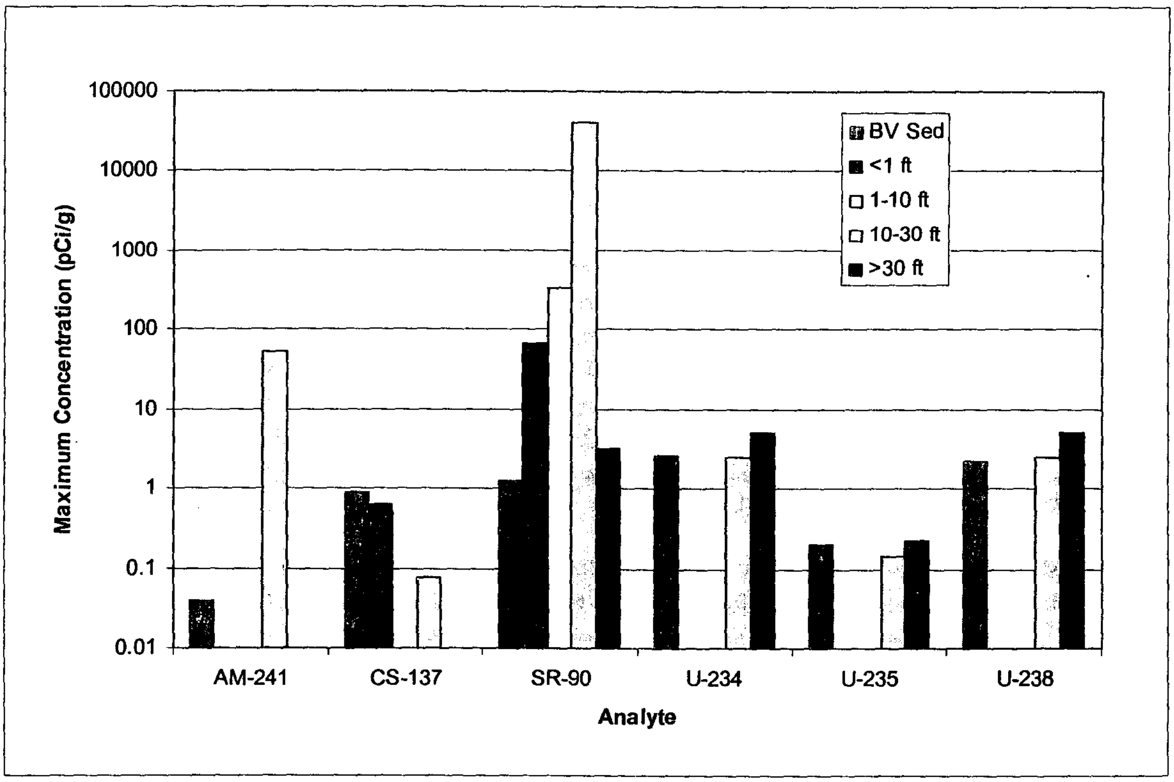
Seven additional test holes were drilled in Bayo Canyon in 1980 to further define the extent of potential contaminants identified in previous investigations. The boreholes were drilled to depths of 12 to 37 ft (3.6 to 11.2 m). The soil/tuff contact generally was encountered at depths from 6 ft to 27 ft (1.8 to 8.2 m). Groundwater was not detected (Purtymun 1994, 58233, p. 97-1). Samples collected within 10 ft (3 m) of the surface were within background levels for gross alpha and gross beta activity at all locations. At greater depths, strontium-90 concentrations were found to be above 100 pCi/g (FBD Inc. 1981, 8032, p.1-4).

In 1996, three samples were collected from a borehole drilled to 4.5 ft (1.4 m) during the RFI at PRS 00-028(b), located on North Mesa within the Bayo Canyon watershed. Samples were collected at depths of 0 to 0.5 ft, 2.5 to 3 ft, and 4 to 4.5 ft (0 to 0.2 m, 0.8 to 0.9 m, and 1.2 to 1.4 m). The samples were analyzed for radionuclides, metals, volatile organic compounds (VOCs), SVOCs, and PCB compounds

(LANL 1996, 54837, p. 19). Metals generally were found in concentrations below the sediment BV; however, metals measured in concentrations slightly above sediment BVs included silver, uranium, and vanadium (LANL 1996, 54837).

The RFI for PRSs at former TA-10 in Bayo Canyon was performed from 1994 through 1996. Surface and subsurface sediment samples were collected from 93 boreholes. At least 4 subsurface samples were collected from each borehole and analyzed for SVOCs, metals, total uranium, and strontium-90; about 50% of the samples were analyzed for HE compounds. The results of the investigation were reported in the RFI reports for former TA-10 in OU 1071 (LANL 1995, 49073; LANL 1995, 49974; LANL 1996, 54332) and the supplemental RFI report (LANL 1996, 54617). Two of the boreholes were completed as observation wells. BCM-1, a moisture monitoring tube and BCO-1, a shallow observation well, were installed in middle Bayo Canyon in 1994. The moisture access tube and the observation well were dry at the time of installation and since 1995 have not been monitored.

Figure 3.4-15 shows the maximum radionuclide concentrations measured in samples from different depths in the RFI boreholes. The radionuclide detected most often was strontium-90. Of 349 samples collected from the subsurface (deeper than 1 ft [0.3 m]) in middle Bayo Canyon, 44 samples (13%) contained strontium-90 in concentrations greater than the sediment BV. The highest concentrations of strontium-90 were observed at depths from 10 to 30 ft (3 to 9 m), where numerous locations contained strontium-90 in concentrations of several hundred picocuries per gram up to a maximum observed concentration of 40,325 pCi/g (LANL 1996, 54617).

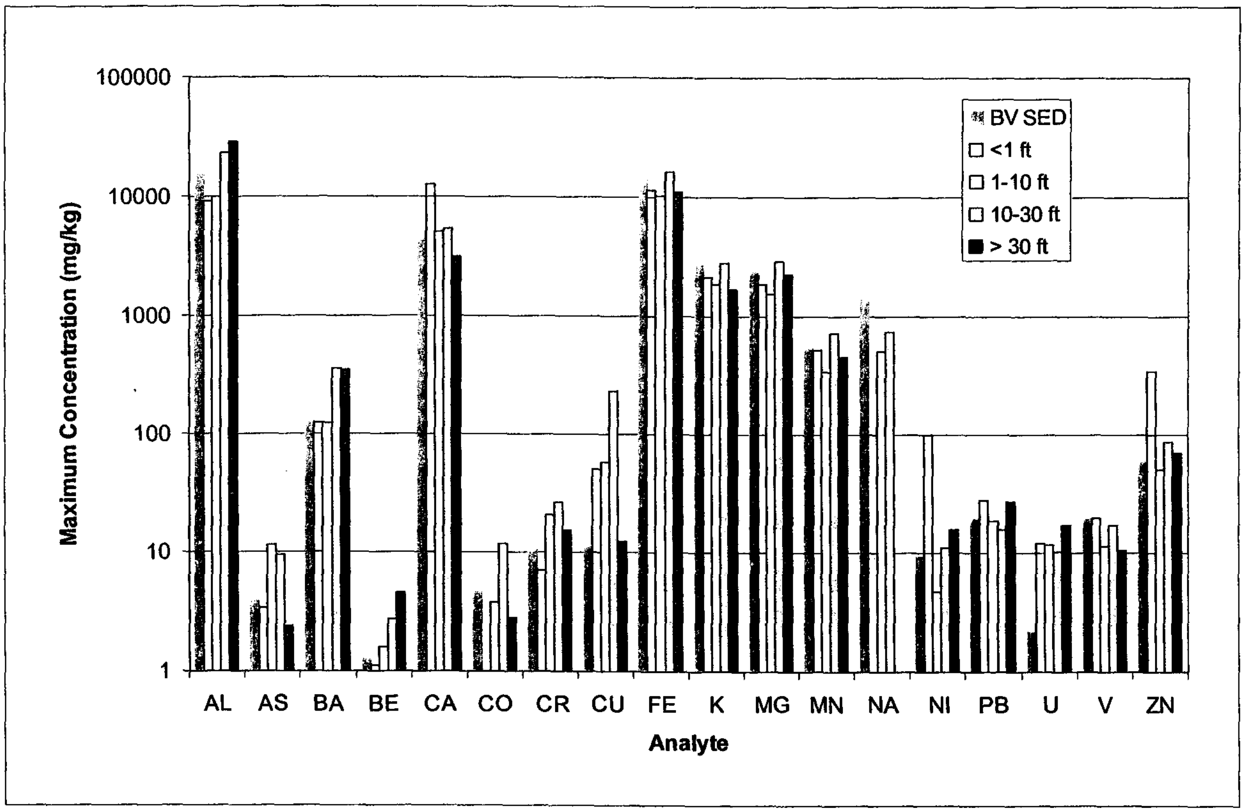


Source: LANL 1996, 54617.

Figure 3.4-15. Summary of radionuclides in RFI subsurface samples from middle Bayo Canyon

Other radionuclides measured in concentrations above sediment BVs in Bayo Canyon included americium-241, uranium-234, and uranium-238, which were detected in samples collected deeper than 10 ft (3 m). Americium-241 (using gamma spectroscopy) was detected in two of 21 samples with a maximum value of 51 pCi/g. Uranium-234 was detected above the sediment BV in 1 of 17 samples (maximum value 5.15 pCi/g) and uranium-238 (maximum value 5.11 pCi/g) was detected above the sediment BV in 2 of 17 samples. These samples were collected from deeper geologic formations present beneath the canyon floor that may not be representative of sediment background conditions (LANL 1996, 54617).

The summary of inorganic analyses (maximum concentrations) for surface and subsurface sediments collected in Bayo Canyon is shown on Figure 3.4-16. Inorganic constituents in subsurface samples measured in concentrations higher than the sediment BV include arsenic, barium, beryllium, cobalt, chromium, copper, and uranium (LANL 1995, 49974; LANL 1996, 54332). The units present in the subsurface in middle Bayo Canyon may not be comparable with sediment BVs.



Source: LANL 1996, 54332.

Figure 3.4-16. Summary of inorganic constituents in subsurface sediments in Bayo Canyon

HE compounds were not detected in subsurface samples in concentrations above the method detection limit (LANL 1995, 49974; LANL 1996, 54332).

3.4.2.2 Guaje Canyon

In 1946, test wells were installed in lower Los Alamos and Guaje Canyons to determine if a groundwater supply could be developed for Los Alamos. Test well GT-4 (also known as LA-3A) was installed in lower

Guaje Canyon at the confluence with Los Alamos Canyon to a total depth of 315 ft (96 m). Artesian conditions were encountered, and the well was screened with 2-in., perforated, galvanized steel from 60 to 315 ft (18 to 96 m). The borehole log indicates 54 ft (16.5 m) of alluvium was penetrated. No alluvial groundwater was noted, and no core samples were collected (Purtymun 1995, 45344, pp. 245, 246).

In 1950, the Layne Western company installed a well to supply water to drill and construct the municipal supply wells in the Guaje field. The well, referred to as the "Layne Western well," is located in lower Guaje Canyon and was installed to a depth of 157 ft (48 m). Approximately 12 ft (3.8 m) of alluvium was encountered. No alluvial groundwater was reported, and no samples were collected for analyses (Purtymun 1995, 45344, pp. 211, 219, 226).

From 1950 to 1954, six municipal water supply wells were completed in Guaje Canyon. A seventh well was completed in 1964 (Purtymun 1995, 45344, p. 247). The wells are identified as G-1, G-1A, G-2, G-3, G-4, G-5, and G-6. Alluvium ranged from 8 ft (2.5 m) at G-5 to 40 ft (12.2 m) at G-6. Alluvial groundwater was not reported in any water supply wells (Purtymun 1995, 45344, pp. 253–259). Four replacement wells (GR-1 through GR-4) were installed near the original wells in 1997 and 1998 (LANL 1999, 63516, p. 77).

Two test holes, TH-1 and TH-2, were drilled in Guaje Canyon between the Rendija Canyon and Guaje Mountain faults in fall 1966 to investigate geologic structures and their relationship to the presence of groundwater. For clarification in nomenclature, the boreholes are identified as GCTH-1 and GCTH-2. The boreholes are located approximately 3 mi (4.8 km) downstream of Guaje Reservoir. GCTH-1 was drilled in alluvium to a depth of 23 ft (7 m). The alluvium was saturated from the base of the borehole to approximately stream level. GCTH-2 was drilled to a depth of 103 ft (31.4 m), encountering 17 ft (5.1 m) of alluvium overlying the Puye Formation. Both units were reported as saturated to near-stream level (Purtymun 1995, 45344, p. 299). GCTH-1 and GCTH-2 were completed as 2-in. (5.0-cm)-diameter monitoring wells. Specific screen intervals were not reported (Purtymun 1995, 45344, p. 299).

3.4.2.3 Summary of Subsurface Investigations

Significant information about subsurface sediments provided in Section 3.4.2 is summarized below.

- Subsurface sediments in middle Bayo Canyon at former TA-10 contain arsenic, barium, beryllium, cobalt, chromium, copper, and uranium in concentrations higher than the sediment BV.
- Subsurface sediments in middle Bayo Canyon at former TA-10 contain strontium-90 in concentrations up to a maximum observed concentration of 40,325 pCi/g.
- The alluvium in middle Bayo Canyon was reported to be 5 to 16 ft thick overlying the Guaje Pumice Bed and the Puye Formation.
- Subsurface investigations have not been conducted in Barrancas or Rendija Canyon.
- Two test wells were drilled in middle Guaje Canyon west of the GMFZ in 1966. Saturated alluvium was observed in both wells and saturation was observed to a depth of 103 ft (31 m) in the Puye Formation.
- The alluvium in lower Guaje Canyon in the Guaje well field ranged from 8 ft (2.5 m) to 40 ft (12 m) in thickness.
- No alluvial groundwater has been reported downstream of any north canyons PRSs.

3.4.3 Surface Water

The water that flows through the north canyons is used by plants, may be used by wildlife, and potentially may be used by humans; therefore, surface water constitutes a potential contaminant transport pathway to receptors. Surface water flow also provides one of the primary mechanisms for redistributing contaminants that may be present in the north canyons system. The results of past investigations (see Section 3.4.4) provide the background of conditions needed to assess the importance of these contaminant transport pathways. This section elaborates on surface water as a potential contaminant transport pathway in the north canyons systems.

The general hydrology of the canyon systems is discussed in Section 2.2.2.2 of the IWP (LANL 2000, 66802) and Section 3.5 of the core document (LANL 1997, 62316).

3.4.3.1 Stream Channel System and Streamflow

The stream channel characteristics and geomorphology of the north canyons and their tributaries are described in Sections 3.1 and 3.3.2. The watershed areas of each canyon are shown in Appendix A, Figure A-1. Streamflow in Bayo Canyon, Barrancas Canyon, and Rendija Canyon is entirely ephemeral. Perennial streamflow in upper Guaje Canyon is maintained by two springs in the upper watershed. Streamflow characteristics of each canyon are described in the following sections.

3.4.3.1.1 Bayo Canyon

Currently, there are no outfalls or National Pollutant Discharge Elimination System (NPDES)-permitted discharges in or into the Bayo Canyon watershed. Streamflow in the canyon is entirely ephemeral, arising from storm water runoff and snowmelt. Runoff is augmented by storm water discharges from a portion of Los Alamos town site on North Mesa and Barranca Mesa. Other runoff comes from San Ildefonso Pueblo land and Laboratory property in TA-74. During periods of heavy thunderstorms, streamflow from runoff in Bayo Canyon may extend beyond the Laboratory boundary to Los Alamos Canyon. However, there are no stream gaging stations in Bayo Canyon so no data for runoff events are available.

3.4.3.1.2 Barrancas Canyon

Barrancas Canyon and its three tributaries contain entirely ephemeral streams. The canyon receives storm water runoff and snowmelt from a small portion of Los Alamos town site on Barranca Mesa and Otowi Mesa, from USFS land, and from a small part of Laboratory property at TA-74. There are no outfalls or NPDES-permitted discharges into the Barrancas Canyon watershed. During periods of heavy thunderstorms streamflow from Barrancas Canyon runoff may discharge into Guaje Canyon. However, no data for runoff events are available because there are no stream gaging stations in Barrancas Canyon.

3.4.3.1.3 Rendija Canyon

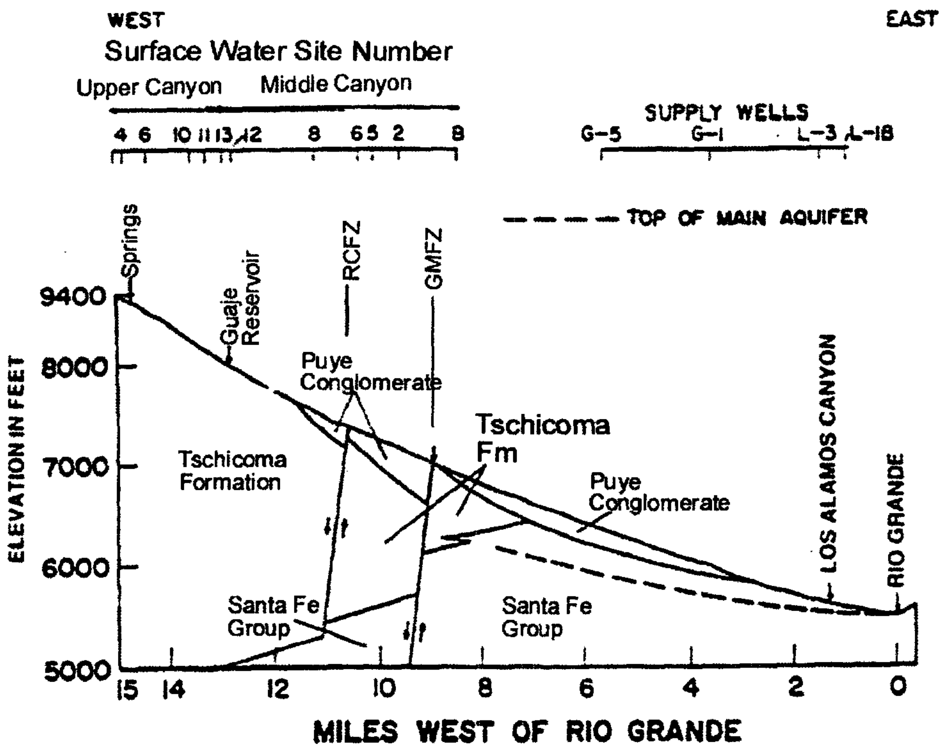
Rendija Canyon and its tributaries contain ephemeral streams. The watershed receives storm water runoff and snowmelt from portions of Los Alamos town site, GSA land containing former firing sites and mortar impact areas, and USFS land (Figure A-1). No data for runoff events is available because no gaging stations are located in Rendija Canyon. The installation of a new gaging station in lower Rendija Canyon above the confluence with Guaje Canyon is planned for 2001.

Two NPDES-permitted outfalls associated with wells G-6 (04A-176) and GR-4 (04A-177) in the Guaje well field were located in lower Rendija Canyon. These NPDES-permitted outfalls were transferred from the Laboratory to Los Alamos County with the transfer of the water supply system. Discharges from these outfalls are intermittent and are associated with start-up of the pumps after the pumps were shut down for maintenance. Discharge rates and volumes are not known.

3.4.3.1.4 Guaje Canyon

Two springs in upper Guaje Canyon supply perennial streamflow to the upper part of the canyon. Agua Piedra Spring in Agua Piedra Canyon supplies base flow for a short distance downstream. Guaje Canyon receives storm water runoff and snowmelt primarily from USFS land in the upper and middle part of the canyon and occasional runoff from Rendija and Barrancas Canyons in the lower part of the canyon. Five NPDES-permitted outfalls associated with wells in the Guaje well field were located in middle and lower Guaje Canyon. These NPDES-permitted outfalls were transferred from the Laboratory to Los Alamos County with the transfer of the water supply system. Discharges from these outfalls are intermittent and are associated with start-up of the pumps after the pumps were shut down for maintenance. Discharge rates and volumes are not known.

Figure A-1 shows locations of the springs and the approximate perennial reach. Figure 3.4-17 shows the stream channel profile of Guaje Canyon and the locations of streamflow monitoring stations that were monitored periodically from 1958 to 1967.



Source: Purtymun 1995, 45344, p. 317; Purtymun 1975, 11787, p. 279.
GMFZ = Guaje Mountain fault zone.
RCFZ = Rendija Canyon fault zone.

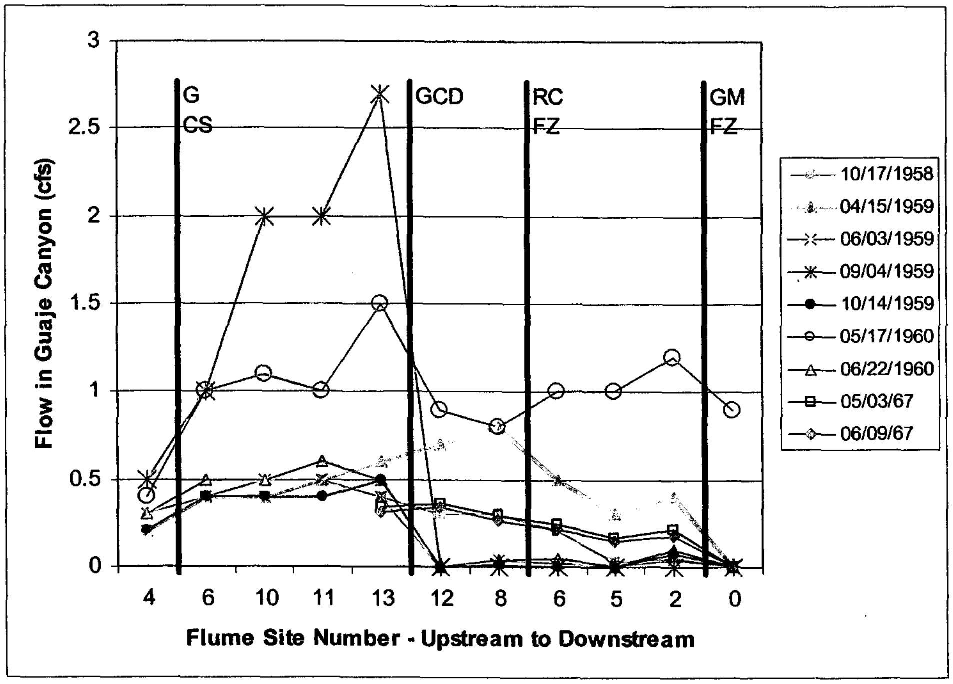
Figure 3.4-17. Channel profile of Guaje Canyon showing locations of historical surface water monitoring stations

Flow investigations were conducted in Guaje Canyon periodically from 1958 through 1960 to relate geologic structure to loss or gain in streamflow. Flow measurements were collected at 11 sites located from approximately 2 mi (3.2 km) upstream to about 4 mi (6.4 km) downstream of the reservoir. During this period (1958–1960), flows obtained in the months of September were 0.5 to 2.7 cfs and in the months of May, 0.4 to 1.5 cfs, which likely reflected the effect of seasonal precipitation events and snowmelt. Flows obtained downstream of Guaje Reservoir typically ranged from 0.0 to 0.3 cfs; however, at the time of the investigation, surface water was being diverted from the reservoir to Los Alamos town site. On one occasion, when water was not diverted, downstream flows were slightly higher than those upstream (Purtymun 1995, 45344, pp. 315–321).

The installation of two new gaging stations in Guaje Canyon is planned for 2001. One gaging station is planned for Guaje Canyon upstream of the confluence with Rendija Canyon and another gaging station is planned for lower Guaje Canyon upstream of the confluence with Los Alamos Canyon.

The springs in upper Guaje Canyon provide perennial base flow in Guaje Canyon as far as the Guaje Reservoir, and when water is not diverted at the reservoir, for a distance of approximately 6 mi (9.7 km) downstream (Purtymun, 1975, 11787, pp. 276–279). Water from the reservoir has not been diverted to Los Alamos since 1992 (McLin et al. 1998, 63506, p.13).

Figure 3.4-18 shows the results of monitoring low streamflow in Guaje Canyon at nine discrete times from October 1958 to June 1967. Flow was measured using Parshall flumes at 11 sites in the upper part of the canyon. The flume monitoring sites were numbered in descending integers (from 13) away from the intake to the reservoir both upstream and downstream; however the numbers attached to the flume sites do not represent a unit of distance away from the reservoir. Figure 3.4-17 shows the locations of the flume sites in upper Guaje Canyon (Purtymun 1975, 11787, p. 180; Purtymun 1995, 45344, p. 317).



Source: Purtymun 1975, 11787, p. 280.
GCS = Guaje Canyon springs.
GCD = Guaje Canyon Dam.
RCFZ = Rendija Canyon fault zone.
GMFZ = Guaje Mountain fault zone.

Figure 3.4-18. Streamflow in upper Guaje Canyon measured at 11 Parshall flume sites

The uppermost flume measurement site was upstream of Guaje Canyon Spring 1, where streamflow ranged from 0.2 to 0.5 cfs (90 to 220 gal./min). Flow measured downstream of Guaje Canyon Spring 1 increased to 0.4 to 1.0 cfs (180 to 450 gal./min), indicating that flow from the spring contributed from 0.1 to 0.6 cfs (45 to 270 gal./min). At most measurement times, flow from Guaje Canyon Spring 1 to the reservoir was relatively steady at about 0.4 to 0.6 cfs (180 to 270 gal./min). Measurements obtained on September 4, 1959, and May 17, 1960, however, showed increased flow downstream from Guaje Canyon Spring 1 to the reservoir, up to 2.7 cfs (1200 gal./min), possibly from storm water runoff and snowmelt runoff, respectively, and possibly from tributaries above the reservoir (Purtymun 1975, 11787, p. 180; Purtymun 1995, 45344, p. 317).

Water was being diverted from the reservoir when measurements were obtained, except on April 15, 1959. When water was diverted form the reservoir, flow in the channel downstream of the reservoir was always less than the flow entering the reservoir. All six measurements obtained in 1959 and 1960 showed no streamflow downstream of the reservoir. In 1959 and 1967 when flow measurements above the reservoir were about 0.5 cfs (220 gal./min), streamflow downstream of the reservoir was 0.3 cfs (135 gal./min), indicating a diverted volume of flow of about 0.2 cfs (90 gal./min). The streamflow measurements obtained on April 15, 1959, when water was not diverted from the reservoir, increased in the reach below the reservoir from 0.6 cfs (above the reservoir) to 0.8 cfs (270 to 360 gal./min), a gain of 0.2 cfs (90 gal./min) (Purtymun 1975, 11787, p. 180; Purtymun 1995, 45344, p. 317).

During four of the eight measurement periods when water was being diverted from the reservoir, streamflow downstream of the reservoir was 0.3 to 0.9 cfs (135 to 405 gal./min). At these times streamflow usually decreased downstream by about 0.1 cfs (45 gal./min) between each flume station, probably due to evapotranspiration (ET) and infiltration into the alluvium. During four measurement periods when there was no discharge from the reservoir at station #12, streamflow was observed downstream at station 8; this streamflow continued downstream to station #6 during two measurement periods (Purtymun 1975, 11787, p. 180; Purtymun 1995, 45344, p. 317). Flow in the channel downstream of the reservoir was likely from baseflow emerging from the alluvium downstream from the reservoir.

The Rendija Canyon fault zone (RCFZ) is located downstream of the reservoir between flume stations 8 and 6. The GMFZ is located downstream of the RCFZ between stations 2 and 0. Of 11 measurement periods, 10 showed that flow in the channel decreased across the RCFZ. One measurement period obtained on May 17, 1960, showed an increase in flow across the RCFZ from 0.8 to 1 cfs (360 to 450 gal./min), possibly due to snowmelt runoff contributions from tributaries.

3.4.3.2 Springs

There are no known springs or seeps in Bayo, Barrancas, or Rendija Canyons or their tributaries. Springs on the eastern flank of the Sierra de los Valles supply base flow in the upper reaches of Guaje Canyon. Guaje Canyon Spring 1 and Guaje Canyon Spring 2 are present in upper Guaje Canyon at an elevation of 8850 ft (2698 m) and 8840 ft (2695 m), respectively. Guaje Canyon Spring 1 is located in the main Guaje channel and Guaje Canyon Spring 2 is located in a small southern tributary near the head of Guaje Canyon (Figure A-1). Both springs are located on canyon floors in Bandelier Tuff. The estimated spring flow is 25 and 40 gal./min (Purtymun 1995, 45344, pp. 26, 282, 284; Griggs 1964, 65649, p. 137).

Aqua Piedra Spring is located at an elevation of 8100 ft (2470 m) in Aqua Piedra Canyon, a tributary to Guaje Canyon. The flow volume from Agua Piedra Spring has not been documented. Streamflow from Agua Piedra Spring extends downstream for an unknown distance.

3.4.3.3 Storm Water and Snowmelt Runoff Investigations

Personnel from ESH-18 have sampled storm water runoff periodically at several sites in the north canyons area. Runoff samples have been collected from Rendija Canyon near the confluence with Guaje Canyon at municipal well G-6, and from Guaje Canyon near SR 502. The results are reported in the annual environmental surveillance reports. Results of the analyses of runoff samples are discussed in Section 3.4.3.7. Because no gaging stations are present in the north canyons area, flow volumes of runoff were not obtained at sampling times. Three new gaging stations in lower Rendija and Guaje Canyons are planned for installation in 2001.

3.4.3.4 Flooding Potential

Flow and floodplain estimates for the Los Alamos region were developed using computer-based models (HEC 1 and HEC 2) developed by the US Army Corps of Engineers Hydrologic Engineering Center (McLin 1992, 12014, p. 4). The models project the effects of severe thunderstorms on all watersheds in the Los Alamos area and the effects of storm runoff on flood elevations within the canyons and on different Laboratory areas and structures. Precipitation totals and floodplain elevations were projected for 2-, 5-, 10-, 25-, 50-, and 100-yr storms.

A theoretically estimated 24-hr runoff resulting from a 2-yr recurrent, 6-hr thunderstorm event and an estimated 24-hr runoff, 50-yr recurrent, 6-hr thunderstorm event were modeled for Bayo, Barrancas, and Guaje Canyons. The model assessed the runoff for the events at specific locations for each watershed. Table 3.4-2 shows the estimates for the 24-hr runoff volumes, the associated 50-yr peak flow at the eastern Laboratory boundary, and the calculated precipitation for the 50-yr event for Bayo, Barrancas, and Guaje Canyons.

Table 3.4-2
Estimates of 24-hr Runoff in the North Canyons Area

Canyon	Locations for Runoff Estimates	2-yr/6-hr Runoff (ac-ft)	50-yr/6-hr Runoff (ac-ft)	50-yr/6-hr Peak Flow (cfs)	50-yr/6-hr Subbasin Precipitation (in.) and Average Elevation (ft)
Bayo	Tributary confluence upstream of east Laboratory boundary	<1	44	111	2.32 in. at town site (7220 ft) 1.75 in. at the main channel (6500 ft) 1.43 in. at the southern tributary at Totavi (6100 ft)
Barrancas	Tributary confluence below east Laboratory boundary	<1	24	67	1.81 in. at town site tributary (6580 ft) 1.51 in. at southern tributary (6200 ft) 1.83 in. at northern 2 tributaries (6600 ft) 1.46 in. above elevation of 5897 ft
Guaje	Above Barrancas Canyon confluence	8	333	666	3.03 in. above 7172 ft 1.91 in. above 6253 ft 2.23 in. near Rendija Canyon at 6253 ft 1.67 in. at Barrancas Canyon above 5897 ft 1.29 in. above the Los Alamos Canyon confluence (5920 ft)

Source: McLin 1992, 12014, pp. 13, 19, 20.

In most canyons on the Pajarito Plateau, and likely for the north canyons, the 100-yr floodplain occupies an area along the canyon floor that is more or less centered on the stream channel (McLin 1992, 12014, p. 4). PRSs at former TA-10 in Bayo Canyon are located near the channel and are thus in the potential flood areas.

In May 2000, the Cerro Grande fire severely burned portions of numerous watersheds in the Los Alamos area. Figure 3.4-19 shows the areas in the north canyons that were affected by the fire. The upper portions of both Guaje and Rendija Canyon watersheds were damaged.

The fire burned approximately 56% of the Guaje Canyon watershed and about 78% of the Rendija Canyon watershed. About 30% of the burned acreage in the Guaje Canyon watershed and about 51% in the Rendija Canyon watershed were classified as high-burn severity (BAER 2000, 68662, p. 280). The areas with high-burn severity generate more runoff than unburned areas and increase the volume of storm water runoff from a storm event. The anticipated time needed to return to prefire hydrologic conditions is approximately 5 yr.

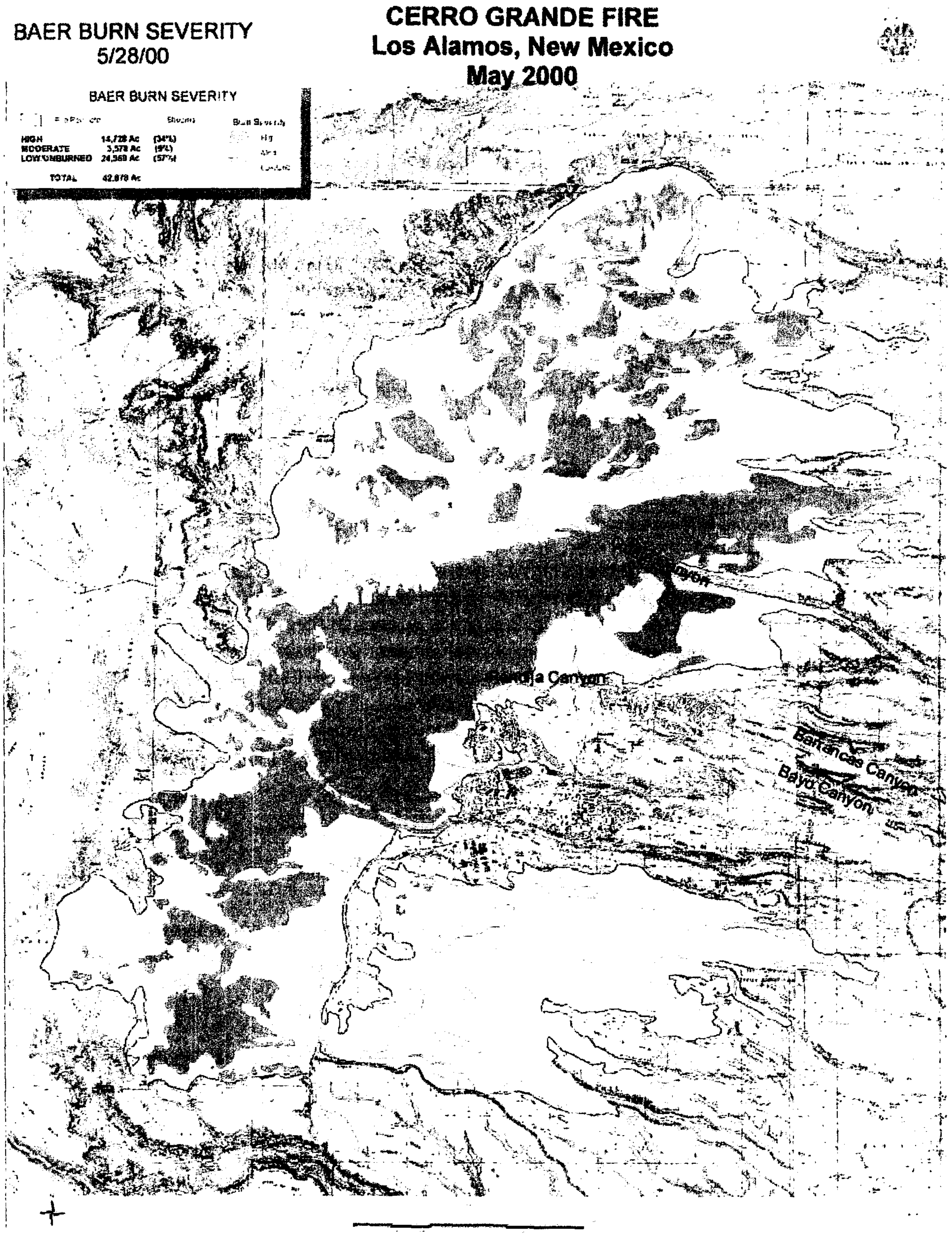
Storm water runoff projections were modeled after the Cerro Grande fire using pre- and postfire parameters. Results of modeling for the Guaje Canyon watershed under prefire conditions for a 25-yr, 1-hr event (1.9 in.) predicted a peak flow of 30 cfs at the Rendija Canyon confluence. Flow projections calculated for after the fire for the same 25-yr, 1-hr event are a maximum of 437 cfs at the Guaje Reservoir. Total runoff for the watershed at the Rendija Canyon confluence was predicted to be 179 ac-ft (BAER 2000, 68662, p. 287).

Storm water runoff flow modeling in Rendija Canyon using prefire parameters for a 25-yr, 1-hr event (1.9 in.) predicted a peak flow of 4 cfs. Flow modeling for after the fire for the same 25 yr, 1-hr event predicted a peak flow of 2398 cfs at the Guaje Pines Cemetery and 686 cfs at the confluence with Guaje Canyon. Total postfire runoff for the watershed was projected to be 283 ac-ft (BAER 2000, 68662, pp. 280, 286, 287).

3.4.3.5 Infiltration Below Stream Bed

Surface water enters the north canyons channels from storm water runoff and snowmelt. As the surface water flows downstream, the water infiltrates into the alluvium, into underlying formations, or is lost to ET. Site-specific infiltration data for the north canyons are not available, although infiltration beneath canyon floors is higher than beneath mesa-tops and has been calculated to be approximately 0.18 in. (4.4 mm)/yr beneath Cañada del Buey and between 0.8 and 4 in. (20 and 100 mm)/yr beneath Pajarito Canyon (LANL 1998, 57576, p. 54).

Geologic investigations in Guaje Canyon have provided data that can be used to infer general rates of infiltration in the canyon. In the upper part of the canyon to about the confluence with the south fork of Guaje Canyon (Figure A-1), the channel is underlain by thin deposits of alluvium overlying the Tschicoma Formation. The upper surface of the Tschicoma Formation may form a barrier to the infiltration of water from the streambed. Streamflow measurements obtained above and below Guaje Reservoir indicate no significant loss by infiltration into the underlying rocks (Tschicoma Formation) at the reservoir. Downstream, in middle Guaje Canyon, the channel is underlain by thicker deposits of alluvium that overlie the Puye Formation. In this reach surface water is lost by ET and infiltration. When water is not diverted at Guaje Reservoir, continuous surface water flow is maintained for approximately 3 mi (4.8 km) below the reservoir before ET and infiltration into the alluvium and underlying Puye Formation depletes the surface water flow (Purtymun 1975, 11787, pp. 276–282).



Source: BAER 2000, 68662.

Figure 3.4-19. Burn severity of the Cerro Grande fire in the north canyons area

Two shallow test holes were drilled west of the Guaje Mountain fault in 1966. The holes contained saturation to depth and indicated that infiltration of surface water into the shallow alluvium and underlying formation may be occurring. The test holes, GCTH-1 and GCTH-2, were drilled to 23 ft (7 m) and 103 ft (31.4 m), respectively. GCTH-1 was completed in the alluvium and was saturated to near-stream level. GCTH-2 encountered 17 ft (5.2 m) of alluvium and 86 ft (26.2 m) of Puye Formation gravel. GCTH-2 was also saturated to near-stream level (Purtymun 1995, 45344, p. 299). The results of the investigation suggested that surface water was being lost to the alluvium and underlying bedrock in middle Guaje Canyon. The surface water may be providing direct recharge to the regional aquifer (Purtymun 1975, 11787, p. 281).

In the lower reaches of Guaje Canyon, NPDES-permitted outfalls are associated with the Guaje water supply wells. The rate and frequency of discharge are not known; however, portions of the discharges likely infiltrate into the shallow alluvium.

When BCO-1 and BCM-1 were installed in middle Bayo Canyon in 1994, dampness was noted in the cuttings at the base of the alluvium at about 30-ft (9.1-m) depth, indicating that some infiltration to depth below the base of the alluvium likely occurred.

3.4.3.6 Surface Water and Runoff Quality and Contaminant Data

3.4.3.6.1 Environmental Surveillance Sampling of Perennial Surface Water

Surface water samples have been collected from Guaje Canyon since 1968. Most stream channels within the north canyons have ephemeral flow and therefore are not subject to surface water monitoring. Guaje Canyon is the only canyon within the north canyons that has a reach of perennial flow. Historic surface water sampling locations include the Guaje Canyon Reservoir and "Guaje Canyon," a sampling location in Guaje Canyon below the confluence with Aqua Piedra Canyon (e.g., ESP 2000, 68661, p. 291). Figure A-1 shows the locations of surface water sample-collection sites. Laboratory personnel have not collected surface water samples from Bayo Canyon, Rendija Canyon, or Barrancas Canyon. Surface water samples identified as Bayo-1, Bayo-2, and Bayo Sewage Treatment Plant (STP) are located in Pueblo Canyon downstream of the Bayo STP.

Guaje Canyon

Guaje Reservoir

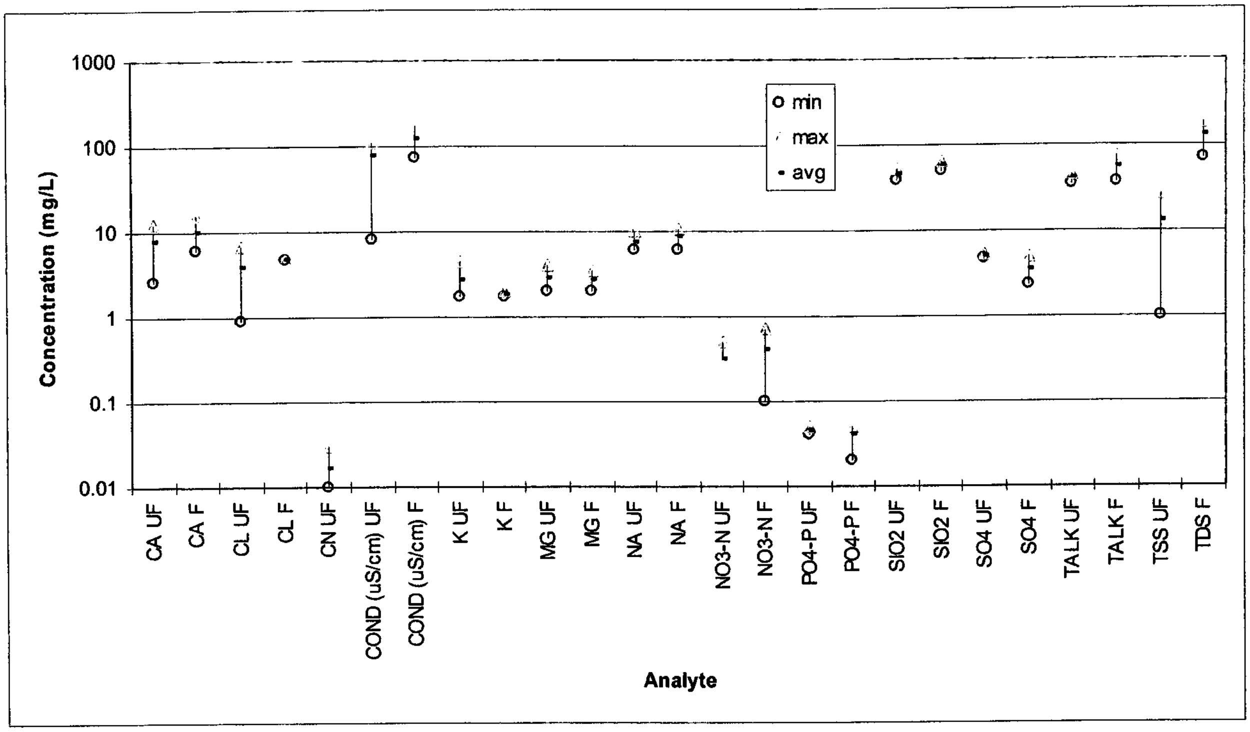
In 1968, 1986, 1988, and 1989 unfiltered surface water samples were collected from Guaje Reservoir and analyzed for radionuclides. Table 3.4-3 shows the radionuclide concentrations obtained from the analyses. The maximum concentration for cesium-137 was 6 pCi/L and for tritium was 2400 pCi/L.

Table 3.4-3
Radionuclides in Unfiltered Surface Water from Guaje Reservoir, 1968-1989

Sample Date	Cs-137 (pCi/L)	Gross Beta (pCi/L)	Gross Gamma (pCi/L)	H-3 (pCi/L)	Pu-238 (pCi/L)	Pu-239,240 (pCi/L)	U (μg/L)
24-Apr-68		2					0.5
02-Sep-86	-14		-840	2400	0.014	0.019	1
01-Jan-88	6		48	-800	0	-0.009	1
15-Mar-89	-46		-624	200	-0.005	-0.011	2.4

Source: Environmental Surveillance Reports, 1968, 1986, 1988, 1989.

In 1989 the surface water samples from Guaje Reservoir were also analyzed for general inorganic constituents. The total dissolved solids (TDS) values were 97 mg/L and the hardness was 23 mg/L. The summary of the results of the analyses including surface water from the Guaje Canyon site is shown in Figure 3.4-20.



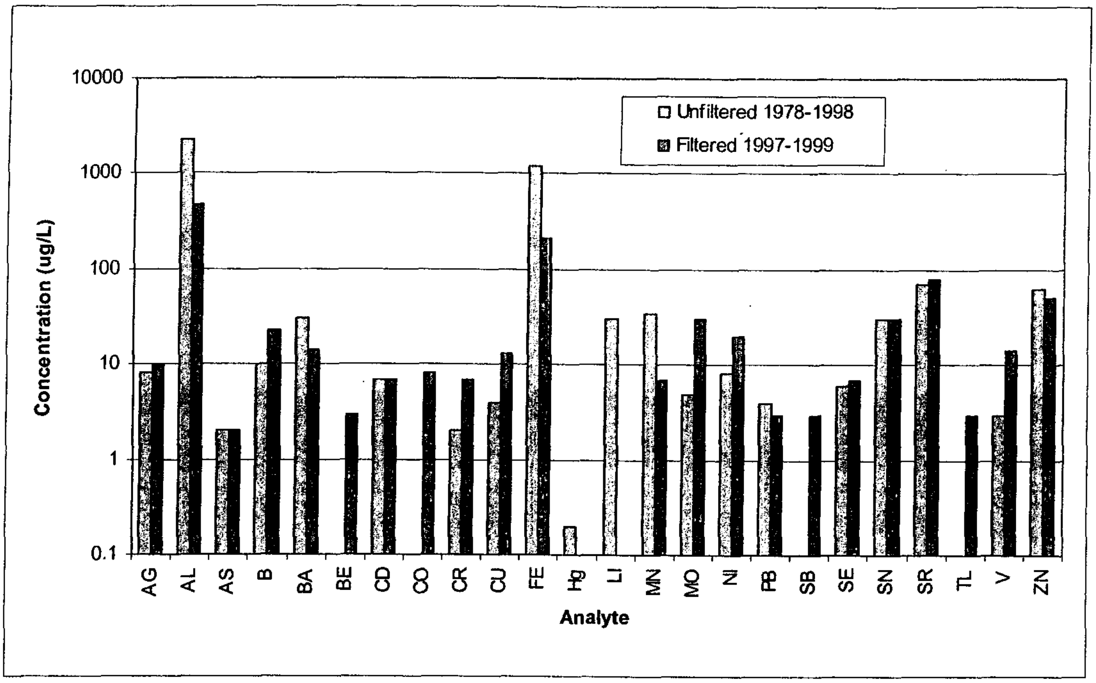
Source: Environmental Surveillance Reports, 1978, 1981–1999.
F = filtered, UF = unfiltered.

Figure 3.4-20. Summary of general inorganic constituents in filtered and unfiltered surface water from Guaje Canyon site, 1978, 1981–1999

Guaje Canyon Site

Surface water samples were collected from Guaje Canyon below the confluence with Agua Piedra Canyon in 1978 and annually since 1981. From 1978 through 1996, analyses were performed on unfiltered samples for general inorganic constituents and radionuclides. Since 1997, the samples were filtered for the analyses of general inorganic constituents and the samples remained unfiltered for radionuclide analyses. The summary of the results of the analyses for general inorganic constituents (filtered and unfiltered samples) is shown in Figure 3.4-20.

Surface water samples from the Guaje Canyon site were analyzed for metals in 1978 and from 1991 through 1999. Early analyses were performed on unfiltered samples but since 1997 analyses have been performed on filtered samples. Figure 3.4-21 shows the maximum values obtained for metals in both filtered and unfiltered samples. In 1998 selenium was observed in a concentration of 3 μg/L, above the New Mexico Water Quality Control Commission (NMWQCC) wildlife habitat standard of 2 μg/L (ESG 1999, 64034, pp. 140, 172).



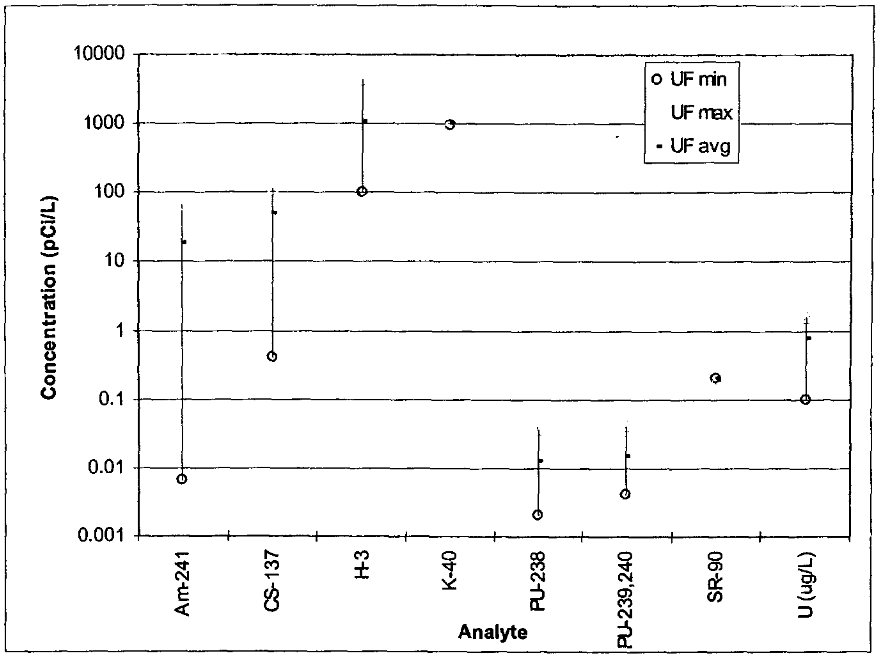
Source: Environmental Surveillance Reports, 1978, 1991–1999.

Figure 3.4-21. Maximum metals values in filtered and unfiltered surface water from Guaje Canyon site, 1978, 1991–1999

Surface water samples from the Guaje Canyon site were analyzed for radionuclides in 1974 and annually since 1978. Most analyses were performed on unfiltered samples. Figure 3.4-22 summarizes the analyses for radionuclides on the unfiltered samples. During the early 1980s tritium concentrations ranged from 1000 to 2000 pCi/L with the highest concentration, 4500 pCi/L, observed in 1983. Since 1985 tritium has been measured at near-detection limits. The sample collected in November 1998 contained 68 pCi/L americium-241, the highest recorded; the concentration measured in November 1999 was 4.29 pCi/L. The highest cesium-137 concentration was 115 pCi/L in 1984, but since 1995 the cesium-137 concentration has been near or below detection limits. The highest plutonium isotope concentrations were observed in the 1980s, when detection limits were higher than in recent years. In the late 1990s, the plutonium isotope concentrations were below detection limits.

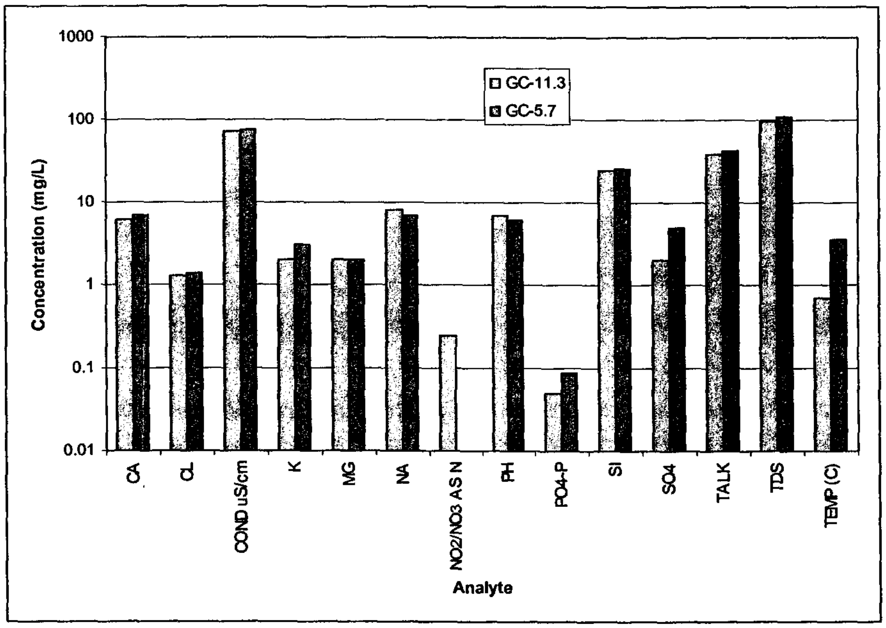
3.4.3.6.2 Other Surface Water Sampling

Personnel of the NMED Oversight Bureau conducted surface water sampling on February 26, 1997, at two locations in Guaje Canyon, Guaje Canyon Spring 5.7, and Guaje Canyon Spring 11.3 (Figure A-1). Guaje Canyon Spring 5.7 was located in middle Guaje Canyon and Guaje Canyon Spring 11.3 was located in upper Guaje Canyon downstream of Guaje Reservoir. Filtered surface water samples were collected and analyzed for general inorganic constituents, metals, and gross-alpha and –beta radioactivity. These data did not undergo validation review by the ER Project. Figure 3.4-23 shows the results of the analyses for general inorganic constituents. The TDSs of the samples were 96 and 110 mg/L and sodium was less than 10 mg/L. Gross alpha activity was less than 1 pCi/g; gross beta activity was 6.1 pCi/L at Guaje Canyon Spring 11.3 and 2.6 pCi/L at Guaje Canyon Spring 5.7. Metals detected in Guaje Canyon Spring 5.7 were aluminum (300 µg/L), iron (200 µg/L), and strontium (40 µg/L). Metals detected in Guaje Canyon Spring 11.3 were lithium (10 µg/L) and strontium (30 µg/L) (Yanicak 1998, 57583).



Source: Environmental Surveillance Reports, 1974, 1978–1999.
UF = unfiltered.

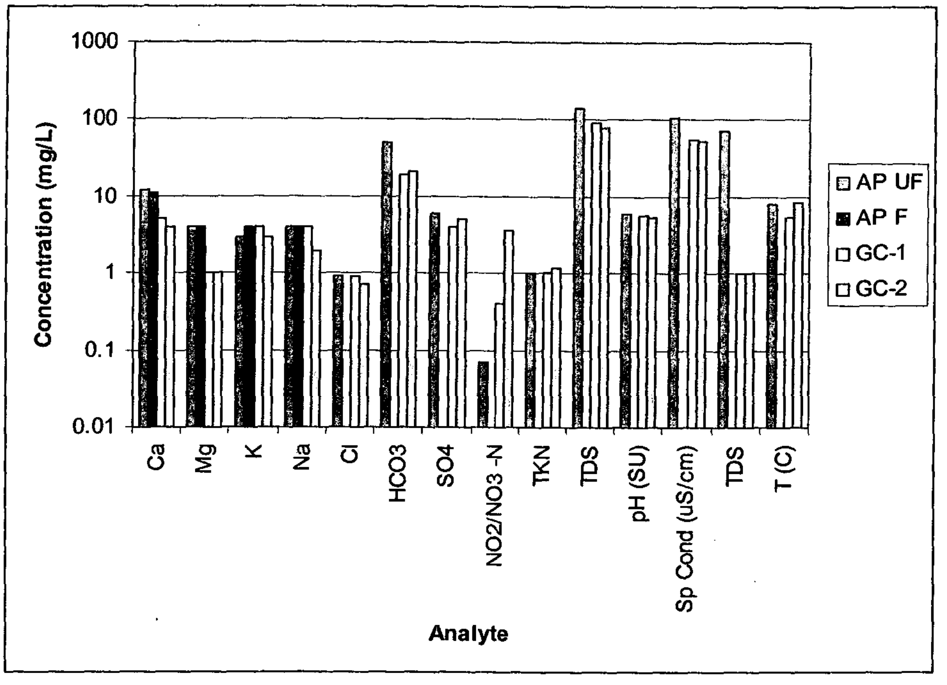
Figure 3.4-22. Summary of radionuclides in unfiltered surface water at the Guaje Canyon collection site, 1974, 1978–1999



Source: Yanicak 1998, 57583.

Figure 3.4-23. Results of NMED surface water sampling in Guaje Canyon, 1997

The NMED Oversight Bureau personnel collected samples from the two springs in Guaje Canyon and from Agua Piedra Spring in Agua Piedra Canyon in August 1997. The samples were analyzed for general inorganic constituents, metals, and selected radionuclides. Both filtered and unfiltered samples were collected from Agua Piedra Spring and unfiltered samples were collected from Guaje Canyon Spring 1 and Guaje Canyon Spring 2 (Yanicak 1998, 57583). These data did not undergo validation review by the ER Project. Figure 3.4-24 shows the results of the analyses for selected general inorganic constituents. Total suspended solids (TSS) in the samples were less than the detection limit of 20 mg/L. As a result, the filtered and unfiltered samples collected from Agua Piedra Spring were very similar in chemical composition. TDSs in Guaje Canyon Spring 1 and Guaje Canyon Spring 2 were less than 100 mg/L but the TDSs in Agua Piedra Spring were 140 mg/L. The concentration of bicarbonate (HCO_3) in Agua Piedra Spring was 50 mg/L, significantly higher than in Guaje Canyon Spring 1 and Guaje Canyon Spring 2, which contained 19 and 21 mg/L bicarbonate, respectively (Yanicak 1998, 57583).



Source: Yanicak 1998, 57583.
AP = Agua Piedra Spring, GC = Guaje Canyon spring.

Figure 3.4-24. Summary of general inorganic constituents in springs in Guaje Canyon, 1997

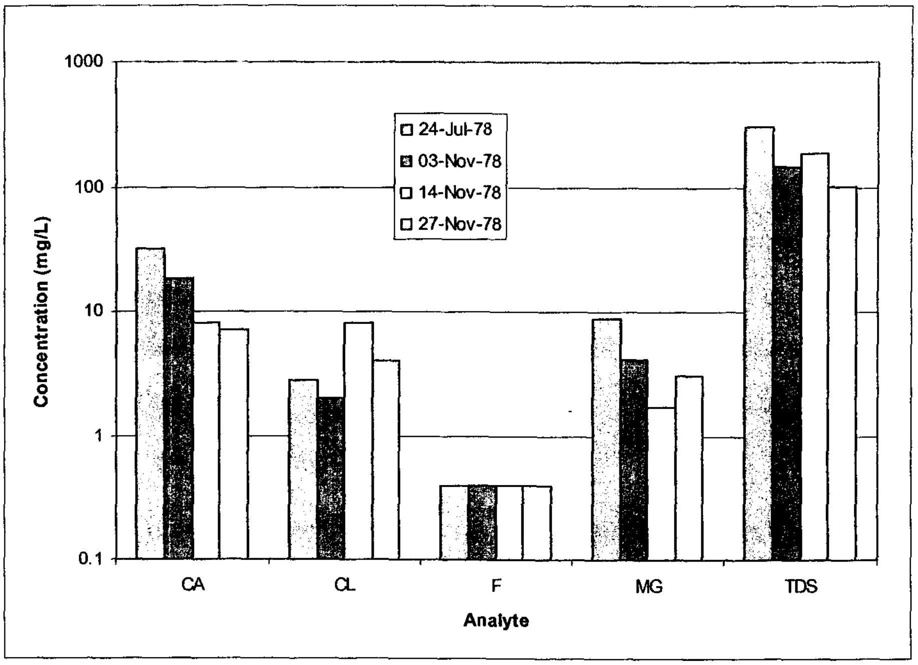
Agua Piedra Spring contained 0.12 µg/L uranium and gross alpha; gross beta activities were below detection limits. Guaje Canyon Spring 1 contained 0.074 pCi/L uranium-234, 0.013 pCi/L uranium-235, and 0.046 pCi/L uranium-238. Other radionuclides were not analyzed. Most trace metals were not observed in concentrations above the method detection limit (Yanicak 1998, 57583).

3.4.3.6.3 Environmental Surveillance Runoff Sampling

ESH-18 and its predecessors periodically have collected storm water runoff samples from Rendija Canyon, near the confluence with Guaje Canyon at municipal well G-6 and from Guaje Canyon near SR 502.

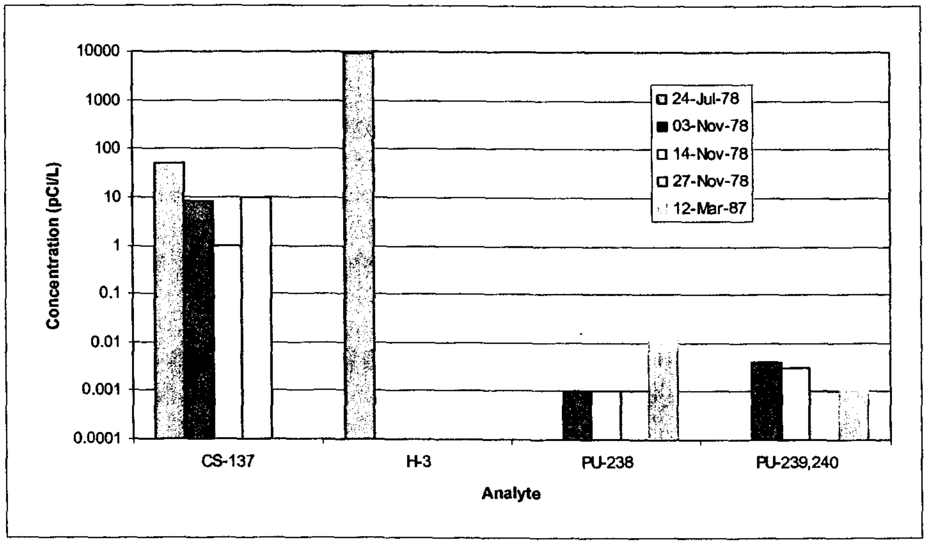
Rendija Canyon

Storm water runoff samples were collected from Rendija Canyon near well G-6 during four runoff events in July and November 1978. The samples were filtered; aliquots were analyzed for general inorganic constituents and radionuclides. Additionally, runoff samples were collected from Rendija Canyon in March 1987 and analyzed for plutonium-238 and plutonium-239/240. The summary of the results of the analyses of these samples is shown in Figures 3.4-25, 3.4-26, and 3.4-27. The highest TDS observed in the filtered samples was 300 mg/L. Tritium was measured in the July runoff event at 9300 pCi/L; tritium analyses were not performed on subsequent samples (ESG 1979, 05819).



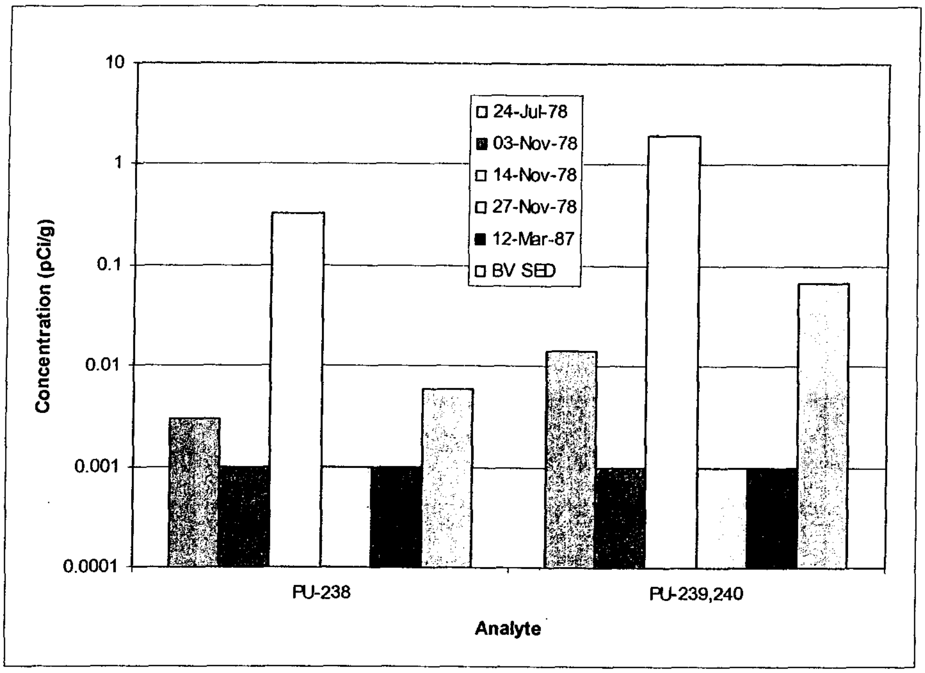
Source: ESG 1979, 05819.

Figure 3.4-25. Summary of general inorganic constituents in filtered storm water runoff in Rendija Canyon, 1978



Source: ESG 1979, 05819; ESG 1988, 6894.

Figure 3.4-26. Summary of radionuclides in filtered storm water collected in Rendija Canyon, 1978 and 1987



Source: ESG 1979, 05819; ESG 1988, 6894.

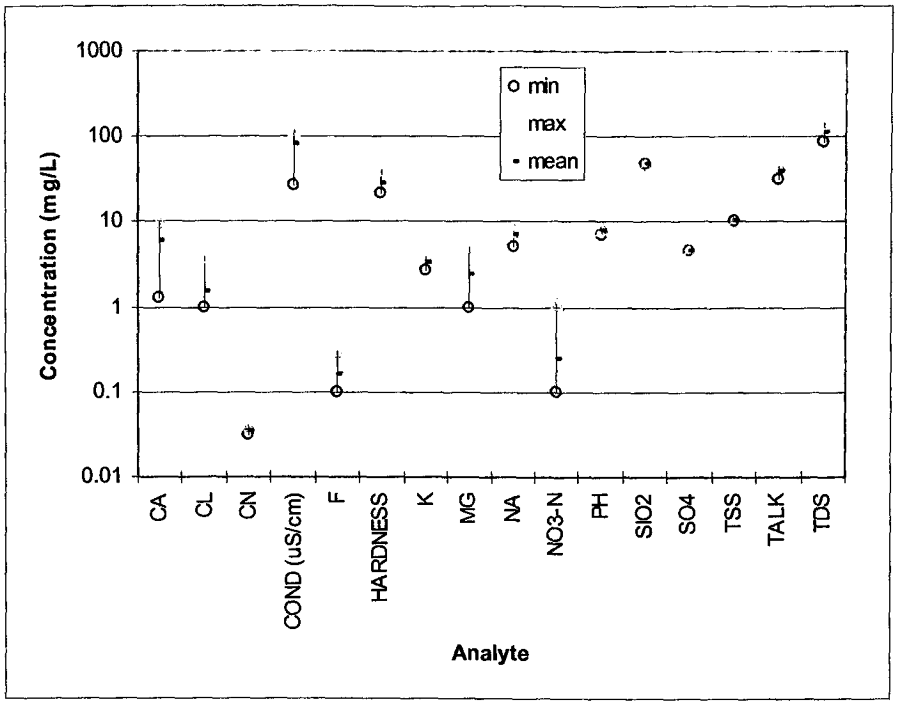
Figure 3.4-27. Summary of radionuclides in suspended sediment fraction of storm water runoff from Rendija Canyon, 1978 and 1987

The suspended sediment fraction of the samples was analyzed for plutonium-238 and plutonium-239/240 (Figure 3.4-27). The plutonium isotopes were measured in concentrations generally below the BVs for sediments, except for one runoff event in November 1978 when the suspended sediments yielded results of 0.32 pCi/g plutonium-238 and 1.93 pCi/g plutonium-239/240 (ESG 1979, 05819). No known Laboratory activities in the watershed involved radionuclides; the suspended sediment results may reflect regional fallout levels.

Guaje Canyon

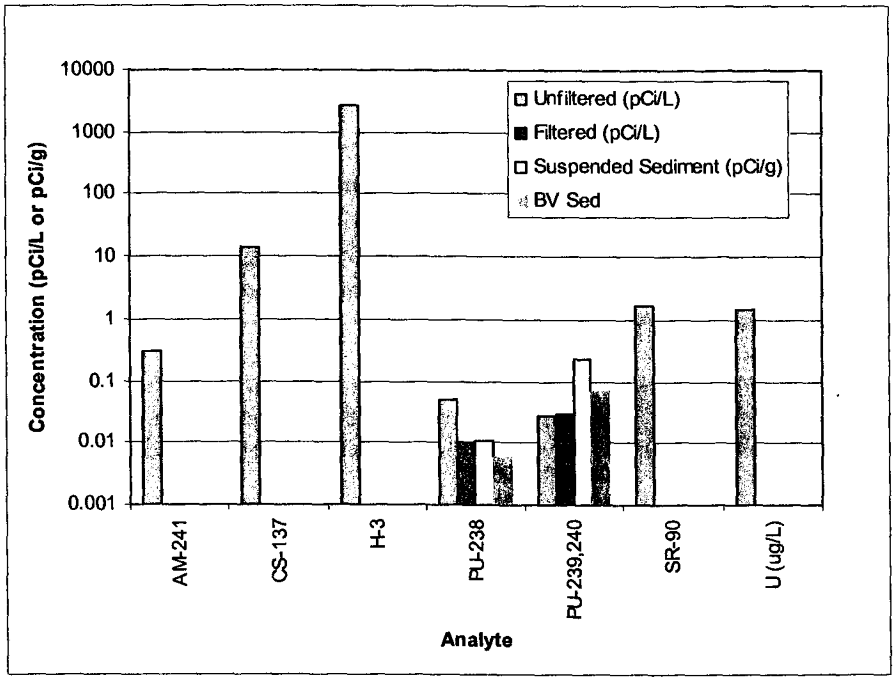
From 1973 to 1977 and in 1980 and 1987 storm water runoff samples were collected in Guaje Canyon at SR 502, above the confluence with Los Alamos Canyon. The samples were analyzed for radionuclides; from 1974 to 1980 they also were analyzed for general inorganic constituents. Figure 3.4-28 shows results of the analyses for general inorganic constituents in unfiltered samples. The TDS and hardness values were obtained from filtered samples. The TDS values ranged from 86 to 148 mg/L (Environmental Surveillance Reports, 1973–1977, 1980–1987).

From 1973 through 1980, unfiltered runoff samples collected in Guaje Canyon at SR 502 were analyzed for radionuclides. In 1987 runoff samples were collected during three separate runoff events; filtered samples were analyzed for radionuclides and the suspended sediment fractions of the samples were analyzed for plutonium isotopes. Figure 3.4-29 shows maximum concentrations of radionuclides measured in the runoff and the suspended sediment. Tritium values as high as 2600 pCi/L were measured in 1976. Maximum concentrations of plutonium-238 (0.011 pCi/g) and plutonium-239,240 (0.233 pCi/g) in the suspended sediment were above sediment BVs in 1987, although no known Laboratory activities involve these radionuclides in the watershed. No runoff samples were collected in Guaje Canyon at SR 502 from 1988 through 1999 (Environmental Surveillance Reports, 1973–1987).



Source: Environmental Surveillance Reports, 1973–1977, 1980–1987.

Figure 3.4-28. Summary of general inorganic constituents in unfiltered runoff from Guaje Canyon at SR 502



Source: Environmental Surveillance Reports, 1973–1987.

Figure 3.4-29. Maximum concentrations of radionuclides in runoff and suspended sediment collected in Guaje Canyon at SR 502, 1973–1987

3.4.3.7 Summary of Surface Water

The surface water hydrology of the north canyons is summarized below.

- Natural streamflow in Bayo, Barrancas, and Rendija Canyons is ephemeral. A reach of upper Guaje Canyon has perennial flow from springs located in the upper reaches of the Canyon. The continuous flow combined with storm water runoff usually does not extend beyond the middle part of the canyon.
- NPDES outfalls in lower Rendija Canyon and lower Guaje Canyon discharge an unknown volume of water. Flow from the discharges infiltrates the alluvium.
- Storm water runoff samples collected in Rendija Canyon near well G-6 in 1978 contained tritium in a concentration of 9300 pCi/L. The suspended sediment fraction of a runoff sample contained 0.32 pCi/g plutonium-238 and 1.93 pCi/g plutonium-239/240, which is above sediment BVs.
- Surface water samples from Guaje Reservoir have contained cesium-137 at 6 pCi/L and tritium at 2400 pCi/L.
- Surface water samples from the Guaje Canyon site contained selenium in a concentration of 3 μg/L, above the NMWQCC wildlife habitat standard for 2 μg/L. During the early 1980s tritium concentrations ranged from 1000 to 2000 pCi/L, with the highest concentration 4500 pCi/L; however, since 1985 tritium has been measured at near-detection limits.
- Runoff samples collected from lower Guaje Canyon have contained tritium in concentrations as high as 2600 pCi/L in 1976. Maximum concentrations of plutonium-238 and plutonium-239,240 in suspended sediment were above sediment BVs in 1987, although the cause of these results is unknown.

3.4.4 Alluvial Groundwater

3.4.4.1 Alluvial Groundwater Investigations

Few investigations of alluvium and shallow groundwater have been conducted in the north canyons. Information regarding the alluvial zones is largely inferred from boreholes drilled in middle Bayo Canyon and middle and lower Guaje Canyon and from conceptual models describing the relation of surface water recharge to the presence of alluvial groundwater. No monitoring or groundwater investigations have been conducted in Barrancas or Rendija Canyons.

During periods of precipitation and increased runoff and streamflow, the surface waterfront advances downstream. As the surface water infiltrates the alluvial sediments, the alluvium may become locally saturated for short periods following these runoff events, but this saturation is not likely to persist.

Bayo Canyon

In 1956, a geologic survey was conducted in Bayo Canyon to assess the potential for contaminant migration pathways. The survey suggested that a possible hydraulic connection existed between Bayo Canyon and Pueblo Canyon in the vicinity of Hamilton Bend Spring and Otowi Seep. Water samples from Hamilton Bend Spring in Pueblo Canyon were often high in nitrates, and wastes from TA-10 in Bayo Canyon were treated with nitric acid (Abrahams 1956, 5319). However, investigations conducted in 1961, 1973, and 1974 (described below) determined that the migration of contaminants from TA-10 in Bayo

Canyon to Pueblo Canyon was unlikely, due to the limited quantity of surface water, and alluvial groundwater in Bayo Canyon was insufficient to move contaminants from the liquid waste disposal pit through the subsurface (Mayfield et al. 1979, 11717, pp. 13, 48, 49).

In 1961 four test holes, BCTH-1 through BCTH-4, were drilled at former TA-10 to determine if groundwater served as a migration pathway for contaminants from former firing sites in Bayo Canyon. The boreholes penetrated the alluvium into the underlying Puye Formation. Alluvial groundwater and significant moisture were not encountered (Mayfield et al. 1979, 11717, pp. 50, 51). Additional information on the test holes is found in Section 3.4.2.

Several subsurface investigations designed to determine nature and extent of contaminants at former TA-10 in Bayo Canyon have not encountered groundwater in the alluvium or the underlying formations. These investigations have included drilling approximately 14 boreholes in 1973 and 1974. Results of the investigations did not indicate the presence of groundwater or significant amounts of moisture in subsurface sediments. Borehole depths ranged from 8 ft (2.4 m) to 40 ft (12.2 m). Most boreholes were located within 250 ft (76 m) of the Bayo Canyon channel (Mayfield et al. 1979, 11717, pp. 47–59). Seven additional test holes were drilled in Bayo Canyon on November 12 and 13, 1980, to depths from 12 to 37 ft (3.6 to 11.2 m). The soil/tuff contact generally was encountered at depths of 6 to 27 ft (1.8 to 8.2 m). The bedrock beneath the streambed (Otowi Member of the Bandelier Tuff) usually was found to be weathered and some boreholes encountered pumice (Guaje Pumice Bed). No indications of moisture or groundwater were noted (Purtymun 1994, 58233, pp. 97-1, 97-2).

A total of 93 boreholes were drilled and sampled during the RFI at former TA-10 in Bayo Canyon from May to November 1994. The investigation was conducted to characterize the nature and extent of PRSs where potential subsurface contaminants may be a concern. Each borehole was drilled to a minimum depth of 50 ft (15.2 m). The alluvium in middle Bayo Canyon was approximately 20 to 40 ft (6 to 12 m) thick. Groundwater was not encountered in any of the boreholes. Damp alluvium and Bandelier Tuff were noted (LANL 1996, 54332, p. 9-13). These intermediate-depth boreholes are discussed in Section 3.4.2.

Guaje Canyon

In fall 1966, two shallow test holes were drilled in Guaje Canyon between the Rendija Canyon fault and the Guaje Mountain fault. The boreholes GCTH-1 and GCTH-2 were located approximately 3 mi (4.8 km) downstream of the Guaje Reservoir. GCTH-1, drilled near the intersection of the Guaje Pines Cemetery Road and Guaje Canyon road, encountered alluvium to the total depth of 23 ft (7 m). GCTH-2, drilled west of the Guaje Mountain fault to a total depth of 103 ft (31.4 m) encountered alluvium from 0 to 17 ft (5.2 m) and Puye Formation to total depth. Both boreholes were completed as 2-in.-diameter monitoring wells. The screened intervals of the wells are not known. Saturation in the boreholes was reported from the approximate level of the Guaje Canyon stream channel to total depth (Purtymun 1995, 45344, p. 299). Groundwater samples were not collected and the wells have not been monitored routinely.

In 1946 test wells were installed in lower Los Alamos and Guaje Canyons to determine if a water supply could be developed for Los Alamos. GT-4 was drilled in the lower reaches of Guaje Canyon at the confluence with Los Alamos Canyon at an elevation of 5675 ft (1730 m). The total depth of the well was 315 ft (96 m). Alluvium was encountered from surface to a depth of 54 ft (16.5 m) and the Santa Fe Group was encountered to the total depth of the test hole. Specific references to saturation within the alluvium were not noted. However, it was determined that the alluvium was too thin to support a municipal water supply (Purtymun 1995, 45344, pp. 245, 246).

Based on information from these investigations, shallow alluvial groundwater likely is present in the upper and middle reaches of Guaje Canyon, supported by infiltration from spring-fed surface water. Streamflow losses due to ET and infiltration and possible losses to geologic structures (faults) reduce the volume of surface water downstream. The saturated thickness of alluvial groundwater likely decreases downstream in the middle part of the canyon.

3.4.4.2 Relationship Between Alluvium and Bedrock Stratigraphic Units

Little information on the relationship of the alluvium to underlying formations, groundwater, or presence of potential contaminants is available for most parts of the north canyons and their tributaries. Subsurface investigations have been conducted in small sections of Bayo Canyon and Guaje Canyon.

Bayo Canyon

The alluvium in the Bayo Canyon floor ranges from a thin veneer to approximately 40 ft (12.2 m) deep near of the stream channel. Figure 3.4-30 is a cross section across Bayo Canyon at former TA-10 that shows the general relationship of the bedrock stratigraphic units identified from subsurface investigations. Because Bayo Canyon heads on the Pajarito Plateau, alluvium at TA-10 is derived entirely from the Tshirege and Otowi Members of the Bandelier Tuff. The alluvium thickens downstream and in the center of the modern drainage, indicating that a deeper inner canyon was cut in the Bandelier Tuff prior to the deposition of the alluvium. The poorly sorted, clay-rich sand and gravel alluvium overlies the Otowi Member of the Bandelier Tuff in the vicinity of the former TA-10. The Guaje Pumice Bed at the base of the Otowi Member was encountered in the RFI boreholes drilled at former TA-10. Generally, the Guaje pumice was in contact with the overlying alluvium. However, in some locations away from the center of the canyon, particularly in the southeast section of former TA-10, the Otowi Member was encountered beneath alluvium (see Figure 3.4-30). In the lower reaches of Bayo Canyon, the alluvium is underlain by the Puye Formation (Mayfield et al. 1979, 11717, p. 47).

The Puye Formation underlies the Guaje Pumice Bed in middle Bayo Canyon. The Puye Formation consists of fine- to coarse-grained sediments interbedded locally with thin tephras, axial river gravels, and lacustrine siltstone and clays. Several low-permeability paleosols have been observed in the upper portion of the Puye Formation that, if present, may serve locally as a layer that is impermeable to the infiltration of groundwater (LANL 1996, 54332, pp. 9–13; Broxton and Eller 1995, 1162).

The bedrock units in Bayo Canyon at the former TA-10 site dip southeast. If shallow alluvial groundwater were present and could come into contact with subsurface contaminants, the water may infiltrate bedrock units such as the Guaje Pumice Bed and continue down-dip in the bedrock units, potentially on a path not parallel to the canyon.

Guaje Canyon

The alluvium in upper and middle Guaje Canyon is derived from the Tschicoma Formation and the Bandelier Tuff, producing angular to sub-rounded clasts of Tschicoma Formation rocks with minerals derived from the Puye Formation. These minerals include feldspar, biotite, and other ferromagnesium minerals and quartz of the Tschicoma Formation. Quartz, sanidine, and silts and clays from the Bandelier Tuff are also present in the alluvium in Guaje Canyon.

In 1966 two shallow test holes were drilled in middle Guaje Canyon to evaluate subsurface conditions. GCTH-1 was drilled to 23 ft (7 m) into alluvium. GCTH-2 was drilled to 103 ft (31.4 m) in 17 ft (5.2 m) of alluvium underlain by the Puye conglomerate to the total depth of the borehole. Both units were saturated from the base of the borehole to near-stream level, indicating hydrologic communication between the alluvium and underlying Puye Formation at this location (Purtymun 1995, 45344, p. 299).

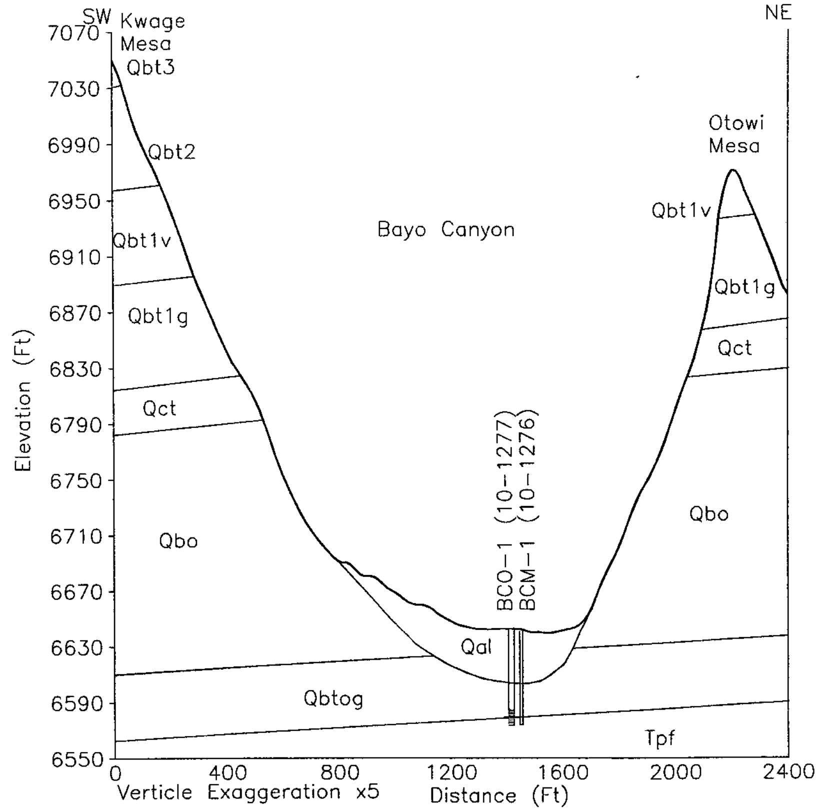


Figure 3.4-30. Cross section of Bayo Canyon at former TA-10 showing monitoring well locations

GCTH-2 was drilled in a structural basin located upstream from the GMFZ. The fault is down-thrown on the west and juxtaposes Puye Formation fanglomerate on the west against Tschicoma Formation dacite on the east. GCTH-2 encountered saturation throughout the alluvium and Puye Formation to total depth. At the time of the investigation, a small amount of water was observed emerging from the GMFZ and flowing for a short distance downstream before infiltrating the alluvium. Purtymun postulated that the Puye Formation in the small structural basin formed by the normal fault was saturated with water from the stream (see Figure 3.4-17). Relatively impermeable rocks of the Tschicoma Formation underlie the Puye Formation and are adjacent to the Puye Formation across the fault. Recharge from the stream infiltrates into the Puye Formation in the structural basin ("ponding") and then overflows at the fault into the stream channel, which is cut into the downstream Tschicoma Formation. The "pond" of groundwater in the structural basin adjacent to the fault also may provide recharge to the regional aquifer via the GMFZ (Purtymun 1975, 11787, p. 281).

Another small structural basin is formed where the Rendija Canyon fault crosses Guaje Canyon. A similar situation develops where a small structural basin of Puye Formation fanglomerates overlies less-permeable Tschicoma Formation dacite and is adjacent to the Tschicoma Formation across the fault (see Figure 3.4-17). No detailed information about saturation in this structural basin is available.

GT-4, drilled in 1946 in the lower reaches of Guaje Canyon near the confluence with Los Alamos Canyon, encountered alluvium from surface to a depth of 54 ft (16.5 m). The alluvium was underlain by the Santa

Fe Group to the total depth of the test hole (315 ft [96 m]). Alluvial groundwater was not noted (Purtymun 1995, 45344, pp. 245, 246).

Municipal water supply wells have been installed in the middle and lower reaches of Guaje Canyon. The alluvium is typically 12 to 17 ft (3.6 to 5.2 m) thick. The minimum thickness of 8 ft (2.4 m) was recorded at G-5, the furthest upstream well. The maximum thickness of alluvium (40 ft [12.2 m]) was reported at well G-6, located in Rendija Canyon approximately 0.8 mi (1.3 km) from the confluence with Guaje Canyon. Alluvial groundwater was not noted at well G-6. The alluvium in all wells is underlain by Puye Formation fanglomerate (Purtymun 1995, 45344, pp. 253, 259).

The Guaje Canyon water supply wells were installed at the edge of the canyon floor and may not have been located sufficiently near the center of the canyon to intersect alluvial groundwater, if present in the lower part of the canyon.

3.4.4.3 Summary of Alluvial Groundwater

Information about the alluvial groundwater in the north canyons is summarized below.

- Available data indicate no persistent alluvial groundwater in the north canyons downstream from PRSs.
- In upper Guaje Canyon surface water is likely a source of recharge to the alluvium and possibly to deeper units.
- There are no known alluvial groundwater discharge points in Bayo Canyon, Rendija Canyon, and Barrancas Canyon. Losses from ET and infiltration into deeper units are the likely sources of moisture loss in the alluvium and of any loss of alluvial groundwater. An unknown volume of infiltrated water may seep downward into subsurface units at locations upstream of PRSs.
- In Guaje Canyon, alluvial groundwater may discharge into deeper formations located in structural basins upstream from the Rendija Canyon fault and the Guaje Mountain fault.
- One intermediate-depth groundwater monitoring well and one subsurface moisture-monitoring well were installed in unsaturated material in Bayo Canyon in 1995. These wells initially were dry, and have not been monitored regularly since 1996. No monitoring wells have been installed in the lower reaches of Bayo Canyon.

3.4.5 Air Monitoring Investigations

3.4.5.1 Historical Monitoring

During 1950, an aerial study of air emissions from TA-10 in Bayo Canyon was conducted by the Air Force Research Laboratory. A Boeing B-17 was equipped with an ion-conductivity measuring device designed to correlate values in an attempt to measure the path of dust clouds containing active particulate and fall-out pattern following test shots from Bayo Canyon. Approximately seven flights were conducted with at least two flights tracking radioactive lanthanum (RaLa) shots from Bayo site. A later review of these investigations concluded that difficulties relating the Air Force Research Laboratory measurements with ionizing radiation were caused by variations from altitude and weather (Dummer 1996, 55951, p. 9).

The 1974 FUSRAP investigation included air sampling around former TA-10 in Bayo Canyon to ascertain if residual radionuclides from the former firing activities were a potential health concern. Airborne concentrations of strontium-90 and uranium were compared to that of other Northern New Mexico locations. The results did not reveal a statistically significant difference in concentrations (Mayfield et al. 1979, 11717, pp. 4, 11).

3.4.5.2 AIRNET Monitoring

The Laboratory operates a network of more than 50 environmental air monitoring stations ("AIRNET") to sample radionuclides in ambient air. The network is designed to measure environmental levels of airborne radionuclides that may be released from Laboratory operations. Annual Laboratory emissions include microcurie (μCi) quantities of plutonium and americium, millicurie (mCi) quantities of uranium, and curie (Ci) quantities of tritium and activation products. In addition to Laboratory emissions, natural atmospheric and fallout radioactivity levels fluctuate and affect measurements made by the air surveillance program. Each station collects both a total particulate matter sample and a water vapor sample for analysis (ESP 2000, 68661, p. 88). Particulate matter in the atmosphere primarily is caused by resuspension of soil, which is dependent on meteorological conditions. Windy, dry days can increase the soil resuspension, but precipitation can wash particulate matter out of the air. Consequently, there are often large daily and seasonal fluctuations in airborne radioactivity concentrations caused by changing meteorological conditions. The measured airborne concentrations generally are several orders of magnitude less than the EPA concentration limit for the general public. The EPA limit represents a concentration that would result in an annual dose of 10 mrem (ESP 2000, 68661, pp. 88, 108).

AIRNET sampling locations are categorized as regional, pueblo, perimeter, quality assurance, technical area, or other on-site locations (ESP 2000, 68661, p. 88). The environmental surveillance program monitors one station within the Bayo Canyon watershed annually. The station is a perimeter sampling location at Barranca School (see Figure A-1) located at the head of the Bayo Canyon watershed. Air samples are analyzed for tritium; americium-241; plutonium-238; plutonium-239, 240; uranium-234; uranium-235; uranium-238; gamma spectroscopy; and gross alpha and beta radioactivity (ESP 2000, 68661, pp. 89-93, 140).

Routine publication of AIRNET data on the World Wide Web began during 1997, and data are now available on the World Wide Web within two to three months following the sampling period. The web site is located at http://www.esh.lanl.gov/~AirQuality/. The web site also includes follow-up information on investigations of higher-than-normal values.

3.4.5.3 TLDNET Monitoring

The Laboratory Air Quality Group (ESH-17) monitors for cosmic, gamma, and neutron radiation. These types of radioactivity are both naturally occurring and man-made. As the natural background radiation doses from terrestrial and cosmic sources are much larger than those from man-made sources, the man-made sources are difficult to distinguish from natural sources. As of 1999, the Laboratory's monitoring program included 97 thermoluminescent dosimeter (TLD) stations located on the Laboratory and at off-site regional stations to detect any impact from Laboratory operations. Monitoring locations have changed over the duration of the program. In 1999, the Laboratory monitored three locations in the Bayo Canyon watershed, all classified as perimeter locations. These stations are located at Barranca School (station #5), Cumbres (Middle) School (station #7), and at the end of Los Pueblos Street on Otowi Mesa (station #46). Two TLD monitoring stations are located in Pueblo Canyon; they are identified as "Bayo Canyon Well" and "Bayo Canyon."

In 1999, the annual dose recorded at Barranca School (#5) was 134 +/- 17 mrem, the dose at Cumbres School (#7) was 132 +/- 17 mrem, and the dose at the end of Los Pueblos Street (#46) was 153 +/- 20 mrem. The annual dose equivalents at the perimeter and regional stations ranged from 100 to 180 mrem. These dose rates are consistent with natural background measurements (ESP 2000 68661, pp. 100, 101, 130, 150).

3.4.5.4 NEWNET

Neighborhood Environmental Watch Network (NEWNET) is a Laboratory Nonproliferation and International Security Division program for radiological monitoring in local communities. The program establishes meteorological and external penetrating radiation monitoring stations in the local community and around radiological sources. The data include the current date, time, gross gamma radiation, wind direction, wind speed, barometric pressure, temperature, and humidity. Figure A-1 shows the locations of nearby NEWNET meteorological stations. The data are posted with at most a 24-hr delay on the World Wide Web at the NEWNET site at http://newnet.lanl.gov/ (ESG 2000, 68661, p. 107). NEWNET stations located nearest the north canyons are located at Los Alamos High School and at Eastgate near the Los Alamos Airport.

3.5 Biological Setting of the Northern Canyons

The general biological setting for the Los Alamos region and the canyons is discussed in Section 3.8 of the core document (LANL 1997, 62316). The unique aspects of the biological setting of the northern canyon systems are described here.

The biological assessments discussed below include fauna evaluations conducted in many TAs within the north canyons watershed areas (Dunham 1992, 31276; Banar 1996, 58192; Biggs and Cross 1995, 52028). This discussion also summarizes the threatened, endangered, and sensitive species that potentially are present, based on the habitats identified by these assessments.

Potentially threatened and endangered species in the canyon systems are listed in Table 3-6 of the core document (LANL 1997, 62316). Surveys conducted during the biological assessments discussed in Section 3.5.6.1.1 of this work plan did not confirm the presence of threatened, endangered, and sensitive species in the study areas. Preliminary risk assessments for the threatened Mexican spotted owl, the southwestern willow flycatcher, and the bald eagle have been completed. The results of the risk assessments determined that no unacceptable risks were present (Gallegos et al. 1997, 57915; Gallegos et al. 1997, 59790; Gonzales et al. 1998, 62349; Gonzales et al. 1998, 62350).

This section discusses the threatened, endangered, and sensitive species that potentially are present within the north canyons watersheds. The information is based on the habitats identified in the biological assessments conducted by the Laboratory Ecology Group (ESH-20) for the ER Project.

3.5.1 Bayo Canyon Biotic Environment

During 1991, field surveys were conducted in OU 1079 for compliance with the Federal Endangered Species Act of 1973; New Mexico's Wildlife Conservation Act; New Mexico Endangered Plant Species Act; US Department of Energy (DOE) Executive Order 11990, "Protection of Wetlands," and DOE Executive Order 11988, "Floodplain Management"; 10 CFR 1022, "Compliance with Floodplain/Wetlands Environmental Review Requirements"; and DOE Order 5400.1, "General Environmental Protection Program."

3.5.1.1 Flora

During August 1991, the Biological Resource Evaluation Team (BRET) of the Laboratory's Environmental Protection Group (EM-8) conducted field surveys for OU 1079, TAs-10, -31, -32, and -45. Vegetation ranged from a ponderosa pine-mixed conifer series in the western portions of the OU to a piñon-juniper series in the lower east portion of the OUs (Biggs 1993, 48979).

The steep-sided and narrow upper part of Bayo Canon is relatively moist and cool and supports a pine-fir (*Pinus ponderosa, Pseudotsuga menziesii, Abies concolor*) forest (Table 3.5-1). As the canyon widens into the section where the old TA-10 site was located, the pine-fir overstory thins and is restricted to the north-facing slope of Kwage Mesa. The canyon bottom supports many ponderosa pine trees (*Pinus ponderosa*) scattered throughout the old TA-10 site, except in the vicinity of the old firing sites, where all vegetation was removed during the period of active site operation. Ponderosa pine gives way to a piñon-juniper woodland (*Pinus edulis, Juniperus monosperma*) on the drier south-facing slope of Otowi Mesa (Ferenbaugh et al. 1982, 6293).

Table 3.5-1
Common Vegetative Species in Bayo Canyon

Scientific Name	Common Name
Grasses and Forbs	
Andropogon scoparius	Little bluestem
Bouteloua gracilis	Blue grama
Bromus tectorum	Cheatgrass
Koelaria cristata	Junegrass
Taraxicum officinale	Dandelion
Verascum thapsis	Woolly mullein
Shrubs and Subshrubs	
Artemesia tridentata	Big sagebrush
Atriplex canescens	Saltbush
Chrysothamnus nauseosus	Chamisa or rabbitbrush
Fallugia paradoxa	Apache plume
Forestiera neomexicana	New Mexico olive
Gutierrezia microcephala	Snakeweed
Prunus virginiana, var. *melancarpa*	Chokecherry
Quercus gambelii	Gambel oak
Quercus undulata	Scrub oak
Rhus trilobata	Squawbush
Robinia neomexicana	New Mexico locust
Disturbed-Habitat Plants	
Artemisia frigida	Wormwood
Chenopodium fremontii	Lambsquarters
Chrysopsis villosa	Goldenweed
Croton texensis	Doveweed
Cryptantha jamesii	James cryptantha

Table 3.5-1 (continued)
Common Vegetative Species in Bayo Canyon

Scientific Name	Common Name
Erodium cirdutarium	Filaree
Heliathus petiolaris	Prairie sunflower
Lupinus caudatus	Lupine
Mirabilis mulriflora	Wild four o'clock
Salsola iberica	Russian thistle or tumbleweed
Viguiera multiflora	Crownbeard

Source: Ferenbaugh et al. 1982, 6293, p. 31.

3.5.1.2 Fauna

The plant community type found west of the town site and extending into Bayo Canyon supports characteristic fauna such as mule deer, Abert's squirrel, Steller's jay, montane vole, deer mouse, and pipistrelle bat. Characteristic fauna in the north-facing slopes in upper Bayo Canyon include mule deer, red squirrel, and mountain cottontail.

Threatened and endangered animals that regionally nest or forage in the ponderosa pine forest habitats include the meadow jumping mouse, northern goshawk, and spotted bat (LANL 1995, 49974, pp. 7, 8).

3.5.1.3 Threatened and Endangered Species

Biological surveys did not find any threatened and endangered plant or animal species in Bayo Canyon (Biggs 1993, 48979). The spotted bat (*Euderma maculatum)*, a candidate for federal protection and a New Mexico-protected endangered species, may use the rocky cliffs as a roosting area. The northern goshawk *(Accipter gentillis)*, a candidate for federal protection, prefers ponderosa pine/oak and mixed conifer habitats, which occur on the north-facing slopes in the upper portion of the canyon. However, the goshawk tends to avoid humans, and its presence is unlikely because of the suburban areas on the mesa tops above the upper canyon. The Mexican spotted owl (*Strix occidentalis lucida)* nests in lower Pueblo Canyon and is expected to forage into middle Pueblo Canyon and possibly adjacent Bayo Canyon.

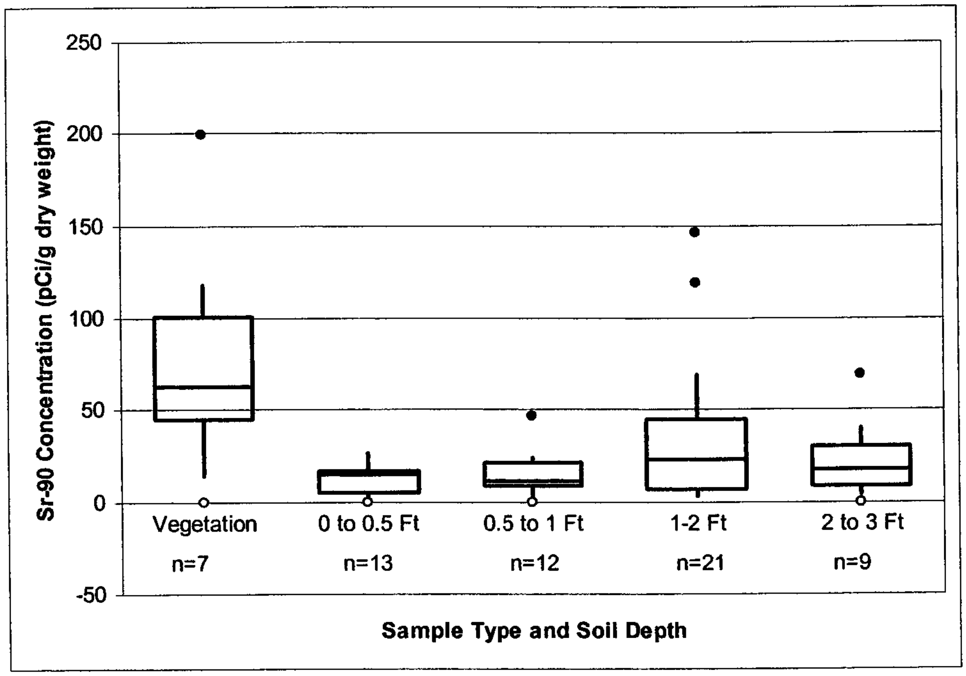
The Laboratory's BRET conducted Level 2 (habitat-evaluation) and Level 3 (species-specific) surveys during 1991 to provide information for a site characterization plan. The purpose of the field surveys was three-fold: to determine if species protected by the state or federal government were present before soil sampling took place; to determine if sensitive habitats were present; and to gather baseline data for future studies on plant and wildlife species in OU 1079. Information gathered from the field surveys was compared with habitat requirements of potentially occurring protected species (both threatened and endangered) (Biggs 1993, 48979).

After a search of the BRET threatened, endangered, and sensitive species database, and after consulting with state and federal agencies, several plant and wildlife species were listed as potentially occurring in the area. No protected species currently are known to use the areas of TA-10.

3.5.1.4 Radionuclide Concentrations in Biota

Chamisa (*Chrysothamnus nauseosus*) growing in a former liquid waste disposal site (PRS 10-007) in Bayo Canyon were collected and analyzed for strontium-90 and total uranium. The vegetation samples were ashed and the ash was analyzed. Surface soil samples also were collected from below (understory) and between (interspace) shrub canopies. Both chamisa plants growing at PRS 10-007 contained significantly higher concentrations of strontium-90 than a control plant. Top growth material from one plant contained 90,500 pCi/g strontium-90 in ash. Similarly, surface soil samples collected beneath and between plants contained strontium-90 concentrations above background levels and screening action levels. This may have occurred as a result of the chamisa plant's bringing strontium-90 from the subsurface and incorporating the radionuclide in the leaf material; leaf fall and plant litter may have contaminated the soil understory area followed by water and/or winds moving strontium-90 to the soil interspace area. Although some migration of strontium-90 in the surface soil has occurred at PRS 10-007, the concentration of strontium-90 in stream channel sediments collected downstream of former TA-10 at the Bayo Canyon-SR 502 intersection has been within regional background concentrations (Fresquez et al. 1995, 68471, p. 1).

Another investigation was conducted in 1996 and 1997 to address strontium-90 in vegetation at the former site of the central portion of TA-10 in Bayo Canyon. An interim action was planned to remediate chamisa plants containing elevated activity (LANL 1996, 55698, p. 1). However, the results of a radiation survey that was conducted to determine which chamisa plants should be removed indicated that several plant species in addition to chamisa contained elevated radioactivity. Other vegetation samples that contained elevated radioactivity included ponderosa pine, annuals, and grasses. Figure 3.5-1 shows the results of vegetation and soil sampling obtained during the investigation at former TA-10. Vegetation samples were dried and the dried material was submitted to a fixed laboratory for analyses. Soil samples were measured using a beta-gamma meter and the results were converted to concentration values using a conversion factor. Strontium-90 in seven vegetation samples ranged from 14 to 199 pCi/g dry weight, and strontium-90 in surface soil samples (0 to 0.5 ft [0 to 15 cm] depth) ranged from 2 to 27 pCi/g. Higher concentrations of strontium-90 were observed at depths of 1 to 2 ft (0.3 to 0.6 m) (LANL 1997, 56358, Table 1).



Source: LANL 1997, 56358, pp. 6–9.

Figure 3.5-1. Box plots showing strontium-90 concentrations in vegetation and soil samples at former TA-10

A risk assessment was developed from the characterization data obtained during the investigation. Pathways used in the assessment included (1) inhalation of resuspended dust and soil, (2) ingestion of soil, (3) ingestion of plant material, (4) ingestion of meat from animals that had foraged in the area, and (5) inhalation of wood smoke from firewood gathered at the site. Plant ingestion was the primary contributor (93%) to annual dose and ingestion of game meat was the second highest contributor (5%). The annual dose calculated from the plant ingestion scenario was less than 10 mrem/yr (LANL 1997, 56358, p. 11).

3.5.2 Rendija Canyon Biotic Environment

In 1991, the BRET conducted Level 2 (habitat evaluation) and Level 3 (species-specific) surveys to provide information for a site characterization plan. One purpose of the field surveys was to gather baseline data for future studies on plant and wildlife species in OU 1071 (Biggs 1996, 62928, p. 3). Surveys were conducted in Rendija Canyon as part of this assessment. The surveys were conducted for compliance with the Federal Endangered Species Act; the New Mexico Wildlife Conservation Act; the New Mexico Endangered Plant Species Act; DOE Executive Orders 11990, "Protection of Wetlands," and 11988, "Floodplain Management"; 10 CFR 1022; "Compliance with Floodplain/Wetlands Environmental Review Requirements"; and DOE Order 5400.1, "General Environmental Protection Program."

3.5.2.1 Flora

Several vegetation analyses and surveys have been conducted in portions of the canyons and mesa tops of OU 1071. These studies include a vegetation survey of Cabra Canyon, a tributary of Rendija Canyon; a winter plant survey of Cabra Canyon; a vegetation and ecological survey of the Pueblo Canyon-Los Alamos Canyon confluence; a vegetation survey of an old farm field in Rendija Canyon; and several smaller surveys in various scattered locations. These studies and surveys were conducted between 1980 and 1991 (Biggs 1996, 62928, p. 16).

The vegetation survey of Cabra Canyon was conducted to determine if any threatened, endangered, and sensitive plant species were present in an area proposed for disturbance and none was found (Biggs 1996, 62928, p. 18). Habitat at the Cabra Canyon site was not suitable for any federally proposed endangered or threatened plant species. It was noted that the site could be potential habitat for state-protected species if the site were not so disturbed (Biggs 1996, 62928, p. 19).

The old farm fields in Rendija Canyon were dominated by wormwood and brome grass and an open area near the canyon road was dominated by blue juniper, ponderosa pine, and cottonwood (Biggs 1996, 62928, p. 4). Vegetation transects in Rendija Canyon were established on the north- and east-facing slopes and along the canyon bottom where the terrain is relatively open (near the access road to the firing range and archery range) (Biggs 1996, 62928, p. 37). Ponderosa pine was the dominant overstory species in the canyon bottom, along the north-facing slope, and at the old field. Piñon pine was the dominant species along the east-facing slope. The diameter at breast height (DBH) of ponderosa pine along the north-facing slope was more than twice that of ponderosa pine in the canyon bottom (8.38 and 20.91 in., respectively). The old field consisted of a young ponderosa pine stand (DBH of 5 in.). Douglas fir was found only along the canyon bottom but is expected to also occur on the north-facing slope. Juniper was found in all areas but occurred most often along the north-facing slopes (Biggs 1996, 62928, pp. 37–38). A complete checklist of plant species identified during these surveys and of species identified in the most recent field surveys is given in Appendix A of the "Biological and Floodplain/Wetlands Assessment for Environmental Restoration Program, Operable Unit 1071, TAs-0, -19, -26, -73, and -74" (Biggs 1996, 62928).

3.5.2.2 Fauna

The biological assessments discussed above in Section 3.5.3.1 include fauna investigations for the technical areas located within the Rendija Canyon watershed for OU 1071 (Biggs 1996, 62928). The investigation conducted habitat evaluation surveys (Level 2) after searching a BRET database containing the habitat requirements for all state- and federally listed threatened, endangered, and sensitive plant and animal species known to occur within the boundaries of the Laboratory and the surrounding areas. The habitat information gathered during the field surveys was compared with the habitat requirements for each species of concern that was identified in the database search. If habitat requirements were not met for any species of concern, no further surveys were conducted. If habitat requirements were met, specific surveys for the species of concern were conducted.

Based on the results of the Level 2 survey, a Level 3 survey was conducted for the meadow jumping mouse in August 1991 along a portion of the stream channel in Rendija Canyon. The meadow jumping mouse inhabits meadows along streams or other similar water sources. No meadow jumping mice were found during the survey (Biggs 1996, 62928, p. 29). Although water was flowing through the canyon at the time of the survey, it was due to recent, heavy rainfall. This species is not expected to occur in the Rendija Canyon area, based on the results of this survey and the lack of a perennial flowing stream and associated suitable habitat (Biggs 1996, 62928, p. 4-5).

In summer 1992, an investigation was conducted to compare nocturnal, small-mammal communities at wet area created by wastewater outfalls with communities in naturally created wet and dry areas. Of the 13 locations chosen for sampling, 1 was in Rendija Canyon. Data were collected on-site type (dry, outfall, or natural), location, and species trapped, and the tag number of each individual captured was recorded. The site in Rendija Canyon was considered a dry area. One species of small mammal, the deer mouse, was captured in Rendija Canyon (Biggs and Raymer 1994, 56038, p. 8). The data were used to determine the mean number of species, percent capture rate, and species diversity. When data from each type of site were pooled, no significant differences were observed in these variables between dry, outfall, and natural location types (Biggs and Raymer 1994, 56038, p. 1).

3.5.2.3 Threatened and Endangered Species

A search of the database and consultation with state and federal agencies found that potential species of concern for the Rendija Canyon area (OU 1071) (based on habitat and known occurrences) are the northern goshawk, Mexican spotted owl, black hawk, bald eagle, Mississippi kite, broad-billed hummingbird, willow flycatcher, spotted bat, meadow jumping mouse, Say's pond snail, Wright's fishhook cactus, Santa Fe cholla, grama grass cactus, sessile-flowered false carrot, threadleaf horsebrush, Plank's catchfly, Santa Fe milk vetch, cyanic milk vetch, Taos milk vetch, tufted sand verbena, wood lily, checker lily, sandia alumroot, and Pagosa phlox (Biggs 1996, 62928, p. 4). Table 3.5-2 lists the occurrence potential of species likely to be found in Rendija Canyon. A habitat evaluation for OU 1071 and the middle part of Rendija Canyon found that two species appear to have at least a moderate potential for occurrence in the area: the spotted bat and the meadow jumping mouse.

3.5.3 Barrancas Canyon Biotic Environment

No specific biological studies have been conducted in Barrancas Canyon. A portion of Barrancas Canyon is located in TA-74 and can be partially grouped with OUs 1071 and 1079. See Section 3.5.1 for Bayo Canyon biotic environmental factors.

Table 3.5-2
Threatened, Endangered, and Sensitive Species
Potentially Occurring in the Rendija Canyon Watershed

Scientific Name	Common Name	Legal Status	Potential for Occurrence
Wildlife			
Buteogallus anthracinus	Common black hawk	State protected	Low to none
Cyantyhs latirostris	Broad-billed hummingbird	State endangered	Low to none
Empidonax traillii	Willow flycatcher	Federal candidate	Low to none
Euderma maculatum	Spotted bat	Federal candidate/state threatened	Moderate to high
Haliaeetus leucocephalus	Bald eagle	Federally endangered	Low to none
Accipiter gentilis	Northern goshawk	Federal candidate	Low
Ictinia mississippiensis	Mississippi kite	State endangered	Low to none
Abronia bigelovii	Tufted sand verbena	Federal candidate/state sensitive	Low to none
Aletes sessiliflorus	Sessile-flowered false carrot	State sensitive	Low to none
Strix occidentalis lucida	Mexican spotted owl	Federal candidate	Low to none
Zapus hudsonius	Meadow jumping mouse	Federal candidate/state endangered	Moderate to high
Lymnaea captera	Say's pond snail	State endangered	Low to none
Astragalus cyaneus	Cyanic milk vetch	State sensitive	Low to none
Plants			
Astragalus feensis	Santa Fe milk vetch	State sensitive	Low to none
Astragalus Mathewsii	Mathew's woolly milk vetch	State sensitive	Low to none
Astragalus puniceus var. gertudis	Taos milk vetch	State sensitive	Low to none
Mammillaria wrightii	Wright fishhook cactus	State sensitive	Low to none
Opunita viridiflora	Santa Fe cholla	Federal candidate	Low to none
Phlox caryophylla	Pagosa phlox	State sensitive	Low to none
Silene plankii	Plank's catchfly	State sensitive	Low to none
Lilium philadelphicum var. *andium*	Wood lily	State endangered	Low to none
Fritillaria atropurpurea	Checker lily	State sensitive	Low to none
Heuchera pulchella	Sandia alumroot	State endangered	Low to none
Tetradymia filifolia	Threadleaf horsebrush	State sensitive	Low to none
Toumeya papyracantha	Gramma grass cactus	Federal candidate/state endangered	Low to none

Source: Biggs 1996, 62928, pp. 31, 32, Appendix C.

3.5.4 Guaje Canyon Biotic Environment

During the summers of 1993 and 1994, the BRET conducted baseline studies within two canyon systems, Los Alamos Canyon and Guaje Canyon. Biological data were collected within each canyon to provide background and baseline information for ecological risk models (Foxx 1995, 50039, p. vii).

3.5.4.1 Flora

Table 3.5-3 lists the dominant trees and shrubs in Guaje Canyon. Vegetation in upper Guaje Canyon is characterized by mixed conifer with aspen, and ponderosa pine. The National Wetlands Inventory (NWI) classifies this area as riverine, upper perennial, unconsolidated bottom, and permanently flooded (Foxx 1995, 50039, p. xiii).

The terrain in the mid-portion of Guaje Canyon is much like that in the upper portion. Although the canyon sides are not as steep as those in upper Guaje Canyon, the canyon bottom is narrow and is characterized by dense vegetation (mixed conifer with aspen). Water flow in the stream channel in middle Guaje Canyon is ephemeral. The NWI classifies this area similar to upper Guaje Canyon.

The lower section of Guaje Canyon is broader than the upper and middle sections. Where surveys were conducted in lower Guaje, the stream is ephemeral. The NWI classifies this area as riverine, intermittent, streambed, and seasonally flooded. Vegetation in lower Guaje Canyon is characterized by mixed conifer, ponderosa pine, and piñon-juniper (Foxx 1995, 50039, p. xiii).

For the canyon bottom and riparian vegetation, vegetation surveys along the stream channel and within the canyon bottom showed 126 species in Guaje Canyon. Understory species with the highest importance values were as follows: cutleaf coneflower, goosegrass, Richardson's geranium, and meadow horsetail (Foxx 1995, 50039, p. xvi).

Table 3.5-3
Dominant Trees and Shrubs of Guaje Canyon

Area of Canyon	Dominant Trees	Dominant Shrubs
Upper	Alder	Cliff bush
	New Mexico maple	Serviceberry
	Engelmann spruce	
	Ponderosa pine	
Middle	Alder	Serviceberry
	Water birch	Rose
	Aspen	
	Douglas fir	
Lower	New Mexico maple	Gooseberry
	Alder	Fendler
	Narrowleaf cottonwood	Barberry
	Ponderosa pine	

Source: Foxx 1995, 50039, p. xv.

3.5.4.2 Fauna

The Ecological Studies Team (EST) of the Laboratory's Ecology Group (ESH-20) collected aquatic samples from the streams within Guaje Canyon during two six-month sampling seasons in 1993 and 1994. The EST measured water quality parameters and collected aquatic macroinvertebrates from permanent sampling stations (Foxx 1995, 50039, p. 91). Over 35,000 individual aquatic invertebrates within 81 taxa in Guaje Canyon were collected, identified, and analyzed (Foxx 1995, 50039, p. xvii).

In 1993 and 1994, 6 plant litter samples were collected from below deciduous trees or shrubs in Guaje Canyon. Using standardized sorting and identification techniques, a total of 997 individual snails representing 8 families and 13 species were sorted and identified. Species richness and numbers of individuals varied greatly between samples (Foxx 1995, 50039, p. 195).

For two consecutive years (1993 and 1994), terrestrial arthropod studies were conducted in Guaje Canyon. More than 22,500 arthropods were captured and identified. All arthropods were identified down to the family level (Foxx 1995, 50039, p. 225). The EST also conducted surveys of the birds in Guaje Canyon in 1993 and 1994. In 1993, they found 48 species and 669 birds and in 1994 the census revealed 42 species and 568 birds in Guaje Canyon.

In July and August 1993 and 1994, the BRET conducted field surveys in Guaje Canyon. Biological data were collected, including live-capture and release studies on rodent populations. The primary purpose of collecting small mammal data was to obtain sufficient information to estimate population size, density, and species diversity. The trapping sites were located in two habitat types: mixed conifer and ponderosa pine, and a transition zone of these two types. Deer mice were captured in all trapping locations. Shrews and voles were captured in the upper locations of the canyon and deer mice and a small number of harvest mice were captured in the ponderosa pine habitat of the lower portion of the canyon (Foxx 1995, 50039, p. 255).

Eleven small mammals were captured from Los Alamos and Guaje Canyons. Eight percent (8%) of the deer mice and four percent (4%) of the voles captured in Guaje and Los Alamos Canyons were positive for hantavirus. Three other species were questionably positive.

3.5.4.3 Threatened and Endangered Species

The BRET maintains a threatened, endangered, and sensitive database of all species that potentially occur in Los Alamos and surrounding counties. The threatened, endangered, and sensitive database search identified 23 species that might be present in Guaje Canyon. Four species (Mexican spotted owl, spotted bat, meadow jumping mouse, and Jemez Mountain salamander) have a high or high-to-moderate potential for actually occurring within Guaje Canyon. In addition, eight species were identified but more data were required to determine their presence in the canyon (Foxx 1995, 50039, p. 277). Threatened, endangered, and sensitive species that potentially occur in the Guaje Canyon watershed are listed in Table 3.5-4.

Table 3.5-4
Threatened, Endangered, and Sensitive Species Potentially Occurring in the Guaje Canyon Watershed

Common Name	Scientific Name	Legal Status	Potential for Occurrence
Western toad	*Bufo boreas*	State endangered	Low
Jemez Mountain salamander	*Plethodon neomxicanus*	State-endangered candidate for federal listing	Moderate to high
Mexican spotted owl	*Strix occidentalis lucida*	Federally threatened	Low
Northern goshawk	*Accipiter gentilis*	Federal candidate	Low
Common black hawk	*Buteogallus anthracinus*	State protected	Low to none
Bald eagle	*Haliaeetus leucocephalus*	Federally endangered	Low to none
Mississippi kite	*Ictinia mississippiensis*	State endangered	Low to none
Whooping crane	*Grus americana*	Federally endangered	Low
Least tern	*Sterna antillarum*	Federally endangered and state-endangered	Low
White-faced Ibis	*Plegadis chihi*	Candidate for federal listing	Low
Broad-billed hummingbird	*Cyantyhs latirostris*	State endangered	Low to none
Willow flycatcher	*Empidonax traillii*	Federal candidate	Low to none
Rio Grande silvery minnow	*Hybognathus amarus*	Federally proposed and state endangered	Low
Bluntnose shiner	*Notropis simus*	State endangered	Low
Pine marten	*Martes americana*	State endangered	Moderate
Spotted bat	*Euderma maculatum*	Federal candidate/state threatened	Moderate to high
Meadow jumping mouse	*Zapus hudsonius luteus*	Candidate for federal listing/state endangered	Moderate to high
Occult little brown bat	*Myotis lucfugus occultus*	Candidate for federal listing/state endangered	Moderate
Wood lily	*Lilium philadelphicum*	Candidate for federal listing/state endangered	Moderate
Helleborine orchid	*Epipactis gigantea*	State endangered	Moderate
Lilljeborg's pea-clam	*Pisidium lilljeborgi*	State endangered	Low to moderate
Say's pond snail	*Lymnaea caperata*	State endangered	Low

Source: Foxx 1995, 50039, p. 280; LANL 1997, 62316, p. 3-49.

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Copies of the reference library are maintained at the New Mexico Environment Department Hazardous Waste Bureau; the US Department of Energy-Los Alamos Area Office; US Environmental Protection Agency, Region 6; and the ER Project Canyons Focus Area. This library is a living document that was developed to ensure that the administrative authority has all the necessary material to review the decisions and actions proposed in this document. However, documents previously submitted to the administrative authority are not included in the reference library.

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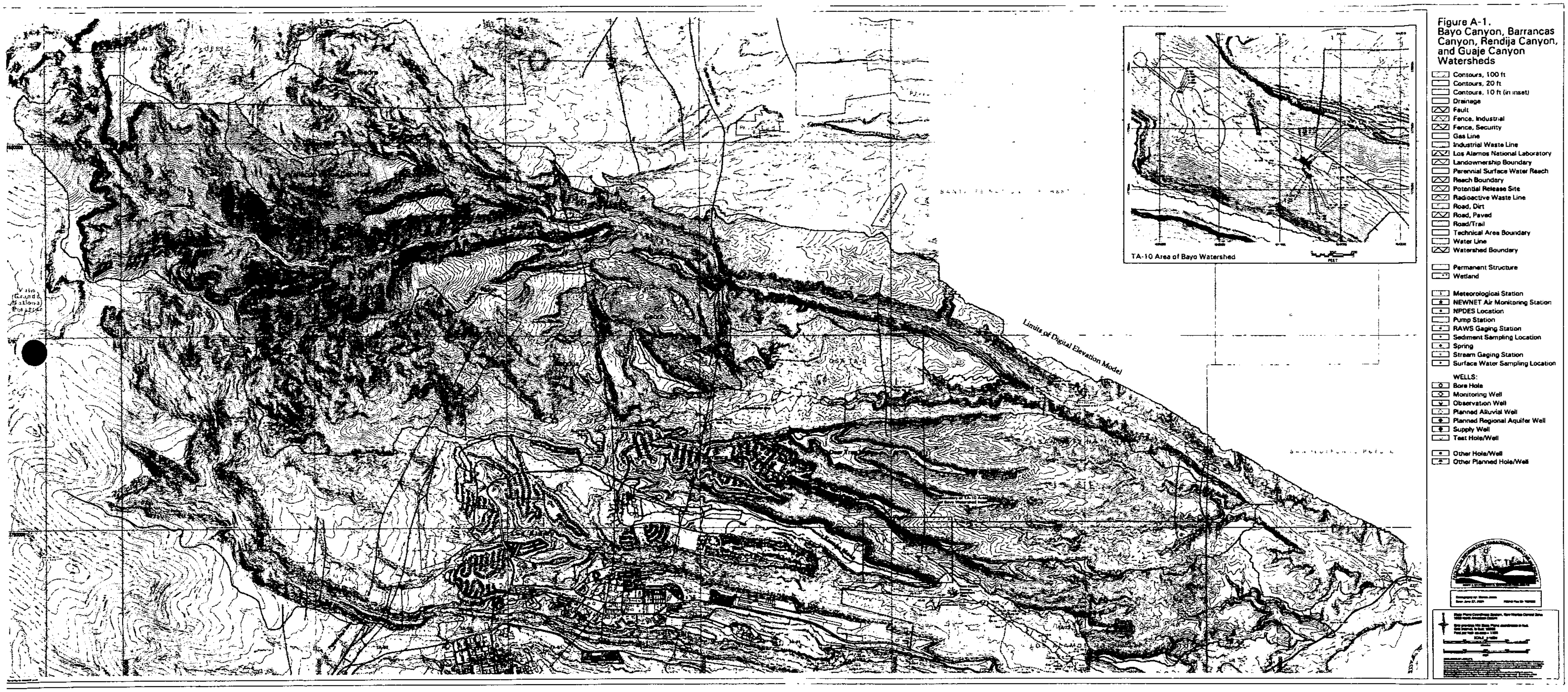


Figure A-1.
Bayo Canyon, Barrancas Canyon, Rendija Canyon, and Guaje Canyon Watersheds

Appendix E

Geophysical Investigation

DATA ITEM DESCRIPTION

Title: Geophysical Investigation Plan

Number: MR-005-05 **Approval Date:** 20031201
AMSC Number: **Limitation:**
DTIC Applicable: No **GIDEP Applicable:** No
Office of Primary Responsibility: CEHNC-ED-CS-G
Applicable Forms: Attachment A – Field Data Sheet, Attachment B – Quality Control Frequency & Acceptance Criteria Chart, Attachment C – Geophysical Dig Sheet and Target History, Attachment D – Geophysical Map Deliverable Format
Use/Relationship: The Geophysical Investigation Plan will be used to provide details of the approach, methods, and operational procedures to be employed in performing geophysical investigations for Munitions Response or other munitions related projects. This Data Item Description contains instructions for preparing work plan chapters and data requirements when addressing geophysical investigations for Munitions Response or other munitions related projects. Additional references include EM 1110-1-4009.

Requirements:

1. Unexploded Ordnance (UXO) Safety. During all initial fieldwork and all intrusive activities, the geophysical crew shall be accompanied by a UXO Technician II. Prior to the survey crew entering an area potentially containing UXO, the UXO Technician II shall conduct visual surveys for surface ordnance and a magnetometer or electromagnetic survey of each intrusive activity site to ensure the site is anomaly free prior to the crew setting monuments or driving stakes. The UXO Technician II will not be required on a full time basis for non-intrusive activities.

2. Personnel Qualifications. All geophysical investigations shall be managed by a qualified geophysicist meeting the qualification requirements listed in Section C of the Basic Contract.

3. Geophysical Investigation Plan Outline. The contractor shall prepare a geophysical investigation plan in accordance with the following outline:

3.1 Site Description.

a. Geophysical Data Quality Objectives. Define target objectives and Site Specific Project constraints. Refer to MR-005-05A for Geophysical Prove-out (GPO) requirements.

b. Specific area(s) to be investigated, including a Survey Mission Plan Map.

c. Past, current and future use

d. Anticipated UXO type, composition and quantity

e. Depth anticipated

f. Digital topographic maps

g. Vegetation (digital air photos if available)

h. Geologic conditions (including bedrock type, mineralization and depth)

i. Soil conditions - including soil type/composition, typical moisture content, and thickness. Include Soil Conservation Service (SCS) map if available.

j. Shallow groundwater conditions (including depth, mineralization, existence of perched tables, and seasonal and tidal variations)

k. Geophysical conditions, including background geophysical gradients, regional magnetic field intensity, inclination, declination, local variation.

l. Site utilities

m. Man-made features potentially affecting geophysical investigations

n. Site-specific dynamic events such as tides, unusually strong winds, or other unusual factors affecting site operations

o. Overall site accessibility and impediments

p. Potential worker hazards

3.2 Geophysical Investigation.

a. Survey type – fixed pattern, transect, meandering path, hybrid

b. Equipment
- Survey platforms
- Detectors
- Sampling rates
- Navigation and mapping system (Note- If GPS systems are used, correlate satellite availability with work/rest periods)
- Data processing system

c. Procedures. Refer to Attachment A for Field Data Sheet

d. Personnel – Identify key personnel and project team members with designated responsibilities and requirements

e. Production rates

f. Data spatial density (define data in-line spacing and lane width)

3.3 Instrument Standardization. Refer to Attachment B for minimum test frequency requirements and acceptance criteria.

3.4 Data Processing, Corrections and Analysis. Detail initial field processing, standard data analysis methods, advanced data analysis techniques that may be required by certain project specific conditions, anomaly selection and decision criteria.

a. Initial field processing
Data file QC review and correction
- Grid name and location
- Line numbers, survey direction, fiducial locations, start and end points
- Removal of data drop-outs, spikes and physical feature interference sources

b. Standard data analysis
- Diurnal correction (magnetic data)
- Positional offset correction
- Sensor bias, background leveling and/or standardization adjustment
- Sensor drift removal
- Latency Correction
- Heading error removal (magnetic data)
- Geophysical noise identification and removal (spatial, temporal, motional, terrain induced)

- Gridding method and search criteria
- Contour level selection with background shading and analysis

c. Advanced data processing, digital filtering and enhancement (if applicable)
- Dipole match, or Analytic Signal calculation (magnetic data)
- Adaptive (matched) filtering
- Approximate magnetic volume/mass estimates (magnetic data)
- Approximate depth determination
- Time decay curve analysis (TDEM data)
- Amplitude and Phase response analysis (FDEM)
- Data Fusion
- Digital filtering and Enhancement (low pass, high pass, band pass, Convolution, Correlation, Non-linear, etc…)

d. Anomaly selection and decision criteria

3.5 Dig Sheet Development. Refer to Attachment C for form.

3.6 Anomaly Reacquisition.

3.7 Feed-Back Process (Comparison of dig-sheet predictions with ground-truth excavation results).

3.8 Quality Control.

3.9 Corrective Measures.

3.10 Records Management (Life Cycle Data Management, resource loaded schedule in Microsoft Project 2000 format, data transfer, and data storage).

3.11 Interim Reporting. (Include frequency of data submittals, dig-sheet and excavation results submittals.)

3.12 Map Format. Refer to Attachment D.

4. Geophysical Investigation Performance Goals.

4.1 Detection of Munitions and Explosives of Concern (MEC) or other munitions.

a. A simplified expression for maximum depth of detection is calculated as:

Estimated Detection Depth (meters) = 11*diameter (mm) / 1000

b. Minimum ordnance item diameter must be determined on a project-specific basis. The contractor shall detect and remove all metallic items located within the target objective performance box on Figure 1 (blue area).

c. Any unexcavated (missed) item that has an intermediate principal axis diameter that fits within the target acceptance box is considered to be a Quality failure. The contractor will, at no expense to the Government, correct the Quality deficiency and re-sweep and perform QC on all affected areas again before re-submitting to the Government for verification and acceptance.

d. If the contractor believes the target objective performance goals cannot be achieved at a particular site, then the contractor shall propose and document alternative goals for the Contracting Officer's consideration. The contractor will not be held liable for technically unachievable goals, as determined during the GPO and initial phase of field work.

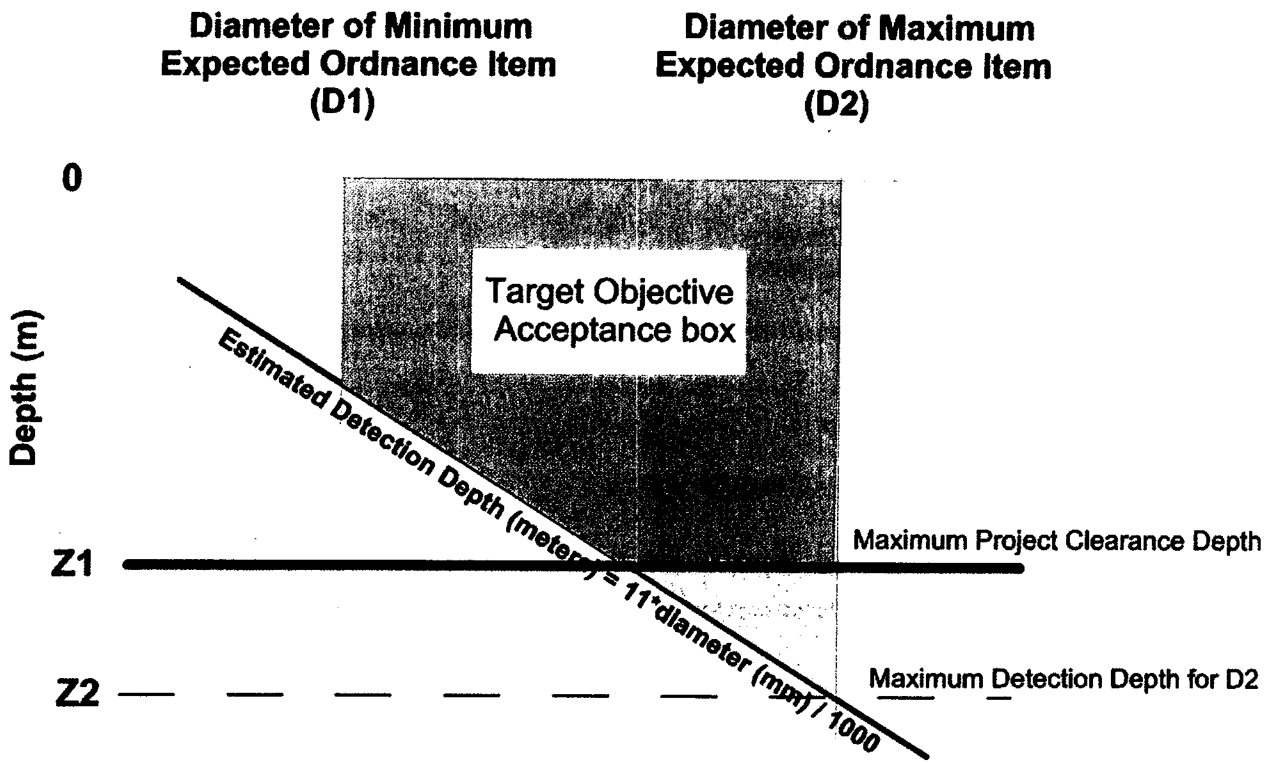


Figure 1 – Geophysical Target Objective Acceptance Box

4.2 Horizontal Accuracy. Horizontally, 95% of all reacquired anomaly locations must lie within a one (1) meter radius of their original surface location as marked on the dig sheet. Horizontally, 95% of all excavated items must lie within a 35 cm radius of their mapped surface location as marked in the field after reacquisition.

4.3 False Positives. If there are more than 15% "false positives" (anomalies reacquired by the Contractor result in no detectable metallic material recovered during excavations, calculated as a running average for the sector), a re-evaluation of the data, detection methods being utilized, and overall project QC shall be performed at no cost to the Government. A written response explaining the reason for the excessive false positive results and a Corrective Action Plan, if appropriate, shall be submitted to the Contracting Officer within 10 days of identification of the situation.

5. Geophysical Mapping Data.

5.1 The Contractor shall correlate all sensor data with navigational data based upon a local "third order" (1:5,000) monument or survey marker. If a suitable point is not available, the Contractor shall have a Professional Land Surveyor (PLS) establish a minimum of two (2) new monuments or survey markers per sector with a minimum of "third order" accuracy. All sensor data shall be preprocessed for sensor offsets, diurnal magnetic variations, latency corrections, drift corrections, etc. and correlated with navigation data. Diurnal magnetic variations measured at a base-station must be collected at a minimum of once per minute. The approved geophysical mapping technology shall digitally capture the instrument readings into a file coincident with the grid coordinates. All raw and final processed data shall be delivered corrected and processed in ASCII files. Corrections such as for navigation, instrument bias, and diurnal magnetic shift shall be applied. All corrections shall be documented. Geophysically mapped grids shall be exactly coincident with the grid system used by the UXO removal or remedial action contractor and shall use exactly the same datum and coordinate system. However, the geophysical contractor may choose to provide geophysical data files in grids of up to 400 ft. x 400 ft. square. The data shall be presented in delineated fields as x, y, z, v1, v2, etc., where x and y are UTM Grid Plane Coordinates in Easting (meters) and Northing (meters) directions, z (elevation is an optional field in meters), and v1, v2, v3, etc., are the instrument readings. The last data field should be a time stamp. Each data field shall be separated by a comma or tab. No individual file may be more than 100 megabytes in size and no more than 600,000 lines long. Each grid of data shall be logically and sequentially named so that the file name can be easily correlated with the grid name used by other project personnel. The formats specified in this paragraph are REQUIRED to be exactly followed, although the Contractor may choose to submit the data in additional formats as well. No later than 36 hours after collection, the Contractor shall furnish each day's data to USAESCH, via internet using FTP, E-mail attachment for small files under 5 Mb, digital compact disk (CD) or other approved method, for inspection. Such data is considered to be in draft form. This data shall be corrected for sensor offsets, diurnal variations, latency, heading error, and drift. The Contractor shall also provide a digital planimetric map, in Intergraph .DGN, Surfer .srf, ESRI ArcView or Geosoft format, and coincident with the location of the geophysical survey, so that each day's geophysical data set can be registered within the original mission plan survey map. Within 10 days after collection, the Contractor shall furnish interim dig sheets for each day's data to USAESCH via email. Within 14 days of completion of survey activity the Contractor shall provide USAESCH all final geophysical maps, dig-sheets and supporting geophysical interpretations. All geophysical data shall be accompanied by a Microsoft Word 6.0 or higher file documenting the field activities associated with the data, and the processing performed. The Government will periodically perform validation checks to assure positional accuracy, proper instrument calibration or other analysis. Draft Data shall be provided within 24 hours of request to the government representative performing QA activities on the project.

5.2 Geophysical Data Analysis, Field Reacquisition, and Reporting. The Contractor shall analyze the geophysical data and provide complete digital "dig-sheets" in Microsoft Excel spreadsheet format utilizing Attachment C. Microsoft Access '97(or higher) database tables that include pre-built queries for the required information are also acceptable.

5.3 Anomaly Reacquisition and Marking. The same contractor that geophysically mapped and analyzed the survey area shall reacquire all geophysical anomalies identified for excavation on the dig sheets using the re-acquisition method tested by the Contractor and approved by CEHNC on the GPO. The Contractor shall flag (PVC flag with the unique identifier number recorded in indelible ink on the flag) the actual field location of each re-acquired anomaly shown on the "dig-sheet" and paint the ground (if feasible and allowable) at the flag location with high-visibility paint. Such reacquisition shall be carried out concurrently with other site activities and shall be completed no later than 14 days after geophysical field investigations are completed. If a longer than 14 day hiatus between the geophysical survey work and re-acquisition is expected, this should be so stated in the resource loaded Project Schedule that is submitted for Government approval. The Contractor shall record and report on all discrepancies between final reacquired mapped locations of anomalies as shown on the dig-sheet, and actual locations of the excavated anomalies. The Contractor shall also report any anomalies that could not be reacquired.

5.4 Anomaly Excavation Reporting. The Contractor shall, in full accordance with the project work plan, excavate the reacquired anomalies in the field. The disposition and final location details of each anomaly shall be recorded on the final dig sheets, which shall be submitted to the USAESCH within 10 days of completed excavations for that individual grid and also submitted in the Site Inspection, Remedial Investigation/Feasibility Study, Engineering Evaluation/Cost Analysis, or Site Specific Final Report.

6. End of DID MR-005-05.

DID MR-005-05
Attachment A

Field Data Sheet

☐ QC checked by ____________
Date: ____________

☐ QA checked by ________
Date: ________

Project Name: ______________________________ **Project Location:** ______________________________

Geophysical Contractor: ______________________ **Design Center POC:** ___________________________

Project Geophysicist: ________________________ **Site Geophysicist:** ____________________________

Survey Area ID: __________ **Date:** __________ **Field Team:** ______________________________

Survey Type: ☐Grid ☐Meandering Path ☐Transect ☐Other __________

Coordinate System: ☐UTM ☐State Plane NAD _____ ☐Local ☐Other __________ **Unit of Measure:** ☐ meters ☐ feet

Sketch of Survey Area: **Approx. Scale:** __________ **North Arrow:**

Terrain:

☐Level ☐Moderate Slope ☐Steep

☐Rolling ☐Ruts ☐Gullies

☐Rocky ☐Swampy ☐Dangerous

Tree Cover: **Tree Height:** ____

☐None ☐Light ☐Medium ☐Thick

Brush:

☐None ☐Light ☐Medium ☐Thick

Weather:

☐Sunny ☐Cloudy ☐Drizzle

☐Rain ☐Thunderstorms ☐Hail

☐Fog ☐Humid ☐Snow

Grid Corner Coordinates:

	UTM/State Plane	Local
SW	________, ________	________, ________
NW	________, ________	________, ________
NE	________, ________	________, ________
SE	________, ________	________, ________

	Start	End	File Name
Battery Voltage:	_____	_____	
Static Background Value:	_____	_____	______, ______
Static Response Value:	_____	_____	______, ______

Instrument Clock Drift: __________

Raw Data File Name: ______________________ **Repeat Data File Name:** ______________________

Geophysical Instrumentation: ______________________________ **Serial Number:** __________

Base Station: ______________________________ **Serial Number:** __________

Navigation Method: ______________________________ **Serial Number:** __________

Additional Comments: ____

Quality Control Frequency & Acceptance Criteria Chart

To facilitate the detection of buried munitions, the U.S. Army Engineering and Support Center, Huntsville (USAESCH) has defined standard equipment tests and data quality. It is imperative to perform and review QC tests before carrying out production geophysical work. This ensures that the geophysical system is functioning properly and optimized for the target objectives.
The most common instruments in use today for metallic munitions detection are magnetometers, and electromagnetic metal detectors. This chart identifies the minimum USAESCH required QC tests and acceptance criteria for these types of instruments.

Test #	Test Description	Acceptance Criteria	Power on	Beginning of	Beginning & Day	1st P each o	1 Lir '00 ft. per Linear Mile
1	Equipment Warm-up	Equipment Specific (typically 5 min)	X				
2	Record Sensor Positions	+/- 1 inch (2.54 cm)		X			
3	Personnel Test	EM61 2mV p-p, Mag 3nT p-p		X			
4	Vibration Test (Cable Shake)	Data Profile does not exhibit data spikes		X			
5	Static Background & Static Spike	Background: EM61 2.5 mV p-p, Mag 1nT p-p;			X		
		Spike : +/- 20% of standard item response, after background correction.					
6	Azimuthal Test *	Sensor Orientation that minimizes drop-outs				X	
7	Height Optimization	Maximum S/N ratio that reliably detects smallest target objective.				X	
8	6 Line Test	Repeatability of response amplitude +/-20%, Positional Accuracy +/- 20cm				X	
9	Octant Test (Heading Error Test) *	Document heading error for post-processing correction				X	
10	Repeat Data	Repeatability of response amplitude +/-20%, Positional Accuracy +/- 20cm					X

* Magnetometer Only

Geophysical Dig Sheet and Target History

Page ____ of _____

Reacquisition Geophysical Equipment Used	Component	Serial #	Grid Background Value (mV / nT)	Date	Time

Project Name: ______________________

Project Location: ______________________

Date: ______________________

Coordinate System: ______________________

Survey Area ID: ______________________

Sector: ________ Grid: ________

Field Book ID: ______________________

Geophysical Contractor: ______________________

Project Geophysicist: ______________________

Site Geophysicist: ______________________

Field Team: ______________________

COE Design Center POC: ______________________

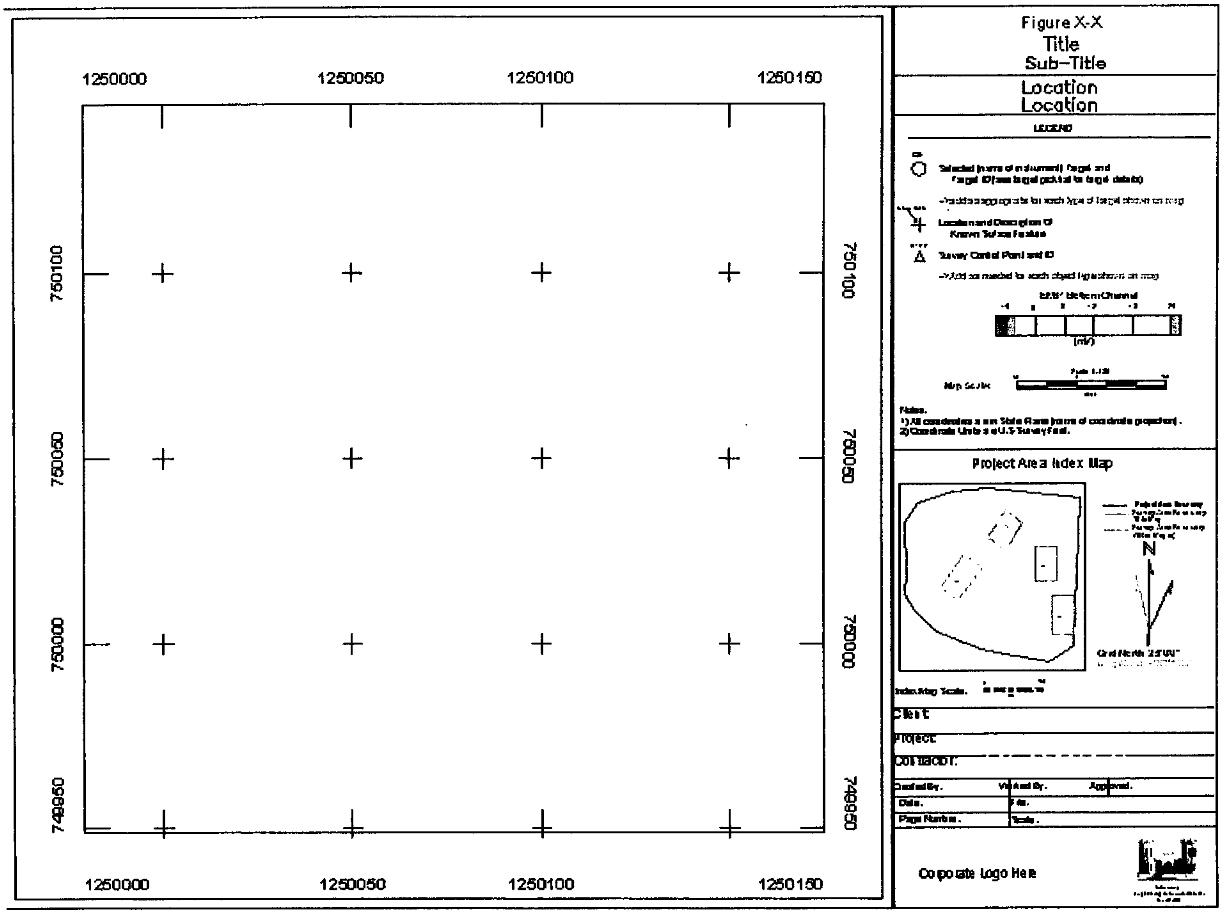
COE Project Engineer: ______________________

COE Geophysicist: ______________________

	Original Survey						Reacquisition Survey			Dig Results											Post-Dig UXO QC Results			Post-Dig Geophysical QC		
													Offset													
Unique Target ID	Easting Coord. (ft/m)	Northing Coord. (ft/m)	Channel ID (ie-C1 ....C4, top sensor, gradient, etc)	Response Amplitude (units*)	Dig Priority (0 is no dig-known anomaly source,1 is highest dig recommendation, etc..)	Date	Channel ID (ie-C1 or C4, top sensor, gradient)	Response Amplitude (units*)**	Date	Anomaly type ***	Approx. weight (lbs-oz / kg-g)	Comments	Distance (ft / m)	Direction (N, NE, etc.)	Orientation of Nose (Azimuth deg) **	Inclination of Nose (deg) **	Depth to Top of Item (in/cm)	Digital Photo Filename **	Date	Team Leader Initials	Excavation Hole Cleared?	UXO QC Spec. Initials	Date	Agreement between Dig Results & Geophysical Data? (G=good, P=poor, U=unacceptable)	Geophysicist QC Initials	Date

DID MR-005-05
Attachment D

Geophysical Map Deliverable Format



DATA ITEM DESCRIPTION

Title: Geophysical Prove-Out (GPO) Plan and Report

Number: MR-005-05A **Approval Date:** 20031201
AMSC Number: **Limitation:**
DTIC Applicable: No **GIDEP Applicable:** No
Office of Primary Responsibility: CEHNC-ED-CS-G
Applicable Forms:
Use/Relationship: The Geophysical Prove-out (GPO) Plan will be used to provide details of the approach, methods, and operational procedures to be (1) employed to perform GPOs for Munitions Response or other munitions related projects and (2) documented as part of the Geophysical Investigation Plan. This Data Item Description contains instructions for preparing GPO Plans and Reports. Additional references include EM 1110-1-4009.

Requirements:

1. GPO Plan. The elements described in the following sub-sections shall be addressed in the GPO Plan.

1.1 Test Plot/Test Strip Design. The proposed test plot/test strip layout shall be included in the GPO Plan.

a. Prove-out Size and Location. Selection of the prove-out area should be based upon the technical and site-specific considerations developed and finalized during the Technical Project Planning process and/or project team meetings, and follow anticipated layout for project data collection. It may be necessary to prepare more than one prove-out grid, mini-grid, or test strip if site conditions vary significantly. It may be advantageous to plan the prove-out location outside of areas where digging is restricted to UXO technicians and/or oversight by UXO technicians.

b. Seed Items. A tabulated list, available in digital format, containing the seed items, ID numbers, proposed X, Y, Z locations, proposed inclination and declination (or survey information on the nose, tail, and center point of the item) shall be included. Inert ordnance items should be used whenever possible.

1.2 Site Preparation. Describe any preparation that may be necessary to allow accessibility with geophysical instruments including vegetation removal and/or surface removal. After this step, the test plot should duplicate, as closely as possible, the conditions under which the geophysical surveys will be conducted.

1.3 Location Surveying. Describe the location methods to be employed. The location of the test plot corners and seed items shall be surveyed by a professional land surveyor (PLS) to a horizontal accuracy of 3 cm and a vertical accuracy of 5 cm. The center and both ends of seed items shall be surveyed. In addition, surface elevation shall be measured after seed item burial, to accurately determine depth below ground surface.

1.4 Pre-Seeding (Background) Geophysical Mapping. Describe background geophysical mapping. After a site has been selected and the surface prepared, pre-seeding geophysical surveys shall be performed with each detector type in order to determine and document base-line geophysical conditions at the site.

1.5 Quality Control. Describe Quality Control (QC) measures to be implemented. At a minimum, the tests outlined in Attachment B of DID MR-005-05 shall be performed.

1.6 Anomaly Avoidance. A statement that the contractor shall use anomaly avoidance techniques shall be included. This is to ensure the location of each excavation and corner marker/stake is clear of metallic anomalies before placing seed items or site corner markers, and includes utilizing the background geophysical data.

1.7 Seeding. Describe the planned seeding methodology for known items. In addition to the known seed items, blind seed items may be buried by the Government, and/or the contractor's UXO QC Specialist, for quality control. The contractor shall allot ample time for burial of blind seed items and ensure that adequate excavating equipment is available to attain the seed item burial depths planned. Once placed, all seeded items and corner markers should be surveyed and photographed. The planned GPO target layout plan shall be updated to reflect the "as built" configuration. The seeded items should be painted blue and tagged with a non-biodegradable label identifying the items as inert and providing a contract reference, a point of contact address, phone number, and a target identifier.

1.8 Data Collection Variables. It is important to collect and analyze test plot data using the same equipment and procedures that are planned for field use. It is strongly recommended that key personnel from the GPO perform the production survey to minimize the learning curve and provide project continuity. Some data collection elements are subject to modification and evaluation and multiple geophysical surveys using each proposed geophysical instrument may be performed. These elements include: instrument height, instrument orientation and direction of travel, instrument channel selections, measurement interval along survey line, lane width, etc.

1.9 Data Analysis and Interpretation. All data collected at the prove-out grid from each geophysical instrument will be post-processed and analyzed. It is required that all data channels are analyzed to ensure the best methodology is established for each site. A dig-sheet, provided as Attachment C of DID MR-005-05, of selected target anomalies shall be prepared and provided to the project team for comparison with seeded item locations.

1.10 Reacquisition. The contractor shall perform anomaly reacquisition and verification, and record these measurements on the dig-sheet. This should be done to the same extent and with the same equipment as planned for the production geophysical investigation. If the GPO location is situated in an area where digging of unknown targets is permitted (e.g., beyond project site boundaries), it may be advantageous, based upon the professional judgment of the project geophysicist, in concurrence with CEHNC, to excavate a limited number of unknown anomalies that are identified during the pre-seeding background surveys. It is anticipated that such information would be used to aid in characterizing false positive responses in the project area.

1.11 Data Evaluation.

a. The geophysical data must be evaluated and scored so that the different geophysical approaches can be compared and ranked. Scoring criteria should include, as a minimum, the following: percent of seeded items detected (by class or size, and overall); number of unknown targets; production rate; cost per unit area; equipment durability and safety.

b. No single geophysical system is likely to achieve maximum scores in all evaluated areas. Therefore, the evaluation team must determine which approach is likely to be most efficient for the site.

2. GPO Letter Report.

3.1 After the GPO field work has been completed, the contractor shall prepare a GPO Letter Report including the following:

a. As-built drawing of the GPO plot;

b. Pictures of the seed items;

c. Color maps of the geophysical data;

d. Summary of the GPO results;

e. Proposed geophysical equipment, techniques, and methodologies; and

f. Sufficient supporting information to justify the project team's recommendations, including manufacturer specifications for all recommended geophysical equipment, a definition of the expected target anomalies based upon the Archives Search Report, Site Inspection Report, Remedial Investigation/Feasibility Study or Engineering Evaluation/Cost Analysis results, or any other pertinent data/information used in decision making.

2.2 A CD shall be delivered with the letter report containing the following files:

a. The GPO Letter Report (Microsoft Word format);

b. All raw and processed geophysical data. All data, except raw instrument data, shall be provided in column delineated ASCII files in the format x, y, z, v1, v2, etc., where x and y are UTM Grid Plane Coordinates in Easting (meters) and Northing (meters) directions, z (elevation) is an optional field in meters, and v1, v2, v3, etc., are the instrument readings. The last data field should be a time stamp. Each data field shall be separated by a comma or tab.

c. Geophysical maps in their native format (Surfur®, Geosoft Oasis montaj™, Intergraph, or ESRI ArcView format) and/or as raster bit-map images such as BMP, JPEG, TIFF or GIF;

d. Seed item location spreadsheet (Microsoft Excel format);

e. Spreadsheet (Microsoft Excel format) of contractor picks for each sensor type, including reacquisition; and

f. Spreadsheet (Microsoft Excel format) of all control points, survey points and benchmarks established or used during the Location Surveying task.

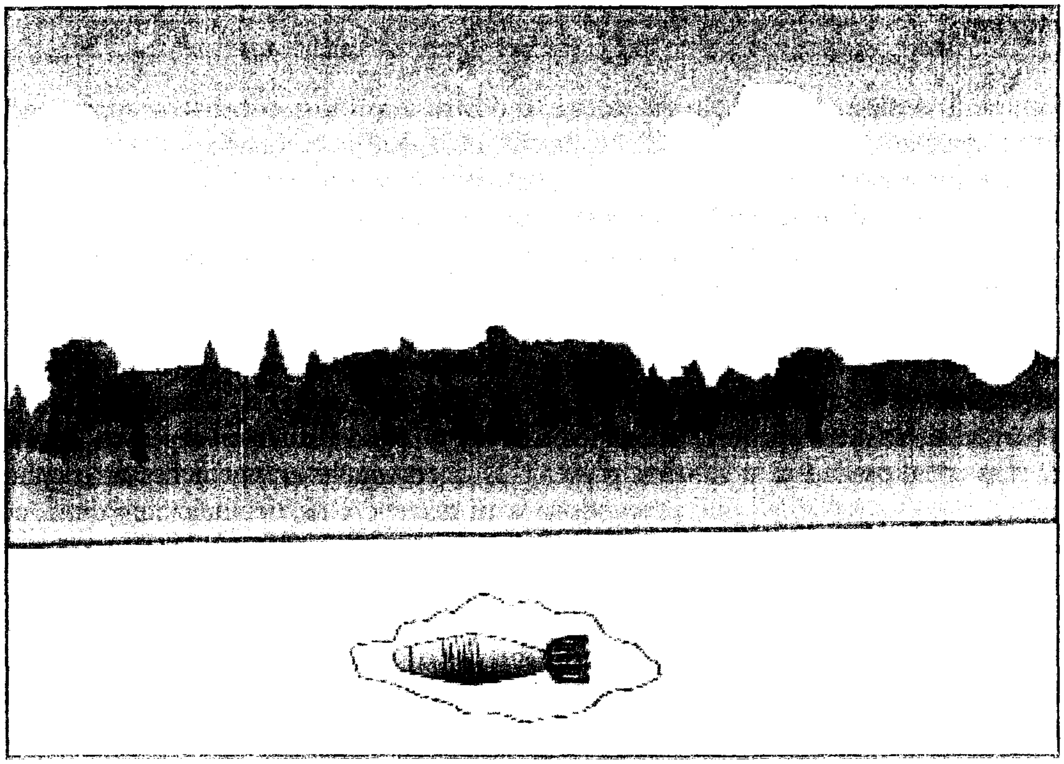
2.3 The contractor may not proceed with production geophysical mapping until the Government approves the GPO results as provided in the GPO Letter Report.

2.4 The GPO Letter Report and Contracting Officer Approval Letter shall be included in future geophysical reports and work plans associated with the survey area.

3. End of DID MR-005-05A.

Technical/Regulatory Guideline

Geophysical Prove-Outs for Munitions Response Projects



November 2004

Prepared by
The Interstate Technology & Regulatory Council
Unexploded Ordnance Team

ABOUT ITRC

Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of some 40 states and the District of Columbia; three federal agencies; tribes; and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at **www.itrcweb.org**.

DISCLAIMER

Geophysical Prove-Outs for Munitions Response Projects

November 2004

Prepared by
The Interstate Technology & Regulatory Council
Unexploded Ordnance Team

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Geophysical systems are integral to munitions response efforts because they detect surface and subsurface anomalies such as unexploded ordnance and discarded military munitions during geophysical surveys at munition response sites. Detection of munitions and explosives of concern is critical to the success of the overall munitions response effort because items that are not detected will not be removed.

Before conducting a geophysical survey of an entire munitions response site, a site-specific geophysical prove-out (GPO) is conducted to test, evaluate, and demonstrate these geophysical systems. Information collected during the prove-out is analyzed and used to select or confirm the selection of a geophysical system that can meet the performance requirements established for the geophysical survey.

This document introduces the purpose and scope of GPOs, provides examples of goals and objectives associated with GPOs, and presents detailed information needed to understand and evaluate the design, construction, implementation and reporting of GPOs. This document also communicates the expectations of state regulators to those designing, executing, and reporting GPOs. Because not everyone who will need or want to evaluate a GPO has a background in geophysics, this document includes a background chapter on geophysical surveys as conducted during the course of munitions response actions.

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APPENDICES

GEOPHYSICAL PROVE-OUTS FOR MUNITIONS RESPONSE PROJECTS

1. INTRODUCTION

The fundamental goal of a geophysical prove-out (GPO) is to determine whether a particular geophysical investigation approach will provide satisfactory results for a munitions response (MR) action on a munitions response site (MRS). The GPO process tests, evaluates, and demonstrates the site-specific capabilities of one or several geophysical systems under consideration for an MR action. GPO results are used to help select or confirm the capabilities of the most appropriate technology. This document provides the following guidance regarding the role and use of site-specific GPOs:

- background information on geophysical surveys and equipment;
- explanations of the purpose, scope, content, and terminology of GPOs;
- technical guidance for reviewing the design, execution, and reporting of GPOs; and
- the means to communicate the expectations of state regulators to those designing, executing, and reporting GPOs.

This document is designed primarily for state[1] regulators who may not be familiar with geophysical surveys and/or GPOs. Therefore, this document begins with introductory and background information on the context of the GPO in the munitions response process. The document then goes into detail regarding the GPO technical process. Last, it provides a frequently asked questions–style chapter to facilitate discussion and answer questions likely to occur during the different phases of the GPO process. Regardless of the level of familiarity with GPOs, this document will be useful to all members of the munitions response community and stakeholders in the munitions response process.

1.1 State Regulator Role in GPOs

The state may be the lead regulator for environmental investigations and response pertaining to munitions response actions on other than operational ranges, including Formerly Used Defense Sites (FUDS) and Base Realignment and Closure (BRAC) sites. This document focuses on one technical aspect of the munitions response process—the GPO conducted prior to a geophysical survey of an MRS. During the GPO process, a state regulator with oversight authority should

- understand the purpose and limitations of GPOs in general;
- evaluate whether or not the goals and objectives of a GPO are appropriate for the planned geophysical survey;
- understand GPO-related performance metrics and how they are determined;
- perform field oversight to ensure the GPO construction and implementation are as consistent as possible with the sampling design as documented in the work plan;

[1] Throughout this document, the term "state" is used to refer to all regulatory entities having the general regulatory responsibilities of the states, including U.S. territories and commonwealths.

- evaluate whether or not the quality assurance/quality control (QA/QC) protocol established for the GPO has been followed;
- review the GPO report for completeness; and
- evaluate whether or not the GPO objectives have been achieved and documented.

By providing this information, this document will assist state regulators and others communicate with U.S. Department of Defense (DoD) staff and their contractors regarding munitions response actions. Furthermore, state participation in the GPO process will help to facilitate regulatory acceptance of munitions response actions and results.

1.2 Geophysics in Munitions Response

Geophysical systems are integral to MR efforts because it is these systems that detect potential munitions and explosives of concern (MEC), i.e., unexploded ordnance (UXO) and discarded military munitions (DMM)[2] present at an MRS. Detection of MEC is critical to the success of the overall munitions response because items that are not detected will not be removed. Therefore, Chapter 2 of this document provides an overview of the geophysical systems and methods typically used for geophysical surveys. Please note that this document focuses primarily on detecting MEC for munitions response; categorizing MEC (i.e., munition type) is still a focus of research and development efforts and is currently possible in only extremely limited conditions.

The system or systems selected to conduct the geophysical survey of an MRS must be able to detect the munitions items expected to be present on the site. Demonstrations of this capability take place on both standardized test sites and on MRSs during GPOs.

Standardized test sites are used to evaluate the capability of geophysical systems under controlled conditions. To meet these broad testing needs, the U.S. Army established the Standardized UXO Technology Demonstration Site Program. The U.S. Army Environmental Center (USAEC) spearheads this multiagency program, which is funded and supported by the Environmental Security Technology Certification Program (ESTCP), the Strategic Environmental Research and Development Program (SERDP), and the Army Environmental Quality Technology (EQT) program. This program provides geophysical sensor technology users and developers with two standardized sites—encompassing flat, uneven, open, and forested settings—to define the range of applicability of specific technologies, gather data on sensor and system performance, compare results, and document real-life cost and performance information.[3] Standardized test site information provides valuable guidance about basic technological capabilities of geophysical systems, but this information is not sufficient for making site-specific decisions.

[2]Unexploded ordnance and discarded military munitions are subsets of munitions and explosives of concern. This document refers to UXO and DMM as MEC.
[3] For more information on the Standardized UXO Technology Demonstration Site Program, see the program's Web page at http://www.uxotestsites.org.

Because demonstrating the ability of a geophysical system to detect an item under ideal conditions alone is not enough, the detection threshold of a geophysical system under consideration for a geophysical survey must be clearly established and documented under the actual field conditions to be encountered at the MRS. The geophysical system must also be capable of distinguishing the item of interest from background noise and of identifying or selecting the item's signature within the raw data as an anomaly. Site-specific conditions—such as the types of munitions present, depth of interest, soil composition, vegetation, terrain, and cultural interferences—influence the effectiveness of geophysical surveys, often in unpredictable ways. For many MRSs, multiple geophysical systems and approaches could potentially be used to detect surface and subsurface anomalies (i.e., MEC). Because all geophysical approaches have inherent strengths and weaknesses, very seldom does one instrument or approach have the best performance in all measurable categories. Therefore, the GPO is a vital step in evaluating the strengths and weaknesses of each geophysical system under consideration.

What is an anomaly?

In general, an anomaly is any response above the noise threshold that merits further investigation. This document uses "anomaly" to mean a subsurface feature detected by a geophysical instrument that warrants further investigation.

On large sites, more than one GPO may be required. For example, widely differing terrain, geology, or weapons systems may require multiple prove-out locations to gather representative information for varying site conditions unless a single prove-out area can be established that incorporates these differing site characteristics. Other reasons for performing more than one GPO can include multiple field seasons where remobilization and reestablishment of prove-out parameters are required, new information about site conditions that causes revisions to conceptual site models and geophysical methods (e.g., changing geophysical sensors), or nonconformance problems that require reevaluation of equipment and/or process team elements.

1.3 Definitions

The terminology used in munitions response has evolved over the years. In 2003, DoD established the following standardized terminology for its Military Munitions Response Program (MMRP)(DoD 2003):

- defense sites—locations that are or were owned by, leased to, or otherwise possessed or used by the Department of Defense. The term does not include any operational range, operating storage or manufacturing facility, or facility that is used for or was permitted for the treatment or disposal of military munitions (10 U.S.C. 2710[e][1]).

- discarded military munitions (DMM)—military munitions that have been abandoned without proper disposal or removed from storage in a military magazine or other storage area for the purpose of disposal. The term does not include unexploded ordnance, military munitions that are being held for future use or planned disposal, or military munitions that have been properly disposed of consistent with applicable environmental laws and regulations (10 U.S.C. 2710[e][2]).

- explosives or munitions emergency response—all immediate response activities by an explosives and munitions emergency response specialist to control, mitigate, or eliminate the actual or potential threat encountered during an explosives or munitions emergency. An explosives or munitions emergency response may include in-place render-safe procedures, treatment or destruction of the explosives or munitions, and/or transporting those items to another location to be rendered safe, treated, or destroyed. Any reasonable delay in the completion of an explosives or munitions emergency response caused by a necessary, unforeseen, or uncontrollable circumstance will not terminate the explosives or munitions emergency. Explosives and munitions emergency responses can occur on either public or private lands and are not limited to responses at RCRA [Resource Conservation and Recovery Act] facilities (Military Munitions Rule, 40 CFR 260.10).

- munitions constituents (MC)—any materials originating from unexploded ordnance, discarded military munitions, or other military munitions, including explosive and nonexplosive materials, and emission, degradation, or breakdown elements of such ordnance or munitions (10 U.S.C. 2710 [e][4]).

- munitions and explosives of concern (MEC)—this term, which distinguishes specific categories of military munitions that may pose unique explosives safety risks, means (A) UXO, as defined in 10 U.S.C. 2710 (e)(9); (B) discarded military munitions (DMM), as defined in 10 U.S.C. 2710 (e)(2); or (C) explosive munitions constituents (e.g., TNT, RDX) present in high enough concentrations to pose an explosive hazard.

- munitions response (MR)—response actions, including investigation, removal, and remedial actions to address the explosives safety, human health, or environmental risks presented by unexploded ordnance (UXO), discarded military munitions (DMM), or munitions constituents (MC).

- munitions response area (MRA)—any area on a defense site that is known or suspected to contain UXO, DMM, or MC. Examples include former ranges and munitions burial areas. An MRA comprises one or more munitions response sites.

- munitions response site (MRS)—a discrete location within a MRA that is known to require a munitions response.

- military munitions[4]—military munitions means all ammunition products and components produced for or used by the armed forces for national defense and security, including ammunition products or components under the control of the Department of Defense, the Coast Guard, the Department of Energy, and the National Guard. The term includes confined gaseous, liquid, and solid propellants, explosives, pyrotechnics, chemical and riot control agents, smokes and incendiaries, including bulk explosives and chemical warfare agents, chemical munitions, rockets, guided and ballistic missiles, bombs, warheads, mortar rounds, artillery ammunition, small arms ammunition, grenades, mines, torpedoes, depth charges, cluster munitions and dispensers, demolition charges, and devices and components thereof.

  The term does not include wholly inert items, improvised explosive devices, and nuclear weapons, nuclear devices, and nuclear components, other than nonnuclear components of nuclear devices that are managed under the nuclear weapons program of the Department of Energy after all required sanitization operations under the Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq.) have been completed (10 U.S.C. 101(e)(4).

- operational range—a range that is under the jurisdiction, custody, or control of the Secretary of Defense and (A) that is used for range activities or (B) although not currently being used for range activities, that is still considered by the Secretary to be a range and has not been put to a new use that is incompatible with range activities (10 U.S.C. 101 [e][3]).

- range—the term "range," when used in a geographic sense, means a designated land or water area that is set aside, managed, and used for range activities of the Department of Defense. Such term includes the following: (A) Firing lines and positions, maneuver areas, firing lanes, test pads, detonation pads, impact areas, electronic scoring sites, buffer zones with restricted access, and exclusionary areas. (B) Airspace areas designated for military use in accordance with regulations and procedures prescribed by the Administrator of the Federal Aviation Administration (10 U.S.C. 101[e][3]).

- unexploded ordnance (UXO)—military munitions that (A) have been primed, fused, armed, or otherwise prepared for action; (B) have been fired, dropped, launched, projected, or placed in such a manner as to constitute a hazard to operations, installations, personnel, or material; and (C) remain unexploded whether by malfunction, design, or any other cause (10 U.S.C. 101 [e][5]).

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[4] Military munitions is also defined by federal regulation; 40 CFR 260.10 defines "military munitions" as all ammunition products and components produced or used by or for the U.S. Department of Defense or the U.S. Armed Services for national defense and security, including military munitions under the control of the Department of Defense, the U.S. Coast Guard, the U.S. Department of Energy (DOE), and National Guard personnel. The term "military munitions" includes confined gaseous, liquid, and solid propellants, explosives, pyrotechnics, chemical and riot control agents, smokes, and incendiaries used by DoD components, including bulk explosives and chemical warfare agents, chemical munitions, rockets, guided and ballistic missiles, bombs, warheads, mortar rounds, artillery ammunition, small-arms ammunition, grenades, mines, torpedoes, depth charges, cluster munitions and dispensers, demolition charges, and devices and components thereof. Military munitions do not include wholly inert items, improvised explosive devices, and nuclear weapons, nuclear devices, and nuclear components thereof. However, the term does include nonnuclear components of nuclear devices, managed under DOE's nuclear weapons program after all required sanitization operations under the Atomic Energy Act of 1954, as amended, have been completed.

Readers of this and other documents concerning munitions response should be aware that they will see other terminology related to munitions response. The most likely term that will be encountered is "ordnance and explosives" (OE), which has been officially replaced by "MEC" and has essentially the same meaning.

1.4 Document Organization and How to Use this Document

This document has been organized for use as both guidance and reference. Consequently, it provides information not only on GPOs, but also on the broader topics of geophysical surveys, equipment, and methodologies currently used in munitions response actions. This broader topic information is provided to give the reader the background necessary to understand the context of GPOs in munitions response actions.

This document is not necessarily intended to be read cover to cover. Instead, the reader is encouraged to explore the document and focus on those chapters and topics of specific interest or relevance.

- Chapter 1 provides the basic introduction to this document and geophysical prove-outs, as well as current MR terminology.

- Chapter 2 provides an introduction to geophysics and geophysical technology, equipment, and techniques currently used for munitions response actions. It is recommended that those not familiar with UXO geophysics read Chapter 2 because it provides the basic background information needed by anyone participating in the review and evaluation of a GPO plan or report. Readers of this document already familiar with geophysics used in munitions response may find a brief review this chapter adequate.

- Chapter 3 is an introduction to the goals of GPOs and provides several examples of GPO objectives and the influence of the objectives on the GPO design.

- Chapter 4 is an introduction to the GPO technical process. It introduces each of the following major steps in the GPO process:
  - *Design*—encompassing the development of GPO objectives, site location selection, GPO design, and work plan development
  - *Construction*—preparing the site, followed by burying (seeding) of items to be detected in the test plot
  - *Implementation*—testing of candidate geophysical systems in accordance with the work plan, including reacquisition and evaluation
  - *Reporting*—documenting the performance of the instrument(s) used in the GPO, survey maps, anomaly maps, and dig sheets.

- Chapter 5 is intended as an encyclopedic reference covering GPO data quality objectives (DQOs) and performance metrics. Specifically, it explains how objectives are established for a GPO, the importance of data quality, and the calculation and application of example GPO performance measures. It is critical that project goals and objectives be identified before undertaking a GPO. These goals and objectives may vary dependent on whether the project in question is an investigation, a removal, or a remedial action.

- Chapter 6 covers specific issues, concerns, and recommendations for each major step of a GPO. It is presented in a question-and-answer format to assist state regulators in facilitating dialogue and communicating expectations for a planned GPO and assessing the adequacy of completed GPOs.

2. INTRODUCTION TO GEOPHYSICAL SURVEYS

Geophysics involves the application of physical theories and measurements to discover the properties of the earth. Geophysical surveys are typically noninvasive investigations of the earth's surface and subsurface involving the measuring, analyzing, and interpreting of physical fields. While some studies can extend to depths of tens of meters or more below ground surface (bgs), geophysical surveys for MR actions are used to investigate the near subsurface (the upper meter or so).

Geophysical surveys for MR actions utilize the equipment, personnel, and procedures necessary to detect subsurface anomalies in a nonintrusive manner. If buried military munitions can be confidently and efficiently located, excavation is a relatively straightforward process. However, if the geophysical investigation process is not adequate, then one of two things may happen as a result: some of the military munitions will not be detected and will be left in the ground or items that are not military munitions will be detected but not properly identified, resulting in unnecessary excavations.

2.1 Geophysics and Geophysical Equipment

For MR efforts, the selection of the equipment, personnel, and procedures used to detect and locate anomalies greatly affects the efficiency and effectiveness of the geophysical survey.

Geophysical detection and positioning methods range from basic to more complex. The simplest methods utilize handheld instruments that alert the operator to anomalies with a visible or audio signal. The operator records the anomaly location with a pin and flag. This method is commonly referred to as "mag and flag." More sophisticated devices acquire geophysical data using self-recording instruments. The data is post-processed to identify anomalies for further investigation. This method is called digital geophysical mapping (DGM).

> **Effectiveness**—The degree to which the geophysical process meets or exceeds the needs and requirements of the stakeholders (owner, client, regulator and public). It answers the question, *"How well does the geophysical system perform?"*
>
> **Efficiency**—The degree of effectiveness of the process compared to the resources used. Optimizing efficiency leads to customer satisfaction by minimizing time and cost and maximizing value. It answers the question, *"How long does it take and how much does it cost ?"*

The methodology selected should ultimately be the one that will meet the performance objectives for the response action and should be able to detect the items of interest to specified depths. Because there are relatively wide variances in both the capabilities and cost in currently available geophysical investigation technologies and procedures, trade-offs between effectiveness and efficiency may be necessary. These trade-offs should be understood and explicitly incorporated into the decision-making process as necessary.

2.1.1 Mag and Flag Method

For analog mag and flag surveys, UXO personnel survey the area with geophysical sensors and manually interpret anomalies and surface-mark them with nonmetallic flags for excavation (Figures 2-1 and 2-2). A summary of the excavation results (often referred to as a "dig sheet") is produced for the area as is documentation of quality control results.

Figure 2-1. Mag and flag survey.

Figure 2-2. Flags marking selected anomalies following a mag and flag survey.

Mag and flag surveys may be the most appropriate option, or even the only option, for conducting a geophysical survey, especially where high MEC density, high magnetic noise, and/or access may be issues. In addition, there is a low capital cost for equipment associated with this methodology. However, there are several disadvantages in using mag and flag surveys: the process is difficult to QC (i.e., to measure the ability of the technician to interpret the geophysical instrument's signal); the tools most commonly used are significantly less sensitive to the physical parameters being measured than most digital geophysical equipment; it is impossible to verify that the entire search was covered by the geophysical sensor operators; and last, no direct record of geophysical data or the decision-making process is produced.

2.1.2 Digital Geophysical Mapping Methods

As a result of advances in geophysical sensors, field techniques, and global positioning systems (GPS), the use of digital geophysical methods for geophysical surveys has become more widespread for MR projects. Using DGM methods, the ground is "mapped" by correlating sensor data points with GPS coordinates. The survey data from the geophysical survey is processed and analyzed, and anomalies within the data are selected. As a result, a dig sheets are compiled that record the anomalies selected for excavation (Figure 2-3). After excavation, the dig sheets also show the results of those excavations. The dig sheets and the electronic records of geophysical and positioning data should be archived and available for data quality review.

						Dig Results								Excavation Results		
									Offset							
Target ID	Northing	Easting	Amplitude (mv)	Date	Date Reacquired	Anomaly Type	# of Contacts	weight (lbs)	Distance (ft)	Direction	Depth to Top	Date	Team Leader Initials	Excavation Hole Cleared?	QC Initials	Date

Figure 2-3. Typical dig sheet information.

This methodology represents an improvement over mag and flag methods because of the improved ability not only to locate anomalies but to locate them to a greater depth and, in some limited circumstances, the ability to characterize a buried item as MEC or non-MEC.[5]

2.2 Geophysical Survey Process

This section is intended as a general overview of a complex, and at times highly technical, geophysical survey process. For more detailed information regarding the overall geophysical survey process, refer to Chapter 7 of *Ordnance and Explosives Response* (USACE 2000b).

The geophysical survey process for munitions response actions consists of a series of steps. This document breaks this process into nine possible steps—from defining the survey area, to selecting and deploying the survey equipment, to reporting the results (Figure 2-4). The actual number and sequence of steps in this process varies from site to site and depends on the type of geophysical survey conducted (mag and flag or DGM) and whether a GPO is needed to select the equipment to be used in the survey.

2.2.1 Define Survey Area

The geophysical investigation area will have been previously identified in the conceptual site model (CSM) as the area where potential munitions contamination is to be investigated. During the course of the geophysical investigation, the CSM and geophysical investigation area may be further refined based on geophysical survey results. A professional land survey is typically conducted to delineate the boundaries of the investigation area before the geophysical survey is conducted.

[5] Target size and depth can be reliably recovered from magnetometer data for single items. On sites with limited munitions types with low to moderate densities where isolated signatures can be measured, cultural and munitions debris can be screened reliably from military munitions.

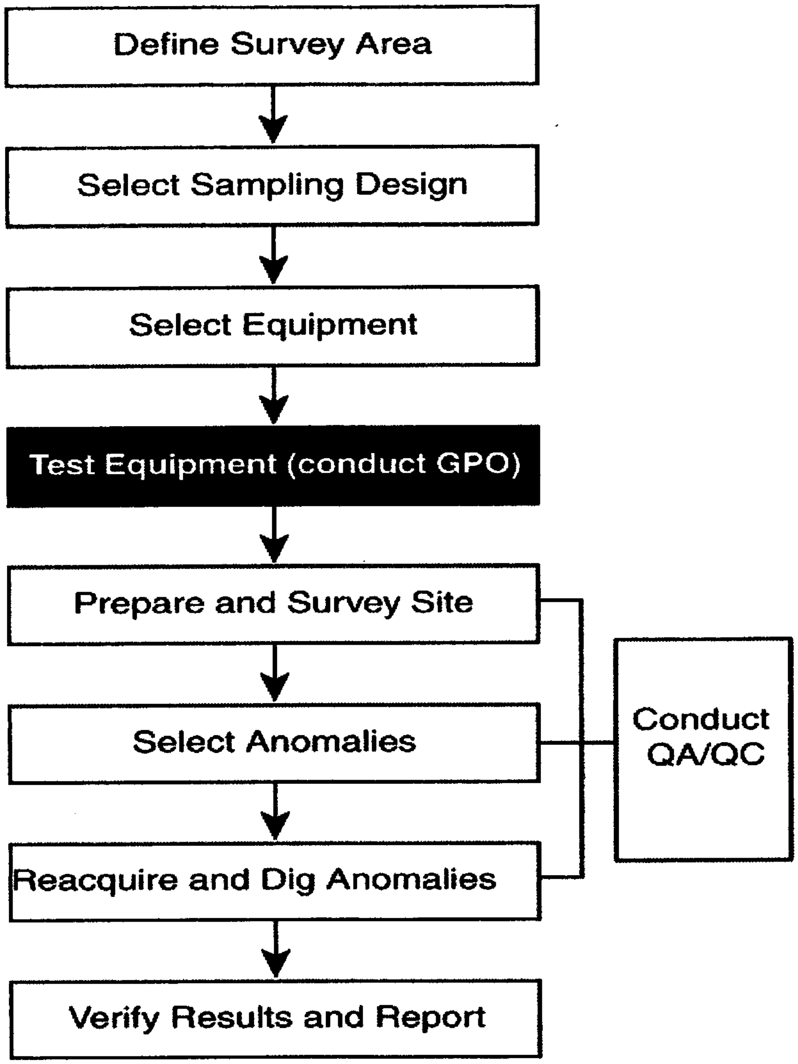

Figure 2-4. Geophysical survey process. A GPO may be conducted to test equipment and, if necessary, to select equipment.

2.2.2 Select Sampling Design

The determination of the survey approach (mag and flag or DGM) is a critical component of the sampling design. Sampling design is influenced by the phase of the response action (i.e., site inspection, detailed investigation, or cleanup action), the overall goals and objectives for that response action, the type of military munitions expected to be found, and the terrain and vegetation of the site. Therefore, these goals and objectives need to be defined and documented before beginning the sampling design.

The sampling design includes the general types of equipment, methods, and personnel to be used in the geophysical survey. The equipment design includes the type of sensor, deployment platform, positioning and navigational equipment, and data processing systems to be used in the survey. The methodology includes the type of survey coverage scheme and minimum data collection parameters to be used in the survey. The equipment and methodology will be dictated largely by the type and size of munitions of concern, the site's terrain, and specific project DQOs.

2.2.3 Select Equipment

The sampling design process may have already identified the equipment to be used for the geophysical survey. If not, a GPO can be used to select the equipment to be used for the survey. In some cases, several different types of equipment can be expected to meet the sampling design criteria. In this situation, a GPO designed as a competitive field demonstration may not be needed but may be helpful in selecting the equipment that will most efficiently meet the design criteria. In other cases, the types of equipment that could meet the design criteria may not be known, especially at sites with challenging conditions. In this situation, several types of equipment may be evaluated to determine which has the best chance of successfully meeting the survey goals, objectives, and specific DQOs. In either case, standardized geophysical test sites results can be used to help select the equipment to be tested using a GPO (see *Standardized UXO Technology Demonstration Handbook* [U.S. Army Aberdeen Test Center 2002]).

2.2.4 Test Equipment (Conduct GPO)

The equipment selected to perform the geophysical investigation must be tested under site-specific conditions to determine and document its capability to meet the project's overall goals and objectives as well as specific DQOs. A GPO determines and documents this capability. If a GPO is used to select equipment as described above, the GPO to test the equipment may be conducted concurrently.

In a GPO, the survey equipment is deployed over an area representative of the proposed survey area in terms of site characteristics. The prove-out area is seeded with inert military munitions or their surrogates to determine the capabilities of the proposed survey methods to detect the military munitions expected to be found on the site. The GPO tests the entire survey process from field data collection to anomaly selection to anomaly reacquisition. The GPO process is discussed in greater detail in Chapter 4.

The Importance of GPOs in the Geophysical Survey Process

The recent experience of a geophysics specialty contractor on a MRS in Colorado highlights the importance of performing an adequate GPO. This project was near the contractor's office, the geology of the area was well known, and the contractor had previously worked on MRSs in the same area.

The contractor's first attempt at the GPO did not meet the established DQOs. During this attempt, the data was found to be inadequate. Upon investigation, it was determined that the geophysical sensor used in the GPO had been modified for use at another site and subsequently did not perform as expected on the site in question.

The second GPO attempt did not meet the DQOs either. Upon investigation, it was determined that transmissions from a nearby aircraft control tower were interfering with the GPS signal from the contractor's ground base station and corrupting the positioning data. Use of a different model GPS solved this problem.

The contractor met the DQOs on the third GPO attempt. The use of a GPO on this project resulted in a significant time and cost savings by avoiding the collection of inadequate geophysical and positioning data during the geophysical survey.

2.2.5 Prepare and Survey Site

Once the equipment has been selected and a GPO conducted to verify its performance capabilities, the survey site is prepared for the geophysical survey by conducting any necessary safety work and site preparation activities. This process typically includes a MEC surface clearance to remove any MEC potential hazards to the survey team, removal of surficial metallic objects to eliminate potential interference, vegetation clearance, and establishment of survey grids and control points.

Vegetation clearance is conducted in areas where grass, brush, or trees must be removed to gain access to map the survey area. Methods of vegetation clearance can include mowing, grubbing, and controlled burns. For surveys of large areas, the site is typically gridded to create a local location reference system. During survey preparation, the grid is set in the field by placing flags, laths, steel nails, or spikes at the corners of each grid to establish survey controls for the geophysical data.

After the site is prepared, the survey is conducted by deploying the selected equipment utilizing the methods and procedures defined in the geophysical survey plan. Production geophysical survey rates are site- and equipment-dependent and can vary from less than an acre per day for man-portable equipment to several tens or hundreds of acres per day for towed arrays or airborne surveys on open terrain.

2.2.6 Select Anomalies

For mag and flag projects, UXO technicians put a nonmetallic flag in the ground where anomalies are detected. For DGM surveys, the raw data is collected in the field, then further processed and analyzed by project geophysicists to develop a map of subsurface geophysical anomalies. The anomalies are then evaluated using the geophysical target selection criteria to establish a dig list. The dig list shows anomaly locations to be investigated by field UXO personnel. As a QC measure and a false negative check, a random percentage of anomalies not selected as digs may also be investigated.

2.2.7 Reacquire and Dig Anomalies

In DGM surveys, anomaly locations identified during the selection phase must be reacquired (relocated) in the field. Anomaly locations are sent to the field as coordinates on the dig sheet. The exact coordinates are then reacquired. A search radius based on positioning system accuracy is established around each coordinate. Within the search radius, handheld detectors are used to pinpoint specific anomalies for excavation. It is not uncommon to find multiple discrete anomalies within a search radius. In mag and flag surveys, anomaly locations are identified in real time with a flag and therefore do not have to be reacquired.

Regardless of the type of survey conducted, each anomaly is excavated. The amount of data collected during the digs is dependent on the survey goals, objectives, and specific DQOs. The amount of data can also vary greatly depending on the phase of the response action (i.e., site inspection, detailed investigation, or cleanup action).

At this step, potentially hazardous excavated items are either destroyed in situ (known as "blown in place," or "BIP") or removed from the immediate area to be destroyed with other recovered remnants. Nonhazardous munitions scrap is processed for disposal, while cultural debris (nails, fence wire, horseshoes, etc.) is removed. After excavation of the anomalies, the area is rescreened with the handheld instrument(s) to ensure that no items have been missed. Each dig location is checked and verified in the field to ensure that all potential anomalies are located, dug, and investigated.

2.2.8 Conduct Quality Assurance/Quality Control

Standard, accepted QA/QC procedures that are applicable to other deliverable products are applicable to the process of geophysical surveys for munitions response. Traditionally, the person, company, or organization performing the work performs QC to ensure that the performed work meets internal or contractual standards for quality. The party accepting the work usually performs the QA to verify that the required quality standards have been achieved.

DGM surveys require additional QA/QC measures. For example, daily sensor function checks should be conducted before data collection begins. Also, the dig results are sent to the project geophysicist to evaluate the target anomaly signature against the items removed from the location. In some instances, the geophysical mapping equipment is also deployed to remap areas and/or individual anomalies and verify removals and the resulting data checked to make sure it meets specifications. There are additional QC/QA measures throughout the geophysical survey process not specifically mentioned in this summary. Specific QC procedures are required when anomaly resolution decisions use instruments that differ from those used to initially select the anomalies.

Regardless of the type of survey performed, the DQOs for the survey are reviewed against the survey results to verify that the survey has met its objectives and quality standards.

2.2.9 Verify and Report the Results

The final step in the process is to verify the process and report the results. Again, the level of verification and reporting depend on the type of survey, its overall goals and objectives, and the DQOs. At this step, the results of the survey are compiled, achievement of DQOs is documented, data files are compiled for final submission, and a final survey report is prepared.

2.3 Geophysical Survey Tools and Equipment

A geophysical survey system for either mag and flag or DGM is composed of four main elements: the geophysical sensor, survey platform, positioning system, and data processing system. These elements are discussed below in general and in more detail in the following subsections.

With its central role in detecting anomalies, the geophysical sensor is generally the main focus in equipment selection. However, the three remaining elements are also critical to the success of the overall geophysical system. The survey platform deploys the geophysical sensor and not only governs the terrain in which the system can be operated, but is also a major factor in system and motion noise, as well. The positioning equipment determines the geophysical sensor's geographic location at each data point recorded during the survey. The data processing system ultimately determines how data is handled and how targets are selected and interpreted.

For mag and flag surveys, these elements are inherent to the survey method—the UXO technician holding the sensor is both the survey platform and the data processing system. For DGM surveys, the elements are usually more complex, and many are integrated into the mapping system.

2.3.1 Geophysical Sensors

There are currently two types of geophysical sensors commonly used at most munitions response sites: magnetometers (mag) and electromagnetic induction (EMI) devices. These sensors are well characterized and broadly accepted by the industry. Ground-penetrating radar (GPR) instruments have also been used but have a very limited applicability for munitions response. These technologies are all nonintrusive tools to identify subsurface anomalies, including those that may be caused by subsurface MEC. Table 2-1 summarizes the capabilities and limitations for each method.

- ***Magnetometers.*** Magnetometry is the science of measurement and interpretation of magnetic fields. Magnetometers locate buried munitions by detecting irregularities in the earth's magnetic field caused by the ferromagnetic materials in munitions. Magnetometers are passive devices and respond to ferrous materials, such as iron, steel, and brass. Magnetometers do not respond to metals that are not ferromagnetic, such as copper, tin, and aluminum. Typically these sensors perform better for large, deep, ferrous objects. They may also detect small ferrous objects at or near the surface better than electromagnetic sensors with large sensor coils.

  Fluxgate magnetometers are typically the type of magnetometers used for mag and flag surveys, although a wide variety of handheld digital and analog magnetometers can be used. Typically inexpensive and easy to operate, fluxgate magnetometers are also used for anomaly reacquisition. Although many fluxgate magnetometers do not digitally record data, data loggers can be adapted to be used with this type of magnetometer. One disadvantage of this type of magnetometer is that it must be leveled to provide accurate measurements. Also, it typically has a higher noise floor than other instruments.

  Another type of magnetometer used for mag and flag surveys is the cesium vapor magnetometer. Lightweight and portable, the principal advantage of cesium vapor magnetometers is their rapid data collection capability. One disadvantage of this type of magnetometer is that it is insensitive to the magnetic field in certain directions. Also, dropouts can occur where the magnetic field is not measured; however, this problem can be avoided with proper field procedures.

Table 2-1. Comparison of detection technologies for geophysical surveys

Technology	Description	Capabilities	Limitations
Magnetometry	Magnetometry locates buried military munitions by detecting irregularities in the earth's magnetic field caused by materials in munitions. This is a completely passive system that emits no electromagnetic (EM) radiation.	• Can detect larger ferrous objects at deeper depths than EMI methods. • Can detect small ferrous objects at or near the surface better than EM sensors with large sensor coils. • Multiple systems can be linked together in an array to enhance production rates and increase efficiency. • Data can be analyzed to estimate target size and depth.	• Detects only ferrous materials. • Influenced by high concentrations of surface munitions fragments, background magnetic noise, and site-specific soil properties. • Commonly used magnetometers are less sensitive than most EM sensors. • Instrument response may be affected by nearby power lines and cultural features.
Electromagnetic induction	EMI systems induce an electromagnetic field and measure the response of objects near the sensor. These systems measure the secondary magnetic field induced in metal objects either in the time domain or frequency domain. Conductive objects such as UXO have very different EM properties from soils.	• Detects both ferrous and nonferrous metallic objects. • Advanced systems have multiple frequency and time gates. • Additional data can provide information on target shape, orientation, and material properties. • Multiple sensors can be linked together in an array to enhance production rates and increase efficiency. • EM systems are less susceptible to cultural noise sources, such as utilities, fences, etc. than magnetic methods.	• Influenced by high concentrations of surface munitions fragments. • Limited depth of investigation because the signal falls off with distance—$1/R^6$ vs. $1/R^3$ for magnetometry. EM radiation may be a hazard around electrosensitive munitions, particularly certain fuzes. • Limited by vegetation and steep terrain. • Although less susceptible to cultural noise, EM systems may still be affected by nearby power lines and cultural features in close proximity to the sensor.
Ground-penetrating radar	GPR systems transmit short pulses of electromagnetic energy into the ground; buried objects reflect the signals back to the receiving unit, where they are recorded and may be processed into an image.	• GPR responds to both ferrous and nonferrous materials. • Multiple systems can be linked together in an array to enhance production rates and increase efficiency.	• Extremely site specific with minimal applicability to MRSs; generally not recommended for most sites. • Performance is severely degraded by conductive and metallic soils. • Saturated soils can attenuate signal response. • Limited by vegetation and steep terrain. • Can be computationally intensive. • Susceptible to clutter from a wide variety of sources.

- ***Electromagnetic Induction.*** EMI is a geophysical technology used to transmit an electromagnetic field beneath the earth's surface, which in turn induces a secondary magnetic field around objects (ferrous and nonferrous metallic materials) that have conductive properties. When secondary magnetic fields of military munitions and other conductive items exceed background responses, they can be identified as potential anomalies requiring further investigation.

  There are two basic modes of EMI operation: frequency domain and time domain. Frequency-domain electromagnetic (FDEM) systems measure the response of the subsurface as a function of frequency. These systems are used for MEC detection and discrimination; some have also been used for detecting boundaries of trenches that may be MEC disposal sites. Time-domain electromagnetic (TDEM) systems measure the response of the subsurface to a pulsed electromagnetic field. In more advanced instruments, measurements can be made in multiple time gates (TDEM systems) and multiple frequencies (FDEM systems), which can increase the information obtained about the physical properties of the targets.

- ***Dual Sensor Systems.*** Dual sensor systems incorporate both mag and electromagnetic sensors onto a single platform and perform both mag and EMI surveys. However, no system is currently capable of measuring co-registered magnetic and EM data simultaneously because the magnetic field can be measured only after the EM field has completely decayed. Therefore, new sampling electronics are being developed that alternately sample the magnetometer and the pulsed EM data.

- ***Ground-Penetrating Radar.*** GPR can detect metallic and nonmetallic items under ideal circumstances. A GPR system radiates short pulses of high-frequency EM energy into the ground from a transmitting antenna. This EM wave propagates into the ground at a velocity related to the electrical properties of subsurface materials. When this wave encounters the interface of two materials having different dielectric properties (e.g., soil and MEC), a portion of the energy is reflected back to the surface, where it is detected by a receiver antenna and transmitted to a control unit for processing and display.

  The performance of GPR systems is strongly dependent on site-specific conditions. It can be computationally intensive and produce large data volumes. Due to the current limitations of this technology, GPR is not a good candidate for detecting individual items as magnetic and EM methods are more effective and much more efficient for MR actions. However, GPR can be useful for detecting large concentrations of buried military munitions, as well as detecting the boundaries of impact areas.

- ***Emerging Sensor Technology.*** New sensor technologies are currently being developed for detecting and characterizing MEC and are in various stages of demonstration and validation. DoD funds research and development, including efforts to explore new technologies capable of cost-effectively characterizing and remediating sites contaminated with MEC. The Army's EQT program focuses specifically on MEC detection and discrimination technologies. DoD's SERDP supports basic and applied research on MEC-related innovative technology. DoD's

ESTCP demonstrates and validates emerging technologies. Additional information on emerging sensor technology is available on the programs' Web sites (see Section 7.2).

2.3.2 Survey Platforms

Survey platforms deploy geophysical sensors to survey an area. There are four basic types of survey platforms: handheld, cart-mounted, towed array, and airborne. The choice of survey platform is dictated by terrain, vegetation, and the accessibility and size of the survey site. Handheld or cart-mounted survey platforms are also referred to as "man-portable" systems. A variation on the handheld survey platform has a technician carrying the survey equipment using a shoulder harness.

- ***Handheld.*** Handheld platforms have the advantage of being deployable under most site conditions. Handheld platforms can include handheld instruments (Figures 2-5 and 2-6) as well as larger, man-portable systems (i.e., shoulder harness platforms) and can be used to collect either mag and flag or DGM data.

  The procedures used for deployment of handheld sensors depend on the type of survey being conducted. These procedures include the following:
  - sweeping an analog sensor back and forth across a designated survey lane and listening for an audible alarm indicating an anomaly;
  - carrying a handheld sensor on a steady, predetermined path to collect DGM data; or
  - a combination of the two where the operator walks a predetermined path but also has the freedom to stop and investigate specific areas while data is continuously recorded using DGM and GPS positioning.

Figure 2-5. Handheld magnetometer.

Figure 2-6. Handheld electromagnetic detector.

  In heavily wooded areas or areas with steep or uneven terrain, handheld sensors may be the only suitable sensor deployment method. However, there are several disadvantages of handheld sensor deployment—it is relatively slow when compared to towed array and airborne deployment, and second, sensor height above the ground surface tends to be more variable when compared to cart-mounted systems. These fluctuations in height above the ground increase noise and the system's sensitivity for detecting anomalies.

- ***Cart-Mounted.*** In cart-mounted systems, the geophysical sensor is on a wheeled cart transported across the survey area by a person (Figures 2-7 and 2-8). Cart platforms can be deployed for single- or multisensor mag or EM systems.

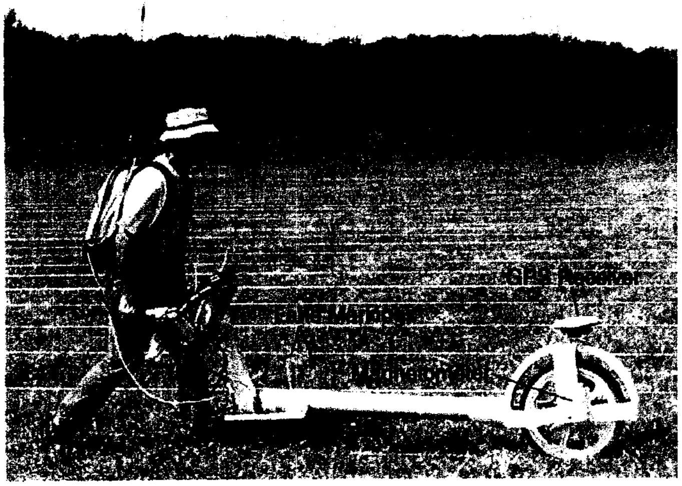

Figure 2-7. Cart-mounted magnetometer.

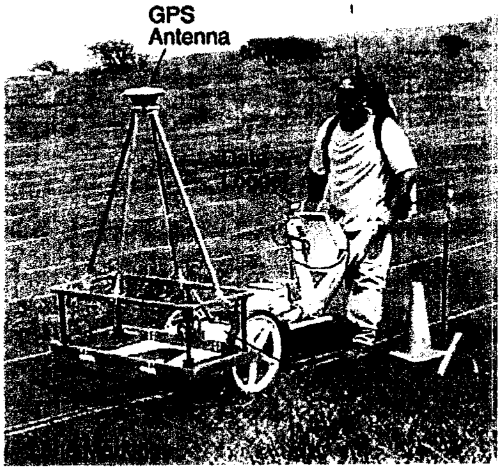

Figure 2-8. Cart-mounted EM.

Advantages of cart-mounted over handheld systems include greater stability, efficient areal coverage, and ability to carry more weight. Fixed sensor height minimizes ground strikes and fluctuating sensor height, which degrade the geophysical data collected during the survey. However, cart-mounted systems can be limited by topography and vegetation and require significant operator stamina and physical strength to operate. Cart-mounted systems generally have lower survey rates than vehicle-towed and airborne systems.

- ***Towed Arrays.*** Towed-array systems incorporate a vehicle to tow cart-mounted sensors (Figure 2-9). These sensors are placed horizontally and/or vertically on a cart, increasing their spatial coverage during a single pass. Whereas handheld and cart-mounted systems are limited to a walking speed of 1–2 mph or less, towed-array systems allow for greater survey speeds. They also allow for very controlled data acquisition and greater platform weight; however, they have the potential for mechanical failure and can be used on only relatively flat and sparsely vegetated areas. Man-portable systems may be used to augment surveys in areas not accessible to the towed-array system.

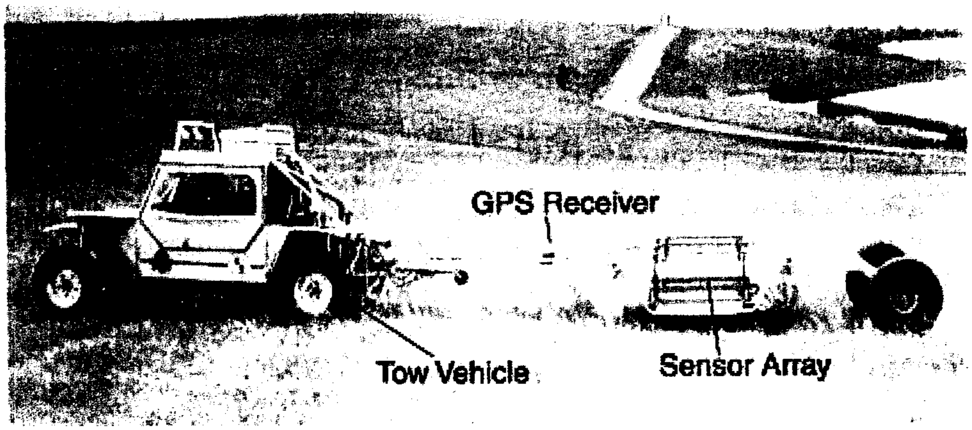

Figure 2-9. Towed sensor array.

- ***Airborne.*** Airborne survey platforms have been deployed using helicopter and fixed-wing aircraft. Helicopter-based systems (Figure 2-10) have the ability to rapidly collect magnetic or EM data. These surveys require very low flying heights, typically 1–3 meters, to maximize detection capability. The main advantage of these systems is their ability to collect data very rapidly over a large survey area. The main disadvantages are a lower detection capability than ground-based systems (especially for smaller MEC), platform noise, safety issues, and the requirement for the survey area to be relatively flat and free of trees, shrubs, and other obstacles with heights above a meter or so.

Figure 2-10. Helicopter-based survey.

  Fixed-wing systems (Figure 2-11) can cover large areas very rapidly, but the requirement to fly at a safe ground clearance means that magnetic or EM data collection is impractical. Instead, fixed-wing aircraft typically carry sensors that indirectly detect the presence of subsurface military munitions through their surface expression. Examples include the use of synthetic aperture radar (SAR) to detect surface metal and light detection and ranging (LiDAR) to detect topographic depressions characteristic of bomb craters.

Figure 2-11. Airborne survey.

  Thus, fixed-wing and helicopter airborne sensors are typically used in a wide area assessment role where the task is to identify areas of mass UXO contamination that require additional investigation. Helicopter systems can also be used for individual target detection on large bombing targets.

- ***Survey Coverage Schemes.*** Methods and procedures include determining the survey coverage scheme (Figure 2-12) and defining minimum data collection parameters, such as line spacing and sampling distances. Selection of the survey pattern, instrumentation, and line spacing are dictated largely by the survey DQOs and also by the type and size of munitions believed to be buried.

<u>2.3.3 Positioning Equipment</u>

A positioning technology is needed in digital geophysics to produce any type of representation or mapping of the earth's surface or subsurface. Positioning technologies determine the sensor's

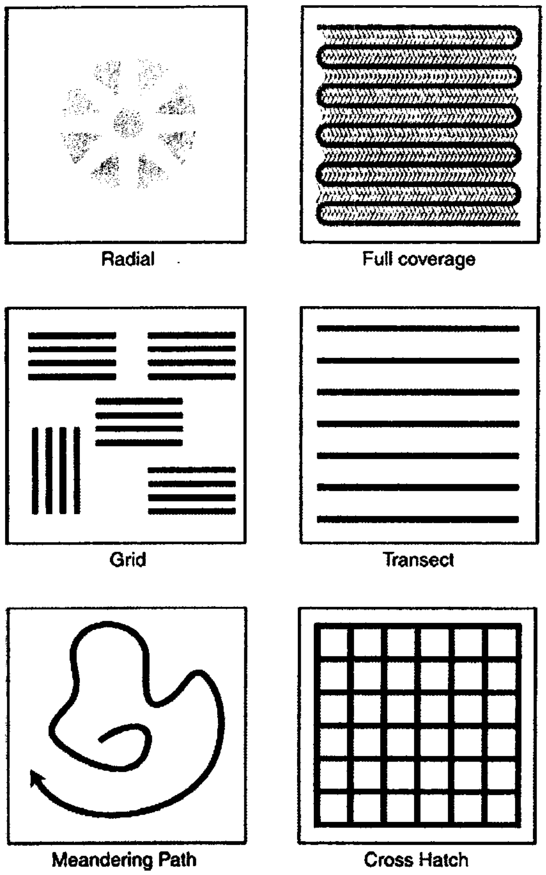

Figure 2-12. Geophysical survey coverage schemes.

geographic location at each data point recorded. From this information, a map of the sensor response and a record of the travel pathways can be produced. Accuracy, effects of terrain, tree canopy, line of site, ease of use, and costs are generally the most significant criteria for technology selection. Therefore, part of the purpose of a GPO is to test the capability of the positioning technology to be used at the site, including the procedures used to merge the positional data and the geophysical data.

Locations can be determined by many different techniques of varying sophistication. Traditional surveying techniques may use tapes and trigonometry to determine relative positions from known ground points. Highly accurate optical laser–based measuring equipment can provide centimeter accuracy in a continuous tracking mode. Other techniques rely upon various applications of differential GPS (DGPS), ultrasonic radio ranging, and inertial navigation systems. In more advanced systems, positioning technologies are directly integrated with geophysical sensors to provide a digital output that can be directly merged with sensor readings for creation of a site map.

For DGM surveys, positioning systems locate the sensor position to enable data interpretation and geophysical anomaly selection for production of a dig list. The ability to correctly locate the position of an emplaced item from the geophysical data depends not only on the positioning technology selected, but also on the physical size of the sensor and the manner in which the geophysical data is processed to determine the location of the anomaly. Various other error sources can degrade anomaly location, including uncorrected motion of the platform in rough terrain, poor data analysis procedures, or timing discrepancies between sensor and navigation system readings. The positioning system used in the survey or a separate system may then be used for the reacquisition of anomalies. It is common practice to employ a second sensor to "pinpoint" anomalies based on locations identified from the initial mapping and the data analysis. This practice may in fact introduce additional positioning errors, depending on the characteristics of the reacquisition sensor and positioning system. The determination of overall system positioning accuracy can be measured by the location picked either during data processing or during reacquisition. Which one is the appropriate measure of overall system location accuracy depends on how the contractor proposes to pick and reacquire targets and should be documented in the work plan.

Acceptable positioning accuracy results are based on site conditions, project objectives, and costs. The most desirable positioning systems are ones that are directly integrated with geophysical sensors, record data digitally, and map data to provide anomaly locations in all terrain and tree canopies.

- ***Laser-Based Systems.*** Laser-based survey and tracking systems measure a highly accurate position relative to a fixed base station location. In a common implementation, a base station is surveyed in at a known location. The base station tripod holds a transmit laser on a robotic mount. The roving sensor platform is outfitted with a prism that reflects the laser from the transmitter. The distance to between the base station and the prism is measured by the time of flight of the laser pulse and the azimuth and elevation angles are accurately tracked by the robotic mount. This information is processed by an on-board computer to calculate the position of the prism in three dimensions. The computer also contains software to lock on to and track the position of the prism in real time to allow on-the-fly data acquisition.

- ***Differential GPS.*** GPS satellites orbit the earth transmitting a signal, which can be detected by anyone with a GPS receiver. DGPS increases the accuracy of GPS readings by using two receivers: a stationary receiver that acts as a base station and collects data at a known location and a second roving receiver that makes the position measurements. Base stations can be configured either to transmit the correction data to the rover system or to save the data to be used to correct positional data during post-processing. These corrections increase the accuracy of the GPS readings, with most modern systems capable of locating individual data points with an accuracy of 20–30 cm.

  Advantages of positioning using DGPS methods include the accuracy that can be achieved in open terrain, rapid update rate, unlimited range, and ease of operation. System weaknesses include intermittent loss of adequate satellite coverage, which affects the accuracy of the results, and the potential for operators to be unfamiliar with the system's capabilities and limitations. In addition, tree canopy, deep ravines, or other topographical features can also degrade the system's accuracy because they can interfere with the GPS receiver's ability to detect satellite signals.

- ***Fiducial Positioning.*** Fiducial positioning is a method of placing electronic markers indicating locations within a set of recorded geophysical data. To perform the geophysical survey using fiducial positioning, the surveyor depresses the electronic switch to insert a fiducial marker at the beginning of a data set and simultaneously starts walking a straight line at a constant pace. The surveyor continues walking at a constant pace and depresses the electronic switch to place fiducial markers as he crosses the marker ropes. Fiducial markers are typically placed at 25-, 50-, or 100-foot intervals, depending on site-specific needs. It is generally accepted that a well-trained operator can maintain a constant pace and a straight line dead-reckoning (to within 1 foot) between distances of up to 100 feet under good conditions (line-of-site, only minor obstructions, and relatively even ground). Greater distances can be achieved if range markers are used.

  The purpose of placing fiducial markers in the geophysical data is to compensate for variances in the speed with which the surveyor walks or drives the geophysical sensor while acquiring data. Fiducial positioning can also be used in the event that the surveyor has to stop due to an obstruction in his path. The process for dealing with obstructions should be defined ahead of time in the work plan, demonstrated during the GPO, and documented in a field logbook during the geophysical survey.

Key factors governing the success of line and fiducial positioning are the assumptions that a straight line was maintained between fiducial marker points and that a constant pace was maintained during each segment. If either of these assumptions is not maintained, the accuracy of line and fiducial positioned data degrade. It should also be noted that it is very difficult to quantify the accuracy of line and fiducial positioning because, unlike DGPS or any other electronic positioning method, there is no physical or digital record of where the operator actually traveled while collecting the data.

- ***Ropes-and-Lanes Positioning.*** Rope and lanes can also be used as a local positioning method. Most commonly associated with "mag and flag" surveys, this method has the advantage of being very "low tech" and can work when other more sophisticated positioning methods break down.

  The concept of ropes-and-lanes positioning is to use physical markers on the ground (i.e., the ropes) to create lanes to guide the surveyors (Figure 2-13). Two baselines are established across the opposite ends of the survey area (usually a grid, which is often a 100- × 100- or 200- × 200-foot area). Grid lane lines can then be tied to the baseline knotted rope or stakes. The lane lines mark the boundaries of each 5-foot-wide lane and are used as guides by the magnetometer operators to help ensure complete coverage of the grid. The grid lanes are then surveyed. The survey results are recorded by lane with the relative position of anomalies or other features displayed on a lane or grid map. This method can be accurate within 1 foot if care is taken when recording data on the lane or grid maps and field notes.

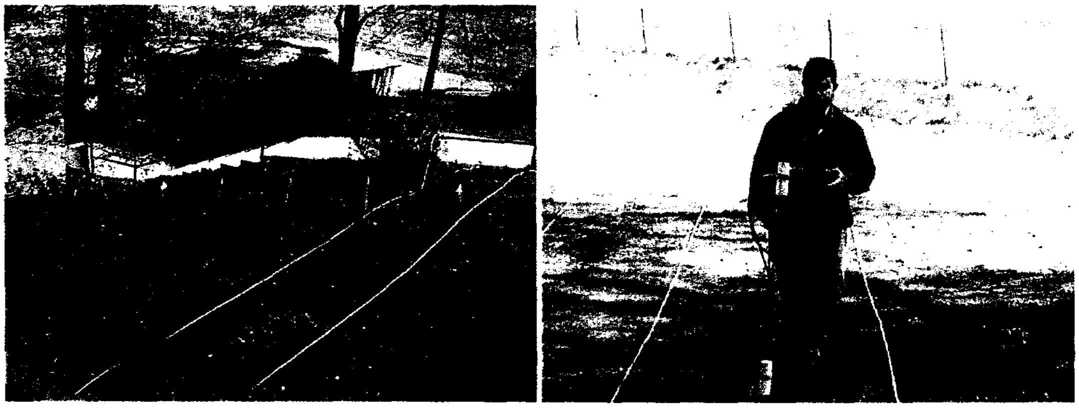

Figure 2-13. Ropes-and-lanes navigation in a geophysical survey area.

2.3.4 Data Processing

Data processing encompasses the steps necessary to convert raw survey data into anomaly locations. For mag and flag surveys using analog instruments, the UXO technician interprets the data (i.e., the instrument's signals) in real time while conducting the survey and immediately identifies and flags anomaly locations. For DGM surveys, digital sensor data is recorded in the field by a data acquisition system (i.e., data logger or computer) and is processed and analyzed after the survey is completed. Digital data processing includes corrections made to the raw data to account for sensor drift, heading errors, etc. This sensor data is tabulated and often reported in an ASCII-delimited data file or spreadsheet and includes X and Y coordinate information. Additional information that may be recorded includes values of the measured potential field, time stamp, positioning quality indicators, and instrument operating response. Post-processing of digital data consists of merging the geophysical sensor and positional data, filtering, de-medianing, and gridding. The resulting data set represents the potential fields that were measured.

Outputs from data analysis and interpretations usually include maps of the interpreted data and databases of anomaly selections that include coordinate information and anomaly characteristics.

2.4 Geophysical Survey Results and Outcome

In general, the products of the geophysical surveys on an MRS are a map and a geophysical report containing a discussion of site conditions, methods, equipment and procedures, data processing methods, and the QA/QC process for both the survey process and the data management phases of the projects. The report may also include items such as production rates, difficulties encountered in the survey process, and path forward recommendations. The complexity of the report reflects the complexity of the geophysical survey. In addition, the types of maps included in the report vary depending on the type of survey conducted because magnetic and electromagnetic surveys measure different physical properties of the subsurface anomalies.

Dig sheets are produced by geophysicists based on analysis of sensor data. Dig sheets may vary in format but always include northing/easting coordinates and anomaly number. In addition, depending on the instrument(s) employed, information about anomaly depth, size, and orientation may also be presented (see dig sheet example in Appendix B). UXO technicians fill in as-recovered information once anomalies are excavated.

3. GPO GOALS AND OBJECTIVES

The fundamental goal of the GPO is to determine whether a particular geophysical investigation approach will work on a given site. Specific objectives of GPOs differ with the unique issues and challenges present at every MRS. Therefore, it is critical that the scope, purpose, and objectives of a GPO be formally developed and documented before starting the GPO's design. This procedure allows appropriate and specific DQOs to be developed for the GPO. See Chapter 5 for more information on DQOs.

The possible objectives of a GPO vary from site to site. The following are some examples of these possible objectives:

- Document the consideration given to various geophysical detection instruments for use at an MRS, the criteria used to identify geophysical instruments for consideration, and the causes for their respective selection or rejection.
- Document the capabilities and limitations of each geophysical detection instrument selected for consideration at the site-specific GPO.

- Confirm the achievable probability of detection and confidence levels or confidence intervals to support decision making at the site.
- Observe each geophysical detection instrument operating in the contractor's configuration, using the contractor's personnel and methodologies.
- Evaluate the contractor's data collection, data transfer quality, and data QC method(s).
- Evaluate the contractor's method(s) of data analysis and evaluation.
- Evaluate estimated field production rates and estimated false positive ratios, as related to project cost.
- Establish anomaly selection criteria.
- Document system reliability.

The following examples of GPO objectives show how each objective influences GPO design.

Example 1: Compare and Evaluate Technologies and Systems

One common GPO objective is the comparison and evaluation of multiple geophysical technologies, systems, and/or contractors. A GPO area designed to support this objective is likely to be used by multiple demonstrators using different geophysical systems. The purpose of this GPO objective is to demonstrate or compete various geophysical systems and obtain information to use in selecting an optimum geophysical approach at a site.

In this case it is important to identify a location for the GPO that is easily accessible to allow for the efficient implementation of the GPO, while still incorporating the geologic, terrain, and vegetation characteristics of the MRS. It may also be desirable to select representative targets and to bury them beyond the predicted detection depths to allow the demonstrators the opportunity to exceed expectations in this area.

Every seeded target becomes an individual test of each system's capabilities. The individual systems' results on each target can be directly compared and analyzed to identify each system's strengths and weaknesses.

All geophysical approaches have inherent strengths and weaknesses. Very seldom does one instrument or approach have the best absolute detection rate, the lowest false alarm rate, the highest production rate, and the lowest cost. Therefore, a GPO can provide information used to evaluate each system's strengths and weaknesses and select an optimum approach for the site.

Example 2: Demonstrate Capabilities of a Selected Geophysical System

At many sites, a geophysical system is proposed for use without a competitive demonstration. This situation can occur when performance of the system under expected site conditions is not anticipated to be of concern. At many of these sites, specific performance objectives have also been established for the geophysical system. In these instances, the purpose of the GPO is not to select a geophysical system or establish performance objectives, but rather to demonstrate that the selected system can meet the project DQOs for the munitions response action.

There are several important differences between supporting the objective in Example 1 and supporting this objective that may cause changes to the design of the GPO area and the procedures used. The demonstration GPO performed under Example 1 may use any sensor and operators to demonstrate the system's relative performance, but demonstrating the capabilities of a selected geophysical system requires testing the entire system—the specific sensor, the specific personnel performing the sensor operation and data processing, and the procedures to be used on the production survey. These individual components of the selected geophysical system are critical to achieving consistent performance from the system, and achieving this objective requires that the system be evaluated as a whole.

Other differences from Example 1 include potentially modifying the GPO area to include more targets and modifying the depth of the seeded targets. An analysis of the specific requirements of the production geophysical system may indicate that additional changes need to be made to the GPO area to achieve additional data to support this objective.

Example 3: Determine and Document the Performance of a Selected Geophysical System

The third type of a GPO arises when a geophysical system has been selected, either by a selection prove-out or by other means. Rather than to compare the performance of the system to a specific performance objective, the goal of this GPO is to establish the performance capability of the system. For example, the geophysical team may want to know the depth to which the selected system can detect a specific target type.

It is not uncommon for both a performance determination and a performance demonstration GPO to be conducted within the same site-specific GPO. This situation typically occurs when a contractor is required to demonstrate a specific contractual performance standard and the regulatory agencies require demonstration of the full capability of the system. In such a case, targets buried at depths deeper than the contractual performance depth may be excluded from the calculation of contractual performance objectives, while all are included in determining the system's performance.

4. GPO TECHNICAL PROCESS INTRODUCTION

This chapter gives a general introduction to each of the major steps in the GPO process for MR actions. It is intended not to describe the technical details of how to accomplish each step, but rather to provide a clear understanding of the overall GPO process and key aspects of each step.

The GPO process outlined in this chapter is intended to apply generally to all geophysical survey systems used for MR projects; however, some aspects of GPO design discussed in this guidance may not be applicable to analog, nonrecording instruments. The concepts are still applicable, and a successful GPO can be implemented with little modification.

The GPO process can be broken into four distinct phases: design, construction, implementation, and reporting (Figure 4-1). Each phase entails specific activities and deliverables which must be carefully conducted and thoroughly documented. This chapter identifies those activities and defines the general process for conducting a site-specific GPO in support of a munitions response

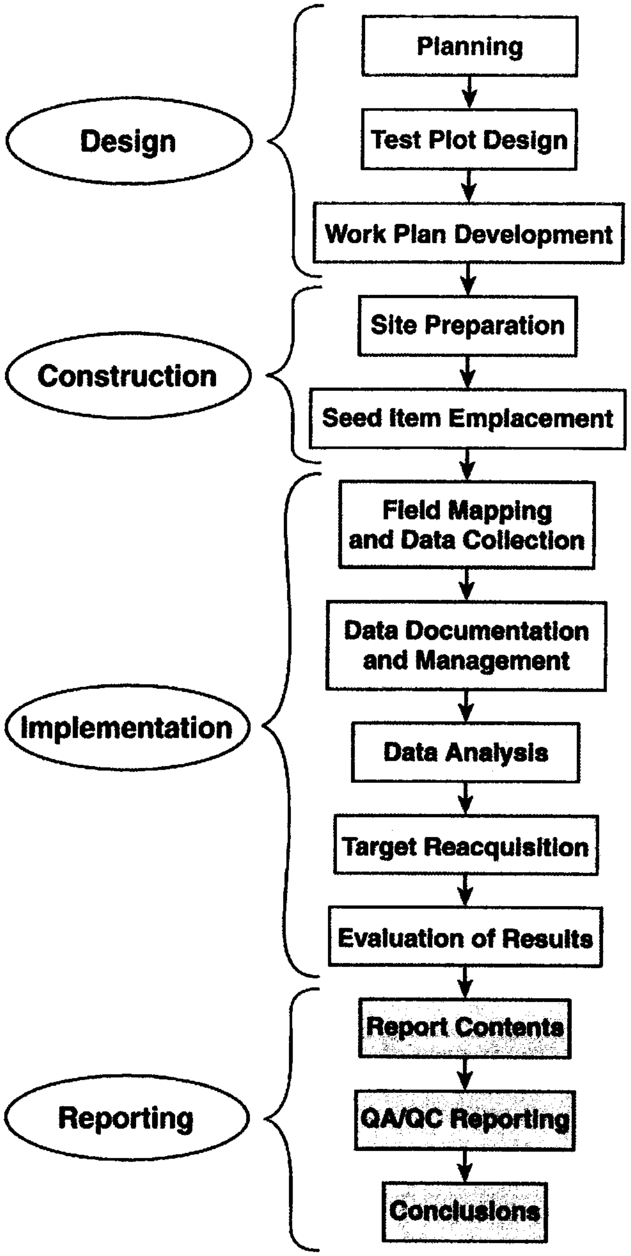

Figure 4-1. GPO technical process.

action. Detailed information regarding specific regulatory considerations in each phase in the process is presented in Chapter 6.

As discussed in the previous chapter, GPOs can have a variety of goals and objectives, which are determined by the site-specific needs and considerations of the site. One or several GPO objectives may be combined—for example, conducting one GPO to both select equipment and validate performance. The determination of the number of GPOs is typically based on the number of competing systems, GPO implementation costs, and technical practicality of performing concurrent levels of evaluation.

4.1 GPO Design

GPO design typically refers to the phase of the GPO from initial scoping to completion of the GPO work plan. The GPO design must be tailored to match the overall approach and objectives of the geophysical survey. The GPO design must also be consistent with the geophysical survey approach planned for the MR action.

The design phase incorporates several key components—planning, test plot design, and work plan development. In the actual design of a GPO, planning and design are typically considered in parallel, with the eventual design being documented in the GPO work plan.

4.1.1 GPO Planning

The GPO scope and complexity must be consistent with the goals and objectives of the geophysical survey. To design a GPO that meets project needs, planners must identify and agree on several basic site-specific GPO design parameters during the DQO development process. Information contained in the CSM (military munition type, expected depth, delivery mechanism, etc.) can be used to help determine some of the criteria to be used in designing a GPO. Table 4-1 presents the basic criteria typically necessary for designing a GPO. For example, because detection becomes more difficult as depth below ground surface or the size of the munition decreases, the size of the seed items and the depths of placement are criteria that should be used in designing a GPO. In addition, GPO designers must have a thorough understanding of the physical conditions of the survey site and any possible limitations under which the geophysical survey, and thus the GPO, will be conducted. This minimum baseline knowledge is necessary before beginning the detailed design of the GPO.

Table 4-1. Basic site-specific GPO criteria

Design criteria	Importance	GPO parameters influenced
Munition(s) of interest	The specific munition(s) of interest should be included in the GPO design to ensure that the detection system used can locate the item(s) at varying, yet realistic, depths and orientations.	• Size, shape, depth, orientation, and composition of seed items
Depth of interest for each munition	Detection becomes more difficult as the depth below ground surface increases or the size of the munition decreases. Therefore, it is important to identify the depth of interest for each munition to ensure that the detection system used can locate each item at the depth needed to meet project objectives.	• Size of seed items • Depth of placement
Size of smallest munition(s) of interest (i.e., fuzes, bursters, other components)	Smaller items are more difficult to detect than larger items. Therefore, it is important to identify the smallest munition of interest at a depth needed to meet project objectives, as this item will likely dictate the minimum detection level required.	• Size of seed items • Depth of placement
Composition of munition(s) of interest	If nonferrous items like brass fuzes or aluminum-case flares are anticipated to be found on the site, it is important to understand that magnetic geophysical detection instruments are ineffective at locating these types of items, even though the instruments may detect similarly sized ferrous items at similar depths.	• Composition of seed items
Quantity of munitions	The quantity of munitions to be seeded should be included in the GPO design to ensure that the project objectives are met.	• Number of seed items
Project objectives (characterization, remediation, or removal objectives)	The GPO design should include sufficient number and types of items at critical depths to demonstrate attainment of the GPO objectives.	• Size of seed items • Depth of placement • Number of seed items
Acceptable geophysical survey confidence and uncertainty levels	The minimum number of seed items required is a function of the probability of detection and confidence level.	• Number of seed items • Size of seed items • Depth of placement
Survey coverage and geometry	The GPO should be designed to evaluate the specific type of survey coverage being considered (full coverage, transects, meandering path, etc.). The GPO should also evaluate the same sensor geometry as the system that will be deployed during the actual site survey.	• Test grid size and geometry • Target placement geometry

The scope and complexity of the GPO are typically dictated by the goals and objectives of the MR action and geophysical survey. Depending on the project needs, a GPO can range from simple to complex, and on large, complex sites, more than one GPO may be required. The scope of the GPO can also be influenced by the degree of confidence in the survey system's ability to meet project objectives. How difficult is it anticipated to be for the geophysical system to find the munitions of interest? Has the geophysical system been successful at similar projects under similar site conditions? For the occasional site types, it may be appropriate to limit scope and complexity of the GPO. Conversely, an extensive prove-out may be dictated by projects where there are complex or varying site conditions or difficult-to-detect munitions or where a detailed comparison of geophysical systems is required or desired. For these very complex projects, hundreds of inert munitions may be buried in a relatively large area at many depths and orientations to closely match the expected population of munitions in the field.

The GPO scope may also be limited by the scope of the geophysical survey project. For example, if the goal of the survey is limited to identification of areas of potential munitions contamination, the scope of the GPO may be limited to mapping, positioning, and data processing elements. However, if the goal of the MR action is subsurface clearance, the GPO should include evaluation of the reacquisition of the anomalies.

Major GPO Design Components

I. GPO Planning
- Determine goals and objectives
- Determine scope and complexity
- Determine DQOs

II. GPO Test Plot Design
- Site selection
- Seed items
- Search pattern

III. GPO Work Plan
- Document design
- Establish procedures
- Define work tasks

4.1.2 GPO Test Plot Design

Designing a GPO test plot design includes selecting the GPO test site, determining the seed targets, and specifying the GPO search pattern and mapping procedures. This section discusses each of these aspects and how it influences the GPO design.

GPO Site Selection—Several basic parameters must be considered in the selection or evaluation of a suitable GPO location. These location-specific considerations are important to ensure that GPO results will be representative of the conditions expected across the entire survey site and that the GPO, as well as the production survey, can be implemented safely and efficiently. Basic parameters that should be taken into consideration in GPO site selection include the following:

- Terrain and vegetation at the potential GPO site should be similar to those across the survey area.
- The geophysical noise conditions existing at the GPO site should be similar to those expected across the survey area, including the soil type (e.g., moist silty soils, dry sandy soils, moist clayey soils), electrical conductivity, magnetic susceptibility, etc.

Tailoring the GPO Area to the Specific Site Requirements

The GPO for the Adak, Alaska munitions response project presented several challenges to the Navy and its contractor. Significant variations in terrain (steep, moderate, and flat slopes) and vegetation (none/rock, short, medium and tall tundra and hummocks) across the MRS had to be duplicated at the selected GPO site.

Upon analyzing the requirements, the project team determined that 100% survey coverage wasn't required and that the GPO could consist of transect surveys because that method would duplicate the transect surveys planned for characterization of the site.

The Navy's contractor located a potential GPO site that had the following attributes:
- one long (750-m) meandering transect,
- starting and ending at the same location, near a road, and
- covering all of the terrain and vegetation types selected for inclusion in the GPO.

The selected geophysical sensor and process were demonstrated to meet the GPO objectives and DQOs for the identified terrain and vegetation combinations. This resulted in significant project cost savings because one conveniently located GPO was constructed instead of multiple smaller GPOs at various locations, resulting in decreased GPO construction and maintenance costs.

- The GPO site should be large enough to accommodate all necessary GPO tests and equipment and for adequate spacing of the seed items to avoid ambiguities in scoring and data analysis.
- The GPO site should be readily accessible to project personnel but restricted for nonproduction personnel.
- The GPO location should be on or in close proximity to the actual survey site.

A perfect GPO site may not exist; therefore, it is often necessary to balance the above criteria in the selecting the best site. At some sites, a portion of the actual survey area may be the best location for the GPO, or multiple locations may be needed to test varying, diverse site conditions.

GPO Test Areas—GPO test sites typically have two main test areas: a function check area and a test plot, although not every GPO requires a function check area. The function check area is used to ensure that equipment, operators, software, and models work under the general site conditions (soil and munitions types, etc.). Function check area surveys are typically conducted by or under the direct supervision of the senior project geophysicists. The demonstrators are provided detailed information on the types and locations of seeded items in this area. Additionally, the terrain and other site conditions are typically more conducive for geophysical data collection than may be experienced across the MRS. The function check area enables demonstrators to test their geophysical system, build a site library, document signal strength, and deal with site-specific variables in a controlled manner.

The test plot (also referred to as the "field test area") is used to demonstrate that the geophysical detection system works under not only optimal but also typical field conditions. The field test area survey should be conducted by personnel with the same level of expertise and experience as the personnel who are to conduct the geophysical survey of the MRS. Demonstrators test their technology and methodology (equipment, operators, processing, and analysis) against unknown seed items under typical field conditions, which can include uneven terrain, varied vegetation, fences, power lines, clutter, and other site-specific challenges. The locations of seeded items in the test area are not disclosed to the demonstrators (both the field personnel and the data processors) until the data is fully processed and targets are selected.

GPO Seed Item Selection and Placement—The selection of seed items for a GPO includes determining the types of seed items, the quantity of each type of item, the placement of each item (location, depth, and orientation), and the amount and type of clutter, if any, to use. The decisions should reflect the anticipated conditions of the production area. Many of the decisions related to seed item selection and placement are driven by the basic design criteria and DQOs (see Chapter 5 for more information on how these decisions relate to the DQOs).

- Type—Seed items used in the GPO should reflect the types of munitions expected to be present on the MRS and should include the most difficult to detect (often the smallest) items of concern.

- Quantity and Placement—A sufficient number of seeded items should be used to meet project objectives. The quantity and placement should be sufficient to evaluate detection system performance with respect to a variety of variables, including the following:
  - the munitions of interest;
  - the orientation of the munitions (i.e., items should be placed at several different orientations);
  - depth of detection (i.e., items should be placed at different depths);
  - enough encounters to capture random factors such as relative orientation, exact line placement, etc.; and
  - site-specific performance metrics as identified in the DQOs.

  The DQOs may include common contractual performance metrics such as the probability of detection (Pd) at a specified confidence level (CL). Care should be taken to devise an emplacement plan so that Pd and CL can be determined on the specific population of interest (i.e., the population of all munitions and all expected depths vs. specific munitions and specified depths). There may be a practical limit to the number of items that can be accommodated in the GPO, which limits the extent to which items of interest can be subdivided and therefore the ability to demonstrate the actual Pd and CL for the intended population (see also Section 5.2.2.).

- Clutter—The amount and type of clutter seeded in the GPO area should be representative of what is expected in the production site to maximize discrimination effectiveness. Clutter can be added to the GPO area to address two separate issues: detection and discrimination. Clutter can include range scrap metal, salvaged scrap metal, old weapon clips, cartridge cases, etc. Munitions-related clutter items (i.e., fuzes, booster charges, propellant, explosive filler, etc.) must be inspected and certified by a UXO supervisor as free of any explosive materials.

> **Clutter**
>
> Clutter items may include fragments of military munitions (also called "munitions debris") or non-munitions-related, manmade metallic objects (also called "cultural debris") or magnetic rock.

GPO Test Plot Search Patterns—The GPO test plot search pattern must be consistent with the search pattern and/or coverage scheme previously determined for the overall geophysical survey of the MRS (Figure 2-12). GPO search pattern parameters vary depending on the search pattern, coverage scheme, and DQOs.

Different GPO test plot coverage schemes can have significantly different results with the same survey equipment. For example, a full coverage magnetometer survey scheme can provide multiple "looks" (i.e., adjacent passes of the sensor over or near the seed item), while a transect survey may only have one "look" at the seed item. Depending on the size, depth, and orientation of the item, having multiple "looks" may increase the chances of detecting the item. Thus, if a transect coverage scheme will be used for the production survey, it is important that the same coverage scheme be evaluated as part of the GPO.

It is also important to recognize the limitations of a GPO in the design of a transect survey. The GPO can be used to determine the performance capability of the survey method at the transect level. However, the GPO cannot be used to evaluate which transect survey design would best characterize a site. For example, a GPO cannot be used to determine the relative merits of different transect line spacings to characterize a MRS.

4.1.3 GPO Work Plan Development

The GPO work plan documents the GPO goals and objectives, specific DQOs, and GPO design elements. The GPO work plan can be developed as a stand-alone document or as part of the geophysical investigation or removal work plan. The size and complexity of the GPO and geophysical survey, along with regulatory and stakeholder considerations, dictate the need for a separate GPO work plan.

Whether stand-alone or integrated into another work plan, a GPO work plan describes how the GPO will be accomplished by defining work tasks and establishing methods and procedures. The GPO work plan should, at a minimum, address basic elements (Table 4-2) and should be reviewed and approved prior to site construction or GPO implementation.

Table 4-2. GPO work plan elements

GPO element	Work plan content
Test area layout	Include the proposed test area layout, showing the prove-out type, size, location, and search pattern and a list and map of all seed items and their placement.
Site preparation	Describe any preparations that may be necessary to allow accessibility with geophysical instruments. These may include vegetation removal and/or surface removal of MEC.
Survey specifications	Describe the method to be employed to locate test plot corners, seed item burial locations, equipment, monuments, coordinate systems, and angle definitions. On many projects the use of a professional land surveyor is required.
Baseline geophysical survey	Describe background (preseed) geophysical mapping to be performed to document baseline geophysical conditions at the site.
Quality control	Describe the quality control measures to be implemented for the GPO.
Anomaly avoidance	Describe the procedures to be used at the site to ensure that the location of each excavation and corner marker is clear of metallic anomalies before placing seed items.
Seeding	Describe the planned seeding methodology for the site, including known items, blind items, item placement (including approximate depth and orientation), and excavation procedures.
Data collection procedures and variables	Describe the field procedures to be followed during data collection and data elements for each detector type utilized in the GPO. Examples of some of these elements include instrument height, instrument orientation and direction of travel, instrument channel selections, measurement intervals along survey line, lane width, etc. Some data elements are subject to modification and evaluation in the field, which should be noted in the report, along with any limitations related to field implementation.
Data analysis and interpretation	Describe the methodology to be employed for the analysis and interpretation of the geophysical survey data, including all anticipated field and post-processing steps and example dig sheets.
Reacquisition (DGM surveys only)	Describe the procedures for anomaly reacquisition and verification.
Data evaluation	Describe the methodology, performance metrics, and scoring criteria to be used to evaluate results of the GPO. For a GPO to select equipment, these should include how the different systems and/or survey approaches will be evaluated.

4.2 GPO Construction

The GPO construction phase consists of three major tasks—site preparation, seed item emplacement, and site construction documentation. Each task in site construction should be clearly identified and described in the GPO work plan. It is critical to the success of the GPO that these tasks are fully implemented in accordance with the GPO work plan. Any field variations must be fully documented and reported to the geophysical team. As possible, state regulators should perform field oversight to ensure that the construction is consistent with the sampling design as documented in the work plan.

4.2.1 GPO Site Preparation

The first step in GPO site construction is site preparation. GPO site preparation encompasses any tasks necessary to prepare the GPO site before seed item emplacement. Site preparation can include a site boundary survey, surface removal, vegetation clearance, and/or baseline survey. However, not all site preparation tasks are needed at all sites.

Establish Site Boundary—The extent of the survey needed to establish a GPO site depends on the scope and complexity of the GPO and the level of existing data available for the site. At a minimum, the GPO site boundary should be marked and surveyed and a land survey marker or benchmark located. A first-order survey marker is preferred. The survey marker should have both horizontal and vertical controls. Depending on the positioning system being deployed, a survey marker may also need to be placed within line of sight of the test areas.

If not already available, a topographical land survey is also conducted across the site and includes tree lines, telephone lines, utilities, or other features. The topography is useful in obtaining geophysical background characteristics of the entire test site.

The datum and coordinate system used during the survey should be documented and used consistently throughout the entire GPO process.

Surface Removal—If there is a potential for munitions hazards on the GPO test site, the surface and subsurface of the entire area that makes up the proposed GPO site must be cleared of any munitions hazards. Furthermore, anomaly avoidance measures must be followed when selecting seed item burial locations. The GPO work plan must specify how inert munitions items, scrap, fragments, and other surface clutter items will be addressed during surface removal. In most instances, all surface items are removed from the site during the surface sweep. Any clutter needed for the prove-out can then be placed back into the test plot during seed item emplacement.

Vegetation Clearance—The conditions of the GPO site should mimic those found in the production area. Vegetation removal should be conducted to duplicate the production area conditions.

Baseline Survey—The baseline geophysical survey of the GPO site is conducted before seed item emplacement to determine the presence or absence of existing anomalies and to establish background geophysical responses. Existing anomalies can be removed or documented. In addition, any soil sampling, soil property measurements, and/or soil moisture levels determined by the geophysical team to be necessary for the prove-out can also be conducted at this time.

4.2.2 GPO Seed Item Emplacement

Acquisition and Selection—Two types of seed items can be used on a GPO site—munitions and clutter. Potential sources of these seed items include items recovered during previous response actions at the site or at other sites or surrogate items. The lead time for acquiring seed items should be factored into the site activities for realistic planning.

Because surrogates introduce additional uncertainty into the testing process, inert items recovered from the site are the preferred seed items for the GPO. If munitions are unavailable, surrogates of approximately equal size, shape, and material composition should be used. When using surrogates, care must be taken to ensure that the surrogate items' geophysical signatures will be representative of the signatures of items of interest expected to be encountered at the site.

Clutter Considerations—Clutter items emplaced on the test site are considered seed items and should be treated as such. Therefore, the use of clutter on the test site should be representative of the clutter expected to be found on the production survey site.

Emplacement—Seed items are emplaced according to the GPO design. Items should be buried at the depths, attitudes, and orientations that are expected in the MRS. Emplacement is typically conducted by digging a hole to the appropriate depth, placing the item in the hole at the prescribed depth and orientation, surveying its location, photographing the item, and backfilling the hole (Figure 4-2). A backhoe, auger, or posthole digger may be used to place items. Efforts should be made to minimize the size of the disturbance while placing seed items and to ensure that the confidentiality of the site is maintained. Seed placement location can be masked by grading and revegetating seed locations. These locations can also be allowed to weather so that surface scars are not evident. To ensure that items are not being selected due to ground disturbance, several holes should also be dug and filled in without placing items and their locations documented.

Figure 4-2. GPO seed item emplacement.

4.2.3 Site Construction Documentation

As with all phases of the GPO, it is critical that the construction of the GPO test site be clearly and thoroughly documented. Depending on the complexity of the project and GPO, the documentation can vary from a letter report to a full site construction report and as-built drawings. During the design phase, the geophysical team should determine the required level of documentation of the GPO construction.

At a minimum, the GPO construction report should contain a map of the test plot location; a diagrams showing seed item locations; a spreadsheet showing emplaced locations, depths, orientations, depths, etc.; photographs of all seed items; survey data; names of the people that constructed the test plot; and the date of construction.

4.3 GPO Implementation

After the GPO is designed and constructed, geophysical systems are tested in accordance with the work plan. Because the ultimate goal of the GPO is to confirm that selected geophysical survey equipment and methods are appropriate for the site, it is important that the GPO survey be conducted in the same manner as the production survey. Therefore, GPOs should be implemented using key geophysical personnel, equipment types and configurations, survey procedures, data analysis, and anomaly identification and reacquisition methods in the same manner as will be used during the production survey. This helps maintain the integrity of the GPO and adds validity to the GPO process and the data collected.

The skill levels of personnel executing the prove-out, both field personnel and geophysicists, should be specified in the GPO design and should closely match the level of personnel that will execute the production survey. Otherwise the GPO results may not be representative of the system performance to be expected during the production survey The GPO should also imitate the production survey's design elements such as survey speeds, coverage, and data density. Furthermore, the time taken to collect and process the data should be monitored to ensure that excessive time is not spent collecting an idealized GPO data set that would not be representative of actual survey performance.

At some sites, the GPO test plot is also used for geophysical survey system certification (sometimes referred to as "system validation"). In such cases, the GPO is repeated by each field team with the specific equipment that will be used to conduct the actual production survey. Geophysical mapping system certification is a QC tool that can be implemented during the site survey using the GPO test plot. The need for and value of this tool are currently under debate. The need for geophysical system certification should be determined by the geophysical team during the scoping of the response project and may influence the design of the GPO test plot.

4.3.1 GPO Field Mapping and Data Collection

The GPO report should fully document the equipment used, survey speed, survey coverage, and data acquisition rates. In addition, the function checks and setup procedures for all acquisition and sensor equipment should be documented, and any deviances should be noted. For mag and flag surveys, the procedures, equipment settings, and search patterns used should be noted for exact duplication during the production survey.

A daily logbook is typically used to record all on-site activities and field notes and should include such information as the reliability of equipment, number of people, start/end time for data collection, maintenance time, function checks, etc.

4.3.2 GPO Data Documentation and Management

GPO data should be collected and managed using the procedures that will be used during the actual production surveys and that have been documented in the work plan. If possible, state regulators should observe the data collection in the field to verify that the methods and procedures are consistent with the sampling design as documented in the work plan.

4.3.3 GPO Data Analysis

In a mag and flag survey, data analysis consists of the UXO technician making an interpretation of audio and visual signals in real time. Maps are then produced that show the locations of the picked targets (see Appendix C for examples).

In a DGM survey, a geophysicist processes the raw data collected during the survey and then analyzes and interprets the results to select targets. Data analysis and interpretation are generally the result of a multistep process and typically include computer processing, including leveling of the electromagnetic signals recorded by the geophysical sensor. The processed data is analyzed to establish a threshold or minimum signal strength of signal responses, which is based on the geophysical signatures of the military munitions of interest, and may also depend on the background geologic noise level of the site. Signal responses above the established threshold are selected and reviewed by the project geophysicist to minimize false positive responses. The geophysicist also reviews the signals below the established threshold to ensure that there were no false negative responses. All of the targets identified during this analysis are recorded on a dig sheet.

Dig sheets (whether produced by either a mag and flag or DGM survey) include all information available on the instrument response to the target. Dig sheets may vary in format but always include northing/easting coordinates and anomaly number. In addition, depending on the instrument(s) employed, information about anomaly depth, size, and orientation may also be presented. The U.S. Army Corps of Engineers (USACE) uses a standardized dig sheet on all MRSs. During the GPO process, only the first seven columns are typically completed. The remaining columns are completed throughout the investigation and remediation phases of the project.

4.3.4 Target Reacquisition

For DGM surveys, the final GPO field activity is target reacquisition. Target reacquisition tests and demonstrates the ability to accurately record the location of the selected anomaly, navigate back to the selected anomaly, and then determine the precise anomaly location using a geophysical sensor. To do this, a technician searches within a predetermined radius around the identified anomaly location. Once the anomaly is reacquired, the technician marks the exact location of the anomaly with a pin or flag and determines the precise X and Y coordinates of the anomaly. This marked location will be used to score the ability to reacquire the anomaly, the interpretative location, the reacquisition location, and the results of the GPO. Again, in the case of a GPO intended to certify a geophysical system, the exact personnel, equipment, and procedures should be the same as those to be used for the production survey.

4.3.5 Evaluation of GPO Results

Each seeded target should be scored as a "pass" or "fail" based on whether the seeded target was successfully detected and relocated within the maximum allowable radius as described by the DQO for positioning accuracy.

Because site-specific conditions and the types of munitions of interest affect different geophysical systems differently, evaluating the results of a GPO comparing multiple candidate systems can be difficult. Very seldom does one system or approach have the highest Pd, lowest false alarm rate (FAR), greatest efficiency, lowest cost, and least environmental impact. Therefore, the geophysical team members must use the GPO information in a trade-off analysis to select the optimal geophysical approach for the project, and the trade-offs should be communicated to everyone involved in the project before a final decision is made.

4.4 GPO Reporting

The final product of the geophysical prove-out is the GPO report. This report documents the performance of the system(s) used in the GPO and the ability to meet the project objectives. This section discusses the key aspects of the GPO report, including report content, GPO findings and conclusions, and QA/QC. A draft GPO report should be distributed for review before finalizing. The final GPO report should be included in the administrative record established for the munitions response project.

4.4.1 GPO Report Content

The content and complexity of the report is tailored to reflect the complexity of the GPO. The exact contents of the report are dictated by the DQOs established at the onset of the project. Therefore, a report that details the application of sophisticated digital geophysical EM survey equipment will differ from a report on a mag and flag survey.

Example GPO Report Table of Contents

1. Introduction
2. GPO Objectives
3. Test Grid Locations and Design
4. Equipment
5. Procedures
6. Data Processing and Management
7. Results
8. Quality Control
9. Conclusion

Appendix A. GPO Seed Item Pictures
Appendix B. Raw and Processed Data
Appendix C. Dig Sheets

Outline for Reporting, Required Elements—In general, a GPO report discusses site conditions, methods, procedures and instrumentation employed, data processing methods, and the QA/QC process for both the survey process and data management. The following elements should be included in all GPO reports:

- as-built drawing of the GPO plot;
- pictures of the seed items;
- color maps of the geophysical data (DGM surveys only);
- summary of the GPO results;
- proposed geophysical equipment, techniques, and methodologies to be used for the production survey; and
- sufficient supporting information to justify recommendations.

The GPO report may also include items such as production rates, any difficulties encountered in the survey process, and path forward recommendations.

Maps and Photos—The report should include photographs and descriptions of all instruments and equipment used in the survey. The GPO results section should include GPO survey maps, anomaly maps, dig sheets, and reacquisition results similar to those of a production survey. These results should also be compared to the seed item data and discussed in terms of system performance and the ability to meet the DQOs.

Electronic Data Reporting—In addition to the written report, the GPO report should include electronic submittals of all GPO data files. This data should include copies of the raw data files, processed data files, processing logs, and any other intermediate data sets critical to the data processing and analysis. Data sets should be submitted in industry standard formats and include sufficient descriptions to allow for independent auditing and reprocessing.

4.4.2 QA/QC Reporting

The QA/QC procedures used throughout the GPO process should be documented and include discussions of the following:

- equipment function checks,
- personnel qualifications,
- data collection operations procedures,
- target parameters,
- positioning system operations/limitations/accuracy, and
- data management/processing.

QA programs can consist of whatever quality inspections are determined to be appropriate by the accepting agency. These inspections can include observation of field personnel during the performance of their duties to ensure that they are working in compliance with the approved work plan, independent confirmatory sampling, and reporting and documentation of QA results.

QC procedures are conducted throughout any investigation process and typically include morning and evening standard response tests, a static test prior to beginning data collection of each grid, and collected repeat data over each grid.

4.4.3 Reporting Conclusions

The specific finding and conclusions depend on the type of GPO conducted but should address detection capability, along with positioning system capabilities and data quality. Every GPO report should answer the following questions: Did this GPO meet its goals and objectives? Is the selected geophysical survey system appropriate for this site? Will the selected system meet the objectives of the MR action?

5. DATA QUALITY OBJECTIVES AND PERFORMANCE METRICS

In keeping with the philosophy and the systematic planning process recommended by the Interstate Technology & Regulatory Council, GPOs should be planned and executed to determine the type, quantity, and quality of data sufficient for environmental decision making. Both USACE and the U.S. Environmental Protection Agency (EPA) have systematic project planning approaches that are relevant for the planning of munitions response geophysical surveys and GPOs (USACE 1998, EPA 2000). The DQO process established by EPA and discussed below is one example of how the systematic project planning approach has been applied to MR actions. Performance metrics can be used to score the data results of a GPO to determine whether seeded anomalies were successfully detected, identified, and reacquired. Determination of applicable DQOs and performance metrics is site specific and may vary from GPO to GPO.

5.1 Data Quality Objectives

DQOs are quantitative and qualitative statements that specify the type and quality of the data needed to support an investigative activity. They are developed before data are collected as part of sampling program design. EPA has developed a seven-step sequential and reiterative process for developing DQOs as follows:

1. State the problem.
2. Identify the decision.
3. Identify the inputs to the decision.
4. Define the study boundaries.
5. Develop a decision rule.
6. Specify acceptable limits on decision errors.
7. Achieve optimal design for field sampling design.

This seven-step process is aimed at achieving an "optimal design" for obtaining the desired data necessary for geophysical surveys and prove-outs. The outputs from each step of the process result in the DQOs. These DQOs are statements that

- clarify the objective of the data collection effort,
- specify how the data will be used to support the risk management decision being addressed,
- define the most appropriate type of data to collect,

- specify acceptable levels of decision errors that will be used as the basis for establishing the quantity and quality of data needed,[6] and
- specify the quantity and quality of data to be collected.

By using the DQO process, the geophysical team members can clearly define what data and information are needed and develop a data collection design to help them obtain the type, quantity, and quality of data needed to make a sound decision about whether a technology has been effective. Once DQOs are established for the GPO and before the GPO is implemented, the DQOs should be documented in the work plan. DQOs are an integral part of QA/QC that are used to specify the acceptable limits for decisions that will be used as the basis for establishing the quality and quantity of data needed to support decisions. Supporting DQOs establish the quality acceptance criteria such as precision, sensitivity, accuracy, and completeness (Table 5.1). The GPO report should document the meeting of DQOs and any variances. In the event of variances, the QA process and QC checks also should ensure that the variances were documented and that the effect or lack of effect on data usability is understood and accounted for relative to subsequent site decisions. The reported results should be reviewed by the geophysical team prior to the commencement of the production survey to ensure that all technical and project managers are in agreement that the established DQOs are being met.

5.2 Performance Metrics

Performance metrics are the definable and measurable aspects of the various types of data as required by the DQOs. Another way to look at performance metrics is to think of them as the measurable criteria from the GPO data that are scored to determine whether seeded anomalies were successfully detected, identified, and relocated. Like DQOs, determination of appropriate performance metrics is site specific and therefore varies from GPO to GPO.

5.2.1 Probability of Detection

Pd is a statistically meaningful parameter that describes the probability of detecting an item of interest. Although Pd and "percent detected" are often used interchangeably, percent detected is the one-sample measure of the number of MEC items detected divided by the number emplaced. Unlike percent detected, a true probability is calculated on a statistically significant population of items that all have the same chance of being detected and captures the random processes that effect detectability. In other words, true Pd is calculated on a population of items made up of single munition type at a single depth and orientation to capture the effects of the exact location of sample points relative to the item, the positioning uncertainty, etc. However, it is not practical to perform such an exercise on a GPO. As a substitute, an array of munitions of interest is emplaced at a range of depths and orientations, and the Pd is calculated on a single sample of the array of munitions. Therefore, the Pd does not necessarily represent the probability of detecting items in the population as they occur in the field.

[6] A decision error rate is the probability of making an incorrect decision based on data that inaccurately estimate the true conditions at the site.

Table 5-1. Sample GPO DQOs[7]

Data type	Data quality indicator	Example measurement performance criteria
Geophysical survey and anomaly identification		
Geophysical sensor data	Precision	• Response to standardized item will not vary more than ±10%
	Representativeness	• Survey to achieve 0.85 Pd at 90% CL for all 60-mm mortars within 2 feet bgs • Sensor to identify at least 90% of all munitions seed items or their surrogates
	Sensitivity	• Sensor to identify 60-mm mortars at a minimum of 2 feet bgs • Sensor to identify 20-mm projectiles to a depth of 12 inches bgs • Standard deviation of background noise = <3 mV • Signal-to-noise variance = < lesser of 5% or 5 mV
	Accuracy	• Percent false positives not to exceed 15% of all identified anomalies
	Completeness	• At least 98% of possible sensor readings will be captured along a transect
Positional data	Precision	• Positional error at known points will not exceed ±20 cm
	Accuracy	• Interpreted locations of anomalies within 0.5-m radius of actual location
	Completeness	• Search transect spacing to vary no more than ±10% of spacing specified in sampling design • Along track sampling of <0.5 feet • Across track sampling of <0.3 feet, excluding data gaps due to trees or other obstacles • Total acreage of data gaps not to exceed 0.25 acres
Anomaly reacquisition		
Geophysical sensor data	Precision	• Response to standard object will not vary more than ±10%
	Representativeness	• Survey to achieve 0.85 Pd at 90% CL for all 60-mm mortars within 2 feet bgs
	Sensitivity	• Sensor to identify 60-mm mortars at a minimum of 2 feet bgs
	Accuracy	• Percent false positives not to exceed 15% of all identified anomalies
Positional data	Precision	• Positional error at known monuments will not exceed ±20 cm
	Accuracy	• Reacquired locations of anomalies within 0.5-m radius of actual location • Anomaly reacquisition within 2 feet of interpreted locations
Anomaly excavation		
Geophysical sensor data	Precision	• Response to standard object will not vary more than ±10%
	Accuracy	• All excavations cleared of metallic items
Positional data	Precision	• Positional error at known monuments will not exceed ±20 cm
	Accuracy	• Type, condition, and fuzing state (no fuze, unarmed fuze, armed fuze) of munitions items correctly identified
	Completeness	• Anomaly identification forms completely and correctly filled out for each anomaly

5.2.2 Confidence Level

The CL is the probability value that the Pd measured on the GPO is representative within the required limits of the true Pd of the system on the test plot. A common contractual requirement is for a Pd of 0.85 at a 95% confidence level. The number of targets determines the lower bound on

[7] The DQOs shown in this table are examples of DQOs that have been used on MRSs. However, these DQOs are not applicable to all sites. DQOs should be developed for each GPO, based on site specific characteristics, project objectives and methodologies used.

the true Pd at a specified confidence level, with a lower number of targets resulting in a lower confidence level. For example, if the GPO site is seeded with 10 emplaced targets and a demonstrator successfully detects 9 targets, the resulting Pd estimate is 90%. If the same GPO is seeded with 100 emplaced targets and the demonstrator successfully detects 90, the Pd estimate is also 90%. However, in the first scenario, with a smaller number of seeded items, the lower confidence limit at 95% confidence level is 0.55, where in the second example with the larger number of seed items it is 0.82. Therefore, the sample size (i.e., the number of emplaced items) must be large enough to ensure the required statistical significance.

The CL is calculated using statistics that are beyond the scope of this document. Because the populations may differ in depth distribution and relative abundance of different munitions types from the survey area, the Pd and CL from the prove-out are not necessarily accurate estimates of those parameters that can be expected to be achieved in the field survey.

5.2.3 False Negative

A false negative is the omission of MEC from the dig sheet. This may result from either the failure of the geophysical instrument to detect a response to the target or the response being misidentified during data processing. These errors result in risks remaining following the completion of the MR action.

5.2.4 False Alarm/False Positive

A false alarm, also referred to as a "false positive," occurs when an identified anomaly is incorrectly selected as a possible target when no object is present. This term may also be applied to a declared target location that does not correspond with the actual target location.

False alarms typically result in unnecessary excavations, which ultimately inflate project costs. False positives can be the result of sensor noise, motion noise, data collection or processing artifacts, personnel error, or a difference in capabilities of the search and reacquisition sensors.

5.2.5 False Alarm Rate

The FAR is a measure of the number of incorrect target anomalies selected and occurs when geophysical data acquisition or data processing indicates a response that is not associated with a target item. False alarms can occur associated with anomaly detection vs. false alarms associated with anomaly discrimination. An anomaly that exists in the data but turns out to be associated with instrument noise is a false alarm in the context of anomaly detection. However, an anomaly that is selected but turns out to be associated with an iron-bearing rock or a buried utility is not a false alarm in the context of anomaly detection. By contrast, an anomaly that has been passed through an anomaly discrimination process and is declared an item of interest but turns out to be associated with an iron-bearing rock or a buried utility *is* considered a false alarm in the context of anomaly discrimination. For example, one possible cause of a false alarm associated with detection can occur when an active electromagnetic sensor coil bumps into the ground during data acquisition. If this accidental bump produces a spike in data intensity, the data could be interpreted as representing a subsurface anomaly. It is often difficult to determine the cause of a false alarm unless a good background geophysical survey was performed on the GPO site prior to emplacement of seed items. It is also important to note that as sensor sensitivity increases, sensors detect more targets of interest, which may increase the number of false alarms as well.

Some federal contracts specify or define a maximum number of false alarms as a percentage of the number of target picks that can be associated with an actual subsurface metal object. However, there is no absolute rule to determine an acceptable FAR. From a regulator's perspective, a high FAR may increase the possibility that the target items are going to be detected. However, the inefficiencies associated with a high FAR increase field efforts, data processing and handling, and the likelihood of errors and may decrease the overall quality of the GPO and project fieldwork results.

5.2.6 Signal-to-Noise Ratio

When GPOs are used to determine the operating envelope of a system or to confirm the correct functioning of equipment, the appropriate metrics relate to signal strength and the noise environment in which signals must be detected. The signal strength and system noise are often combined in a signal-to-noise ratio (SNR).

The target's signal strength is reported in the operating units of the instrument, i.e., nanoTesla (nT) for a magnetometer and millivolts (mV) for an EM instrument. The appropriate number may be the maximum amplitude of a target signal or the signal integrated over its spatial extent, depending on how the targets are selected. In either case, the signal strength for a selected target at a specified distance and orientation is measured. In the selection of equipment, this value may be compared to the associated noise measurements to establish the operating envelope of the system. The repeatability of this value may be used to determine whether equipment is functioning correctly and being used properly.

Noise is measured in the same operating units as the sensor. Noise is commonly divided into sensor noise and environmental noise. Sensor noise is the fluctuation in sensor output in the absence of an external signal and is generally dominated by noise in the sensor electronics. Depending on the application, the sensor noise may be reported using a peak-to-peak fluctuation, a root mean square measurement, or some other statistical measure. The sensor noise characteristics should remain stable with time, so this quantity is relevant to determining whether a sensor is operating properly. Environmental noise captures other external sources that also compete with the signal of interest. These sources can include electromagnetic interference, geological noise, or other types of clutter. In the case of MEC detection, environmental noise is generally the dominant contributor to the overall noise of the system.

The amount of noise is relevant to determining the signal strength that will be required to reliably detect items of interest in the real-world environment of the site. Consequently, the signal strength of the target must exceed the sum of the sensor noise and the environmental noise. The SNR is the ratio of these two metrics (target strength to noise) and is a dimensionless quantity. In general, SNRs of a minimum of 2–3 are required for reliable detection. Higher values are required to discriminate anomalies from noise and facilitate analysis. It is fairly common to make estimates of target size and depth from magnetometer data, which can be very accurate with good SNR and positioning information.

5.2.7 Positional Accuracy

Positional accuracy is measured by comparing the known location of the emplaced targets to the reported location of the anomalies detected, selected, and reacquired by the GPO demonstrator. The geophysical team must determine the requirement for positional accuracy error based on the expected field requirements and specify this accuracy requirement to the GPO demonstrators. During the reacquisition phase of the field survey, the positioning accuracy requirement is used to determine the size of the radius around an established geophysical anomaly location. Field personnel must search in this radius with another geophysical sensor to reacquire the anomaly and determine its exact location.

5.2.8 Object Depth vs. Diameter

In general, larger objects may be detected at greater depths than smaller objects. Objects in the GPO may be plotted as depth vs. diameter, indicating those detectable with the sensor and process being demonstrated. The primary use of such a plot is to determine whether a sensor can detect the munitions of interest to the required depth. Beyond the specific requirements of the project, such plots also indicate the likelihood of munitions being left at deeper depths. Sites where this may be of concern include regions where frost heave may result in upward migration of these items.

Simplified Expression for Maximum Depth of Detection

USACE uses the following formula to estimate detection depth:

Estimated detection depth (m) = 11 × diameter (mm) / 1000

This rule of thumb for approximating detection depths can be useful for planning but should not be considered the limit of detection capability for all modern survey systems.

5.2.9 Receiver Operating Characteristic Curve

The receiver operating characteristic (ROC) curve, a method of comparing the Pd and FAR metrics, can be used to characterize the performance of sensors. As the sensitivity increases, the sensor detects more targets of interest, but the number of false alarms increases as well. In the ROC curve, the probability of detection is plotted as a function of the probability of false alarms as the threshold for sensor operation is varied (Figure 5-1).

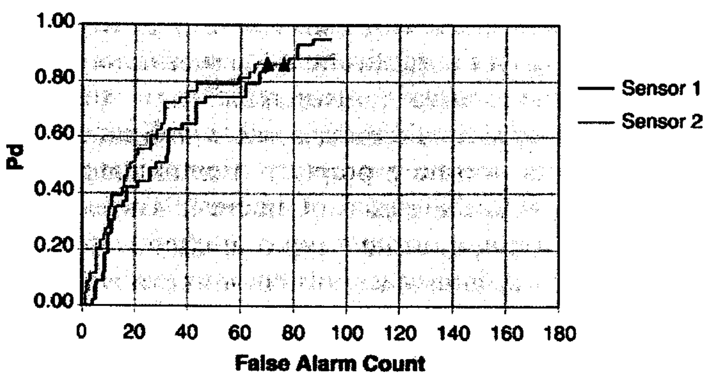

Figure 5-1. ROC curve.

Generally, it is not feasible to collect enough data to construct a ROC curve as part of a GPO. However, it is important to understand the concept which the ROC curve illustrates to understand the relationship of Pd to false alarms. Any sensor can be operated at a threshold selected to maximize detections, which also increases false alarms, or to minimize false alarms, which also decreases detections. The efficiency with which these two parameters trade off is critical to making optimal decisions about which sensors are appropriate for meeting the objectives of a project and how the sensors should be deployed on a site.

5.3 Quality Control Tests

QC procedures are conducted throughout any investigation process. Therefore, they also need to be conducted during the GPO and typically include morning and evening standard response tests, a static test prior to beginning data collection of each grid, a shake test, and collected repeat data over each grid. These QC procedures should be documented in the GPO report.

5.3.1 Standard Response Test

The standard response test consists of a predetermined route (survey line) established on site in an area free of metallic contacts. The beginning, midpoint, and end of the line are marked, and data is collected along the line. Each time the test is performed, the line is surveyed to gather background data and then surveyed a second time with a metallic contact (typically an iron or stainless steel sphere) placed on the ground surface at the line's midpoint. The test is conducted at the beginning and end of each day, prior to and following the collection of survey data. The purpose of the standard response test is to demonstrate consistent instrument response throughout the course of the investigation.

5.3.2 Static Test

Static tests are performed by positioning the survey equipment within the survey boundaries in an area free of metallic contacts and collecting data for a specific period, while holding the instrument in a fixed position. The purpose of the static test is to determine whether unusual levels of instrument or ambient noise exist.

5.3.3 Shake Test

Shake tests check the response of instruments to vibration. On a daily basis, instrument coils are checked for their response to vibrations in the cables, with response transmitted back to the processor and analyzed and checked for spikes in the data that can possibly create false anomalies.

5.3.4 Repeat Data Test

Repeat data tests are tests where a percentage of original survey data is collected for each grid (typically over 2%–5% of grid). This data is used to demonstrate consistency or repeatability in instrument function and instrument operation and the consistency of the survey team.

5.3.5 Positioning Accuracy

Positioning accuracy of the final processed data is demonstrated by operating the equipment over one or more known points, usually in a "cross" or "star" pattern, and plotting the track on a map. It is important that the positioning system be tested in exactly the same manner in which it is to be used during the actual surveys. The accuracy of the data positioning is assessed by calculating the difference between the location where the track plots cross each other on the map and the actual location of the known point(s). Presumably, the actual track plots cross exactly over the known point when the data was collected, and the difference, if any, observed on the final track plot map is a direct measure of the positioning system's accuracy. In some cases where absolute positioning errors need to be quantified, the contractor "forces" the sensors to cross over the known point(s) using guides or rails (wood 2×4s or PVC pipe split in half) placed on the ground, which force the sensor to travel over an exact path while collecting data.

6. ISSUES, CONCERNS, AND RECOMMENDATIONS

The following information on site-specific GPOs provides some key factors to be considered by regulatory agencies during the planning, design, construction, implementation, evaluation, and reporting phases. These factors are presented in a question-and-answer format to provide guidance and to facilitate dialogue during each phase of the GPO. This section is divided into four main subsections corresponding to the four primary phases of a GPO: design, construction, implementation, and reporting.

6.1 Design Phase Considerations

6.1.1 Conceptual GPO Design Considerations

Are the goals and objectives of the GPO clearly defined and documented? It is critical that GPOs be designed by a geophysical technical team with a thorough understanding of the overall goals and objectives of the production geophysical survey. These goals and objectives must be agreed to by the geophysical team and clearly documented before attempting to design the GPO.

Is the CSM being used in the GPO design? It is important to ensure that a current, comprehensive CSM exists for the project. The CSM should be the basis for developing the overall geophysical survey objectives. As such, the CSM is a critical document in guiding the conceptual design of the GPO. The CSM should be updated and refined as new information is available.

Should the overall munitions response team be involved in the GPO design? The design of a GPO should be developed by the geophysical technical team in consultation with the overall munitions response team. It is particularly important that the full team be involved in the early stages of the conceptual GPO design to ensure that the design addresses regulatory and stakeholder concerns. However, in the case of "blind" GPOs, it should be understood that information on the specific location, depth, and orientations of seeded target anomalies will be restricted to a minimal number of individuals. This secrecy can be accomplished by recording the information on a "confidential and restricted" appendix to the GPO plan which is not distributed with the work plan.

Should stakeholders participate in the GPO design? Although the size and complexity of a geophysical survey and GPO vary from site to site, it is necessary to obtain both regulatory and stakeholder participation and concurrence during the design phase to ensure that the GPO and geophysical survey address the concerns and expectations of both regulators and stakeholders.

Some key concurrence points should be agreed upon prior to designing the GPO, including site-specific characterization and/or remediation objectives.

What are the basic design criteria to identify and agree on before starting the GPO design? To design a GPO that meets the project needs, several basic site-specific GPO design parameters must be identified and agreed upon (see the DQO process discussion in Chapter 5). The criteria for determining these parameters should be fundamental information from the CSM. The basic design criteria typically necessary for designing a GPO are listed in Table 4-1.

6.1.2 Equipment Selection Considerations

When is it appropriate to preselect the equipment? A preselection process may be used to limit the systems tested at a specific site to those believed by the geophysical team to have a reasonable likelihood of successful implementation. In most cases, the preselection of equipment is documented on the site or in the GPO work plan and includes at a minimum the rationale for the preselection. The level of documentation required is generally dependant on the regulator and/or community acceptance of the preselection.

Should the number of geophysical survey systems to be tested be limited? The number of practical systems to test may be limited by site terrain and vegetation constraints and/or the types of munitions present.

Is it ever necessary to retest a system? If any one of the components of the separate subsystems (sensors, positional equipment, human operators) changes significantly, the entire system should be reevaluated by performing a GPO to ensure that the entire system is still functioning properly. Also, specific project QC procedures may require recertification of the geophysical system on a periodic basis when equipment is repaired or when the geophysical crew returns from vacation.

How important is the positioning system? The positioning system is a vital part of the overall geophysical survey system. More geophysical survey projects encounter problems due to positioning issues than from any other factor. For automated positioning systems, the GPO should include the static surveying of known points (such as the GPO corners), as well as surveying over small surface targets at known locations. For example, often a small target (such as a trailer hitch ball or similar round object) is placed on the ground at a known location. As part of the GPO, the sensor system goes directly over the center of the object traveling in a north/south direction. The traverse then proceeds without stopping to go over the object in an east/west direction. This "loop test" is executed twice in both directions (south/north and west/east). The final map should show the geophysical anomaly caused by the object on all traverses at the same known location.

For fiducial positioning, the number of measurements should be consistent from line to line. In addition, the methods for accounting for obstacles should be demonstrated during the GPO and documented.

Who determines the geophysical survey system scoring and selection protocols? Who performs the scoring and selection? The GPO work plan must include discussion of how the systems will be scored. The scoring protocol should be made clear to the demonstrators, be applied consistently to every system tested, and reflect contractual requirements. Additionally, those who will perform the scoring and selection should be identified in the GPO design. Those individuals should be integrally involved in the GPO design, have comprehensive knowledge of the project, and have a clear understanding of the goals for both the GPO and the overall geophysical survey project. The criteria for determining a "pass" or "fail" for individual seeded target anomalies should be clearly stated in the GPO work plan.

6.1.3 Location Selection Considerations

Under what conditions will more than one GPO site be necessary? In selecting a GPO location, a perfect candidate site may not exist. Multiple locations may be needed to test varying, diverse site conditions, especially on large sites.

What are the options if there are no suitable GPO locations near the MRS? This situation is likely to occur only at small urban locations where manmade features, unique geology, or other site conditions are not easily recreated. In such situations, the best option is typically to conduct the GPO on the actual geophysical production survey area. The other options available are to select a location farther from the site or to use previous results from a similar site elsewhere. These two options, however, can significantly hinder the demonstration of site-specific geophysical survey system performance and are not recommended.

Why is it important to consider terrain and vegetation in selecting a GPO location? If the GPO area is overly simple in terms of vegetation and topography, the results of the GPO may be skewed toward higher detection rates than will actually be realized during the geophysical survey project. Additionally, positioning system performance can be significantly influenced by vegetation and terrain features. On rough terrain, bumping some geophysical sensors into the ground can corrupt or degrade the data and may increase noise or result in a decrease in Pd and an increase in FAR.

Why is it important to consider geology and soil conditions in the selection of a GPO location? Sensors are affected by many elements of the media in the general proximity of the sensor. For example, if near-surface soils contain ferrous minerals, then the signature of these soils will be recorded by the sensor, along with the response of the targets. It is common to have soil effects significantly impact the data on munitions response sites. It is difficult to address the full range of soil conditions that may be evident at a site; however, it is important to place the GPO site in conditions that reflect the typical soil complexities that will affect the data during the production geophysical survey.

Are weather conditions a consideration in designing a GPO? Unusual variations in site weather conditions should be considered. For example, a site with distinct seasonal weather patterns may produce significantly different seasonal results (e.g., dry vs. wet conditions).

Only under extreme conditions should the GPO be coordinated to reflect strong, adverse weather because adverse weather conditions can present a myriad of health and safety issues, as well as affect productivity. Typically, the GPO should be rescheduled in cases of adverse weather conditions.

What type of regulatory/permit requirements may be required for construction of a GPO area? Regulatory and permit requirements for construction of a GPO area vary by site. For example, if a site is on the National Register of Historic Places, extensive restrictions and documentation requirements may exist regarding the removal of any items from the area, as well as the ground disturbance associated with GPO site preparation and seed item emplacement. Other considerations may include regulatory and permit requirements associated with wetlands or endangered species. In addition, specific construction codes may pertain to the site.

Should GPO site security be a consideration? Yes, GPO area site access should be controlled, preferably with site security or some other means of physical controls. Limited access to the area is important in maintaining the integrity of the test site. Additionally, the presence of geophysical instruments and equipment on site may present concerns with regard to the security of the equipment as well as safety.

How do potential interference sources such as utilities (above or below ground) affect the GPO? The GPO site should be established in an area (or areas) that replicate the conditions expected during the actual survey. The GPO site should not be influenced by nearby structures such as fences, pipelines, power lines, etc. unless the effects of such structures are expected during the actual survey and are part of the GPO design. Subsurface conditions should also be similar to those anticipated on the actual survey site. A surface sweep of candidate GPO areas should be conducted prior to construction to ensure that the sites are clear of subsurface debris and/or structures (utilities, pipelines, etc.). If isolated targets are present on the candidate GPO site, they should be removed or marked for avoidance.

Is a function check area required? A function check area—used by demonstrators to ensure that equipment, operators, software, and models work under the general site conditions—may not be a GPO requirement but should be available to ensure that demonstrators can successfully complete the prove-out.

What is a blind test area? Is it required? The blind test area is the area of the GPO where the demonstrators do not know the types or the locations of seeded items (including clutter) that are present. The blind test area enables demonstrators to test their technology (i.e., equipment, operators, software, and models) against unknown materials and munitions, with varied targets of different calibers, depths, and orientations. A blind test area is not required on all projects; however, individual projects may use a blind test to test the demonstrators' ability to detect unknown items.

What documentation should be collected and reported during GPO site location selection? The GPO location is typically documented in the overall GPO work plan. It is very important that the site selection criteria and the site's precise location be documented. The site selection process documentation consists of a collection of maps, notes, historical documentation, and other data that was used for selecting the site compiled by the geophysical team. At sites where a suitable GPO location is obvious or noncontroversial, documentation may be minimal. However, at large, complex, or controversial sites, detailed documentation is essential to defend the validity of the selected GPO location and may warrant a separate site selection reporting document.

Before site construction, the regulatory agencies and stakeholders should concur with the GPO location as part of the GPO design phase.

6.1.4 Seed Target Selection and Placement Considerations

What are most difficult items to detect, and how does that factor influence seed target selection? Typically the smallest and deepest items expected to be found on the MRS are the most difficult items to detect. Therefore, seed items selection and placement should include these difficult-to-detect items.

When talking about GPO test geometry and coverage, what is the difference between full-coverage surveys and transects during the GPO? Typically the purpose of a GPO is to quantify detection capabilities based on full coverage of a seeded GPO area. However, if transects are expected to be performed on the actual survey site as part of the project, it is reasonable to devise a GPO that evaluates the ability of the transect method to detect (and locate) munitions.

The difference between the two types of surveys relates to the number of opportunities the geophysical sensor has to detect items of interest. The transect method enables the geophysical sensor to have only one "look" at each item. Full-coverage surveys provide the geophysical sensor multiple opportunities to detect items on adjacent passes.

While a GPO can be used to validate that a transect survey is capable of detecting certain munitions at certain depths under prescribed soil conditions, a GPO cannot address the capability of transects to characterize a site.

Can the GPO be used to determine a "probability of detection" for a geophysical survey system? The GPO can be used to determine the Pd, but only for the GPO. The GPO process does not provide a reliable method to establish Pd statistics for the field survey. The reason for this limitation is that real-world conditions of the MRS may vary from the more controlled conditions of the GPO area. The actual detection rates are typically more variable and harder to quantify. The greater the number of seed items, the greater the statistical validity of the results, as discussed in Section 5.2.2.

The GPO can establish the ability of tested technologies (comprising tested deployment methods, data densities, sensor elevations, navigation methods, processing methods, and analysis techniques) to detect different targets at different depths and orientations. Once the technology is selected, data quality specifications are established to ensure that the data collected during the actual survey is of the quality necessary to detect targets at levels comparable to those observed on the GPO site.

What is the effect/importance of depth, orientation, and azimuth of emplaced targets in a GPO area? Geophysical detection capability is influenced by the geometry of the buried target item. The depth and orientation of the target can strongly influence detection; for example, increasing the burial depth of a target just 6 inches can mean the difference between detection and nondetection. Due to these effects, it is important to consider a range of varying depths and orientations for seeded munitions in the GPO area.

What quantity of seeded items is required? The DQOs will determine the number of seed items needed to evaluate the performance of geophysical technologies during a GPO to ensure statistical validity of the results. For example, a sufficient number of seed items should be buried at a range of depths and orientations to document detection limits. One limitation on the number of seed items that can be used is seed item availability. Cost may be another factor that may limit the number of seed items that can be used.

Are actual munitions or surrogates typically used as seed items? Is one preferred over the other? For safety reasons, actual munitions cannot be used for a GPO. Actual inert munitions items are preferred. If munitions are unavailable, then surrogates of approximately equal size, shape, mass, and material composition of metal components should be fabricated. When using surrogates, it is desirable to place an inert munition and its surrogate in the same depth and orientation within a test plot to determine the extent to which the geophysical response of the surrogate is dissimilar to that of the actual munitions item. However, when using inert munitions, be aware that the geophysical response of different models in the same munitions class (e.g., 60-mm mortars) can differ. In particular, practice rounds can be made of different materials entirely.

What is the purpose of adding clutter to a GPO? Adding clutter may be necessary to simulate the expected conditions of the production survey area. Because clutter can mask signals of interest as well as generate signals not of interest, adding clutter to a GPO that represents the type and amount of clutter expected to be found in the production survey area helps establish sensor performance.

Where can standardized targets and clutter items be obtained? Standardized target and clutter items can be obtained in one of two ways: locally, using inert munitions and debris cleared from the GPO test site areas, or through the Aberdeen Test Center. Local clutter is preferred, but munitions-related clutter must be inspected and documented as being free of explosive materials (fuzes, booster charges, propellant, explosive filler, etc.).

6.1.5 Work Plan Considerations

Is a separate work plan always required for a GPO, or can it be documented in the overall project work plan? A separate GPO work plan is not always necessary. The size and complexity of the GPO and geophysical survey dictate the need for a separate GPO work plan.

When should the GPO work plan be developed? After the selection of a GPO site location, seed items, and site geometry, an overall GPO work plan is developed that documents the GPO site location, the criteria used in its selection, the seed items used, site geometry, etc.

What are the key parameters that must be defined in the GPO work plan? The GPO work plan should include a complete discussion of the goals and objectives of the GPO. These may include, but are not limited to, the following: detection capabilities for specific munitions items, characterization of soil effects, sensor technologies to be tested, data density requirements, sensor deployment techniques (single sensors, pushcarts, towed arrays, etc.), navigation technologies, munitions and/or surrogate emplacement strategies, and QC procedures. A clear plan of field activities should be included, as well as a data processing plan. The work plan should also identify all specific tasks, objectives, and procedures to be followed by demonstrators when using the GPO area. It should also clearly describe the criteria for scoring (determining "pass" or "fail") for individual seeded target anomalies.

6.2 Construction Phase Considerations

This section discusses factors to consider in the construction phase of a site-specific GPO. The factors are presented under three major categories—GPO site preparation, target and clutter placement, and GPO construction documentation.

6.2.1 Site Preparation Considerations

Does the GPO site need to be cleared before GPO construction begins? The entire area that makes up the proposed GPO site should be cleared of all munitions and other metallic clutter items to a minimum depth as documented in the GPO design. This is important because the presence of extraneous metallic items not associated with the GPO site construction may adversely affect the integrity of the instrument performance on the site.

Is a baseline geophysical survey necessary? After the entire area is cleared as described above, a baseline survey of the entire GPO site should be conducted to obtain geophysical background characteristics. The baseline survey provides the demonstrators with common geophysical data for use during the GPO. The baseline survey is also used to identify previously buried existing targets located in the GPO area, which should be removed or marked for avoidance.

What are the requirements for a first-order survey marker at the GPO site? The first-order survey marker, having both horizontal and vertical controls, should be placed within line of sight of the GPO test area(s) and be constructed to the minimum industry standards for first-order control points. Coordinates should be established by conducting surveys to first-order survey standards, with minimum requirements of either 1:100,000 accuracy or 5.0 cm, whichever is greater.

GPS surveys meeting first-order standards should provide an elevation accurate to ±2.5 cm; this is sufficient to meet the vertical accuracy standards. However, differential leveling should be performed between survey markers on site to ensure accurate relative elevation data.

Once a GPO site is constructed, what are the maintenance requirements? Typically, maintenance of a GPO site includes mowing the vegetation. Depending on the particular site and the challenges being presented during the GPO, some of the grasses may be allowed to grow while other areas may be kept short to duplicate the conditions in the geophysical survey area.

6.2.2 Target and Clutter Placement

Is there an advantage to using standardized vs. nonstandardized targets on a site-specific GPO test grid? Generally, both standardized and nonstandardized ordnance targets are used on a site-specific GPO test grid. Standardized target signatures have been characterized and are well known. The known signatures are useful during calibration and help to assess the anticipated munitions that may be encountered. To better address site-specific issues, it is necessary to use nonstandardized targets as well. For example, the history of a site may include items not available in the standardized munitions library; therefore, it would be necessary to seed a GPO site with items unique to that site.

Is it necessary for targets to "mature" after placement in the GPO area and before use of the GPO site? There are two issues related to targets getting "equilibrated" to the ground conditions. One is the effect on the ordnance signature (i.e., acquired remanence), which is not currently well understood. The second is visual cues on the surface from the emplacement, which should be eliminated. This "maturing" may take weeks, months, or even years. It is generally agreed, however, that this is a second-order effect and does not significantly affect GPOs.

6.2.3 Construction Documentation

What type and level of documentation should I expect to see before a GPO site is constructed? The following information should be clearly documented (typically in the GPO work plan) before construction of a GPO site begins:

- survey map of the area identifying the locations of the calibration area and test survey area;
- target design layout consisting of a series of maps showing where target items will be placed in the GPO area(s) (to be kept confidential to protect the integrity of the GPO site and the items' depths and orientations); and
- work plan and safety and health plans, which need to be in accord with the host installation's health and safety requirements.

What should be included as part of the documentation for seed item placement? Field target placement should be fully documented, typically on placement worksheets, and certified (by signature). The information on the placement sheet should include the following:

- munition/clutter identification (ID) number—it is extremely important that the ID numbers in this target location placement sheet precisely match the ID numbers recorded on the separate spreadsheet file containing the physical descriptions of targets;
- field test area (i.e., calibration area, blind test area, open field area, etc.);
- field grid location in specified datum and coordinate system;
- ground surface depth—measured from highest point of the object to the ground surface or from the center of the object; whichever method is used should be documented;
- target orientation (dip and azimuth)—should include the reference for dip and azimuth (i.e., is 0° defined as horizontal? What is the definition of positive and negative angles with respect to the position of the nose?);
- coordinate location—typically obtained from the highest point of the object or from the center of the object; whichever method is used should be documented and consistent;
- Z depth relative to survey marker;
- target placement date;
- target removal date;
- field photograph; and
- field notes/comments.

What type of documentation should be submitted after construction? Why should regulators care? Post-construction documentation consists of all target emplacement records and maps. The site construction field office typically keeps this documentation until the GPO is completed and is included in the GPO report. This information is typically available for review at the project site or field office and includes the following:

- site boundary maps—outline the overall site boundaries and the test areas used in the GPO (calibration area, blind test grid area, etc.); can be provided to the demonstrator;
- target placement maps—showing the actual location of the emplaced items; and
- final construction report.

6.3 Implementation and Reporting

This section provides some key factors to be considered by regulatory agencies during the implementation, evaluation, and reporting of a site-specific GPO.

Is the GPO work plan being followed? The first questions to be asked when observing field work are, "Where is the work plan, and is it being followed?" Key site personnel should have a copy of the work plan available during the survey. It is important to verify early in the GPO process that the work plan is implementable and being followed. Any field deviations from the plan should be carefully documented in the field notes and major changes agreed to by the munitions response team.

What data is collected during a prove-out for a handheld mag and flag survey? During GPO for a mag and flag survey, demonstrators must carefully document the procedures, equipment settings and operating conditions, search geometry, etc. to be used during the survey. Since a mag and flag survey is real time, it is beneficial for regulatory personnel to observe the GPO implementation and scoring in the field.

Are the personnel collecting the GPO data the same skill level as those who will be implementing the actual site survey? Not necessarily. The quality of the data may be impacted by the personnel implementing the prove-out. A state regulator should be aware that changes in personnel can impact the results of the actual survey. If the personnel are important to achieving the goals of the GPO, changes in personnel may be important. However, if the GPO is testing system performance, changes in personnel may not be as important.

What is the regulator's role during the implementation of the GPO fieldwork? During implementation of the GPO fieldwork, the regulator should verify that the demonstrator is operating according to the work plan, safety and health plan, and QA plan for conducting the GPO surveys. If possible, this effort should include field oversight to ensure the GPO construction and implementation are consistent with the sampling design as documented in the work plan. Additionally, the regulator may elect to collect data from the demonstrator before the demonstrator leaves the site.

How should the project plans to deploy multiple systems during the production survey be handled during the GPO? When multiple systems are to be deployed using the same technology, it is generally not necessary to test all of the systems during the GPO, as one of the production systems is typically selected and used to perform the GPO. However, it is recommended that all survey equipment being used at a site be tested using the GPO area to verify its performance before deployment for production survey work. In addition, survey equipment should be retested whenever major repairs or system changes are made.

How should a regulator verify that QC issues are addressed? QC of the survey methods and procedures should be specifically addressed in the GPO work plan. Regulators may want to be provided the GPO data for independent evaluation.

What level of documentation should be collected during the GPO fieldwork? Documentation collected during the GPO should include detailed field notes, digital photos, sensor calibration records, equipment setup time, survey times, and notes on survey control. This information should be included in the GPO report and reviewed by the state regulator.

What types of data should be collected in the project field logs? Field site managers should carefully document GPO operations on standardized forms provided in the GPO work plan. Information to be collected includes the following:

- observations relating to the demonstrator's on-site operations;
- equipment (detector/sensor/platform) reliability;
- number of people (including job title and duties) and time required for setup operations, performing the test, and making repairs; and
- daily activities, including the amount of time required at each test area/grid/scenario, etc. (This information is used both during the GPO to evaluate the cost, efficiency, and reliability of the system and during the production survey to verify that the system is being deployed as tested in the GPO.).

How is the data being handled during the GPO survey? Will production data be handled differently? It is important that the geophysical team review the procedures to be used for storage and handling of survey data during both the GPO and the production survey. Key issues to be aware of and address in data handling are chain of custody, preservation of raw data sets, data access and security, and data availability. The GPO typically generates a much smaller data set than the production survey; however, it is generally good practice to use the production survey data handling procedures during the GPO whenever possible.

What data should be submitted in the field during a GPO? The demonstrator should be required to submit field data for each GPO area covered before leaving the site, including data from both sensors and navigation systems (GPS, etc.). The sensor data should be provided on digital storage medium (i.e., computer disk).

How is data analysis being conducted and documented? The GPO does not end with the completion of survey data collection. In many cases, the overall effectiveness of the deployed technology is dependent on the specific techniques and skills of the data processor/data analyst.

Thus, it is important for the demonstrator to define the methods being applied to the data. While it is not necessary for "proprietary" details to be disclosed, the overall techniques should be described.

6.4 Reporting and Review Considerations

The following information on GPO reporting provides some key factors to be considered by regulatory agencies when reviewing and evaluating GPO reports.

Is a GPO report really necessary? The system found everything in the GPO site—can't we just go straight into production and document the GPO at the end of the process? To ensure that the production survey is performed properly and data quality is maintained at a known level, it is critical that the results of the GPO be fully documented, reviewed by the full munitions response team, and accepted as being successful. Shortcutting the reporting of the GPO risks confusion over data collection methods, standards, and performance and should be avoided.

What types of maps and diagrams should I expect to see in the GPO report? At a minimum, the GPO report should include the following:

- an initial, unfiltered plot of the raw data;
- a final processed map used by the detection procedure;
- comparative maps of the data collected at different data densities;
- for digital geophysical mapping surveys, "track maps" of the navigation traverses collected as part of the GPO survey; and
- a final map with all detected targets, annotated with target characterization results (depth, size, mass, etc.).

What is a ROC curve, and why should I care? A ROC curve shows the technology receiver operating characteristics. Essentially, the ROC curve illustrates that as the Pd increases (through more aggressive target picking), the number of false alarms also increases.

Generally, it is not feasible to collect enough data to construct a ROC curve for a GPO. In current practice, decisions are made that involve the features captured by a ROC (such as where to set the sensitivity threshold for a magnetometer), but they do not consider the trade-offs between Pd and false alarms explicitly. Therefore, the importance of the ROC curve is not the literal ROC curve representation but the conceptual understanding of the trade-offs between Pd and FAR in making decisions about which sensors are appropriate and how the sensors should be deployed on a site.

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7.1 Documents

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7.2 Internet Sites

Defense Environmental Network & Information Exchange
https://www.denix.osd.mil/

Environmental Security Technology Certification Program (ESTCP)
http://www.estcp.org/

Standardized UXO Technology Demonstration Site Program
http://www.uxotestsites.org/

Strategic Environmental Research and Development Program (SERDP)
http://www.serdp.org/

U.S. Army Environmental Quality Technology Program
http://aec.army.mil/usaec/technology/eqt00.html

U.S. Department of Defense Environmental Cleanup
http://www.dtic.mil/envirodod/

U.S. Department of Defense Explosives Safety Board (DDESB)
http://www.ddesb.pentagon.mil/

U.S. Department of Defense Office of the Deputy Under Secretary of Defense (Environmental Security)
http://www.acq.osd.mil/ie/

U.S. Environmental Protection Agency Federal Facilities Restoration and Reuse Office
http://www.epa.gov/swerffrr/

U.S. Army Corps of Engineers documents
http://www.usace.army.mil/usace-docs/

U.S. Army Corps of Engineers, U.S. Army Engineering and Support Center, Ordnance and Explosives Mandatory Center of Expertise
http://www.hnd.usace.army.mil/oew/index.asp

APPENDIX A

Acronyms and Abbreviations

ACRONYMS AND ABBREVIATIONS

bgs	below ground surface
BRAC	Base Realignment and Closure
CL	confidence level
CSM	conceptual site model
DGM	digital geophysical mapping
DGPS	differential geographic positioning system
DMM	discarded military munitions
DoD	U.S. Department of Defense
DQO	data quality objective
EM	electromagnetic
EMI	electromagnetic induction
EPA	U.S. Environmental Protection Agency
EQT	Environmental Quality Technology
ESTCP	Environmental Security Technology Certification Program
FAR	false alarm rate
FDEM	frequency-domain electromagnetic
FUDS	Formerly Used Defense Sites
GPO	geophysical prove-out
GPR	ground-penetrating radar
GPS	global positioning system
ID	identification
ITRC	Interstate Technology & Regulatory Council
LiDAR	light detection and ranging
Mag	magnetometer
MC	munitions constituents
MEC	munitions and explosives of concern
MMRP	Military Munitions Response Program
MR	munitions response
MRA	munitions response area
MRS	munitions response site
OE	ordnance and explosives
Pd	probability of detection
QA	quality assurance
QC	quality control
ROC	receiver operating characteristic
SAR	synthetic aperture radar
SERDP	Strategic Environmental Research and Development Program
SNR	signal-to-noise ratio
TDEM	time-domain electromagnetic
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Center
UXO	unexploded ordnance

APPENDIX B

Dig Sheets

MEC Project
Geophysical Dig Sheet

Project Name: Munitions Response Site
Geophysical Contractor: ABC Inc
Project Geophysicist: J. Smith
Field Team: 1
Survey Area ID: A
Sector: 1   Grid: A1

Project Location: Somewhere USA
Design Center POC: ____________
Site Geophysicist: B. Jones
Date: ____________
Coordinate System: UTM Zone 16N

Scanning Geophysical Equipment Used: EMI device
Reacquisition Geophysical Equipment Used: EMI device

Background Value (mV / nT): ________
Background Value (mV / nT): ________

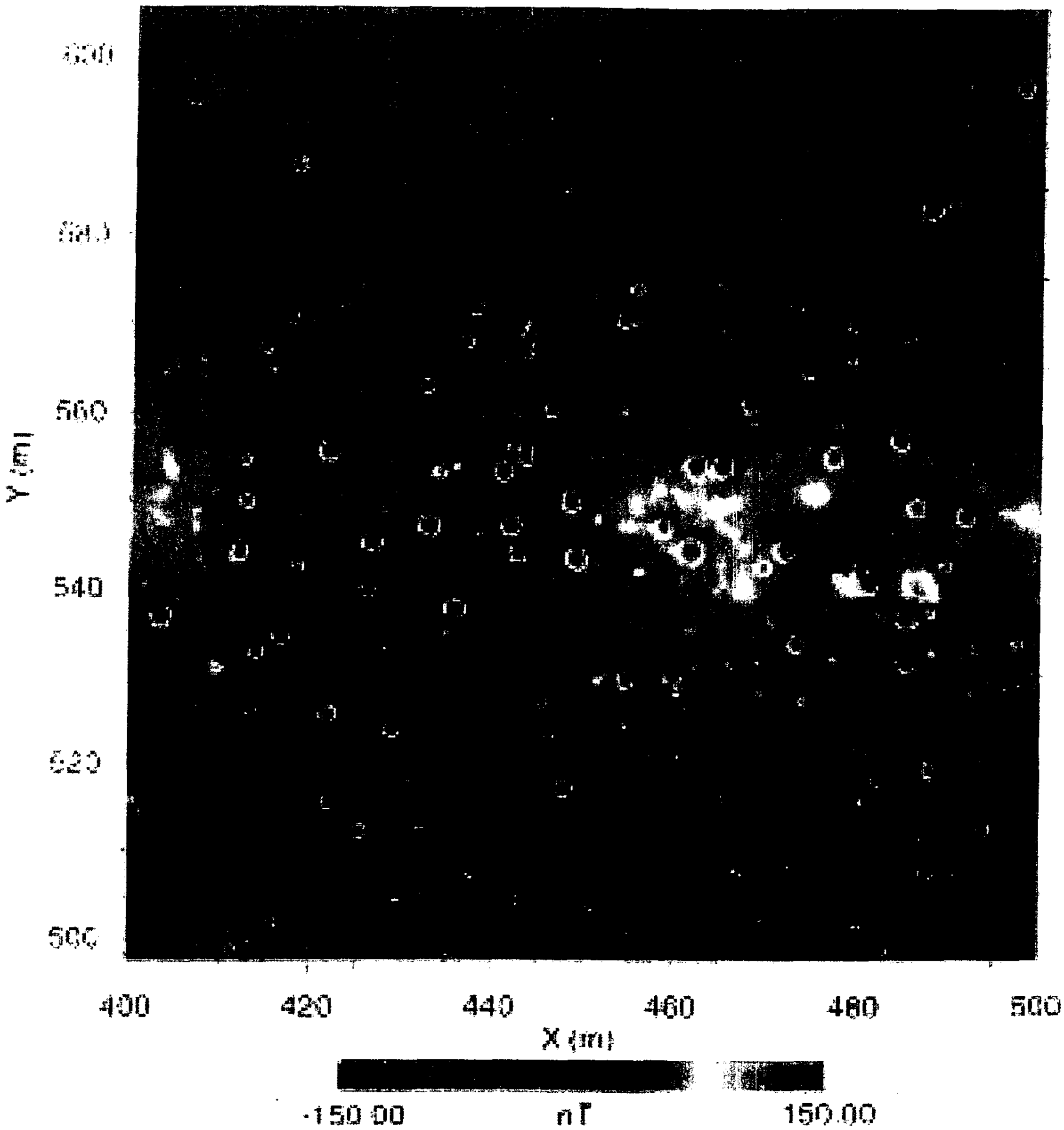
Page   of

Row	Original Survey: Unique Target ID	Northing Coord	Easting Coord	Size (nT)	Size (mV)	Reacquisition Survey: # of Contacts to dig	Maximum Amplitude (nT)	Maximum Amplitude (mV)	Date	Description	# of contacts	Approx. weight (lbs-oz / kg-g)	Offset: Distance (ft / m)	Offset: Direction (N, NE, etc.)	Orientation of Nose (Azimuth deg) **	Inclination of Nose (deg) **
16	5040-1-A	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	Pipe, 1.5 inch by 56in		5-0	<1	n/a	n/a	n/a
17	5040-1-B	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	Pipe, 1.5 inch by 48in		5-0	<1	n/a	n/a	n/a
18	5040-1-C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Pipe, 1.5 inch by 64in		5-0	<1	n/a	n/a	n/a
19	5040-2-A	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	5 Metal rods .25in by 30in		5-0	<1	n/a	n/a	n/a
20	5040-2-B	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	12 Metal rods .25in by 30in		10-0	<1	n/a	n/a	n/a
21	5040-4	[illegible]	[illegible]	[illegible]	[illegible]	2	Remapped	Remapped	[illegible]	Angle iron, 1 foot long, 19 pieces, metal plate, rebar		10-0	<1	n/a	n/a	n/a
22	5040-4-B	Part of 5040-4	Part of 5040-4	Part of 5040-4	Part of 5040-4	2	Remapped	Remapped	[illegible]	Munitions Frag (End of a 75mm)		0-8	<1	n/a	n/a	n/a
23	5040-4-C	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	Munitions Frag (End of a 75mm)		0-8	<1	n/a	n/a	n/a
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	2120	[illegible]	[illegible]	Munitions Frag (End of a 75mm)		0-8	<1	n/a	n/a	n/a
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	Iron rod, 36in x 1in dia under sidewalk		5-0	<1	n/a	n/a	n/a
26	5050-1-A	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	Metal Bucket, 12in dia x 17in deep	1+	1-0	<1	n/a	n/a	n/a
27	5050-1-B	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	Angle iron, 1in by 47in long.	1	3-0	<1	n/a	n/a	n/a
28	5050-1-C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Numerous pieces of metal, sheeting and strapping	1+	10-0*	<1	n/a	n/a	n/a
29	5050-1-D	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	Nail two inches long	1	0-3	<1	n/a	n/a	n/a
30	[illegible]	[illegible]	[illegible]		[illegible]	1	[illegible]	[illegible]	[illegible]	Sod anchors, 8 in long, 8 dug more still in the yard	8	0-5 each	<1	n/a	n/a	n/a

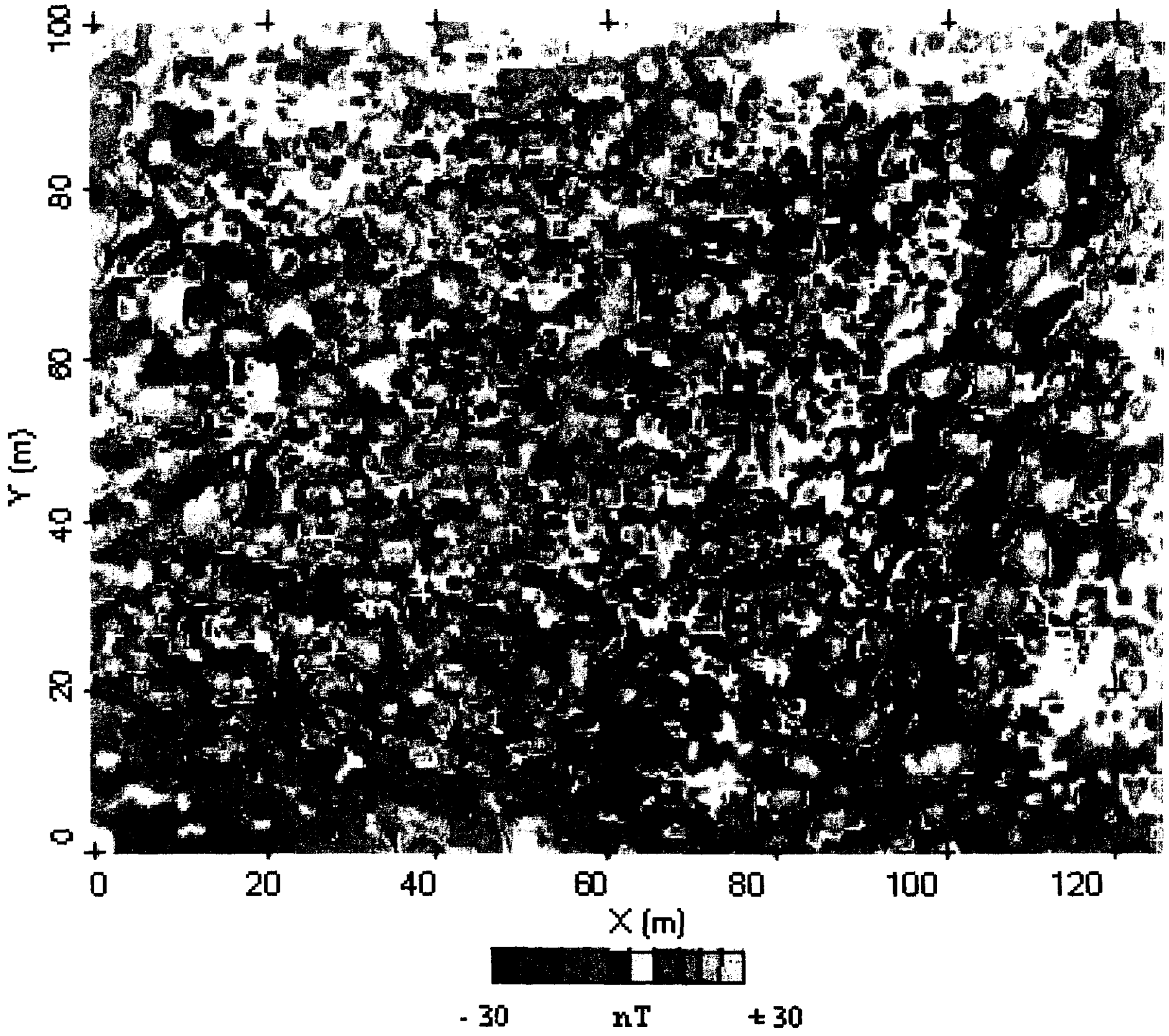
Row	Depth (in/cm): Top	Depth: Center of Mass	Date	Team Leader Initials	Post-Dig Excavation QC Results: Excavate a Hole Cleared?	QC Initials	Date	Post-Dig Geophysical QC: Agreement between Dig Results & Geophysical	Maximum Amplitude (nT)	Maximum Amplitude (mV)	90% Reduction or Reduced	Anomaly Identified or Removed	QC Initials	Date	Comments
16	n/a	1in	3/18/2004	DG	Yes	DOC	3/18/2004	G	70nT	0mV	90% Reduced	Removed	GQC	########	
17	n/a	0in	3/18/2004	DG	Yes	DOC	3/18/2004	G	67nT	0mV	90% Reduced	Removed	GQC	########	
18	n/a	1in	3/18/2004	DG	Yes	DOC	3/18/2004	G	15nT	1mV	90% Reduced	Removed	GQC	########	
19	n/a	1in	3/18/2004	DG	Yes	DOC	3/18/2004	G	30nT	4mV	90% Reduced	Removed	GQC	########	
20	n/a	1in	3/18/2004	DG	Yes	DOC	3/18/2004	G	30nT	4mV	90% Reduced	Removed	GQC	########	
21	n/a	0in	3/18/2004	DG	Yes	DOC	3/23/2004	G	Remapped	Remapped	90% Reduced	Removed	GQC	########	Linear anomaly removed based on the remapping data. OE Frag was part of linear anomaly.
22	n/a	25in	2/23/2004	DG	Yes	DOC	3/23/2004	G	6nT-	0mV	90% Reduced	Removed	GQC	########	Linear anomaly removed based on the remapping data. OE Frag was part of linear anomaly.
23	n/a	0in	3/18/2004	DG	Yes	DOC	3/18/2004	G	2nT-	3mV	90% Reduced	Removed	GQC	########	
24	n/a	8in	3/11/2003	DG	Yes	DOC	3/18/2004	G	6nT-	2mV	90% Reduced	Removed	GQC	########	
25	n/a	8in	3/18/2004	DG	Yes	DOC	3/18/2004	G	2nT-	1mV	90% Reduced	Removed	GQC	########	
26	n/a	20in	3/12/2004	DG	Yes	DOC	3/12/2004	G	10nT	6mV	Reduced	Identified	GQC	########	Reduced significantly but very small pieces of metal and rust still exist in the hole
27	n/a	14in	3/12/2004	DG	Yes	DOC	3/12/2004	G	15nT	0mV	90% Reduced	Removed	GQC	########	
28	n/a	14in-20in	3/12/2004	DG	Yes	DOC	3/12/2004	G	11nT	20mV	Reduced	Identified	GQC	########	Chased metal pipe underground, did not want to remove completely without major damage to yard
29	n/a	3in	3/12/2004	DG	Yes	DOC	3/12/2004	G	151nT	10mV	Reduced	Identified	GQC	########	Instruments detected reading from near by garden area full of metal
30	n/a	2in	3/12/2004	DG	Yes	DOC	3/12/2004	G	20nT	6mV	Reduced	Identified	GQC	########	Reduced significantly from removing 8 sod anchors but more are still in the ground

APPENDIX C

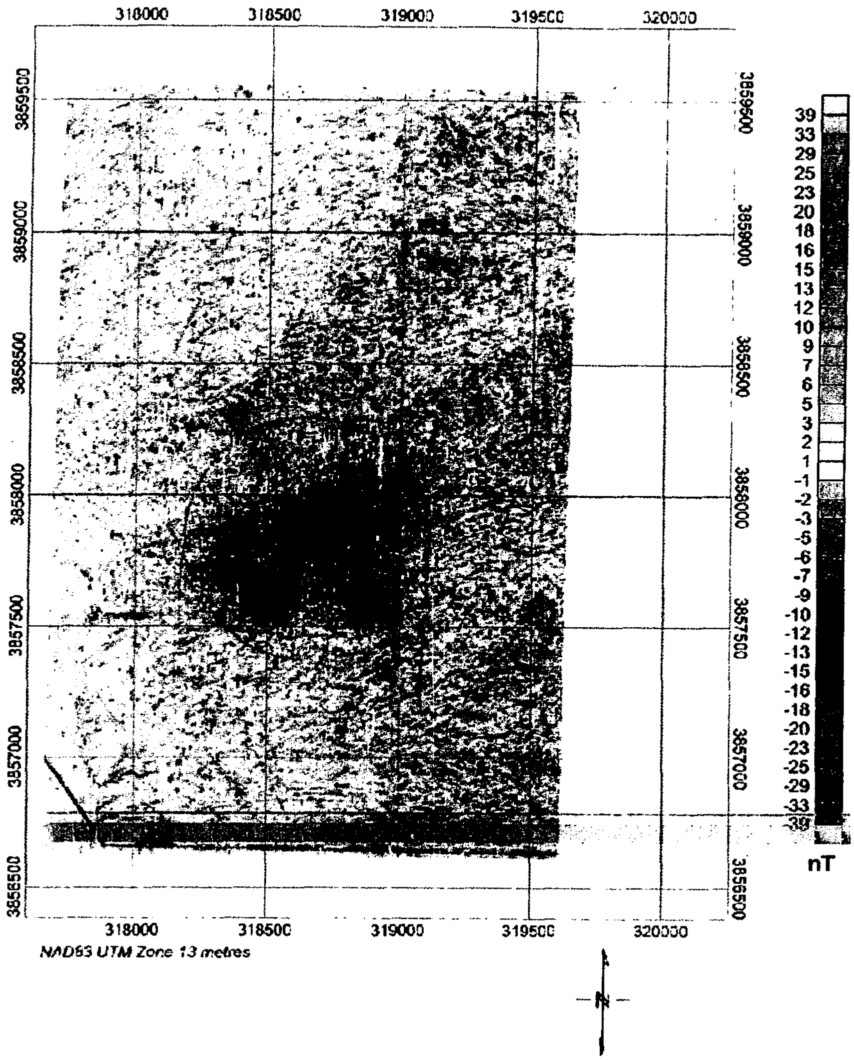
Geophysical Maps



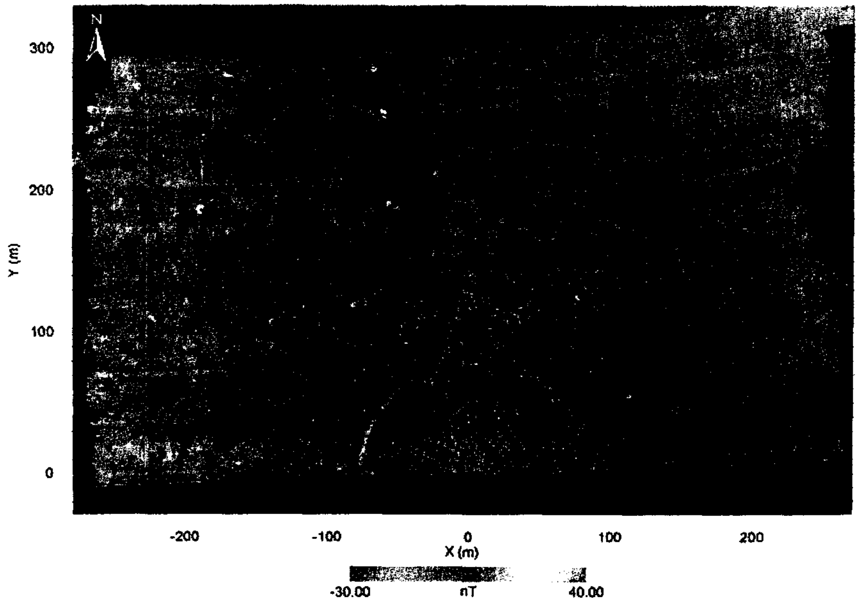
Map 1. Representative anomaly map from a geophysical survey.



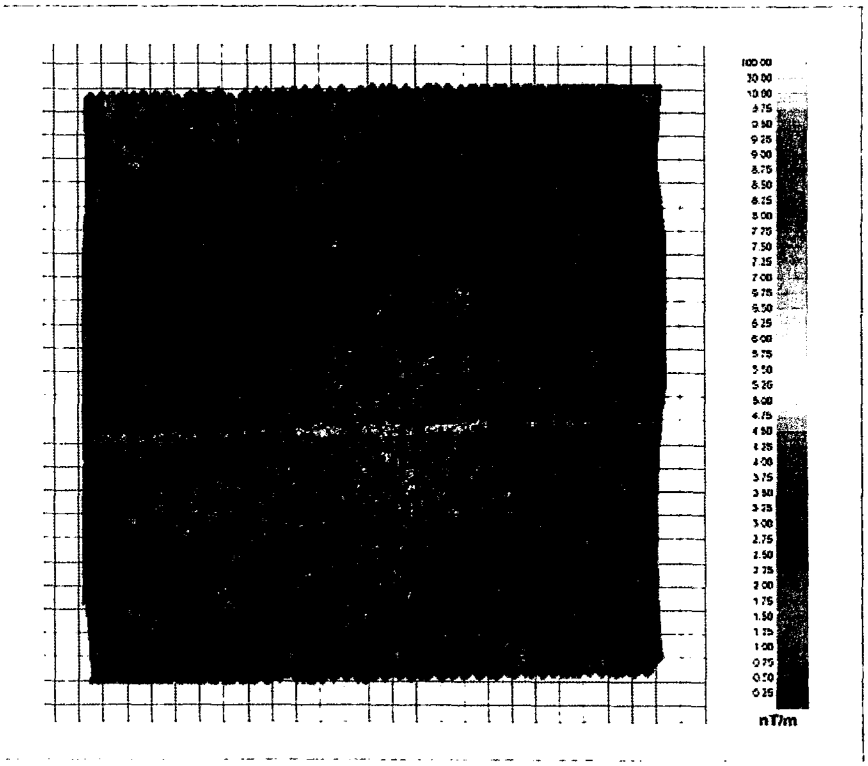
Map 2. This map shows a site with a significant amount of environmental noise because the sensor captured other external sources that compete with the signal of interest. Sources of environmental noise include electromagnetic interference, geological noise, or other types of clutter.



Map 3. Survey results from a total magnetic field, multi, towed array detection system (MTADS)—Airborne survey of the Pueblo of Isleta.



Map 4. Results from a ground-based MTADS survey of the north half of the bombing target area at Badlands Bombing Range.



Map 5. Analytic signal as plotted in computer software. Taken with Oak Ridge National Laboratory helicopter system over bombing target at Badlands Bombing Range. The line feature in the center of the map can probably be attributed to cultural noise (fence, utility line, etc.).

APPENDIX D

UXO Team Contacts, ITRC Fact Sheet and Product List

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