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INNOVATIVE SITE CHARACTERIZATION DEMONSTRATION SAVES TIME AND MONEY

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ABSTRACT

A technology demonstration that optimizes sampling strategies and real-time data collection was carried out at the Kirtland Air Force Base RB-11 Radioactive Burial Site, Albuquerque, New Mexico in August 1994. The project, which was funded by the Strategic Environmental Research and Development Program (SERDP), involved the application of a geostatistical-based "smart sampling" methodology and software with on-site field screening of soils for radiation, organic compounds and metals. The software, known as Plume™, was developed at Argonne National Laboratory as part of the DOE/OTD-funded Mixed Waste Landfill Integrated Demonstration (MWLID).

The objective of the investigation was to compare an innovative Adaptive Sampling approach that stressed real-time decision-making with a conventional RCRA-driven site characterization carried out by the Air Force. The latter investigation used a standard drilling and sampling plan as mandated by the EPA. To make the comparison realistic, the same contractors and sampling equipment (Geoprobe® soil samplers) were used. In both investigations, soil samples were collected at several depths at numerous locations adjacent to burial trenches that contain low-level radioactive waste and animal carcasses; some trenches may also contain mixed waste. Neither study revealed the presence of contaminants appreciably above risk based action levels, indicating that minimal to no migration has occurred away from the trenches. The combination of Adaptive Sampling with field screening achieved a similar level of confidence compared to the RCRA investigation regarding the potential migration of contaminants at the site. By comparison, the Adaptive Sampling program drilled 28 locations (vs. 36 for the conventional investigation), collected 81 samples (vs. 163), and sent 15 samples (vs. 163) off-site for laboratory analysis. In addition, the field work took 3 1/2 days compared to 13 days for the RCRA investigation. These figures translate into large cost savings because 22% fewer boreholes were drilled, 50% fewer samples were collected, and 91% fewer samples were analyzed off-site. Of these costs, the most significant savings involved laboratory analyses which typically cost >$1K/sample. Additional costs associated with the increased level of field screening carried out and costs associated with the use of the Adaptive Sampling software are relatively minor compared to the savings achieved.

During the field demonstration, a SunSPARC workstation containing the geostatistical program was successfully linked via the Internet with an identical workstation at Argonne. In the near future, it will be possible to support real-time sampling decisions in the field from remote locations thousands of miles away.

INTRODUCTION

The Kirtland Air Force Base RB-11 radioactive waste site, located in Bernalillo County, southeast of Albuquerque (Fig. 1A), is a 0.02 sq. km. (4.5 acre) landfill containing nine or ten disposal trenches (the exact number is unknown). Incomplete records suggest that the four earliest trenches located at the southern end of the site (Fig. 1B) are 15 meters (~50 ft.) long by 3 meters (~9 ft.) deep by 0.6 meters (2 ft.) wide and have about 1.2 meters (4 ft.) of earth cover. Two of these trenches are covered with asphalt. The remaining trenches are described as being 30 meters long(~100 ft.), 6-7 meters (20-24 ft.) deep and 2 meters (6 ft.) wide with 1.2 meters (4 ft.) of earth cover.

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DISCLAIMER

The RB-11 landfill was used to dispose of laboratory wastes (gloves, wipes, etc.) and animal carcasses that had received varying exposure doses of radiation as a result of military research activities carried out in the 1960s and early 1970s. Most of the radioactivity was in the form of induced activity and short-lived radionuclides. However, based on interviews with former employees who worked at the site, it is likely that several millicuries of radionuclides with longer half lives are present, e.g., ^{137}Cs ($t_{1/2}$=30 yrs), ^{90},S r ($t_{1/2}$=28 yrs). Only a small portion of the waste appears to have been buried in drums. In addition to the radioactive wastes, an undetermined amount of hazardous and toxic liquid wastes may also have been disposed of in the trenches. These included small amounts of acids, mercury, cyanides and silver.

The purpose of this paper is to describe a case study in which traditional site characterization methods currently approved by EPA, such as grid drilling and off-site laboratory analysis, are compared with an innovative approach that combines sample optimization with real-time field screening. The innovative approach achieves similar results but is considerably more cost-effective and time-efficient because fewer boreholes need to be drilled and fewer samples need be collected and analyzed off-site. In addition, the sample optimization strategy employed allows real-time decisions to be made in the field regarding additional sampling, thus obviating the need for more costly supplemental sampling programs during a revisit of the site.

Our aim here is to present an alternative site characterization methodology that is equivalent to meeting the information needs of a regulatory-driven program, while being more efficient than traditional methods. We consider the present study to be a first step in demonstrating this new approach. Future, similar investigations will be necessary to demonstrate that data quality objectives (QA/QC), statistical validity, and regulatory satisfaction can be achieved at a broader spectrum of sites.

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PREVIOUS STUDIES: KAFB*RCRA* INVESTIGATION

The U.S. Air Force is responsible for implementing a final remediation action plan for the RB-11 site as required by the Resource Conservation and Recovery Act (RCRA) and under the Air Force Installation Restoration Program. Previous investigative activities at the RB-11 site are summarized in an EPA-approved Stage 2B Work Plan for Kirtland Air Force Base, New Mexico (U.S. Geological Survey, 1). In addition, the RB-11 site was the focus of a minimally intrusive field demonstration of innovative site chararacterization technologies carried out by Sandia National Laboratories in 1993 (Floran, 2). None of these previous investigations conclusively identified any type of contamination at the site.

In July 1994, the Air Force Environmental Management Division and their contractor, Halliburton NUS, conducted a RCRA Facility Investigation (RFI) at RB-11 to fulfill requirements of their Part B Permit. The results of that investigation (Halliburton NUS, 3) are briefly summarized here.

Conventional geophysical surveys including ground penetrating radar and EM-31/61 electromagnetic surveys were used in the RCRA investigation to define nine irregular trench areas, called "disturbed areas". These data were also used to choose locations for subsurface soil sampling, which was subsequently carried out with a Geoprobe® soil sampler. The objective of the sampling was to define the extent of contaminant migration, if any, away from the disturbed areas. As required by the Air Force, sampling locations were carefully chosen so that they were outside of the disturbed zones to prevent penetration of contaminant sources within the trenches.

After initial field screening, each soil sample was analyzed in an off-site laboratory for gross alpha and beta radiation; ^{226}Ra and ^{228}Ra; volatile organic compounds (VOCs); semi-volatile organic compounds (SVOCs); cyanide; metals (including mercury); and petroleum hydrocarbons. The RCRA investigation concluded that there has been no significant migration of contaminants (organics, metals, radiation) away from the trenches. However, if a release not detected by field screening had been identified, the Air Force was prepared to revisit the site and conduct a detailed follow-up sampling program.

Over a span of 13 days, 36 boreholes were drilled and 163 soil samples were collected and sent to an off-site laboratory for analysis. These numbers do not include surface soil samples collected, additional drilling and sampling carried out for the EPA, and QA/QC samples that were required by RCRA (duplicates and blanks). If the latter activities were eliminated the total operation would have probably taken about 11 days. It should be noted that the Stage 2D-1 RFI report (Halliburton NUS, 3) revealed that radiation levels averaged slightly above background adjacent to one trench, although the data were insufficient to verify that radiological migration has taken place. In addition, trace amounts of mercury were detected in soil samples near three trenches, suggesting that limited migration of this metal may have occurred at the site.

ADAPTIVE SAMPLING INVESTIGATION

The Adaptive Sampling field demonstration took place during the first week in August 1994, approximately a week after completion of the RCRA investigation. The primary objective was to demonstrate that a "smart sampling" methodology that combines real-time field screening results with sample optimization could do an equivalent or better site characterization than could be achieved by using a conventional approach. The traditional type of site characterization often involves grid sampling, a heavy reliance on costly off-site analyses, and multiple site visits and sampling programs. To accomplish this objective, the Adaptive Sampling plan was compared with the conventional work plan carried out by the Air Force. To make the comparison as realistic as possible, the same drilling contractors (Halliburton NUS) and the same sampling equipment (Geoprobe®) were used in both investigations. Off-site laboratory analyses closely matched those specified in the KAFB Work Plan. The main objective of the analytical work performed during the investigation was to provide data that could be reliably compared with similar data obtained by the Air Force RCRA investigation.

However, there were significant differences in the way the two efforts were carried out. The Air Force followed the required conventional approach of collecting soil samples, conducting field screening (for organics and radiation only), and sending each sample to an off-site contract laboratory for confirmatory analysis as required by EPA in the RFI Work Plan. The RCRA investigation resulted in a four to six-week delay between collection of samples and obtaining analytical results. This time gap was potentially crucial because if any of the samples were found to be contaminated, an expensive follow-up investigation involving a new phase of sampling would have had to be conducted. Although both investigations employed field screening methods, the Adaptive Sampling strategy planned to use these results to obtain additional samples *immediately* if contamination were encountered, thus saving the added costs of revisiting the site.

A second major difference between the two investigations involved the number of samples collected. The modified RFI Work Plan, which addressed all EPA requirements, called for sampling every 5 feet to the bottom of each trench and then 10 feet below each trench. If contamination was encountered, sampling would continue every 3 meters (10 ft.) until no further contamination was detected. By using Plume™ (discussed below), a site characterization can be performed quicker and with fewer samples compared to a conventional RCRA characterization, yet achieve a similar level of confidence regarding potential migration of contaminants.

APPLICATION OF THE SMART SAMPLING METHODOLOGY

A geostatistical-based computer program, Plume™, and "smart sampling" strategy was used to optimize drilling and sampling locations. Plume™ was developed at Argonne National Laboratory and is a module of SitePlanner™, a data management and display program marketed by Consolve, Inc., and currently being used by many government laboratories and private industry. Using Plume™, 28 borehole locations were sited adjacent to the disposal trenches. Sampling locations were numbered sequentially from roughly south to north beginning with S1 at the southwest and ending with S28 at the northeast (Fig. 2A). None of the bores drilled directly into the disturbed areas, which was also the case with the conventional RCRA investigation.

Plume™ combines Bayesian analysis with geostatistics to assist in the location of sampling points. A more complete description of Plume™'s methodology can be found in Johnson (4). Bayesian analysis allows a quantitative merging of "soft" information for a site with hard sampling data. Soft information can include historical records, aerial photographs, non-intrusive geophysical survey results, etc. This kind of information is used to form an initial conceptual image regarding the probable location and extent of contamination. Plume™ uses indicator geostatistics to update and refine the conceptual image as hard sample data become available. Indicator geostatistics allow one to interpolate from areas where samples exist to areas where samples are absent. New sampling locations can then be selected so that the uncertainty associated with contamination extent is minimized.

At RB-11, the soft information available consisted of aerial photos; anecdotal information regarding the number, size, location, and content of each trench; and several non-intrusive geophysical survey results for the site. This information was used to construct a conceptual image of the contamination at the site. Figures 2A and 2B show a plan view and cross-section, respectively, of this conceptual image in which soils are gray-scale coded, ranging from white (highly unlikely that contamination is present) to black (contamination known to exist). Most of the site appears as variations of gray, since relatively little hard sampling data were available at the outset.

PLACE FIGS. 2A AND 2B HERE

The conceptual image served as the basis for both the RCRA sampling program as well as the program designed with Plume™. The sampling strategy for the two investigations was the same: sample as close to trenches as possible without actually penetrating them to determine the likelihood that lateral and/or vertical contaminant migration has taken place. In the case of the RCRA sampling program, soil bore locations were based on a modified grid pattern, with one set of soil bores located west of the trenches, four bores to the east of the trenches and the remainder between the trenches (Fig. 2A).

For the Adaptive Sampling program, soil bore locations (Fig. 2A) were selected incrementally with the aid of Plume™, so that information gain was maximized. Information gain was defined as maximizing the volume of soil in the vicinity of the RB-11 trenches that could be classified as clean at an 80% certainty level. This definition of information gain was equivalent to the stated objective of the RCRA investigation, which was to determine whether contaminant migration had occurred away from the trenches. RCRA investigations never completely remove uncertainty regarding the nature and extent of contamination. The level of uncertainty that can be tolerated during a traditional characterization activity has not been specified by the EPA. For the purposes of this comparison, an 80% certainty level was chosen.

Using the 80% certainty level, the information expected from the RCRA sampling program was evaluated by assuming that the samples would have yielded "clean" results. These samples were used to update the initial conceptual image and measure the volume of soils that would be classified as clean. Locations for the Adaptive Sampling effort were then selected to provide the same information gain, while keeping the number of bores and sampling locations to a minimum. The assumption of clean samples reflects the best possible outcome from the conventional investigation --- confirmation that contaminant migration has not taken place.

In the first phase of the Adaptive Sampling program, enough soil bore locations were selected to provide the same base amount of information as expected from the conventional investigation. Because of the field analytical methods employed by the Adaptive Sampling program, analytical results for radiation and VOC analyses were available the same day that bores were drilled, while most of the metals analyses were available before the end of the first phase. Based on these results, the conceptual site model was updated using Plume™. If contamination had been encountered, a second phase of sampling would have immediately ensued, with Plume™ providing the locations of new bores. Additional soil bores and sampling would have continued until the contamination extent had been fully characterized.

FIELD PROCEDURES

Background Sampling

Prior to the field demonstration, four subsurface soil samples were obtained for background determination of organic compounds, metals and radiation. The samples were collected using a Geoprobe® at various depths between 5 and 8.5 meters (16-28 ft.) from areas known to be uncontaminated near the periphery of the site, approximately 90-120 meters (~300-400 ft.) from the ends of the closest trenches (Fig. 1B). These background samples were analyzed on-site by field screening methods and also in off-site laboratories. The data were used to help formulate a sampling strategy for the demonstration.

A procedure was designed to minimize the amount of material needed for both on-site field screening and off-site analysis. Each soil sample was divided into five splits; three of these were used initially for field screening, and two were sent off-site (Fig. 3). In addition, one of the splits used for radiological screening was also sent to an off-site laboratory for isotopic uranium and thorium determinations. This same procedure was followed during the main sampling phase of the investigation in August.

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Drilling

During the August demonstration, a total of 81 soil samples were collected at depth using two Geoprobe® soil samplers which operated simultaneously in the field (the Air Force also used the same two Geoprobes® during their field sampling) . Twenty-two of the 28 borehole locations were sampled at approximately 3, 6 and 9 meters (10, 20 and 30 ft.) below the surface, while the remaining 6 holes were sampled at depths of 3 and 6 meters (10 and 20 ft). Three additional samples were obtained including two field replicates.

Field Screening Methods

On-site field screening of soil samples for radioactivity and volatile organics was obtained within minutes of bringing the samples to the surface. Similar screening for metals took longer but a substantial number of samples were analyzed prior to the end of the field work.

Field screening instrumentation included a photoionization detector (PID) for headspace analysis of organic vapors; a Geiger-Muller (GM) radiation instrument with an internal sodium iodide detector and pancake probe for gamma radiation; and x-ray fluorescence (XRF) analysis for metals. Soil samples were also scanned for alpha radiation using a scintillometer and beta radiation using a second GM tube. Field screening methods were employed sequentially, with headspace done first to minimize loss of volatile organics. In addition to headspace and gross alpha/beta and gamma detection, a full gamma-ray spectral scan of a split from each sample to be sent off-site was performed within several hours of sample collection (Fig. 3). Metals analysis by XRF was available within 24 hours. These analyses were done at Sandia in a nearby laboratory three miles away, but for the purposes of this paper, are considered to have been done "on-site". It should be stressed that the laboratory XRF unit is field transportable and could have been operated at the RB-11 site within a mobile lab. During background sampling, which preceded the field demonstration, XRF analyses were obtained in one hour. Quick turn-around time for metals was achieved by eliminating a time-consuming grinding step during sample preparation. Previous results using this innovative method have been shown to be reasonably accurate at identifying anomalous samples during field screening (Floran, 5). Such a rapid analysis strategy ensured quick determination of potential contamination at a particular drilling location.

RESULTS

Field Screening

No elevated values above background readings were obtained. All headspace values were 0 ppm (action levels were set at 10 ppm). XRF results were below RCRA action levels for all metals analyzed. Gamma radiation counts on each soil sample were below background plus two standard deviations, which was the action level used to identify radiological contamination.

Laboratory Analytical Results

Approximately 20% of the total number of soil samples collected were sent to off-site laboratories for confirmatory analyses. These included 15 samples plus two field replicate QA/QC samples. Separate splits of each sample (including background samples) were analyzed for a complete suite of organic compounds, metals and radioactivity. These included 34 volatile organic compounds, 67 semi-volatile species, 23 metals (TAL metals + mercury), three uranium isotopes, two thorium isotopes, cyanide, and pH. In addition, 73 radionuclide species were analyzed in an on-site laboratory at Sandia by gamma-ray spectroscopy. These data are tabulated elsewhere (Floran and Bujewski, 6); only the results are discussed below.

VOCs, SVOCs

Two volatile organic compounds, methylene chloride and toluene, were detected in a majority of the soil samples; acetone was found in just three samples. All of these occurrences were below human health risk based (HHRB) standards, as defined by the Air Force's RCRA investigation (Halliburton NUS, 3). The presence of methylene chloride and acetone are likely to be the result of laboratory contamination. Both compounds were noted in laboratory blanks. In addition, methylene chloride was also found in equipment and trip blanks. Toluene ranged from below detection to 22 μg/kg, well below the HHRB action level of 1.6×10^7 μg/kg.

Six semivolatile compounds were detected in the RB-11 soils, all below action levels. One compound, phenol, was found in every sample and another, bis(2-Ethylhexyl)-phthalate, was detected in most samples. The majority of these occurrences were near or below the reporting limit although in one sample, phenol had a concentration of 1700 μg/kg, and in two other samples, bis(2-Ethylhexyl)phthalate had values of 1500 and 1200 μg/kg. The presence of bis(2-Ethylhexyl)phthalate was noted in the equipment blank. Trace quantities of benzoic acid, chysene and benzo(b)fluoranthene were detected in one sample each, and di-n-ocylphthalate was found in two samples, all at levels below reporting limits.

Metals

Only one metal, beryllium, was detected above its action level. All of the samples exceeded this concentration (0.2 mg/kg), ranging from 0.28 to 0.64 mg/kg. These levels of beryllium are typical of the relatively high background values within the area being investigated (Halliburton NUS, 3).

Other (Cyanide; Soil pH)

No evidence of hydrogen cyanide or any other metallic salts of hydrocyanic acids were found. Two samples reported cyanide concentrations at or slightly above the reporting limit (0.5, 0.7 mg/kg). The action level for cyanide is 2000 mg/kg. Soil pH ranged from 8.4 to 9.5.

Radiological Compounds

Three isotopes of uranium ($^{233/234}U$, ^{235}U,^{238}U) and two isotopes of thorium (^{230}Th, ^{232}Th) were analyzed in an off-site laboratory. Ranges for the uranium isotopes were 0.82-4.8 pCi/g ($^{233/234}U$), 0.021-0.11 pCi/g (^{235}U), and 0.74-4.4 pCi/g (^{238}U). Thorium isotopes ranged from 0.59-1.4 pCi/g (^{230}Th) and 0.54-1.4 pCi/g (^{232}Th). None of these values are appreciably above background values determined for the site (Adams, 7).

Radiological contaminants of concern at RB-11 include the source radioisotopes, ^{90}Sr and ^{137}Cs. ^{90}Sr was not determined. ^{137}Cs was measured during the field screening phase of the Adaptive Sampling investigation but no values above background were recorded. Analysis of these radioisotopes was not required by the EPA-approved Work Plan, although gross beta determinations provided an indirect indication that neither was present above background levels (Halliburton NUS, 3).

Data Transfer Using the Smart Sampling Methodology

A SunSPARC workstation at Sandia National Laboratories, New Mexico, where the geostatistical program resided (four miles from the RB-11 site), was successfully linked to an identical workstation at Argonne National Laboratory via the Internet. Communication between the workstations was instantaneous. Data from the RB-11 site were transmitted to both workstations in minutes using a cellular phone/modem hookup from the field. If contamination had been encountered during the RB-11 investigation, we had planned to use the Plume™ software at Argonne to suggest additional sampling locations. In the near future, it is likely that these types of real-time sampling decisions in the field will be possible from remote locations thousands of miles away.

COST SAVINGS

Substantial cost savings can be obtained by optimizing the number of samples obtained during a site characterization investigation, as well as by judiciously choosing how many of these should be analyzed off-site. The Adaptive Sampling program resulted in drilling 22% fewer boreholes, collecting 50% fewer samples, and analyzing 91% fewer samples in an off-site laboratory. A synergistic cost savings was possible with the smart sampling approach because fewer samples were collected (compared to the conventional type of investigation) and only a small fraction of the reduced sample set was analyzed. Of these costs, the most significant savings involved laboratory analyses which typically cost >$1K/sample.

For the analyses performed in this investigation, undiscounted prices per soil sample were as follows: VOCs ($295), SVOCs ($585), TAL metals + mercury ($466), cyanide ($65), pH ($25), isotopic thorium ($178), and isotopic uranium ($166). However, discounts of up to 50% are typically available to long-term customers. Actual costs for the types of analyses done here might range between $1K (~50% discount) to $1.8K (no discount) per sample. Thus, there is a tremendous potential for savings in analytical costs if only 20% of the samples collected are sent to an off-site laboratory, as was done in the present study.

Cost savings achieved by reducing off-site analytical costs must be weighed against additional costs associated with the increased level of effort associated with field screening (labor, depreciation on analytical equipment, report writing, expendables, etc.), as well as the costs associated with the Plume™ software (acquisition, training, personnel required to run the program). In the Adaptive Sampling program, the major additional field screening cost that was not borne by the Air Force investigation was the use of an XRF unit for metals analysis. However, these costs, estimated to be $30/hr or $1,600 for the total project (including labor), were minor compared to the savings in off-site analyses. The cost of the SitePlanner/Plume™ software, which is now available on a PC, has been steadily dropping; present costs including training are ~$6K.

CONCLUSIONS

The combination of smart sampling with field screening enabled our project to achieve a similar level of confidence compared to the conventional investigation regarding potential migration of contaminants away from the trenches. By comparison, the Adaptive Sampling project drilled 28 locations (vs. 36 for the Air Force), collected 81 samples (vs. 163), and sent 15 samples (vs. 163) off-site for laboratory analysis. In addition, the field work took 3 1/2 days compared to 13 days for the Air Force. These figures translate into large cost savings: 22% fewer boreholes drilled, 50% fewer samples collected, and 91% fewer samples analyzed off-site. Of these costs, the most significant savings involve laboratory analyses which typically cost >$1K/sample for the type of analyses done in the present study.

Despite the large number of samples collectively screened and analyzed in both investigations, no significant contamination above background levels of any kind was found. These results suggest that no gross, systematic migration of contaminants away from the trenches has occurred at the site.

The type of site characterization effort described here, in which geostatistically-based iterative sampling is combined with real-time field screening, is best demonstrated when contamination is present. In such a situation, the value of extensive field screening and avoidance of subsequent sampling phases is more easily quantified. Future demonstrations of the smart sampling methodology at sites with known contamination are planned and will be more rigorously compared with conventional approaches to site characterization.

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FIGURE CAPTIONS:

Fig. 1A. Location map of the RB-11 landfill, Kirtland Air Force Base, New Mexico

Fig. 1B. RB-11 site showing infrastructure, inferred location of waste trenches and surrounding disturbed ground. Background sampling points are shown at perimeter (RB11-1 through RB11-4).

Fig. 2A. Plan view of RB-11 conceptual model with locations for Adaptive Sampling and RCRA soil bores.

Fig. 2B. North-south cross-section of RB-11 conceptual model.

Fig. 3. Flow diagram illustrating how splits from each subsurface soil sample were allocated for on-site field screening and off-site laboratory analyses.

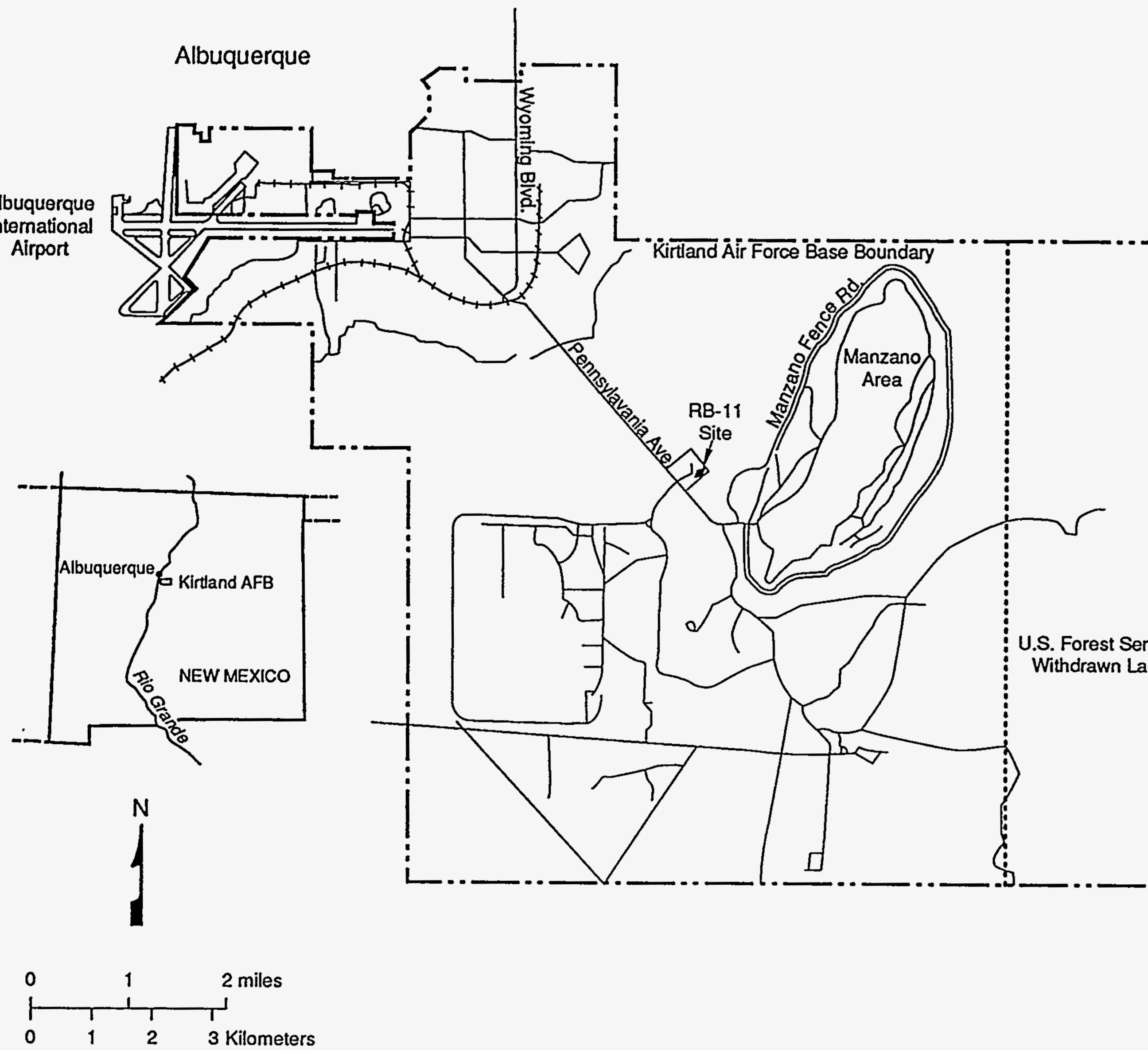

Figure 1A. Location of RB-11 Mixed Waste Landfill, Kirtland Air Force Base, New Mexico

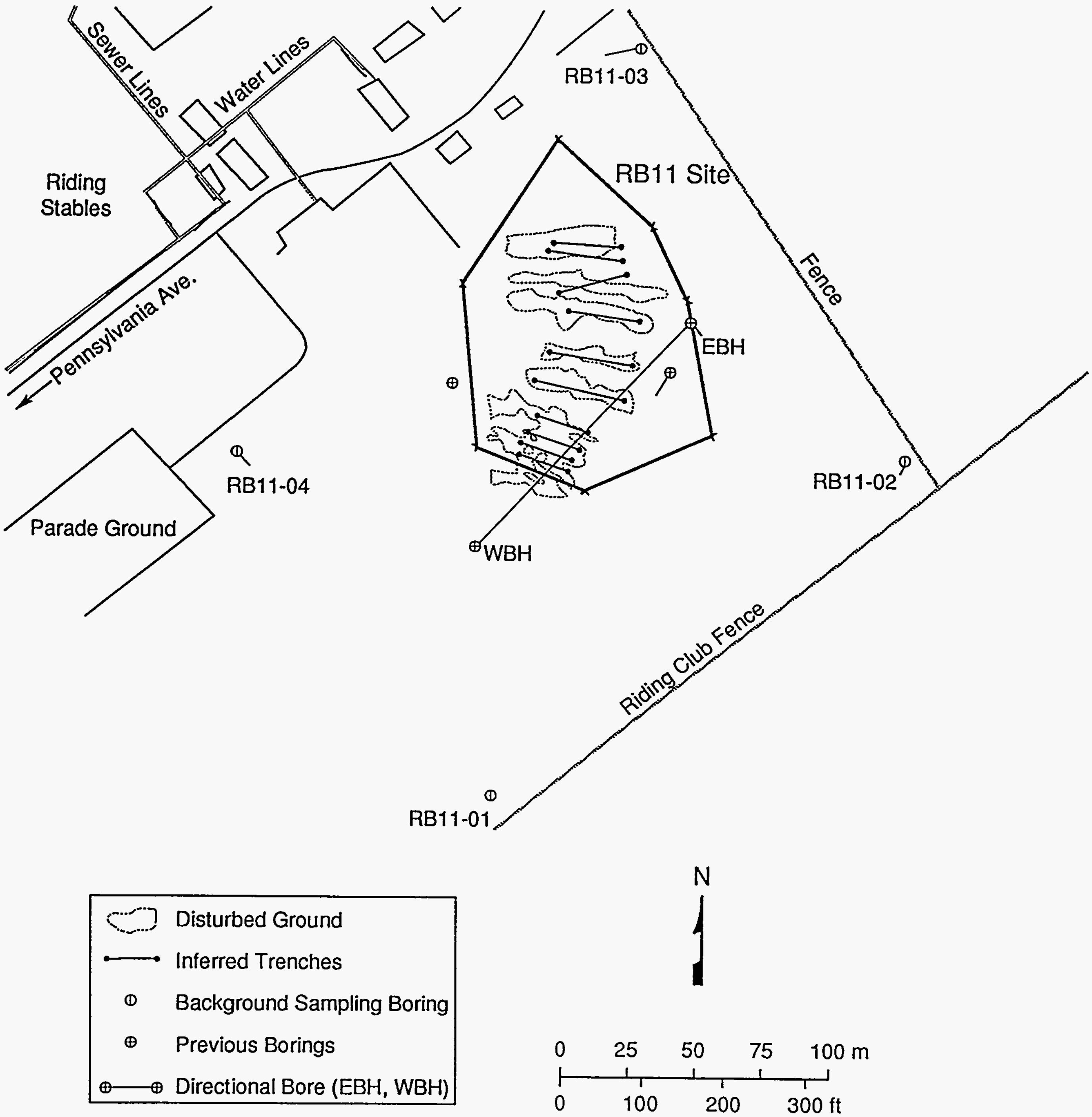

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Figure 1B. RB-11 site showing infrastructure, inferred location of waste trenches and surrounding disturbed ground. Background sampling points are shown at perimeter (RB11-1 through RB11-4).

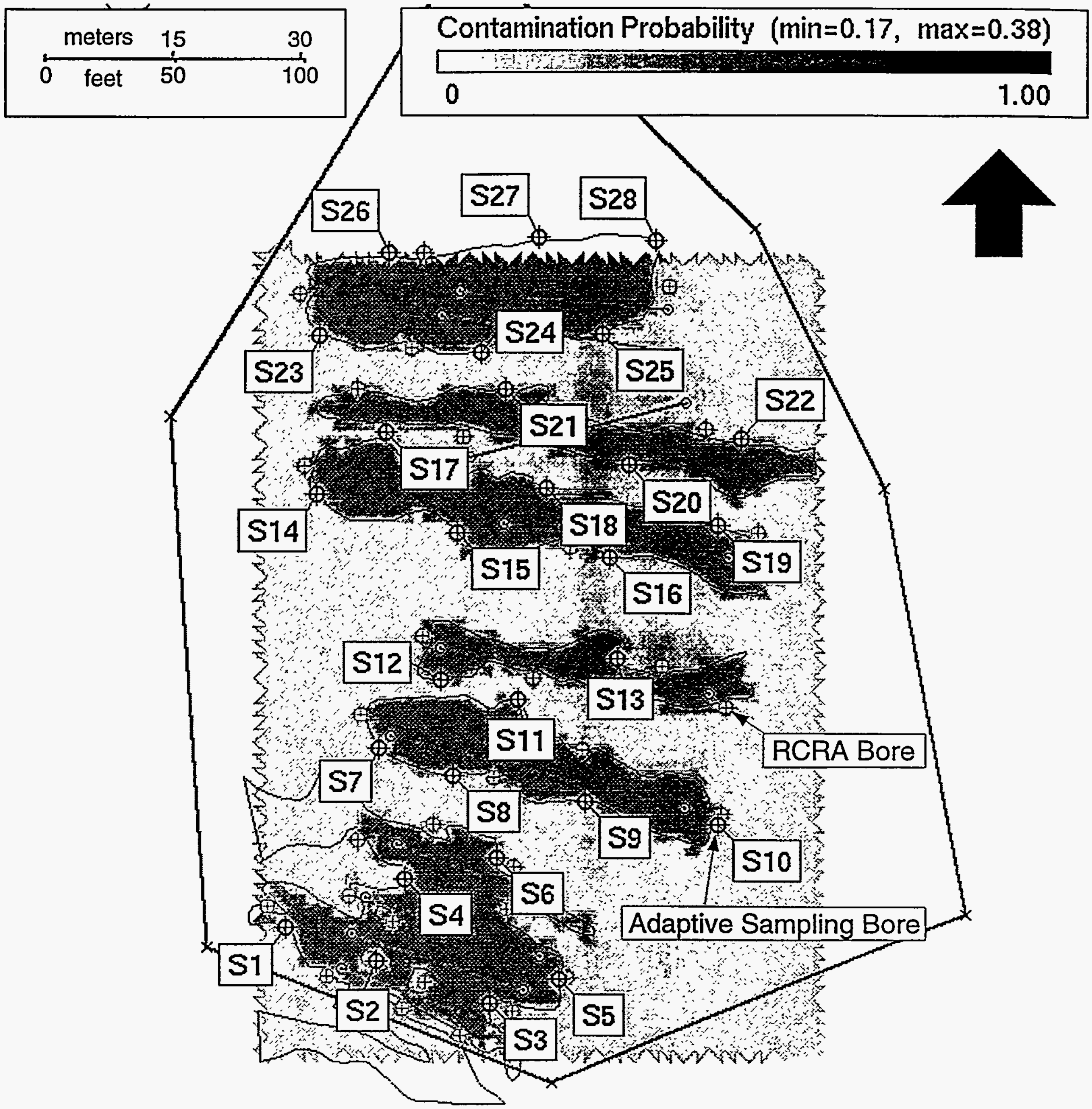
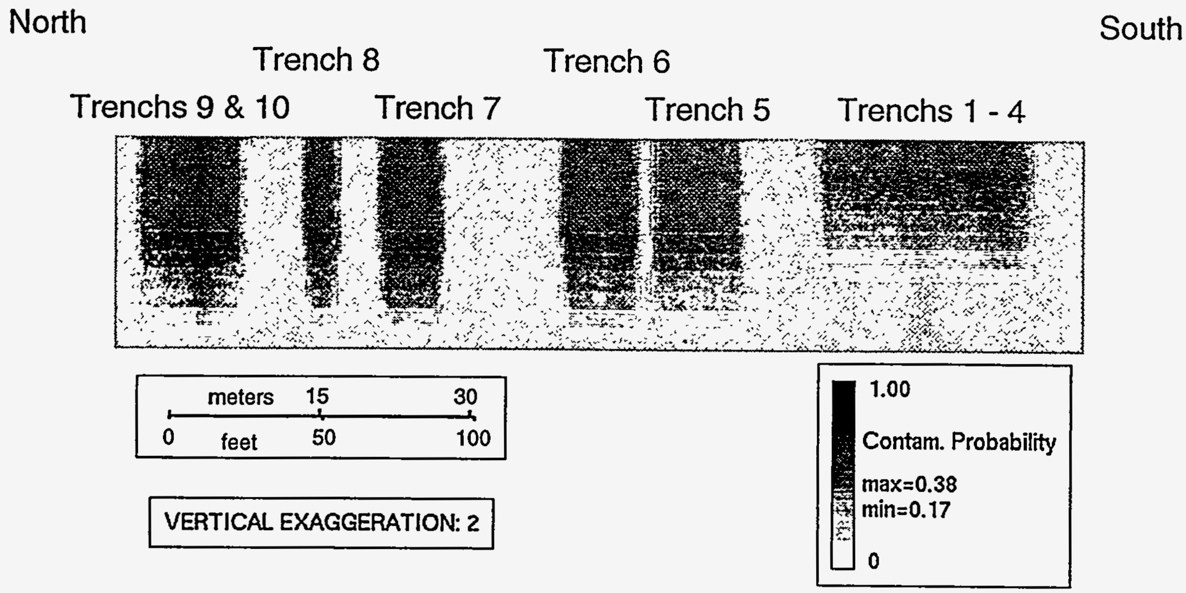


Figure 2A. Plan view of RB-11 conceptual model with locations for Adaptive Sampling and RCRA soil bores.



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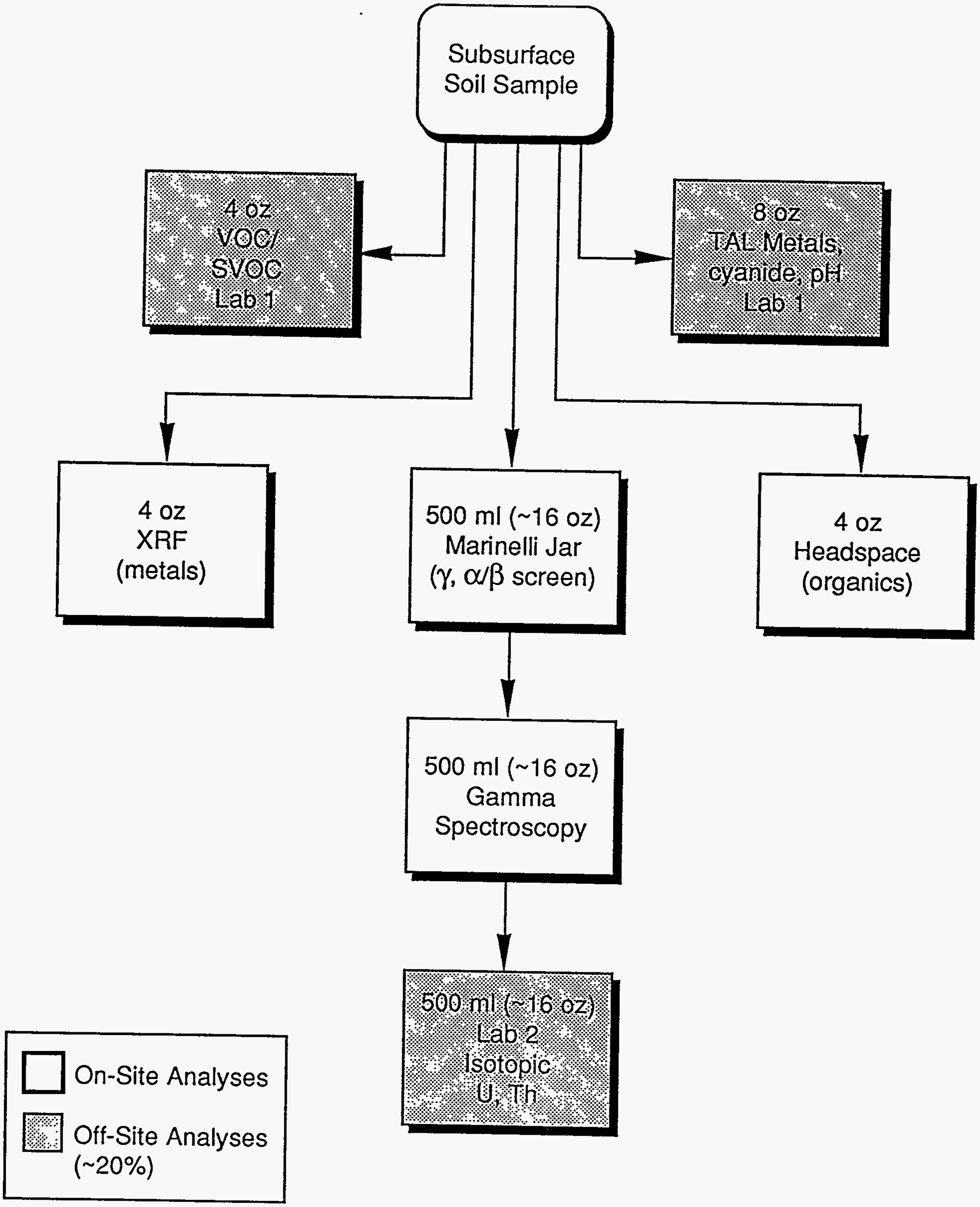

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Figure 3. Flow diagram illustrating how each soil sample was utilized for on-site and off-site analyses.