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EFFECTIVE USE OF SOIL CORING FOR ARCHAEOLOGY AND POLLUTION PREVENTION SITE CHARACTERIZATION

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EFFECTIVE USE OF SOIL CORING FOR ARCHAEOLOGY AND POLLUTION PREVENTION SITE CHARACTERIZATION

1. Purpose.

a. This Public Works Technical Bulletin (PWTB) provides an overview of available soil sampling technologies and practical guidance on their effective use by archaeologists and pollution prevention (PP) personnel.

b. All PWTBs are available electronically (in Adobe® Acrobat® portable document format [PDF]) through the World Wide Web (WWW) at the National Institute of Building Sciences' Whole Building Design Guide web page, which is accessible through URL:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to all continental U.S. (CONUS) and outside CONUS (OCONUS) Army training and testing facilities.

3. References.

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement", 13 December 2007.

b. AR 200-4, "Cultural Resources Management," 1 October 1998.

c. National Historic Preservation Act of 1966, as amended. Title 16 of the U.S. Code, Part 133 (16 U.S.C. 470).

d. Title 36 Part 800 Code of Federal Regulations (CFR), 36 CFR 800, "Protection of Historic Properties," amended 5 August 2004.

e. Pollution Prevention Act of 1990 (42 U.S.C. 133).

4. Discussion.

a. Land managers on U.S. Army installations require inexpensive and minimally invasive field methods for evaluating the presence, nature, and condition of surface and subsurface soil contaminants and archaeological deposits. Traditionally, archaeologists have used hand-excavated test pits and, in some situations, mechanized trenches to document the subsurface soil stratigraphy of a site. These methods are not only labor-intensive, expensive, and time-consuming, but they also result in substantial environmental damage to the site and its archaeological deposits (Stein 1986). Land managers interested in identifying and monitoring soil pollution must balance the need to collect enough data to reduce uncertainty with the need to limit data collection costs (USEPA 1996).

b. Soil coring is a means of examining subsurface stratigraphy that can be useful for a wide range of archaeological projects, from site detection and evaluation of a site's eligibility for the National Register of Historic Places (NRHP) to large-scale excavations (Schuldenrein 1991, Ayala et al. 2007). Soil coring should not be used as a replacement for conventional archaeological evaluations, but can be used effectively to characterize local sedimentary sequences, quickly map stratigraphy across large areas, estimate feature depth and content, and determine if geophysical anomalies are associated with cultural features (Ayala et al. 2007, Hargrave 2006).

c. Environmental protection personnel require both discrete and composite samples of a contaminated site. Discrete samples are collected from a specific horizontal and vertical location. Composite samples are comprised of multiple subsamples from one or more sampling points. Composite samples can be obtained using a variety of bulk unconsolidated soil sampling techniques, such as grab sampling or augering, while discrete sampling is usually done using undisturbed soil sampling methods. The contaminants in the soil can best be identified using three soil sampling techniques: (1) manual surface grab sampling, (2) manual shallow subsurface coring, and (3) deeper subsurface coring using mechanized equipment (Fortunati et al. 1994).

d. This report provides a concise overview of available soil coring sampling devices and guidelines for collecting soil samples for archaeological and PP applications. The report is not intended to be a comprehensive textbook on soil sampling, but rather an overview of accepted soil sampling methods commonly used by archaeologists and environmental protection personnel. In most cases, selection of soil sampling equipment and sampling protocols must be tailored to individual project objectives and site conditions. Guidance provided in this PWTB will assist archaeologists and PP specialists in making such decisions.

e. Appendix A contains background information.

f. Appendix B contains information about soil sampling equipment.

g. Appendix C contains guidelines for sampling approaches.

h. Appendix D contains information about sample retrieval, handling, and processing.

i. Appendix E contains guidelines for both field and laboratory soil analyses.

j. Appendix F contains summary information.

k. Appendix G lists references for the appendices.

l. Appendix H lists acronyms used throughout this PWTB.

m. Note that the mention of trade names and products in this PWTB is meant solely for informational purposes and does not imply Department of Defense endorsement to the exclusion of other similar products.

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Appendix A

Introduction

Land managers on U.S. Army installations require inexpensive and minimally invasive field methods for evaluating the presence, nature, and condition of surface and subsurface soil contaminants and archaeological features. Traditionally, archaeologists have used trench excavations and discontinuous test pits to determine the subsurface soil stratigraphy of a site. These methods are not only labor-intensive and time-consuming, but they also result in substantial environmental damage to the site (Stein 1986). Land managers interested in identifying and monitoring soil pollution must balance the need to collect enough data to reduce uncertainty with the need to limit data collection costs (USEPA 1996).

Soil coring and augering are methods that provide a means to examine subsurface deposits with a moderate amount of effort and far less destruction to the site. Coring and augering have been used by geomorphologists, soil engineers, economic geologists, agricultural engineers, and archaeologists for many years to examine soil conditions and stratigraphical relationships to surface features.

Soil coring is an examination of subsurface stratigraphy that can be useful for a wide range of archaeological projects, from site detection and discovery to research excavation (Schuldenrein 1991, Ayala et al. 2007). However, it is generally agreed that soil coring should not be used as a replacement for conventional archaeological trench evaluations, but is best used as a first phase to characterize local sedimentary sequences and efficiently map and delineate large areas of interest (Ayala et al. 2007).

While archaeologists are mostly interested in the stratigraphy of the soils, environmental protection personnel require both discrete samples and composite samples of a contaminated site. Discrete samples are collected from one specific horizontal location and vertical interval. Composite samples are combinations of several subsamples that have been collected from distinct sampling points located within the contaminated site. Composite samples can be obtained using a variety of bulk unconsolidated soil sampling techniques, such as grab sampling or augering, while discrete sampling is usually accomplished by using undisturbed soil sampling methods. The identification and delineation of contaminants in the soil is best accomplished using three main types of soil sampling techniques: (1) manual surface grab sampling, (2) manual shallow subsurface coring, and (3) subsurface coring with heavy equipment (Fortunati et al. 1994).

This PWTB provides an overview of available soil coring sampling techniques and guidelines for collecting soil samples for field screening and/or laboratory analysis. This bulletin is not intended to be a comprehensive textbook on soil sampling, but rather a summary of accepted soil sampling methods commonly used by archaeologists and environmental protection personnel. In most cases, soil sampling equipment and procedures must be tailored to individual project objectives and site conditions.

Appendix B

Soil Sampling Equipment

Manual/Portable Sampling Devices

In PP studies, soil samples collected from the site are generally used during the initial site surveys to determine soil pH, organic matter, phosphorus, potassium, zinc, and the presence and extent of any other organic/ contaminant compounds of potential interest. Surface samples can be manually collected using simple tools such as scoops or trowels that are made of wood, metal, or plastic. Subsurface samples can be collected using manual or mechanized soil probes or split barrel samplers. Surface and subsurface samples can be used to estimate the horizontal and vertical extent of contamination, respectively.

Stainless steel tools must be used when sampling for organic compounds, while high-density polyethylene tools should be used for inorganic compound sampling (Fortunati et al. 1994). It is recommended that each tool be decontaminated between each sample collection to reduce the likelihood of cross-contamination of samples in the field. Disposable sampling tools may also be used. Decontamination typically involves washing the tool with some specified type of solvent depending upon the organic contaminant of interest (USEPA 2000).

Archaeological applications for soil coring include determining if a site has been plowed, if a culturally enriched (midden) stratum is present, collecting data needed to interpolate or extrapolate information about soil stratigraphy documented in larger excavation units, securing basic information (depth, fill characteristics) about features prior to (or in lieu of) hand excavation, and investigating geophysical anomalies interpreted as possible subsurface features (Stein 1986, Hargrave 2006). Decontamination of soil recovery equipment using solvents is typically not a concern in the context of such archaeological applications, but care must be taken to thoroughly clear soil residues from sampling devices, particularly if the soil samples will be used to quantify chemical elements.

Hand augers can be used in contaminated sites to collect bulk, unconsolidated soil samples at the surface or at shallow depths (USEPA 2000). Augers are designed to cut through the soil when turned in a twisting or screwing motion. Soils recovered using an auger are thus considered unconsolidated. Samples are obtained from the bottom of the bore hole or from the material that adheres to the auger's blades (Stein 1986). Hand augers, therefore, are best suited for the collection of composite samples, but they can also be used to make bore holes to a specific depth for the subsequent collection of undisturbed samples using a soil probe or split barrel sampler. Despite mixing, soil samples recovered with an auger can be examined for generalized color and texture as well as artifact contents.

Several types of hand operated augers are available, including bucket type, continuous flight (screw), and post-hole augers. Bucket augers provide relatively large samples in a short time, making them better for direct sample recovery. Continuous flight augers are preferred when an unconsolidated composite of the entire soil column is needed. Post-hole augers have limited applications for soil sample collection and are generally used to cut through fibrous or heavily rooted soils down to depths approaching 3 ft (0.9 m), where other sampling equipment can then be used. Post-hole augers are sometimes used by archaeologists in lieu of shovel tests. The hole produced is smaller than a shovel test, but volume is more consistent, making differences in the number or weight of artifacts recovered more reliable.

Archaeological applications for hand augers (Stein 1986) include the search for artifacts, midden strata, subsurface features, or other indications of the presence and extent of a site; and the recovery of disturbed samples from particular depth ranges for paleo-environmental studies. Augers can reach greater depths below surface than shovel tests, and they are sometimes used in conjunction with or in lieu of shovel tests. Hand augers are inexpensive and relatively easy to transport in the field. The level of physical effort required for their use is variable, depending upon soil texture, moisture, and vegetation conditions. Hand augers can be used to penetrate firm soils that are difficult to sample with manual soil probes or shovels; can be used in areas where rough terrain makes use of vehicle-mounted, hydraulically operated soil coring equipment impractical; or in situations where preliminary data on site characteristics are needed to evaluate the costs and benefits of using mechanized devices. Hand augers can be used for all types of soils, but there is likely to be some mixing of soils from different depths. Results are best when samples are recovered from a series of narrow depth ranges (Stein 1986). Since the auger scrapes material from the sides of the auger hole while being extracted, the top several inches in the auger bucket should be discarded before placing the subsample into the composite container for processing.

Oakfield push tube samplers and foot pedal corers are the most common soil coring devices used in archaeology. Both are metal push tube corers, but foot pedal devices have one or two side-mounted foot pedals that allow the user to force the tube into the soil using his/her feet and legs. Typical foot pedal corers for dry soils are 3/4 in. (19.05 mm) in diameter and usually have even smaller diameters for use in wet soils. A push tube corer for sampling sediments and benthic organisms in shallow water zones is described by Parada (2008). Oakfield and foot pedal corers are best suited for collecting undisturbed samples as they maintain the vertical structure and orientation of the sediment within the collection chamber or tube (Parada 2008). These devices are compact, lightweight, and user friendly, and the foot pedal mechanism reduces the risk of shoulder, arm, wrist, or back injury with frequent use. Specialized tube extractors are available for both devices to aid core sample recovery in very cohesive soil types.

Thin-walled push tubes, also known as Shelby tubes or Acker thin-walled samplers, can be used to collect subsurface undisturbed samples in clayey, cohesive soils as well as less fine textured soils such as sands and silts. The collected samples can be used for chemical analyses, but are also valuable for characterizing soil profiles. Typically, the sampling tube is 30 in. (76.2 cm) in length with an outside diameter of 3 in. (7.62 cm) and may be constructed of steel, stainless steel, or brass. When collecting samples for organic chemical analysis, stainless steel sampling equipment must be used, but if it is used for collecting soil stratigraphic information, steel or brass material is perfectly acceptable.

A recent development is a magnetic susceptibility sensor designed to be inserted in a previously excavated small diameter (e.g., push tube) hole. The sensor is connected to a magnetic susceptibility instrument and laptop computer. Magnetic susceptibility, which is typically elevated by human occupation (including the introduction of organic and burned materials) can be measured at predetermined intervals as fine as 1 or 2 in. (25.4 or 50.8 mm) Specialized software that can be used in the field produces a graph of vertical variation in magnetic susceptibility and records information about sample location and characteristics. This down-hole system is useful for detecting the presence of buried cultural layers, measuring the thickness of features such as pits and house floors, and determining if geophysical anomalies are associated with cultural features or natural phenomena such as tree roots, rodent burrows, or natural soil lenses (Dalan and Bevan 2002; Dalan and Goodman 2007).

To investigate deeper deposits, thin-walled push tubes can be attached to a drill rod and lowered into a previously excavated borehole, where the sampler is then pressed into the undisturbed clays or silts by hydraulic or kinetic force. Once the tube is brought back to the surface, the soil sample is removed from the sampler head. If the sample is intended for chemical analyses, the soil inside the tube is then removed and placed in a sample container. If the sample is collected to evaluate geotechnical parameters, the thin-walled push tube is capped to maintain the sample in an undisturbed state, and shipped to a geotechnical laboratory.

A split tube sampler is an apparatus for rapid recovery of undisturbed soil core samples. The split tube sampler consists of two stainless steel halves that can be separated after retrieving the sample. Typically, the sampler is driven into the soil with a hammer and then extracted. The tube can then be opened longitudinally, which maintains the integrity of the soil sample.

Many soil sampling equipment vendors can also supply butyrate tube liners for foot pedal, push tube, and split tube corers. These liners prevent cross-contamination and allow samples to be easily retrieved, labeled, stored, and transported for analysis as intact cores. Furthermore, the samples within these liners can later be cut into specific depth increments, thereby facilitating quantitative chemical analyses related to depth.

The appropriate sampling devices to be used should be matched with the type of materials likely to be encountered at the site. Table B-1 lists advantages and disadvantages to different types of soil sampling devices.

Power Sampling Equipment

Mechanized devices to reduce the time and labor requirements associated with soil sample collection are also available (Bohm 1979). Several commercially available hydraulic cylinder devices used to insert and retrieve soil core tubes can be mounted on trucks, tractors, or all-terrain vehicles (e.g., Concord Incorporated, Fargo ND; Giddings Machine Company, Fort Collins, CO). Most of these mechanized systems use the same types of augers and push tubes discussed in the manual/portable sampling devices section above. Mechanized devices can reach greater depths than manual devices, collect larger diameter samples, and penetrate deposits that would be difficult or impossible to sample using manual devices (Stein 1986, Prior et al. 2004). Power sampling devices often rely on hydraulic systems to insert and remove core tubes, therefore requiring transport vehicles and experienced personnel for operation (Swallow et al. 1987). Heavy vehicles provide a more stable platform for powered systems, but are more expensive to operate. Some specialty power devices have been developed to overcome these vehicle weight issues, but these often involve supplemental anchoring systems that increase set up time and may damage near-surface archaeological deposits. Power sampling equipment is also of limited value in rough terrain where vehicle movement can be problematic or dangerous. Where terrain is favorable, however, and collecting numerous deep samples is required, power sampling equipment can result in significant time and cost savings.

Table B-1. Advantages and disadvantages of various soil sampling equipment.

Sampling Device	Use	Advantages	Disadvantages
Trowel or Scoop	Surface samples of soft to firm soils	Easy to use and inexpensive	Difficult to use in hard clays; Difficult to obtain a sample that is representative of a specified depth; Limited ability to recover deep samples
Soil Probe or Corer (i.e., Oakfield Sampler)	Shallow depth samples of soft to firm soils	Easy to use; Core is relatively undisturbed and suitable for volatile analysis if transferred immediately	Limited depth; Difficult to use in hard, stony or dry sandy soils; Difficult to clean when sampling in clays
Bucket Auger	Surface soils to intermediate depths	Can sample to greater depths than trowels or corers; Can be used in firmer soils; Provides a standardized volume of soil (as opposed to archaeological shovel tests)	Depth is limited by soil conditions; Soil mixing occurs during sampling, so not suitable for volatile compounds; Difficult to clean; Difficult to ensure sample is from proper depth

Sampling Device	Use	Advantages	Disadvantages
Hammer type Soil Probe	Surface soils to intermediate depths	Can sample to greater depths than trowels or corers; Can be used in firmer soils; Maintains an undisturbed core; Suitable for volatiles; Can collect specific depth increments	Depth limited by soil conditions (stones and collapsing sidewalls) and length of sampling tool
Hand Operated Power Auger	Shallow soil depths to 5 m (16.4 ft)	Useful in a wide range of soil types; Reasonable depth range	Mixing of soils occur, so not suitable for volatiles; Requires more than one operator; Possible contamination risk; Difficult to use in stony, hard soils; Difficult to clean; Difficult to ensure sample is from proper depth increment
Backhoe, Power Shovel, Truck/Tractor Mounted Coring Equipment	Shallow soil depths to 5 m (16.4 ft)	Useful in a wide range of soil types; Good depth range; Allows view of large profile area for sample collection within soil horizons; Allows collection of undisturbed samples	Expensive relative to other collection methods; Disruptive to the landscape; Not suitable for use in rough, remote terrain; potential personnel hazards in deep trenches.
Split Barrel Sampler	Surface soils to bedrock	Excellent depth range; Useful for hard soils; Reasonably undisturbed soil cores suitable for volatiles	Requires more than one operator; Samples too disturbed for strength tests
Thin-wall Sampler (Shelby tube sampler)	Surface soils to bedrock	Excellent depth range; Reasonably undisturbed soil cores suitable for volatiles	Not durable in rocky soils; Sample can be lost in very soft clays or loose sands below water

Appendix C

Soil Sampling Strategies

Developing a sampling strategy for archaeological or PP investigations of large sites or areas often requires a preliminary field assessment (David et al. 2008). Examination of existing data such as historical records, aerial photographs, maps, state soil surveys, previous investigations of nearby or otherwise comparable sites, and other available background information should be a component of the preliminary assessment (USEPA 1996). A site visit is necessary to document the locations of buildings, roads, utility lines, vegetation cover, contaminant sources, sensitive environmental areas, etc., which will help determine the appropriate sampling strategy for the project (Fortunati et al. 1994). The site visit should include the collection of at least some samples to, for example, evaluate soil conditions and select the appropriate equipment.

A basic objective of all investigations is to differentiate natural variability in physical and chemical soil properties from variability associated with prehistoric or historic cultural activity or, in PP investigations, with contamination. Natural variability in physical and chemical properties is due to factors such as sample size (the size of the area under investigation), soil type, slope, aspect, drainage, vegetation, and landform. These factors can produce spatial variability in soil characteristics that is considerably larger than might be found in air or water samples. Soil sampling strategies should take into account the increased variability to distinguish contamination or anthropogenic impact from the natural variability of physical and chemical properties of the soils.

In PP investigations, additional sources of variability that must be documented by the sampling strategy include the mode of contamination, the physical and chemical properties of the contaminant, and transmission agents (water, wind, vegetation, etc.). Sources of intra-site variability in archaeological deposits include such factors as activity patterning at a residential site, component patterning (shifts in the locations of activities through time), and preservation factors (including the relocation of artifacts and other objects by plants, animals, insects, erosion, agriculture, other earthmoving activities). The interaction of these natural and cultural depositional and post-depositional factors can result in a high level of intra-site variability in the nature, density, and distribution of cultural artifacts, features, and sediments (Schiffer 1987).

The relationships between a project's overall purpose and the specific objectives of the sampling program should be clearly defined. In pollution prevention projects, the project purpose is usually to determine the concentration of contaminants at representative locations across the site within an acceptable degree of accuracy. The sampling strategy must ensure that the recovered samples represent the horizontal and vertical extent of concern, that intra-site variability is adequately documented and understood, and that sample size (number of samples) is adequate to derive reliable conclusions. The sampling objectives should also include statements about the required quality of the data obtained from the overall field sampling program and subsequent laboratory analyses. The U.S. Environmental Protection Agency (USEPA) has well-developed protocols for sampling soils known to be contaminated by various organic compounds (USEPA 2000). These guidelines should be consulted prior to fieldwork to avoid potential problems involving the collection, transport, and analysis of contaminated materials.

For archaeological soil samples, reliable information on a sample's provenience (three-dimensional location) and context (association with natural and cultural deposits) is critical. Artifacts and cultural sediments are often relocated by means of bioturbation (natural agents such as roots, insects, burrowing animals) as well as post-depositional human actions, including later prehistoric or historic construction activities, historic or modern agriculture, etc. (Schiffer 1987). The horizontal and vertical patterning in artifacts and sediments occurs at many spatial scales. Chert debris resulting from a single episode of stone tool production may be dispersed over an area of only several square meters, for example, whereas the remains of butchered animals may be dispersed over much larger areas as a result of food preparation, storage, use of non-meat elements (e.g.,. bone and hide used for the manufacture of tools and clothing), the actions of dogs and other scavengers, etc. Widely spaced soil samples that are fully adequate to recover data relevant to questions about the horizontal and vertical extent of cultural sediments may be entirely inadequate to address questions about the spatial distribution of specific prehistoric activities.

Geophysical surveys of archaeological sites (Johnson 2006) require decisions about sampling at several levels. Factors such as geophysical contrast (the extent to which a targeted feature type may differ from its surroundings in terms of one or more geophysical properties), feature dimensions, depth, and clutter (discrete objects likely to be detected in a survey that are not the primary target) are the basis for decisions about data density (the number of data points per square meter) and distribution. Small, low contrast features typically require data to be systematically collected along a closely spaced (1 or 2 ft (0.3 or 0.6 m) traverse. A second level of sampling concerns the distribution of geophysical survey areas across the site as a whole. Practical considerations such as problems posed by vegetation, near-surface impacts, or modern infrastructure (roads, buildings, utility lines, etc.) often determine which areas can and cannot be investigated. Where such considerations are not primary, large sites can be investigated using a stratified random approach. Where independent data sources (maps, surface artifact distributions, etc.) are informative, the location of geophysical survey areas may be largely non-random (Hargrave 2006).

Geophysical surveys of archaeological sites often result in the detection of a wide range of anomalies (localized areas with geophysical values that are distinct from their surroundings). Given the expense and invasive nature of large area excavations, it is often desirable to investigate a sample of the anomalies using soil cores. Various approaches can be used to group anomalies into sampling strata based on their dimensions, distribution, amplitude, detection by multiple sensor types, etc. (Hargrave 2006, Kvamme et al. 2006, Canti and Meddens 1998). Archaeologists typically attempt to focus their investigations on those anomalies viewed as most likely to represent cultural features. This approach can be productive, although it is sometimes the case that the most distinctive anomalies will prove to be associated with natural or recent phenomena (tree roots, rodent burrows, recent impacts) rather than prehistoric or historic features. An alternative approach is to group the anomalies into several categories and investigate a representative sample of each (Hargrave 2006; Kvamme et al. 2006). This approach provides a more complete understanding of the geophysical data and provides a basis for more reliable extrapolations from the investigated to uninvestigated anomalies, but its use typically requires more extensive excavation.

Fortunati et al. (1994) defines three main categories of soil sampling strategies: (1) random, (2) stratified/systematic, and (3) judgmental. Random sampling is often preferred when little information is known about a site as it allows researchers to draw conclusions over the entire site. If some information about the presence/absence of contaminants or archaeological resources is available, a stratified random sampling strategy that distributes samples within predefined areas of interest may be an appropriate modified random strategy (Fortunati et al. 1994). Dividing the project area into strata based on relevant factors (e.g., topography, vegetation, impacted areas, etc.) helps ensure that major sources of variability are represented in the overall sample, thereby reducing variance due to sampling errors or biases.

The most widely used strategy for soil sampling is stratified / systematic, or sampling along a grid or radial pattern. Archaeological studies often use a systematic sampling strategy. For example, archaeological surveys in areas where vegetation restricts visibility of the ground surface typically include shovel tests excavated at regular 30 to 90 ft (9.1 m to 27.4 m) intervals. Auger tests can be used to supplement shovel tests in areas where deeper deposits are possible. Evaluations of a site's NRHP eligibility status often include more closely spaced 15 to 30 feet (4.6 to 9.1 m) shovel tests to better document artifact distributions and search for sub-surface features. Mechanized soil cores used to document larger scale variation in site stratigraphy are often excavated at wider intervals.

Stratified/systematic distributions of soil cores are also commonly used when evaluating contaminated sites. Systematic sampling can be more representative of the entire site than either single-point or stratified random sampling. Sample intervals in the grid system are determined by the size of the area to sampled, but typically range from 3 to 60 ft (0.9 to 18.3 m) across the entire site (Ayala et al. 2007).

Radial surveys are also a type of stratified/systematic sampling, although they are less common than grid sampling. In a radial survey, transects radiate out from a focal point of an area of known contamination or archaeological significance and samples are taken at regular intervals along each transect line (Ayala et al. 2007). This type of sampling strategy is useful for delimiting the gradients of contamination within a site, identifying the extent of archaeological activity areas or, perhaps most commonly, identifying site boundaries.

Judgmental sampling may be preferred in some cases as an initial approach for developing systematic sampling grids. This approach can also be used to develop a sampling strategy that takes into account the degree of contamination at sampling points. By doing so, judgmental sampling increases the representative value of a single sampling point, while minimizing the sampling effort

(Fortunati et al. 1994). Judgmental sampling can be effective when information is available about the location of archaeological features or sources of contamination (David et al. 2008). The site can be divided into three areas that require different levels of investigation: (1) areas unlikely to be contaminated or contain archaeological resources, (2) areas that may be contaminated or contain archaeological resources or contamination and, therefore, should not be ruled out, and (3) areas that are highly likely to be contaminated or contain archaeological resources (USEPA 1996).

The movement of most contaminants through the soil is usually slow enough that concentrations do not change significantly over short periods of time (<180 days). This allows sampling to be conducted in either one or two stages following the initial site visit. A one-stage sampling plan results in all samples being collected and analyzed during a single survey. A two-stage plan begins with a limited sampling plan to determine the parameters of interest, the variability of chemical concentrations, and the location of any "hot spots" within the site. From the results of this initial sampling, a second sampling scheme can be developed to more precisely define the areas of concern. Two-stage sampling is more time-consuming than a single stage sampling plan, but usually results in a better characterization of the site with fewer analyses because the second stage can pinpoint strategic sampling locations. As indicated earlier, it is important to consult USEPA guidelines for sampling contaminated soils to make sure the sampling protocol used is consistent and compliant with these guidelines (USEPA 2000).

Regardless of the sampling strategy used, sample points must be accurately determined in the field and precisely recorded on a map. Accuracy of the sample positions becomes especially important when points are to be re-sampled at a later date. Sample point locations should be recorded as accurately as possible by recording distances to multiple landmarks that are permanent and visible on aerial photographs, by permanently marking them with rebar, stakes or dyes, or by using electronic distance measurement and/or global positioning system (GPS) equipment. GPS instruments can provide either geographical coordinates or universal transverse Mercator coordinates in an electronic format, although the precision and spatial resolution of GPS instruments must be considered.

Appendix D

Sample Retrieval, Handling, and Processing

Soil samples collected to determine the presence and abundance of chemical contaminants require a somewhat different protocol for safe handling and processing than do those recovered for archaeological purposes. Issues addressed here include equipment and supplies, sample integrity, recordkeeping, and storage.

Discrete Samples

Discrete soil samples are single samples taken at a particular location or depth. This method of sampling is appropriate for the analysis of volatile organic compounds (VOCs), vertical and horizontal extent of potential contaminants, soil profile characterization, and evaluating anthropogenic impacts. Samples are either taken at the surface using trowels or shovels, or by probing to a given depth and retrieving the core sample. Discrete soil sample probes are closed sampling tools used to collect soil samples at random, systematic, or pre-determined horizontal intervals. The inside of the sampler is not exposed and has minimal exposure to the subsurface environment until the sampler reaches the prescribed depth. As mentioned earlier, many soil sampling equipment vendors can also supply butyrate tube liners for foot pedal, push tube, and split tube corers. These liners prevent cross-contamination and allow samples to be easily retrieved, labeled, stored, and transported for analysis as intact, properly oriented cores. Furthermore, the samples within these liners can later be cut into sections representing specific depth increments.

Composite Samples

Due to the high degree of variability found in most soils, it is recommended that PP sampling for potential contaminants other than VOCs should be accomplished by combining a number of samples from the depth of interest into one composite sample. The objective of composite sampling is to ensure that the sample represents the volume of material nearest the point of interest. The sub-samples that make up each composite sample should be spaced no more than 10 ft (~3 m) apart to prevent mixing of contaminated soils with uncontaminated soils during the sampling. Composite sampling should not be used for the collection of samples for VOC analysis since the mixing process results in the loss of some of these compounds, thereby affecting perceived in situ concentration levels (Lock 1996).

Pollution Prevention vs. Archaeology

Soil sampling for PP and archaeological studies differ in data requirements for research, site management, and restoration. Pollution prevention studies are concerned with documenting the presence, areal extent, and movement of hazardous contaminants in soils. Archaeologists have historically used soil sampling surveys to detect and delimit sites, document stratrigraphy, infer site formation processes, evaluate the integrity of cultural deposits, rapidly identify areas for potential excavation, and for preliminary identification of subsurface cultural sedimentation (Schuldenrein 1991). Variability in soil texture and color; the occurrence of artifacts, charcoal, burned soil particles, soil mottling suggestive of mixing; and levels of a narrow range of chemical elements (particularly phosphorus) and organic carbon are important variables in archaeological investigations. Archaeologists typically use undisturbed soil samples, and would rarely, if ever, actually composite samples prior to their analysis.

Field Procedures

The following guidance includes procedures for avoiding cross-contamination between samples that is typically not a serious concern in archaeological investigations. Soil residues should be thoroughly removed from all soil sampling devices between samples, but archaeological samples require no decontamination unless specialized analyses of chemical elements are planned.

For the collection of surface/near surface soil samples, stainless steel or plastic scoops, trowels, shovels, and spades are recommended. Carefully remove the top layer of soil or debris to the desired depth with a pre-cleaned spade. Before collecting the sample at the proper depth, use a pre-cleaned stainless steel scoop, plastic spoon, or trowel to remove and discard a thin layer of soil from the area that came into contact with the spade (USEPA, SOP #2012, 2000). The sample can then be collected at the proper depth and placed into a labeled sampling container for shipment to the laboratory. A flat, pointed mason trowel with sharpened edges is recommended to cut a block of the desired soil when undisturbed profiles are required.

When recovering subsurface samples using augers or thin wall tube samplers, begin by clearing the surface area of debris such as twigs, rocks or litter. It is advisable to remove the first 1–3 in. (2.54–7.62 cm) of surface soil in an area with a radius of 6 in. (15.24 cm) around the sampling location. Begin augering and periodically remove and deposit accumulated soils onto an unused piece of plastic sheet spread near the borehole. This will prevent loose soils from being brushed back into the borehole when removing the auger, adding drill rods, or using sampling tubes. Using a new piece of plastic will prevent cross-contamination between samples and from vegetation or surface soils. After reaching the desired depth, carefully remove the auger from the hole. If it is desirable to collect disturbed samples directly from the auger, collect the sample using a stainless steel or plastic spoon, place it in a labeled container, and seal it for transport.

A procedure for sampling with solid stem augers that prevents cross-contamination is to advance the auger to the sample depth and then retrieve the auger and insert a thin-wall tube sampler. When the tube is pushed below the bottom of the borehole, the exact depth of the sample is known. Also, when the core is extracted from the tube, the sample retains its original orientation and stratification. This method is especially useful for archaeological studies, since the sample will provide information about soil profiles at specific depth increments. A rigid measuring device (e.g., a wooden folding ruler) should be inserted into the hole to secure a reliable measure of actual sample depth, since soil compaction will bias estimates of sample depth based solely on the length of the soil tube. Once the sampling device has been removed from the borehole, care should be taken to disconnect the sampling tube from the sampler without shocks or blows. Discard the top portion of the core (approximately 1 in. or 2.54 cm) as it is representative of material collected before penetration of the layer of concern. Place the remaining core into an appropriately labeled sample container.

All samples should be labeled and documented as they are collected in the field. Samples collected in the context of PP investigations should be labeled using protocols such as the American Society of Testing and Materials (ASTM) International "Standard Practice for Minimum Set of Data Elements to Identify a Soil Sampling Site" (ASTM D 5911-96, 2002). In both archaeological and PP projects, a careful record of the location of each sample should be kept, preferably including GPS coordinates. If this is not possible, a detailed map of the sampled area should be made with each sampling point referenced to the grid position. If photographs are to be used to document the sampling points, each photograph should be annotated with the date, the name of the photographer, the sample number, and the direction in which the camera is pointing.

Sample labels should include the following information, at a minimum: (1) site name, (2) sample location (using horizontal coordinates and depth below surface), (3) collection date, (4) laboratory analysis requested, and (5) the name of the person that collected the sample. Soil samples to be sent to a commercial laboratory for analysis may require labels approved by the laboratory to maintain the appropriate chain of custody.

Most commercial laboratories will also have an approved procedure for transport of samples that requires individual sample containers to be stored and transported to the laboratory in a sealed container, such as a cooler (Minnesota Department of Agriculture 2005). Chain of custody procedures should be adhered to during the shipping of samples to the laboratory. Sample numbers, horizontal locations, and depths should be documented on the paperwork that is submitted to the laboratory with the samples.

Samples for the analysis of contaminants should be kept cool when transported, preferably by using clean freezer packs in the shipping container. If ice is to be used, it should be double wrapped in plastic to keep the sample container labels and seals dry. Moderate ambient temperatures and short travel times may preclude the need to cool the samples; however, it is important that the samples do not overheat.

When PP and archaeological samples arrive at the laboratory, they should be inventoried and the sample condition and labels should be checked before placing them in an upright position in the storage room. If soil samples will not be analyzed within a few days, they should be stored in a cool, moist, frost-free storage area (USACE Engineer Manual 1110-1-1906, 1996). A temperature between 35 and 40 °F (1.65 and 4.4 °C) is recommended to prevent the growth of mold and other organisms. If samples are to be stored for very long periods, they may be frozen for up to 6 months under proper chain of custody protocols.

Appendix E

APPENDIX E: SOIL ANALYSIS

Field Analysis

An analysis in the field can provide important information about a soil sample that cannot be accomplished later in the laboratory. A sample's internal structure, stratigraphic, and landscape context often cannot be reliably inferred from its chemical, biological, and physical properties. Each sample's color, texture, consistency, horizontal and vertical provenience, and stratigraphic context should be recorded in the field for both archaeological and contaminant studies. A written record of this information, supported by photographs and maps, is critical to the success of soil coring projects.

Information about a sample's geomorphic context can be indicative of the geological processes (e.g., sedimentation, colluviation, erosion) that influenced the site. Nuances of topography and drainage discernable in the field are often difficult to derive from the inspection of maps and aerial photographs. Vegetation and land-use patterns at the site should also be noted, as they can provide insights into the likely disturbance of the soil in the past few decades (SASSA 2007).

Before a soil sample is containerized in the field, its color should be noted and, in PP projects, the sample's odor should be noted and pH measured. Soil color can best be determined by comparing the sample to the Munsell soil color charts (1994). If a color chart is unavailable, the color should be noted by observation. Soil color is influenced by its mineral composition, so it is a good indicator of geology, iron content, organic matter content, as well as anthropogenic modifications such as the addition of wood charcoal, ash, and burned soil. Color is also an indication of stratigraphic context, an important variable when evaluating the integrity of archaeological deposits or buried horizons that can influence the movement of contaminants.

Soil texture is determined by the proportion of sand, silt, and clay that is present. Texture can provide information about the nature of the soil's parent material and the development of soils on the site. Wind and water erosion sort sediments according to grain size and the energy available to carry and deposit them in the soil profile. Deposits resulting from wind erosion are generally well-sorted, consisting of silts and fine sands.

Gravity-driven processes, such as rock falls and slope movements, result in poorly sorted soil deposits. These deposits can contain a mixture of grain sizes from clays to boulders, although water action can produce better sorted deposits of sands and gravel. Texture is difficult to quantify in the field and is preferably quantified using sieve analysis. Brady (1974), however, describes a "feel" method that is satisfactory for initial field evaluation. Rubbing a soil between the thumb and fingers is probably the best superficial method available. Slightly wet the sample to estimate plasticity. If the sample develops a continuous ribbon when rolled, it is clayey. If the sample has a flour or talcum powder feel when dry and is only moderately plastic or sticks when wet, it is likely a silt. Sandy textures are obvious with the "feel" method (Brady 1974).

A mixture of soil strata resulting from prehistoric activities (e.g., excavation of storage pits) or post-depositional processes (e.g., roots, burrowing animals) is often indicated by heterogeneity in soil texture and color. Field observations provide the best, sometimes the only, opportunity to evaluate a sample's reliability.

Laboratory Analysis

Laboratory analyses of soil samples include soil pH, organic matter content, quantitative phosphate analysis, particle size analysis, bulk density, and elemental analysis. All of these analyses, except bulk density, can be done from composite samples. Bulk density analysis requires an undisturbed, discrete soil sample, such as would be obtained from a thin-walled or split tube core sampler. Phosphorus is perhaps the most common focus of archaeological soil analyses, although recent investigations have demonstrated that other chemical elements can be used to detect horizontal patterning in past cultural activities (Entwistle et al. 2000, Middleton 2004, Wilson et al. 2006).

Archaeologists have long recognized that elevated levels of phosphorus in the soil are an indicator of human occupation. Phosphorus is introduced into the soil by human and animal waste. Phosphorus in its common form as phosphate is stable and generally immobile in soils. Elevated levels of phosphorus can provide evidence of site boundaries and intra-site variability in the intensity of occupation. In some situations, the distribution of phosphorus can be used to detect activity areas related to livestock and intentional soil enrichment as a fertilizer on agricultural areas (Holliday and Gartner 2007).

Phosphorus reacts rapidly with other compounds in the soils — particularly iron, aluminum, and calcium — so it can exist in a variety of molecular forms. As a consequence, a variety of laboratory analytical procedures can indicate the concentration of soil phosphates. These analytical tests include total phosphate, inorganic phosphate, organic phosphate, and plant-available or exchangeable phosphate. None of these fractions directly measure "archaeologically derived" phosphorus, but concentrations can be accurately interpreted by an archaeologist, especially when compared to similar sites without archaeological impacts.

In PP projects, soil samples should be sent to a certified soils laboratory for analysis. The analytical identification of hazardous materials in contaminated soils requires a laboratory with costly equipment and skilled personnel. The instruments commonly used for hazardous waste analysis in the laboratory are: Gas chromatograph (GC); (2) High-performance liquid chromatography (HPLC); (3) Gas chromatograph/mass spectrometer; and, (4) Inductively-coupled, argon plasma spectrophotometry. GC and HPLC are used to quantitatively determine contamination by known organic materials.

In addition to guidance provided by the USEPA for sampling, storing, and transporting potentially contaminated soil samples (USEPA 2000), experienced personnel at a certified laboratory can provide guidance as to which analysis is most effective for the particular contaminant(s) in question. Table E-1 lists potential analytical methods for common organic and inorganic compounds.

Table E-1. Laboratory methods for analyzing chemical compounds at contaminated sites (modified from Chambers 1991).

Element, Compound, or Property	**Suggested Analytical Method**
Inorganic Chemicals/Properties	
Metals	Sample digestion followed by atomic adsorption spectrophotometry or inductively coupled arc spectrometry
Halides (bromine, chlorine and fluorine)	Various Methods
Nitrogen	Various Methods
Electrical Conductivity	Saturation extracts or other aqueous extracts
pH	Colorimetric or potentiometric
Titratable acids and bases	Aqueous waste suspensions
Organic Chemicals	
Total organic carbon	Dry or wet combustion with CO_2 determinations; dichromate oxidation techniques
Volatile organic compounds	Purge and trap or headspace determinations; GC or GC/MS analysis
Extractable Organics	
Organic acids	GC analysis with capillary or packed columns
Organic bases	GC analysis with capillary or packed columns
Neutrals	GC analysis or HPLC analysis
Residual Solids	Evaporation of water from aqueous fraction of acid-base extraction procedure

Appendix F

Summary

The purpose of this PWTB was to provide guidelines for the use of soil coring in the field to identify and characterize sites having potential contamination or archaeological resources. Soil sampling can be used for prospecting, understanding site formation processes, improving field interpretations, and identifying physical landscape changes through time (Ayala et al. 2007). These guidelines are not intended to be a comprehensive textbook on soil sampling, but rather a summary of accepted soil sampling methods commonly used by archaeologists and environmental protection personnel.

Soil survey techniques used by PP personnel and archaeologists are similar in that they use the same equipment and sampling approaches. The differences occur in the fact that archaeologists are mostly interested in the stratigraphy of the soil profiles, while PP personnel are interested in the presence and movement of contaminants.

Appendix G

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Appendix H

Acronyms and Abbreviations

Term	**Spellout**
AR	Army Regulation
CFR	Code of the Federal Regulations
CONUS	Continental United States
DA	Department of the Army
DC	District of Columbia
HQUSACE	Headquarters, U.S. Army Corps of Engineers
NRHP	National Register of Historic Places
OCONUS	outside continental United States
PDF	Portable Document Format
POC	point of contact
PP	pollution prevention
PWTB	Public Works Technical Bulletin
URL	Universal Resource Locator
USEPA	U.S. Environmental Protection Agency
WWW	World Wide Web