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Permit Guidance Manual on Unsaturated Zone Monitoring for Hazardous Waste Land Treatment Units

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This manual provides guidance on unsaturated zone monitoring at hazardous waste land treatment units for use by permit applicants and permit writers in developing effective monitoring systems to comply with the Part 264, Subpart M regulations. This manual covers both soil core and soil pore-liquid monitoring, and addresses equipment selection, installation, and operation, sampling procedures, chain of custody considerations, and data evaluation. The installation and sampling procedures are presented in a step-by-step format so that the manual may be more readily used by field personnel.

This manual and other EPA guidance documents do not supersede the regulations promulgated under RCRA and published in the Code of Federal Regulations. They provide guidance, interpretations, suggestions, and references to additional information. Also, this guidance is not intended to mean that other designs might not also satisfy the regulatory standards.

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PERMIT GUIDANCE MANUAL ON UNSATURATED ZONE MONITORING FOR HAZARDOUS WASTE LAND TREATMENT UN ITS

Environmental Monitoring Systems Laboratory
U.S. Environmental Protection Agency
Las Vegas, Nevada

Office of Solid Waste and Emergency Response
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Washington, D.C. 20460

NOTICE

This manual is considered the final version of EPA’s guidance on unsaturated zone monitoring at hazardous waste land treatment facilities. It is intended to be used by permit applicants and permit writers as an aid to comply with RCRA Subtitle C monitoring regulations for hazardous waste land treatment units. This guidance is not intended to mean that other designs and equipment might not also satisfy the regulatory standards. This manual has undergone extensive public review and this final version reflects and incorporates the comments received which include cements from both major universities and oil companies. This manual is intended to be a technical aid. It is not Intended to present official policy or supersede any regulations relevant to unsaturated zone monitoring at hazardous waste land treatment facilities. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This manual provides guidance on unsaturated zone monitoring at hazardous waste land treatment units for use by permit applicants and permit writers in developing effective monitoring systems to comply with the Part 264, Subpart M regulations. This manual covers both soil core and soil pore-liquid monitoring, and addresses equipment selection, installation, and operation, sampling procedures, chain of custody considerations, and data evaluation. The installation and sampling procedures are presented in a step-by-step format so that the manual may be more readily used by field personnel .

Subtitle C of the Resource Conservation and Recovery Act (RCRA) requires the Environmental Protection Agency (EPA) to establish a Federal hazardous waste management program. This program must ensure that hazardous wastes are handled safely from generation until final disposition. EPA issued a series of hazardous waste regulations under Subtitle C of RCRA that is published in 40 Code of Federal Regulations (CFR) 260 through 265, 270 and 124.

Parts 264 and 265 of 40 CFR contain standards applicable to owners and operators of all facilities that treat, store, or dispose of hazardous wastes. Wastes are identified or listed as hazardous under 40 CFR Part 261. The Part 264 standards are implemented through permits issued by authorized States or the EPA in accordance with 40 CFR Part 270 and Part 124 regulations. Land treatment, storage, and disposal (LTSD) regulations in 40 CFR Part 264 issued on July 26, 1982, establish performance standards for hazardous waste landfills, surface impoundments, land treatment units, and waste piles.

This manual and other EPA guidance documents do not supersede the regulations promulgated under RCRA and published in the Code of Federal Regulations. They provide guidance, interpretations, suggestions, and references to additional information. Also, this guidance is not intended to mean that other designs might not also satisfy the regulatory standards.

EXECUTIVE SUMMARY

This manual provides guidance on unsaturated zone monitoring at hazardous waste land treatment units. The manual will be useful to both owners or operators of hazardous waste land treatment units and officials in implementing the unsaturated zone monitoring requirements (q264.278) contained in the hazardous waste land treatment, storage, and disposal regulations (40 CFR 264, July 26, 1982). After summarizing the regulations, the manual identifies other available sources of guidance and data on the subject. Complete descriptions for Darcian and macro-pore flow in the unsaturated zone are given.

Soil core monitoring equipment is divided into hand-held samplers and power-driven samplers. Specific descriptions for screw-type augers, barrel augers, post-hole augers, Dutch-type augers, regular or general purpose barrel augers, sand augers, mud augers, in addition to tube-type samplers, including soil sampling tubes, Veihmeyer tubes, thin-walled drive samplers, and peat samplers, are provided. Power-driven samplers, including hand-held power augers, truck-mounted augers, and tripod-mounted power samplers, are described. Procedures for selecting soil samplers, site selection, sample number, size, frequency and depth, sampling procedures, decontamination, safety precautions, and data analysis and evaluation are presented.

Complete descriptions for soil pore-liquid monitoring are provided. Relationships between soil moisture and soil tension are fully described. Soil pore-liquid sampling equipment, including cup-type samplers, cellulose acetate hollow fiber samplers, membrane filter samplers, and pan lysimeters are presented. Criteria for selecting soil pore-liquid samplers, site selection, sample number, size, frequency and depth, installation procedures, and operation of vacuum-pressure sampling units, are presented. Extensive discussion of special problems associated with the use of suction lysimeters are included. Descriptions are provided for pan lysimeter installation and operation, including trench lysimeters and free drainage block glass samplers. A discussion is provided of soil pore-liquid data analysis and evaluation.

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This manual was prepared by L.G. Everett of Kaman Tempo (Santa Barbara, California 93102) and L.G. Wilson of the University of Arizona (Tucson, Arizona 85721) under Contract Number 68-03-3090 from the U.S. Environmental Protection Agency, Office of Research and Development. The EPA Project Officers were L.G. McMillion and L.A. Eccles, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada. Subsequent to the completion of the manual, the responsibility for completion of this manual was shifted to the Office of Solid Waste, under the direction of Mr. Michael Flynn and Mr. Jon Perry in Washington, D.C. Both Mr. Eccles and Mr. Perry played an active role in the manual's final preparation.

Dr. Charles O. Riggs of the Central Mine Equipment Company provided an extensive review of the soil core sampling protocols. Several excellent recommendations were made relative to soil core sampling.

Earlier drafts of this manual were distributed to the EPA regional offices for review and comment (6/83) and presented in the Federal Register for national comment and review (12/84). In addition, extensive reviews were conducted at the Environmental Monitoring Support Laboratory in Las Vegas and at the University of Oklahoma branch of the Groundwater Research Center.

The assistance and cooperation extended by numerous other individuals, not mentioned above, who were contacted on matters related to this manual, is gratefully acknowledged.

SECTION 1

INTRODUCTION

The purpose of this document is to provide guidance on essential elements of an unsaturated zone monitoring program and to assist individuals in developing and evaluating these programs. The scope of this document covers unsaturated zone monitoring at hazardous waste land treatment units. This guidance will be useful to both owners or operators of hazardous waste land treatment units and officials in implementing the unsaturated zone monitoring requirements (§264.278) contained in the hazardous waste land treatment, storage, and disposal regulations (40 CFR Part 264).

This report stresses the selection and application of unsaturated zone monitoring equipment. Both soil core and soil pore-liquid monitoring equipment are highlighted. Sampling protocols, including sampling design, frequency, depth, and sample number, are also presented. These protocols (with minor modifications) are derived from guidance previously issued by EPA (EPA, 1983a; EPA, 1983b). These protocols, which represent interim guidance, are currently being evaluated in EPA's research program.

Land treatment is a viable management practice for treating and disposing of some types of hazardous wastes. Land treatment involves the application of waste on the soil surface or the incorporation of waste into the upper layers of the soil (the treatment zone) in order to degrade, transform, or immobilize hazardous constituents present in hazardous waste. The unsaturated zone monitoring program must include procedures to detect both slow moving hazardous constituents as well as rapidly moving hazardous constituents. This is best accomplished through a monitoring program including both soil core and soil pore liquid monitoring. Both soil core monitoring and soil pore liquid monitoring in the unsaturated zone are discussed in this report. In addition, the unsaturated zone monitoring requirements (§264.278) for background and active portions of land treatment units are briefly reviewed. Procedures for randomly determining the location of soil core and pore-liquid sampling sites in both the background areas and active portions are presented. Sampling depth and frequency are fully evaluated. Soil core monitoring and pore-liquid monitoring equipment are described. Selection criteria for each of the monitoring apparatus are presented. The field implementation and operating requirements for each piece of equipment is presented in a step-by-step format. Sample collection, preservation, storage, chain of custody and shipping are presented.

The unsaturated zone monitoring requirements (§264.278) mentioned above consist of performance-oriented statements and rules, and, as a result, are also general in nature. This provides maximum flexibility to the owner or operator in designing and operating an unsaturated zone monitoring program. However, the permitting official must render a value judgment on the acceptability of the particular monitoring system design proposed for each land treatment unit. EPA wishes to emphasize that the specifications in this document are guidance, not regulations.

Although not addressed in this document, groundwater monitoring is also required at hazardous waste land treatment units. Requirements pertaining to groundwater monitoring are provided in Subpart F of Part 264.

1.1 BRIEF SUMMARY OF REGULATIONS

Under the authority of Subtitle C of the Resource Conservation and Recovery Act (RCRA), EPA promulgated interim-final regulations for the treatment, storage, and disposal of hazardous waste in land disposal facilities on July 26, 1982 (40 CFR, Part 264). Included in these regulations were standards applicable to hazardous waste land treatment units. Section 264.278 of these regulations requires that all land treatment units have an unsaturated zone monitoring program that is capable of determining whether hazardous constituents have migrated below the treatment zone. Appendix C contains a reprint of the §264.278 regulations and supporting preamble. The monitoring program must include both soil-core and soil-pore liquid monitoring. Monitoring for hazardous constituents must be performed on a background plot (until background levels are established) and immediately below the treatment zone (active portion). The number, location, and depth of soil-core and soil-pore liquid samples taken must allow an accurate indication of the quality of soil-pore liquid and soil below the treatment zone and in the background area. The regulations require that background values for soil-pore-liquid be based on at least quarterly sampling for one year on the background plot, whereas background soil core sampling values may be based on one-time sampling. The frequency and timing of soil-core and soil-pore liquid sampling on the active portions must be based on the frequency, time and rate of waste application, proximity of the treatment zone to groundwater, soil permeability, and amount of precipitation. The Regional Administrator will specify in the facility permit the sampling and analytical procedures to be used. The owner or operator must also determine if statistically significant increases in hazardous constituents have occurred below the treatment zone. The regulations provide the option of monitoring for selected indicator hazardous constituents, referred hereafter as "principal hazardous constituents (PHCs)," in lieu of all hazardous constituents.

1.2 OTHER AVAILABLE GUIDANCE

Four EPA documents are available which complement the material in this document on unsaturated zone monitoring. Hazardous Waste Land Treatment (SW-874) (EPA, 1983a) provides information on site selection, waste characterization, treatment demonstration studies, land treatment unit design, operation, monitoring, closure, and other topics useful for design and management of land treatment units. Test Methods for Evaluating Solid Waste (SW-846) (EPA, 1982b) provides procedures that may be used to evaluate the characteristics of hazardous waste as defined in 40 CFR Part 261 of the RCRA regulations. The manual encompasses methods for collecting representative samples of solid wastes, and for determining the reactivity, corrosivity, ignitability, and composition of the waste and the mobility of toxic species present in the waste. The RCRA Guidance Document: Land Treatment Units (EPA, 1983b) identifies specific designs and operational procedures that EPA believes accomplish the performance requirements in RCRA Sections 264.272 (treatment demonstration), 264.273 (design and operating requirements), 264.278 (unsaturated zone monitoring), 264.280 (closure and post-closure care).

A state-of-the-art document entitled Vadose Zone Monitoring at Hazardous Waste Sites (Everett et al., 1983) describes the applicability of vadose zone monitoring techniques to hazardous waste site investigations. Physical, chemical, geologic, topographic, geohydrologic, and climatic constraints for vadose zone monitoring are described. Vadose zone monitoring techniques are categorized for premonitoring, active, and post-closure site assessments. Conceptual vadose zone monitoring approaches are developed for specific waste disposal units including waste piles, landfills, impoundments, and land treatment units.

1.3 SOURCES OF DATA

The main source of soils data is the Soil Conservation Service (Mason, 1982). This Federal agency has offices in each county and also has a main office for each state. The soil survey reports that are produced by the agency provide maps, textural, drainage, erosion, and agricultural information. In addition to the soil survey reports, each county office usually has aerial photographs that provide general information on the soils in a particular area. A local soil scientist often can provide detailed information on the area around the site.

A second source of soils data can often be obtained from the agricultural schools in each state. The Agronomy or Soils Departments often have valuable information that is pertinent to the land treatment site. Access to this data can usually be obtained by contacting the department head or by contacting the State Cooperative Extension Service office located on the campus of the university.

A third source of information on soils in an area is found in County and State Engineering Offices and in the Department of Transportation or Highway Departments of the states. Local drillers that have worked on construction projects or have drilled water wells in the area can often provide information on the soils and also on sources of information about an area.

Regardless of the source of historic data, however, a recent detailed assessment of the soils at the particular site should be made by a qualified soil scientist. This will account for any changes that may have occurred at the site over the years, and provide the necessary detail to evaluate local soil conditions.

SECTION 2

UNSATURATED ZONE DESCRIPTION

Monitoring is carried out at hazardous waste land treatment units for two primary reasons: (1) to assess the efficiency of the soil processes that degrade incorporated wastes, and (2) to detect the migration of hazardous constituents beneath the trea' t zone. The "treatment zone" refers to the area in which all degradati..., transformation, or immobilization must occur (EPA, 1982a). The maximum depth of this zone must be no more than 1.5 m (5 feet) from the initial land surface and at least 1 m (3 feet) above the seasonal high water table (EPA, 1982a).

The geological profile extending from ground surface (including the treatment zone) to the upper surface of the principal water-bearing formation is called the vadose zone. As pointed out by Bouwer (1978), the term "vadose zone" is preferable to the often-used term "unsaturated zone" because saturated regions are frequently present in the vadose zone. The term "zone of aeration" is also often used synonymously. In this report we shall use the term "unsaturated" to be consistent with the terminology used in the regulations. Davis and De Wiest (1966) subdivided the unsaturated zone into three regions designated as: the soil zone, the intermediate unsaturated zone, and the capillary fringe (Figure 2-1).

2.1 SOIL ZONE

The surface soil zone is generally recognized as that region that manifests the effects of weathering of native geological material. The movement of water in the soil zone occurs mainly as unsaturated flow caused by infiltration, percolation, redistribution, and evaporation (Klute, 1965). In some soils, primarily those containing horizons of low permeability, such as heavy clays, saturated regions may develop during waste spreading, creating shallow perched water tables (Everett, 1980).

The physics of unsaturated soil-water movement has been intensively studied by soil physicists, agricultural engineers, and microclimatologists. In fact, copious literature is available on the subject in periodicals (Journal of the Soil Science Society of America, Soil Science) and books (Childs, 1969; Kirkham and Powers, 1972; Hillel, 1971, Hillel, 1980; Hanks and Ashcroft, 1980). Similarly, a number of published references on the theory of flow in shallow perched water tables are available (Luthin, 1957; van Schilfgaarde, 1970). Soil chemists and soil microbiologists have also attempted to quantify chemical-microbiological transformations during soil-water movement (Bohn, McNeal, and O'Connor, 1979; Rhoades and Bernstein, 1971; Dunlap and McNabb, 1973).

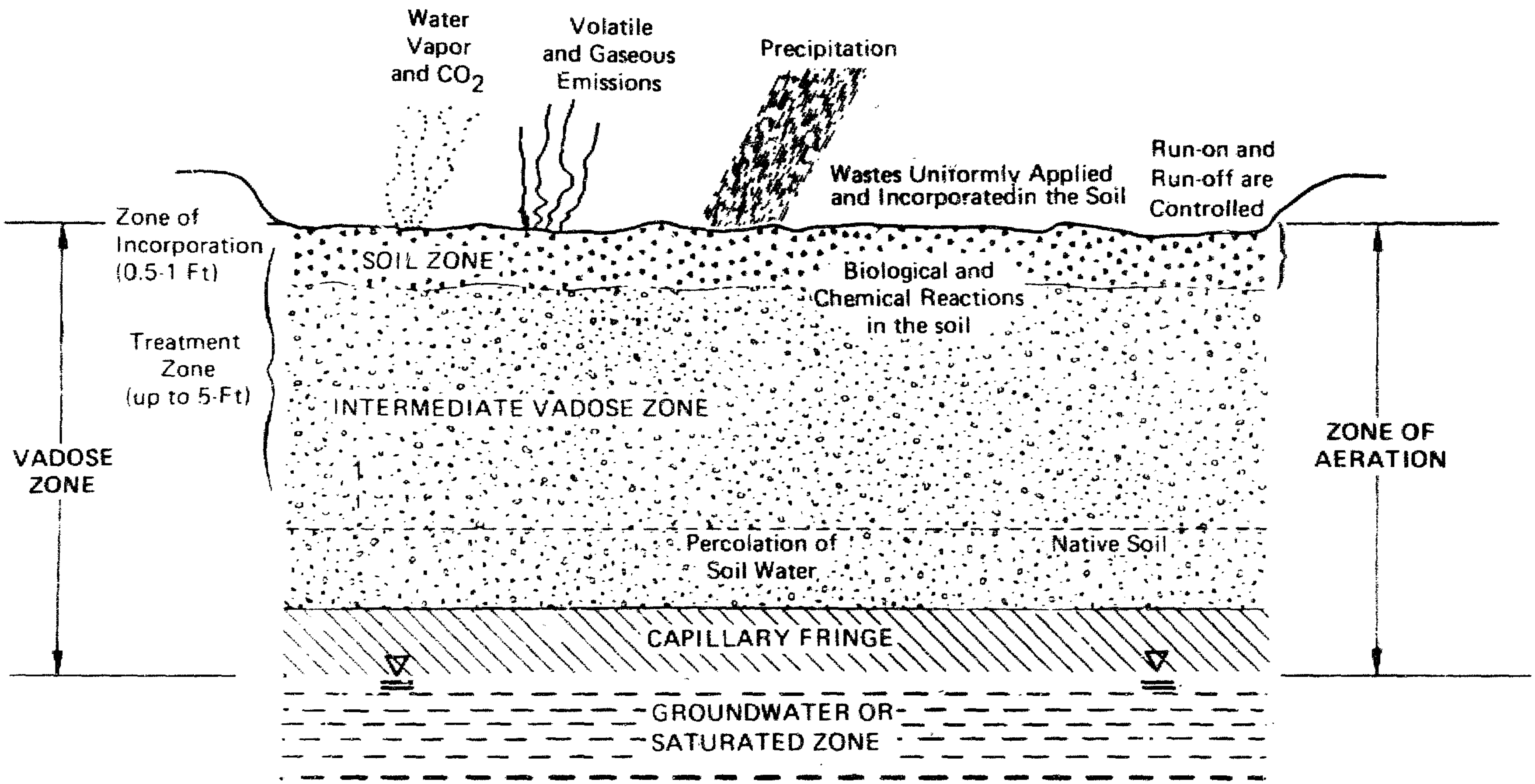

Figure 2-1. Diagrammatic land treatment cross section in the vadose zone

2.2 INTERMEDIATE UNSATURATED ZONE

Weathered materials of the soil zone may gradually merge with underlying deposits, which are generally unweathered, comprising the intermediate unsaturated zone. In some regions, this zone may be practically nonexistent, the soil zone merging directly with bedrock. In alluvial deposits of western valleys, however, this zone may be hundreds of feet thick. Figure 2-2 shows a geologic cross section through an unsaturated zone in an alluvial basin in California. By the nature of the processes by which such alluvium is laid down, this zone is unlikely to be uniform throughout, but may contain micro- or macrolenses of silts and clays interbedding with gravels. Water in the intermediate unsaturated zone may exist primarily in the unsaturated state, and in regions receiving little inflow from above, flow velocities may be negligible. Perched groundwater, however, may develop in the interfacial deposits of regions containing varying textures. Such perching layers may be hydraulically connected to ephemeral or perennial stream channels so that, respectively, temporary or permanent perched water tables may develop. Alternatively, saturated conditions may develop as a result of deep percolation of water from the soil zone during prolonged surface application. Studies by McWhorter and Brookman (1972) and Wilson (1971) have shown that perching layers intercepting downward-moving water may transmit the water laterally at substantial rates. Thus, these layers serve as underground spreading regions transmitting water laterally away from the overlying source area. Eventually, water leaks downward from these layers and may intercept a substantial area of the water table. Because of dilution and mixing below the water table, the effects of waste spreading may not be noticeable until a large volume of the aquifer has been affected.

The number of studies on water movement in the soil zone greatly exceeds the studies in the intermediate zone. Reasoning from Darcy's equation, Hall (1955) developed a number of equations to characterize mound (perched groundwater) development in the intermediate zone. Hall also discusses the hydraulic energy relationships during lateral flow in perched groundwater. Freeze (1969) attempted to describe the continuum of flow between the soil surface and underlying saturated water bodies. Bear et al. (1968) described the requisite conditions for perched groundwater formation when a region of higher permeability overlies a region of lower permeability in the unsaturated zone.

2.3 CAPILLARY FRINGE

The base of the unsaturated zone, the capillary fringe, merges with underlying saturated deposits of the principal water-bearing formation. This zone is not characterized as much by the nature of geological materials as by the presence of water under conditions of saturation or near saturation. Studies by Luthin and Day (1955) and Kraijenhoff van deLeur (1962) have shown that both the hydraulic conductivity and flux may remain high for some vertical distance in the capillary fringe, depending on the nature of the materials. In general, the thickness of the capillary fringe is greater in fine materials than in coarse deposits. Apparently, few studies have been conducted on flow and chemical transformations in this zone. Taylor and Luthin (1969) reported on a computer model to characterize transient flow in this zone and compared results with data from a sand tank model. Freeze and Cherry (1979) indicated that oil reaching the water table following leakage from a surface source

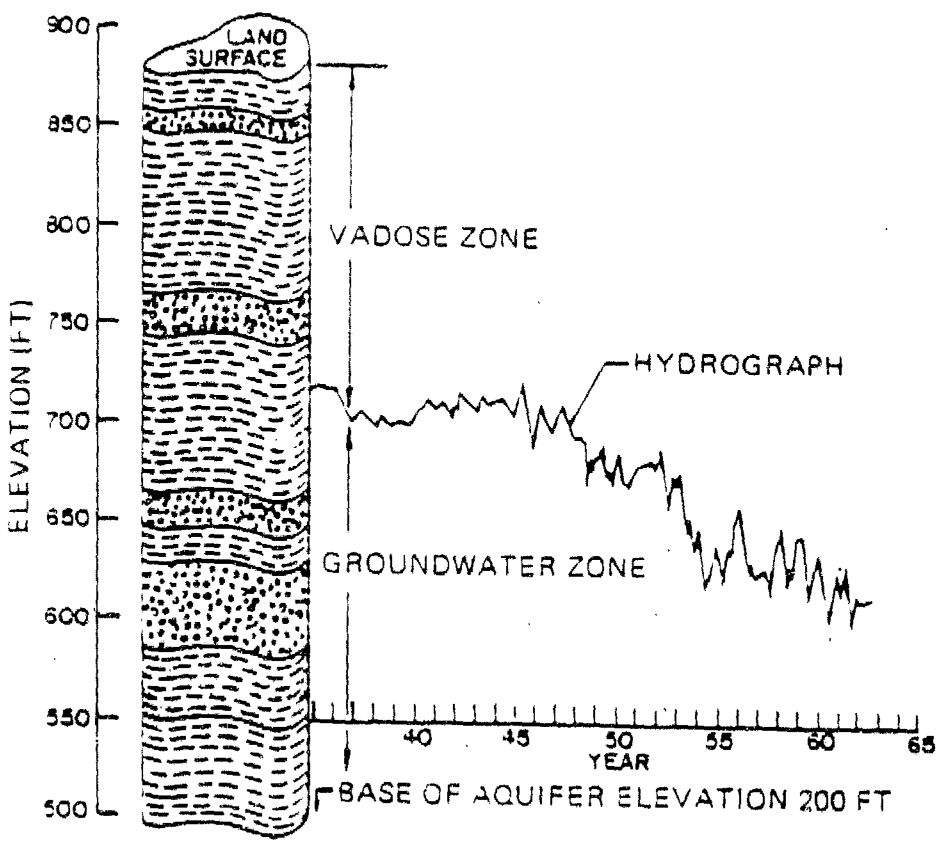

Figure 2-2. Cross section through the unsaturated zone (vadose zone) and groundwater zone (Ayers and Branson, 1973)

flows in a lateral direction within the capillary fringe in close proximity to the water table. Because oil and water are immiscible, oil does not penetrate below the water table, although some dissolution may occur.

The overall thickness of the unsaturated zone is not necessarily constant. For example, as a result of recharge at a water table during a waste disposal operation, a mound may develop throughout the capillary fringe extending into the intermediate zone. Such mounds have been observed during recharge studies (e.g., Wilson, 1971) and efforts have been made to quantify their growth and dissipation (Hantush, 1967; Bouwer, 1978).

As already indicated, the state of knowledge of water movement and chemical-microbiological transformations is greater in the soil zone than elsewhere in the unsaturated zone. Renovation of applied wastewater occurs primarily in the soil zone. This observation is borne out by the well-known studies of McMichael and McKee (1966), Parizek et al. (1967), and Sopper and Kardos (1973). These studies indicate that the soil is essentially a "living filter" that effectively reduces certain microbiological, physical, and chemical constituents to safe levels after passage through a relatively short distance (e.g., Miller, 1973; Thomas, 1973). As a result of such favorable observations, a certain complacency may have developed with respect to the need to monitor only in the soil zone.

Dunlap and McNabb (1973) point out that microbial activity may be significant in the regions underlying the soil. They recommend that investigations be conducted to quantify the extent that such activity modifies the nature of pollutants travelling through the intermediate zone.

For the soil zone, numerous analytical techniques were compiled by Black (1965) into a two-volume series entitled "Methods of Soil Analyses." Monitoring in the intermediate zone and capillary fringe will require the extension of technology developed in both the soil zone and in the groundwater zone. Examples are already available where this approach has been used. For example, Apgar and Langmuir (1971) successfully used suction cups developed for in situ sampling of the soil solution at depths up to 50 feet below a sanitary landfill. J.R. Meyer (personal communication, 1979) reported that suction cups were used to sample at depths greater than 100 feet below land surface at cannery and rock phosphate disposal sites in California.

2.4 FLOW REGIMES

Both soil-core and soil pore-liquid monitoring are required in the unsaturated zone. These two monitoring procedures are intended to complement one another. Soil-core monitoring will provide information primarily on the movement of "slower-moving" hazardous constituents (such as heavy metals), whereas soil pore-liquid monitoring will provide additional data on the movement of fast-moving, highly soluble hazardous constituents.

Current literature on soil water movement in the unsaturated zone describes two flow regimes, the classical wetting front infiltration of Bodman and Colman (1943) and a transport phenomena labeled as flow down macropore, noncapillary flow, subsurface storm flow, channel flow, and other descriptive names, but hereafter referred to as macropore flow. The classical concept of infiltration depicts a distinct, somewhat uniform, wetting front slowly advancing in a Darcian flow regime after a precipitation event. The maximum soil moisture content approaches field capacity. Contemporary models combine this classical concept with the macropore flow phenomena.

2.4.1 Darcian Flow

The fundamental principle of unsaturated and saturated flow is Darcy's law. In 1856 Henry Darcy, in a treatise on water supply, reported on experiments of the flow of water through sands. He found that flows were proportional to the head loss and inversely proportional to the thickness of sand traversed by the water. Considering generalized sand column with a flow rate Q through a cylinder of cross-sectional area A, Darcy's law can be expressed as:

$$Q = KA \frac{hL}{L} \qquad (2\text{-}1)$$

More generally, the velocity

$$v = \frac{Q}{A} = K \frac{dh}{dL} \qquad (2\text{-}2)$$

where dh/dL is the hydraulic gradient. The quantity K is a proportionality constant known as the coefficient of permeability, or hydraulic conductivity. The velocity in Eq. (2-2) is an apparent one, defined in terms of the discharge and the gross cross-sectional area of the porous medium. The actual velocity varies from point to point throughout the column.

Darcy's law assumes one-dimensional, steady state conditions and is applicable only within the laminar range of flow where resistive forces govern flow. As velocities increase, inertial forces, and ultimately turbulent flows, cause deviations from the linear relation of Eq. (2-2). Fortunately, for most natural groundwater motion, Darcy's law can be applied in the equation of continuity.

2.4.2 Macropore Flow

The macropore flow phenomena involves the rapid transmission of free water through large, continuous pores or channels to depths greater than one would expect if flow was evenly distributed. It is important to note that this secondary porosity is made up of continuous fractures or fissures and should not be confused with flow through large porous media. The observation that a significant amount of water movement can occur in soil macropores was first reported by Lawes et al. (1882). Reviews of subsequent work are provided by Whipkey (1967) and Thomas and Phillips (1979). Macropore flow can occur in soils at moisture contents less than field capacity (Thomas et al., 1978). The concept of field capacity, however, is not relevant to this type of flow regime. The depth of macropore flow penetration is a function of initial water content, the intensity and duration of the precipitation event and the nature of the macropores (Aubertin, 1971; Quisenberry and Phillips, 1976). Macropores need not extend to the soil surface for flow down to occur, nor need they be very large or cylindrical (Thomas and Phillips, 1979). Exemplifying the role of macropores, Bouma et al. (1979) reported that planar pores with an effective width of 90 μm occupying a volume of 2.4% were primarily responsible for a relatively high hydraulic conductivity of 60 cm day^{-1} in a clay soil. Aubertin (1971) found that water can move through macropores very quickly to depths of 10 m or more in sloping forested soils. Liquid moving in the macropore flow regime is likely to bypass the soil solution in intraped or matrix pores surrounding the macropores and result in only partial displacement or dispersion of dissolved constituents (Quisenberry and Phillips, 1978; Wild, 1972; Shuford et al., 1977; Kissel et al., 1973; Bouma and Wosten, 1979; Anderson and Bouma, 1977).

The current concept of infiltration in well structured soils combines both classical wetting front movement and macropore flow. Aubertin (1971) found that the bulk of the soil surrounding the macropores was wetted by radial movement from the macropores sometime after macropore flow occurred. A number of researchers have presented mathematical models in an attempt to explain the macropore flow phenomena (Beven and Germann, 1981; Edwards et al., 1979; Hoogmoed and Bouma, 1980; Skopp et al., 1981).

Thomas and Phillips (1979) listed four consequences of rapid macropore flow:

(i) The value of a rain or irrigation to plants will generally not be so high as anticipated since some of the water may move below the root zone.

(ii) Recharge of groundwater and springs can begin long before the soil reaches field capacity.

(iii) Some of the salts in the surface of a soil will be moved to a much greater depth after a rain or irrigation than predicted by piston displacement. On the other hand, much of the salt will be bypassed and remain near the soil surface.

(iv) Because of this, it is not likely that water will carry a surge of contaminants to groundwater at the same time that is predictable by Darcian theory.

The occurrence of macropore flow poses serious implications for unsaturated zone monitoring and the protection of groundwater from the land treatment of hazardous wastes. The first implication is that contaminated water will flow rapidly through the treatment zone and not receive full treatment. Under this short circuit scenario groundwater contamination is probable.

Because of the above concerns, the extent of macropore flow within the treatment zone of the proposed land treatment site should be fully evaluated in the treatment demonstration, which is required for all land treatment units in §264.272 of the regulations. This may be accomplished through a monitoring program including both suction and pan-type lysimeters. This evaluation will assist in determining the acceptability of the site for land treatment and in defining the most appropriate soil pore-liquid monitoring approach for that site. Owners and operators of sites at which macropore flow is the dominate flow regime may be unable to demonstrate successful treatment within the treatment zone.

SECTION 3

SOIL-CORE MONITORING

The purposes of this section are twofold: (1) to describe representative devices for obtaining soil cores during unsaturated zone monitoring at land-treatment units, and (2) to describe procedures for obtaining soil samples using these devices.

3.1 GENERAL EQUIPMENT CLASSIFICATION

Soil sampling devices and systems for unsaturated zone sampling are divided into two general groups, namely: (1) those samplers used in conjunction with multipurpose or auger drill rigs and (2) those samplers used in conjunction with hand-operated drilling devices. In most cases, the hand-operated drilling device is also the sampler.

3.1.1 Sampling with Multipurpose Drill Rigs

For most circumstances the use of hollow-stem augers with some type of cylindrical sampler will provide a greater level of assurance that the soil being sampled within the unsaturated soil zone was not carried downward by the hole excavating or sampling process. For some situations, such as sampling dense to very dense or stiff to very hard ground, the use of multipurpose auger-core-rotary drills will be necessary. For some geologic circumstances the use of continuous flight augers will provide an adequate drilling method.

3.1.1.1 Multipurpose Auger-Core-Rotary Drill Rigs--

Multipurpose auger-core-rotary drill rigs are generally manufactured with rotary power and vertical feed control to advance both hollow-stem augers and continuous flight (solid-stem) augers to depths greater than 100 ft (30 m). These same drills have secondary capability for rotary and core drilling. The larger of these drills have 90 to 130 HP power sources and are typically mounted on 20,000 to 30,000 lb GVW trucks. The same multipurpose drill rigs are readily available in North America on both rubber-tired and track-driven all-terrain carriers. The smaller of the multipurpose drills have 40 to 60 HP power sources and are typically mounted on trailers or one-ton, 4 x 4 trucks.

3.1.1.2 Auger Drills--

Auger drill rigs are similar to multipurpose auger-core-rotary drill rigs. They are manufactured specifically for efficient auger drilling but do not have the pumps and hoists that are required for efficient core or rotary drilling. There are relatively few auger drills available in comparison to multipurpose auger-core-rotary drills.

3.1.1.3 Hollow-Stem Auger Drilling and Sampling

The tools used for hollow-stem auger drilling (Figure 3-1) consist of outer components: hollow auger sections, hollow auger head and drive cap, and inner components: pilot assembly, center rod column and rod-to-cap adaptor. Auger sections are typically 5 ft in length and are interchangeable for assembly, in an articulated but continuously flighted column. Drilling progresses in 5 ft or shorter increments. Sampling can be accomplished at any depth within a 5 ft drilling increment. On completion of a 5 ft (1.5 m) increment of drilling, another 5 ft section of hollow auger and center rod is added. Hollow-stem augers are manufactured and are readily available with inside diameters of 2.25 in., 2.75 in., 3.25 in., 3.75 in., 4.25 in., 6.25 in. and 8.25 in. In general, sampling is accomplished by removing the pilot assembly and center rod and inserting the sampler through the hollow axis of the auger (Figure 3-2).

3.1.1.4 Continuous Flight Auger Drilling and Sampling

When continuous flight (solid-stem) augers are used for sampling, the complete articulated column of 5 ft sections must be removed from the borehole (Figure 3-3). This method can provide an adequately clean borehole in some fine grained soils. When the continuous flight auger method is used in caving or squeezing ground (Figure 3-4), the quality of sample and the origin of the recovered sample is questionable.

3.1.1.5 Cylindrical Soil Samplers

Cylindrical samplers are either pushed or driven in sequence with an increment of drilling or advanced simultaneously with the advance of a hollow auger column.

3.1.1.5.1 Thin walled volumetric samplers--Thin wall volumetric (Shelby tube) samplers (Figure 3-5) are readily available in 2 in., 3in. and 5 in. OD and are commonly 30 in. in length. The 3 in. OD x 30 in. length sampler is most common. During the manufacturing process, the advancing end of the sampler is rolled inwardly and machined to a cutting edge that is usually smaller in diameter than the tube ID. The cutting edge ID reduction, defined as a "clearance ratio", is usually in the range of 0.0050 to 0.0150 or 0.50% to 1.50% (Refer to ASTM D1587).

When Shelby tubes are pushed into soil, the sample recovered is often less than the distance pushed, i.e., the recovery ratio is less than 1.0. The recovery ratio is usually less than one because the friction between the soil and the tube ID becomes greater than the shear strength of the soil in front of the tube; consequently, soil in front of the advancing end of the tube is displaced laterally rather than entering the tube (See Hvorslev 1949). The sampler tube is usually connected with set screws to a sampler head which in turn is threaded to connect with standard drill rods. The sampler head usually has a ball check valve for sampling below the water level.

Plastic sealing caps (Figures 3-6A and 3-6B) and other soil sealing devices are readily available for the 2-, 3- and 5-inch diameter tubes. Shelby tubes are commonly available in carbon steel but can be manufactured from other metal tubing.

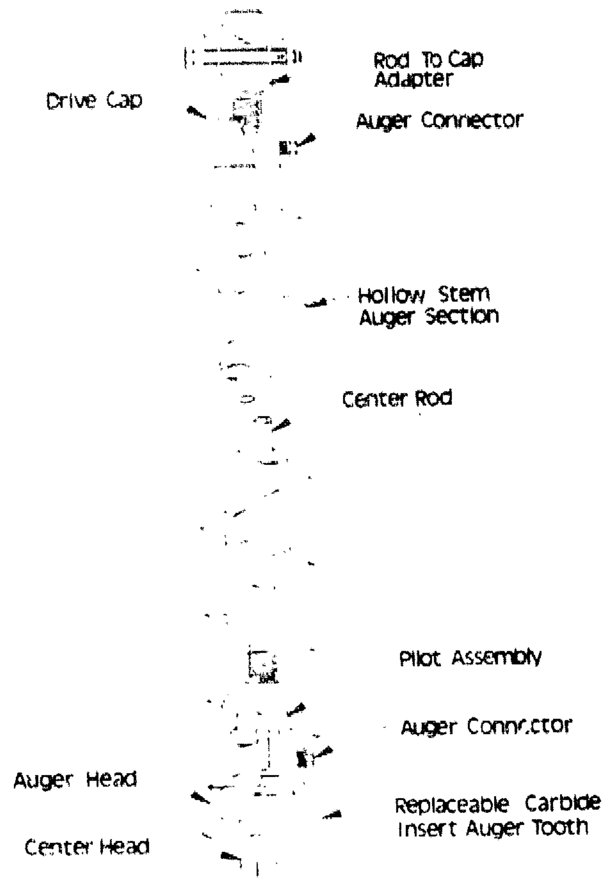

Figure 3-1. Hollow-stem auger drilling tools (Courtesy Central Mine Equiment Co.)

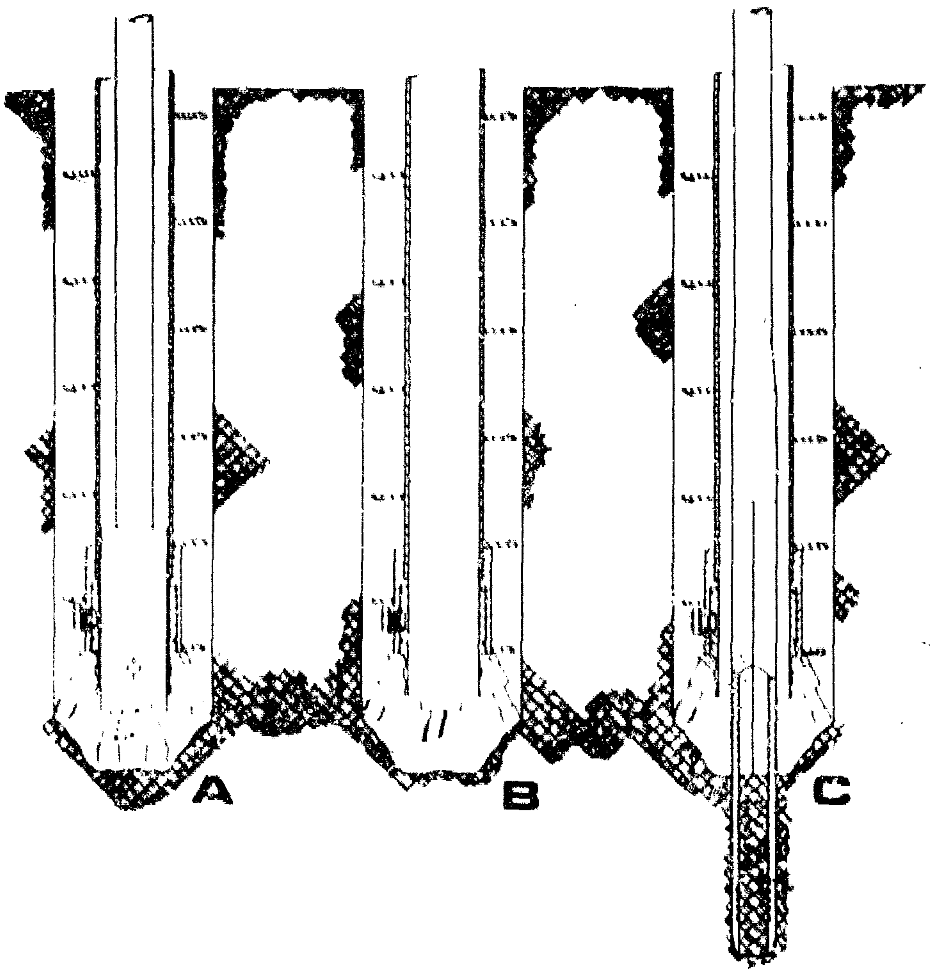

Figure 3-2. Drilling and sampling with hollow-stem augers (Courtesy Central Mine Equipment Co.)

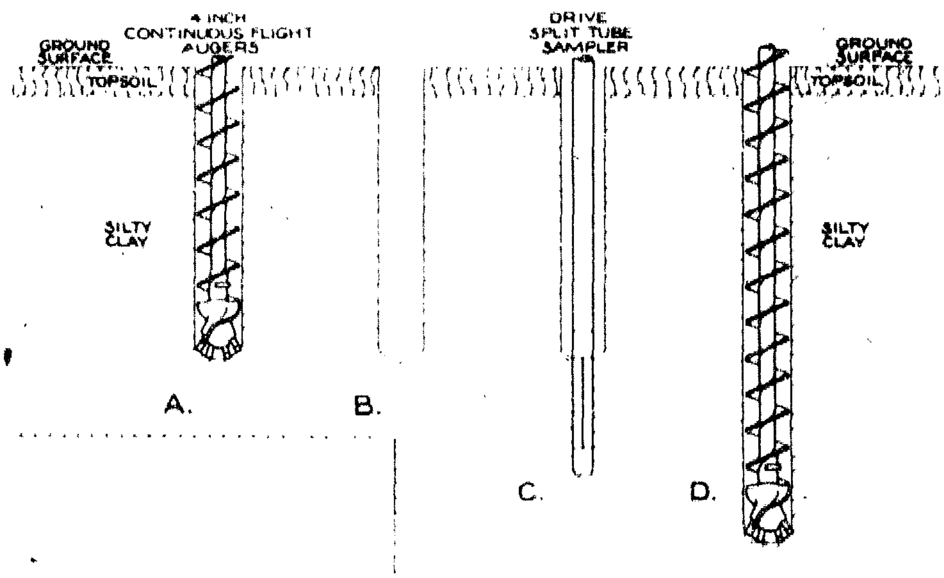

Figure 3-3. Continuous flight auger drilling
(Courtesy Central Mine Equipment Co.)

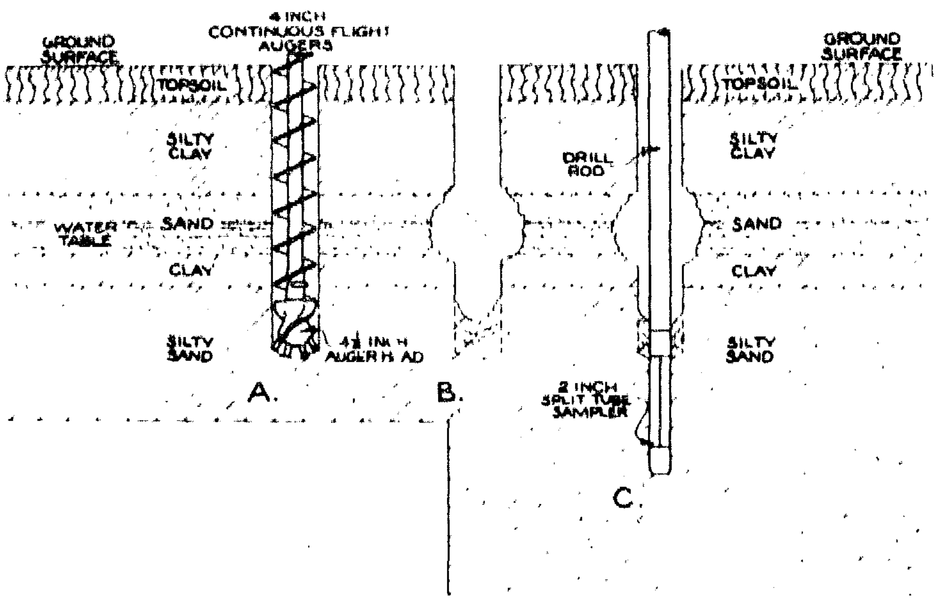

Figure 3-4. Continuous flight auger drilling through coring material (Courtesy Central Mine Equipment Co.)

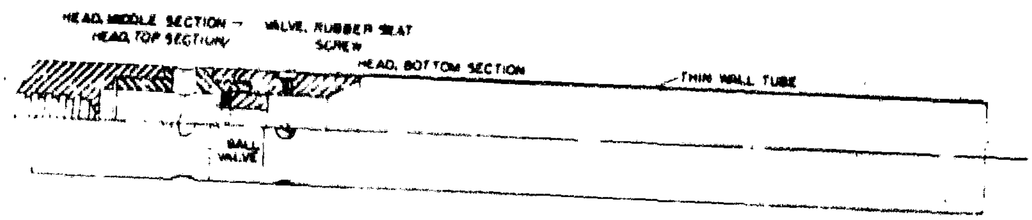

Figure 3-5. Thin-walled (shelby tube) sampler

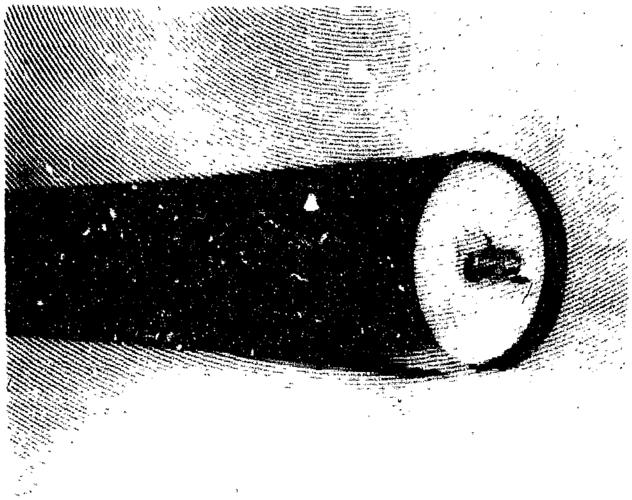

Figure 3-6A. Shelby tube with acetal plastic soil seal inserted (Courtesy Acker Drill Company, Inc.)

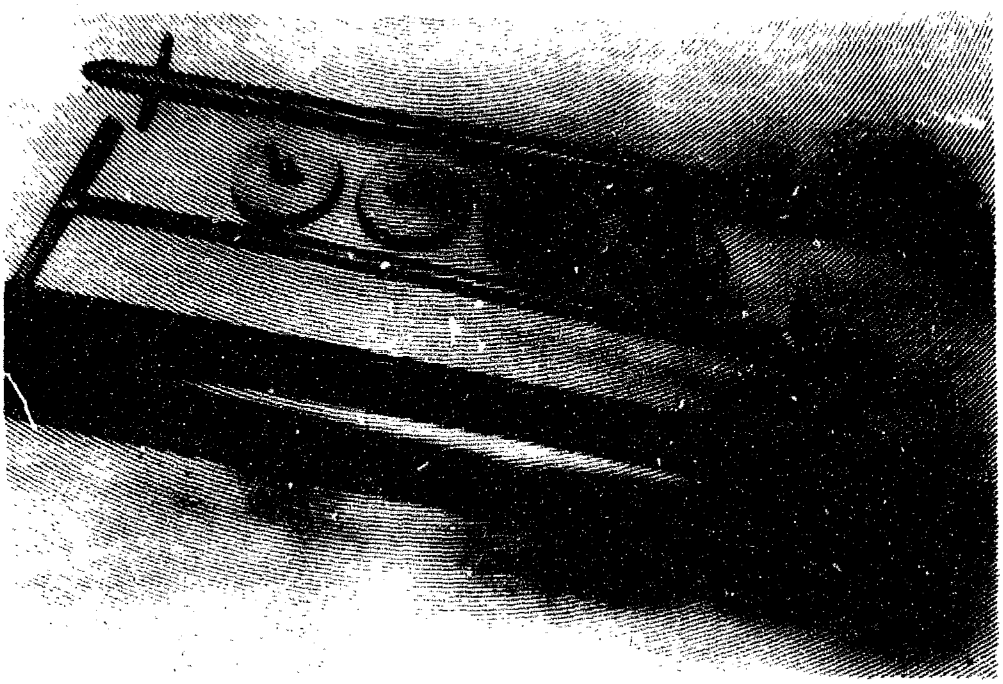

Figure 3-6B. Trimming tool, applicator rod, and seals with cut-away view of soil seal in place (Courtesy Acker Drill Company, Inc.)

3.1.1.5.2 Split-barrel drive samplers--A split-barrel drive sampler consists of two split-barrel halves, a drive shoe and a sampler head containing a ball check valve, all of which are threaded together for the sampler assembly. The most common size has a 2 in. OD and a 1.5 in. ID split barrel with a 1.375 in. ID drive shoe. This sampler is used extensively in geotechnical exploration (Refer to ASTM D1586). When fitted with a 16 gage liner, the sampler has a 1.375 in. ID throughout. A 3 in. OD x 2.5 in. ID split-barrel sampler with a 2.375 in. ID drive shoe is commonly available. Other split-barrel samplers in the size range of 2.5 in. OD to 4.5 in. OD are manufactured but are less common.

3.1.1.5.3 Continuous sample tube system--Continuous sample tube systems that fit within a hollow-stem auger column (Figure 3-7) are manufactured and readily available in North America. These sample barrels are typically 5 ft in length, fit within the lead auger of the hollow auger column and for many ground conditions provide a continuous, 5 ft sample. The soil sample enters the sampling barrel as the hollow auger column is advanced. The barrel can be "split" or "solid" and can be used with or without liners of various metallic and non-metallic materials. Clear "plastic" liners are often used. Usually two 30-inch liner sections are used.

3.1.1.5.4 Peat sampler--At some sites, the soils may contain sufficient organics such that a peat sampler may provide an adequate sample. This sampler consists of a sampling tube and an internal plunger containing a cone-shaped point, which extends beyond the sampling tube, and spring catch at the upper end. Prior to sampling, the unit is forced to the required depth, then the internal plunger is withdrawn by releasing the spring catch via an actuating rod assembly. The next step is to force the cylinder down and the undisturbed soil to the required depth, and then withdrawing the assembly with the collected sample. According to Acker (1974), the sample removed is 3/4 inch diameter and 5½ inches in length.

3.1.2 Hand-Operated Drilling and Sampling Devices

Hand-operated drilling and sampling devices include all devices for obtaining soil cores using manual power. Historically, these devices were developed for obtaining soil samples during agricultural investigations (e.g., determining soil salinity and soil fertility, characterizing soil texture, determining soil-water content, etc.) and during engineering studies (e.g., determining bearing capacity). For convenience of discussion, these samplers are categorized as follows: (a) screw-type augers, (b) barrel augers, and (c) tube-type samplers. Soil samples obtained using either the screw type sampler or barrel augers are disturbed and not truly core samples as obtained by the tube-type samplers. Nevertheless, the samplers are still suitable for use in detecting the presence of pollutants. It is difficult to use these drilling and sampling devices in contaminated ground without transporting shallow contaminants downward.

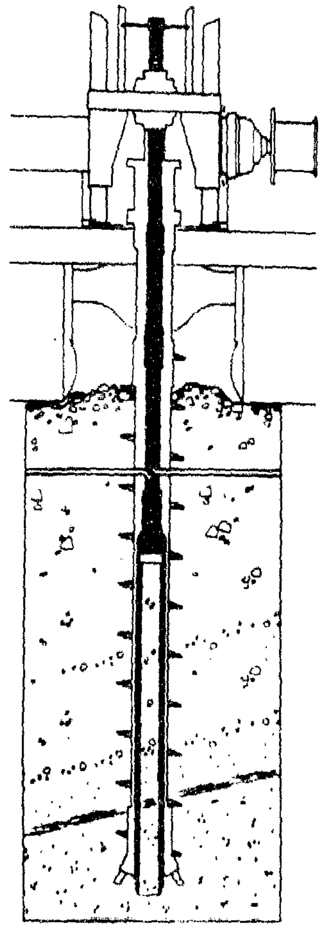

Figure 3-7. Continuous sample tube system (Courtesy Central Mine Equipment Co.)

3.1.2.1 Screw-Type Augers--

The screw or flight auger essentially consists of a small diameter (e.g., 1½ inch) wood auger from which the cutting side flanges and tip have been removed (Soil Survey Staff, 1951). The auger is welded onto a length of tubing or rod. The upper end of this extension contains a threaded coupling for attachment to extension rods (Figure 3-8). As many extension rods are used as are required to reach the total drilling and sampling depth. A wooden or metal handle fits into a tee-type coupling, screwed into the uppermost extension rod. During sampling, the handle is twisted manually and the auger literally screws itself into the soil. Upon removal of the tool, the soil is retained on the auger flights.

According to the Soil Survey Staff (1951), the spiral part of the auger should be about 7 inches long, with the distances between flights about the same as the diameter (e.g., 1½ inches) of the auger to facilitate measuring the depth of penetration of the tool. The rod portion of the auger and the extensions are circumscribed by etched marks in even increments (e.g., in 6 inch increments) above the base of the auger.

Screw-type augers operate more favorably in wet rather than dry soils. Sampling in very dry (e.g., powdery) soils may not be possible with these augers.

3.1.2.2 Barrel Augers--

Basically, barrel augers consist of a short tube or cylinder within which the soil sample is retained. Components of this sampler consist of (1) a penetrating bit with cutting edges, (2) the barrel, and (3) two shanks welded to the barrel at one end and a threaded section at the other end (see Figure 3-9). Extension rods are attached as required to reach the total sampling depth. The uppermost extension rod contains a tee-type coupling for attachment of a handle. The extensions are marked in even depth-wise increments above the base of the tool.

In operation, the sampler is placed vertically into the soil surface and turned to advance the tool into the ground. When the barrel is filled, the unit is withdrawn from the soil cavity and the soil is removed from the barrel. Barrel augers generally provide a greater sample size than the spiral type augers.

3.1.2.3 Post-Hole Augers--

The simplest and most readily available barrel auger is the common post-hole auger (also called the Iwan-type auger, see Acker, 1974). As shown in Figure 3-10, the barrel part of this auger is not completely solid and the barrel is slightly tapered toward the cutting bit. The tapered barrel together with the taper on the penetrating segment help to retain soils within the barrel.

Figure 3-8. Screw-type auger/spiral auger

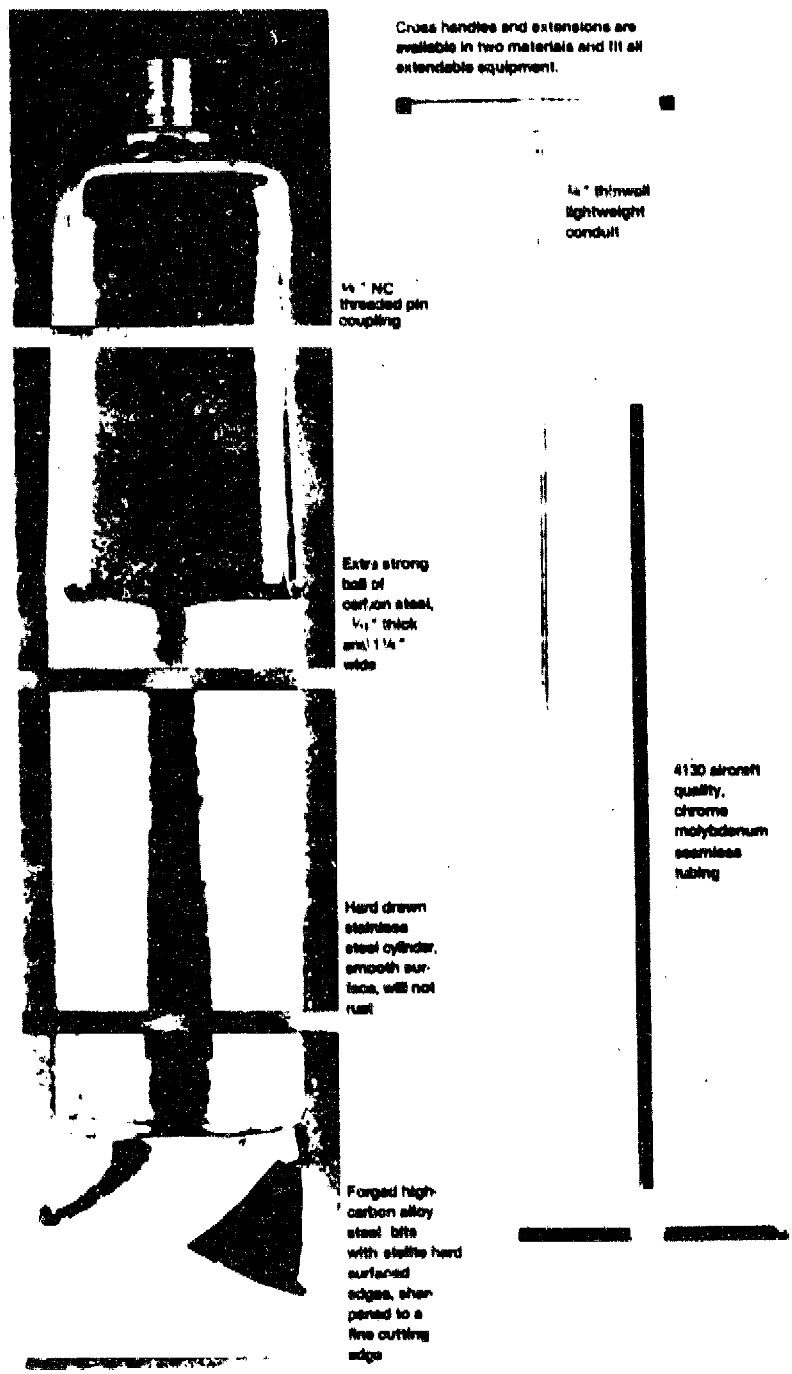

Figure 3-9. Regular auger (Art's Machine Shop, 1982)

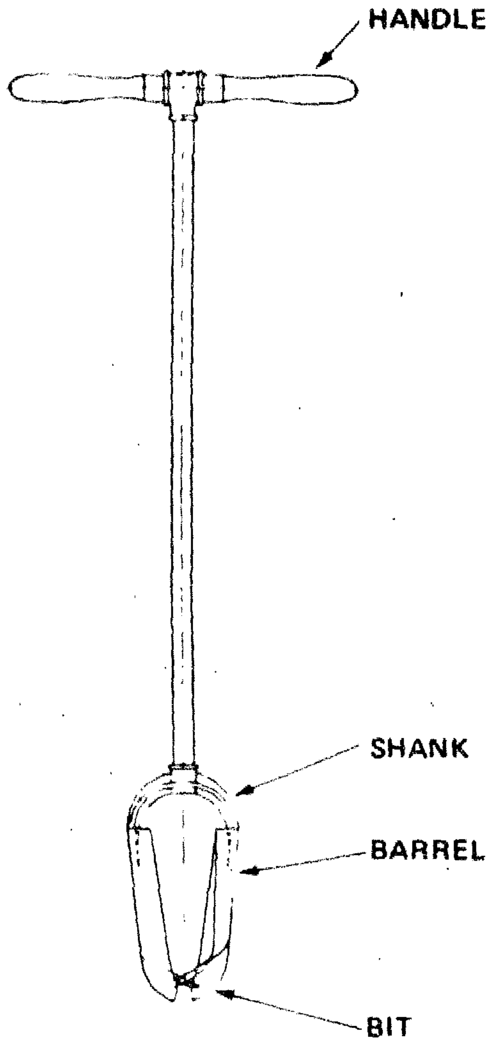

Figure 3-10. Post-hole type of barrel auger

3.1.2.4 Dutch-Type Auger--

The so-called Dutch-type auger is really a smaller variation of the post-hole auger design. As shown in Figure 3-11, the pointed bit is attached to two narrow, curved body segments, welded onto the shanks. The outside diameter of the barrel is generally only about 3 inches. These tools are best suited for sampling in heavy (e.g., clay), wet soils.

3.1.2.5 Regular or General Purpose Barrel Auger--

A version of the barrel auger commonly used by soil scientists and county agents is depicted in Figure 3-9. As shown, the barrel portion of this auger is completely enclosed. As with the post-hole auger, the cutting blades are arranged so that the soil is loosened and forced into the barrel as the unit is rotated and pushed into the soil. Each filling of the barrel corresponds to a depth of penetration of about 3 to 5 inches (Soil Survey Staff, 1951). The most popular barrel diameter is 3½ inches, but sizes ranging from 1½ inches to 5 inches are available (Art's Machine Shop, personal communication, 1983).

The cutting blades are arranged to promote the retention of the sample within the barrel. Extension rods can be made from either standard black pipe or form lightweight conduit or seamless steel tubing. The extensions are circumscribed by evenly-spaced marks to facilitate determining sampling depth.

3.1.2.6 Sand Augers--

The regular type of barrel auger described in the last paragraphs is suitable for core sampling in loam type soils. For extremely dry sandy soils it may be necessary to use a variation of the regular sampler, which includes a specially-formed penetrating bit to retain the sample in the barrel (Figure 3-12).

3.1.2.7 Mud Augers--

Another variation on the standard barrel auger design is available for sampling heavy, wet soils or clay soils. As shown in Figure 3-13, the barrel is designed with open sides to facilitate extraction of the samples. The penetrating bits are the same as those used on the regular barrel auger (Art's Machine Shop, personal communication, 1983).

3.1.2.8 Tube-Type Samplers--

Tube-type samplers differ from barrel augers in that the tube-type units are generally of smaller diameter and their overall length is generally greater than the barrel augers. These units are not as suitable for sampling in dense, stoney soils as are the barrel augers. Commonly used varieties of tube type samplers include soil-sampling tubes, Veihmeyer tubes (also called King tubes), thin-walled drive samplers and peat samplers. The tube-type samplers are preferred if an undisturbed sample is required.

3.1.2.8.1 Soil sampling tubes--As depicted in Figure 3-14, soil sampling tubes consist of a hardened cutting tip, a cut-away barrel and an uppermost threaded segment. The sampling tube is attached to sections of extension rods (tubing) to attain the requisite sampling depth. A cross-handle is attached to the uppermost segment.

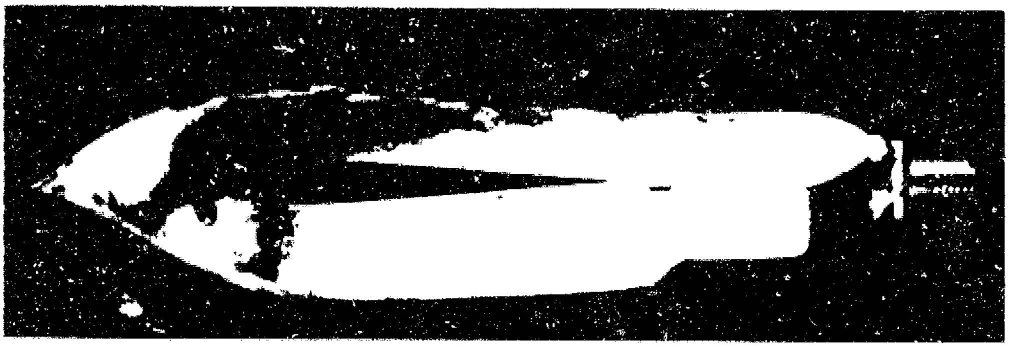

Figure 3-11. Dutch auger (Art's Macnine Shop, 1982)

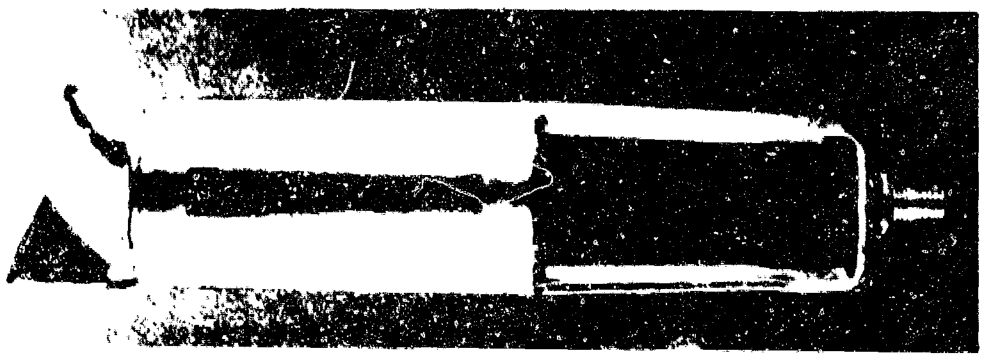

Figure 3-12. Sand auger (Art's Machine Shop, 1982)

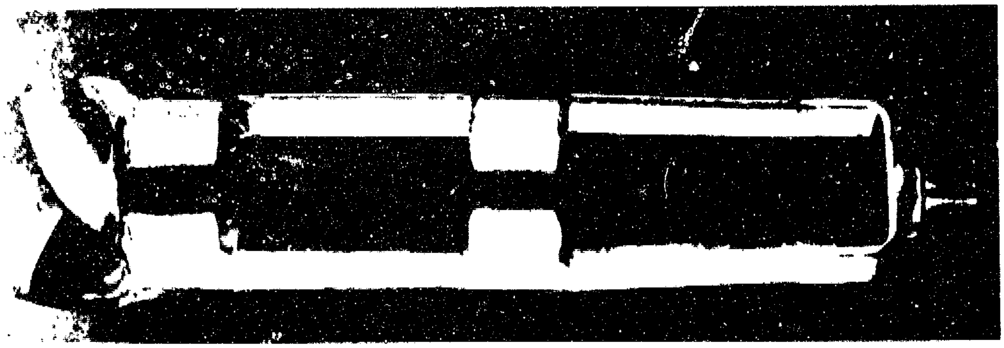

Figure 3-13. Mud auger (Art's Machine Shop, 1982)

Figure 3-14. Soil sampling tube (Clements Associates, Inc., 1983)

The cut-away barrel is designed to facilitate examining soil layering and to allow for the easy removal of soil samples. Generally, the tubes are constructed from high strength alloy steel (Clements Associates Inc., 1983). The sampler is available in three common lengths, namely, 12 inches, 15 inches and 18 inches. Two modified versions of the tip are available for sampling either in wet or dry soils. Depending on the type of cutting edge, the tube samplers obtain samples varying in diameter from 11/16 inches to 3/4 inches.

Extension rods are manufactured from lightweight, durable metal. Extensions are available in a variety of lengths depending on the manufacturer. Markings on the extensions facilitate determining sample depths.

Sampling with these units requires forcing the sampling tube in vertical increments into the soil. When the tube is filled at each depth the handle is twisted and the assembly is then pulled to the surface. Commercial units are available with attachments which allow foot pressure to be applied to force the sampler into the ground.

3.1.2.8.2 Veihmeyer tube--In contrast to the soil probe, the Veihmeyer tube consists of a long, solid tube which is driven to the required sampling depth. Components of the Veihmeyer tube are depicted in Figure 3-15. As shown, these units consist of a bevelled tip which is threated into the body tube. The upper end of the cylinder is threaded into a drive head. A weighted drive hammer fits into the tube to facilitate driving the sampler into the soil. Slots in the hammer head fit into ears on the drive head. Pulling or jerking up on the hammer forces the sampler out of the cavity. The components of this sampler are constructed from hardened metal. The tube is generally marked in even, depth-wise increments.

3.1.3 Hand-Held Power Augers--

A very simple, commercially available auger consists of a flight auger attached to and driven by a small air-cooled engine. A set of two handles are attached to the head assembly to allow two operators to guide the auger into the soil. Throttle and clutch controls are integrated into grips on the handles. It is important that, if the augers "hang up" and the operator looses control of the machine, the operator should not attempt to stop rotation of the machine by grabbing the handles.

3.2 CRITERIA FOR SELECTING SOIL SAMPLERS

Important criteria to consider when selecting soil-sampling tools for soil monitoring at land treatment units include: (1) capability to obtain an encased core sample, an uncased core sample, a depth specific representative sample or just a sample according to the requirements of the chemical analyses, (2) suitability for sampling various soil types, (3) suitability for sampling soils under various moisture conditions, (4) accessibility to the sampling site and general site trafficability, (5) sample size requirements, and (6) personnel requirements and availability. The sampling techniques described in the previous sections were evaluated for these criteria and the results are summarized in Table 3-1. This section briefly reviews the selection criteria. The important capability of being able to obtain a sample at depth that is not contaminated from shallow sources is greatly enhanced by using the hollow-stem auger drilling method.

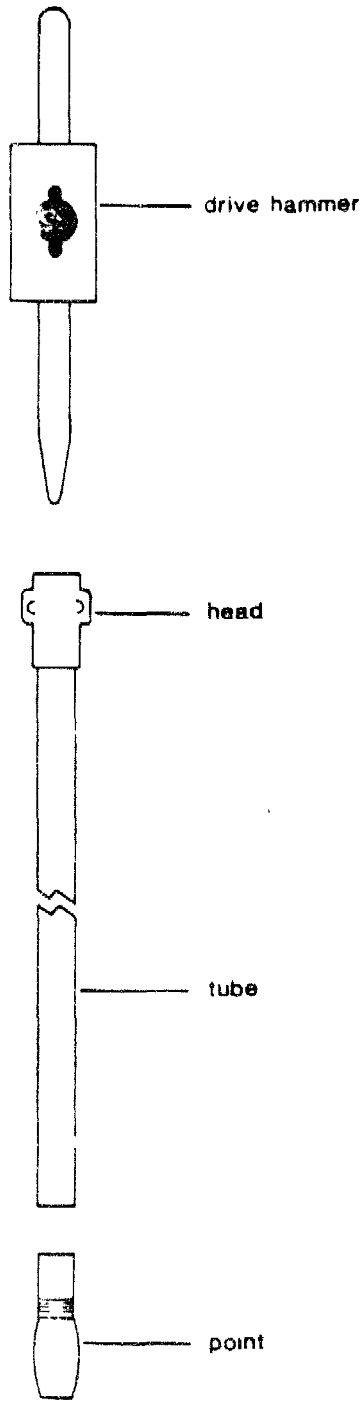

Figure 3-15. Veihmeyer tube

3.2.1 Capability for Obtaining Various Sample Types

An encased core sample can be obtained by using the continuous sample tube system, Shelby tube or piston samplers, and split-barrel drive samplers of the type that can be fitted with sealable liners. The continuous sample tube system must be used with the hollow auger drilling method. Shelby tube, piston and split-barrel drive samplers are best used with hollow auger drilling systems to minimize contamination of otherwise uncontaminated samples.

An uncased core sample can be obtained with the same sampling equipment and procedures that provide an encased core sample. The continuous sample tube system and split-barrel drive samplers can be used without liners to provide an uncased core sample.

A representative sample can be obtained with almost any sampling device, if contaminated, or even uncontaminated, soil has not fallen to the bottom of the borehole or has not been transported downwardly by the drilling process. Use of the hollow auger drilling method provides the greater assurance that contamination has not occurred from the drilling or sampling processes. When representative samples are desired and continuous flight (solid-stem) auger drilling or one of the hand-operated drilling methods is used, the borehole must be made large enough to insert the sampler and extend it to the bottom of the borehole without touching the sides of the borehole. It is suggested that, if a hand-operated auger sampling method is used, a larger auger be used to advance and clean the borehole than the auger-sampler that is used to obtain the retained sample.

3.2.2 Sampling Various Soil Types

A split-barrel drive sampler can be used in all types of soils if the larger grain sizes can enter the opening of the drive shoe.

Shelby tubes and the continuous sample tube system are best used in fine grained (silts and clays) and in fine granular soils. Shelby tubes can be pushed with the hydraulic system of most drill rigs in fine granular soils that are loose to medium dense or in fine grained soils that are soft to medium stiff. If denser or stiffer soils are encountered, driving of the tube sampler may be required. The continuous sample tube system can be used to sample soils that are much denser or harder than can be sampled with Shelby tubes, pushed or driven.

Hand-operated samplers can be used in almost any soil type if there is enough time available--eventually the hole will be completed. Within the above sections, there is guidance provided on which hand-operated drilling device works best according to the soil types and moisture condition.

3.2.3 Site Accessibility and Trafficability

Site accessibility depends upon what the owner will permit. Trafficability relates to the capability of various vehicles to reach a drilling location. The availability of multipurpose drill rigs on 4 x 4 or 6 x 6 trucks or on all-terrain carriers or when the use of helicopters negates the problems of trafficability except in exceptionally steep or wooded terrain. The relative advantages of using hand-operated drilling and sampling devices involve a

TABLE 3-1. CRITERIA FOR SELECTING SOIL SAMPLING EQUIPMENT

Type of Sampler	Obtains Core Sample		Most Suitable Core Types		Operation in Stoney Soils		Most Suitable Soil Moisture Conditions			Access. to Sampl. Sites During Poor Soil Conditions		Relative Sample Size		Labor Req'mts	
	Yes	No	Coh	Coh'less	Fav	Unfav	Wet	Dry	Inter	Yes	No	Sm	Lg	Sngl	2/More
A. Power Drilling															
1. Multipurpose Drill Rig	x		x	x	x		x	x	x	x		x	x		
2. Drive Sampler	x		x		x			x			x		x		x
3. Thin-Walled Tube Sampler	x		x			x			x	x			x		x
4. Peat Sampler	x		x			x	x			x			x		x
5. Continuous Sample Tube System	x		x		x		x	x	x	x		x	x		x
6. Hand-Held Screw Type Power Auger		x			x				x	x			x		x
B. Hand Auger															
1. Screw-Type Auger		x				x	x			x		x		x	
2. Barrel Auger															
a. Post-Hole Auger		x	x		x		x			x			x	x	
b. Dutch Auger		x	x		x		x								
c. Regular Barrel Auger		x	x		x				x	x		x		x	
d. Sand Auger		x		x	x				x	x			x	x	
e. Mud Auger		x	x		x		x			x			x	x	
3. Tube-Type Sampler															
a. Soil Probe															
(1) Wet Tip	x					x	x			x				x	
(2) Dry Tip	x					x	x			x		x		x	
b. Veihmeyer Tube	x								x			x		x	

comparison of the difference in costs of decontaminating a drill rig and tools with the difference in quality of samples that can be obtained with two general methods.

3.2.4 Relative Sample Size

When multipurpose drill rigs are used, the sample size will depend only on the size of drilling tools used. Hollow-stem augers with 6.25-in. ID allow the use of 5-in. OD Shelby tubes, 6-in. OD continuous sample tubes and 4.5-in. OD split barrel drive samplers. If hand-operated tools are used, the use of larger diameter models will facilitate obtaining large samples.

3.2.5 Personnel Requirements

Generally, it is good practice to have at least two people in the field on all types of drilling and sampling operations. When multipurpose auger-core-rotary drills are used, the speed of drilling and sampling which is much greater than the speed of drilling and sampling and hand-operated equipment may require a larger crew to efficiently handle, log, identify and preserve the samples.

3.3 RANDOM SOIL-CORE MONITORING SITE SELECTION

The RCRA Guidance Document on Land Treatment Units recommends that soil-core monitoring sites be randomly selected (EPA, 1983b). If n random sites are to be selected, a simple random sample is defined as a sample obtained in such a manner that each possible combination of n sites has an equal chance of being selected. In practice, each site is selected separately, randomly, and independently of any sites previously drawn. For soil-core monitoring, each site to be included in the "sample" is a volume of soil (soil core).

It should be recognized that adjacent sampling points on a landscape are more often than not spatially dependent. The theory for spatial dependence, known as regionalized variable theory holds that the difference in value for a specific property depends upon the distance between measurement locations and their orientation in the landscape. Geostatistics, the application of regionalized variable theory, has been employed to demonstrate a number of spatial relationships for both soil chemical and physical properties. For many properties, a geostatistic analysis will indicate an approximate distance between two observations for which those observations are expected to be independent (no co-variance). Observations at a closer spacing are expected to be dependent to some degree. A strictly random sampling scheme as presented by EPA (1983a, 1983b) assumes independence between sample locations. This sampling scheme has been slightly modified in this guidance to maintain the assumption of independence between sampling locations. The following sampling scheme specifies that sample point separations should be in excess of 10 meters.

It is convenient to spot the field location for soil-coring devices by selecting random distances on a coordinate system and using the intersection of the two random distances on a coordinate system as the location at which a soil core should be taken (see Figure 3-16). This system works well for fields of both regular and irregular shape, since the points outside the area of interest are merely discarded, and only the points inside the area are used in the sample.

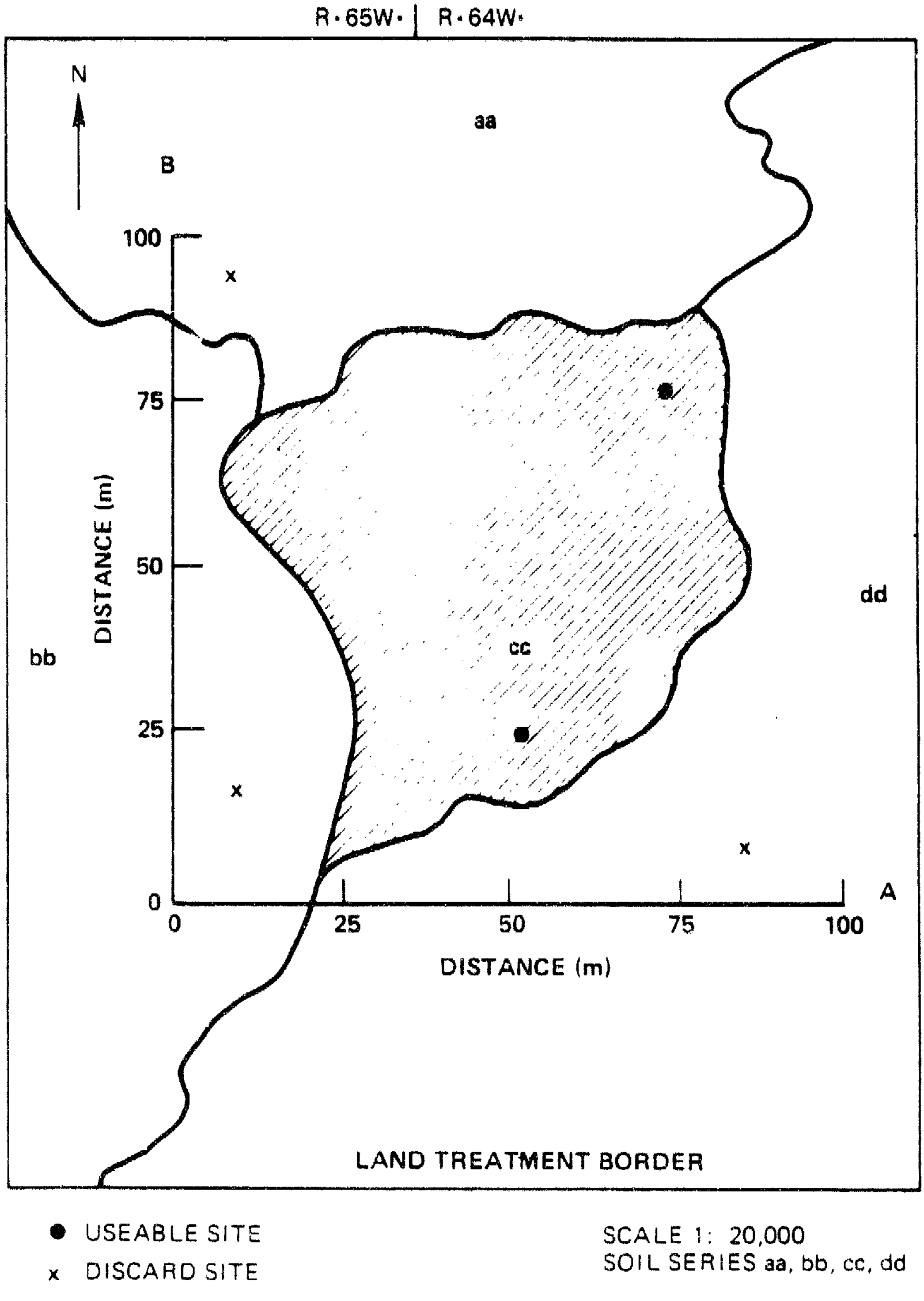

Figure 3-16. Random Site (•) selection example for unit cc

The location, within a given uniform area of a land treatment unit (i.e., active portion monitoring), at which a soil core should be taken should be determined using the following procedure as described by EPA (1983a, 1983b):

(1) Divide the land treatment unit (Figure 3-16) into "uniform" areas (aa, bb, cc, dd). A uniform area is an area of the active portion of a land treatment unit which is composed of soils of the same soil series and to which similar wastes or waste mixtures are applied at similar application rates. Swales are treated as a different uniform area and are discussed in Hazardous Waste Land Treatment (EPA, 1983a) under the heading of "hot spots." A soil scientist may be consulted in completing this step.

(2) Map each uniform area by establishing two base lines (0-A and 0-B) at right angles to each other which intersect at an arbitrarily selected origin (0), for example, the southwest corner. Each baseline should extend to the boundary of the uniform area.

(3) Establish a scale interval (e.g., 100 m) along each base line. The units of this scale may be feet, yards, miles, or other units depending on the size of the uniform area. Both base lines must have the same scale.

(4) Draw two random numbers from a random numbers table (see Appendix A). Specify whether the x or y coordinate is chosen first. Do not reinitiate the use of the table but continue from where the last random number was selected. Use these numbers to locate one point along each of the base lines.

(5) Locate the intersection of two lines drawn perpendicular to these two base line points. This intersection (o) represents one randomly selected location for collection of one soil core. If this location at the intersection is outside the uniform area (x), or within 10 m of another sampling location, disregard this sampling location and repeat the above procedure.

(6) For soil-core monitoring, repeat the above procedure as many times as necessary to obtain six soil coring locations within each uniform area of the land treatment unit. If a uniform area is greater than twelve acres, repeat the above procedure as necessary to provide at least two soil coring locations per four acres. (If the same location is selected twice, disregard the second selection and repeat as necessary to obtain different locations). This procedure for randomly selecting soil coring locations must be repeated at each sampling event (i.e., semi-annually).

Locations for monitoring on background areas should be randomly determined using the following procedure:

(1) The background area must have characteristics (i.e., at least soil series classification) similar to those present in the uniform area of the land treatment unit it is representing.

(2) Map an arbitrarily selected portion of the background area (preferably the same size as the uniform area) by establishing two base lines at right angles to each other which intersect at an arbitrarily selected origin.

(3) Complete steps 3, 4, and 5 as defined above.

(4) For soil-core monitoring, repeat this procedure as necessary to obtain eight soil coring locations within each background area (see Table 3-2).

3.4 SAMPLE NUMBER, SIZE, FREQUENCY AND DEPTHS

Sample number in research designs is typically decided based on a liberal estimate of the variance for a constituent as it is distributed spatially, a specified detection increment (e.g., 5 ppb) and a confidence level for the detection increment. The problem in recommending a set number of samples per sampling event is simply that the variance of a sampling event and/or background study may be sufficiently large to preclude an inference that a statistical difference exists with any confidence. A more appropriate and statistically supportable approach is to set the detection increment per hazardous constituent and the confidence level. The applicant would be required to perform a background study of variability as the basis for determining the number of samples per sampling event. Because this approach is still being evaluated by EPA research, EPA has chosen to provide interim guidance based upon the best judgement of scientists familiar with land treatment units. This interim guidance recommends a specified number of samples, size, frequency and depth per sampling event for both the background soil series and the uniform areas of the active land treatment unit (EPA, 1983b). This guidance may be revised when EPA research studies are completed.

Background concentrations of hazardous constituents should be established using the following procedures.

(1) Take at least eight randomly selected soil cores for each soil series present in the treatment zone from similar soils where waste has not been applied. The recommended soil series classification is defined in the 1975 USDA soil classification system (Soil Conservation Service, 1975). The cores should penetrate to a depth below the treatment zone but no greater *than 15 centimeters (6 inches) below the treatment zone (Figure 3-17).*

(2) Obtain one sample from each soil-core portion taken below the treatment zone.

TABLE 3-2. SUMMARY OF SOIL-CORE SAMPLING PROTOCOL FOR BACKGROUND AND ACTIVE LAND TREAMENT AREAS

Sampling Area	Number of Randomly Selected Core Samples	Sampling Depth	Sampling Frequency
1. Background, in soils with similar mapping characteristics in active area	8	Within 6-in depth below treatment zone on active zone	One time
2. Active land treatment area			
a. Uniform area less than 5 hectares (12 acres)	6	Within treatment zone for determination of pH	Semiannually
		Within 6-in region below treatment zone for PHC's	
b. Uniform area greater than 5 hectares (12 acres)	2 per 1.5 hectares (4 acres) 6 per 5 hectares (12 acres)	Within treatment zone for determination of pH	Semiannually
		Within 6-in region below treatment zone for PHC's	

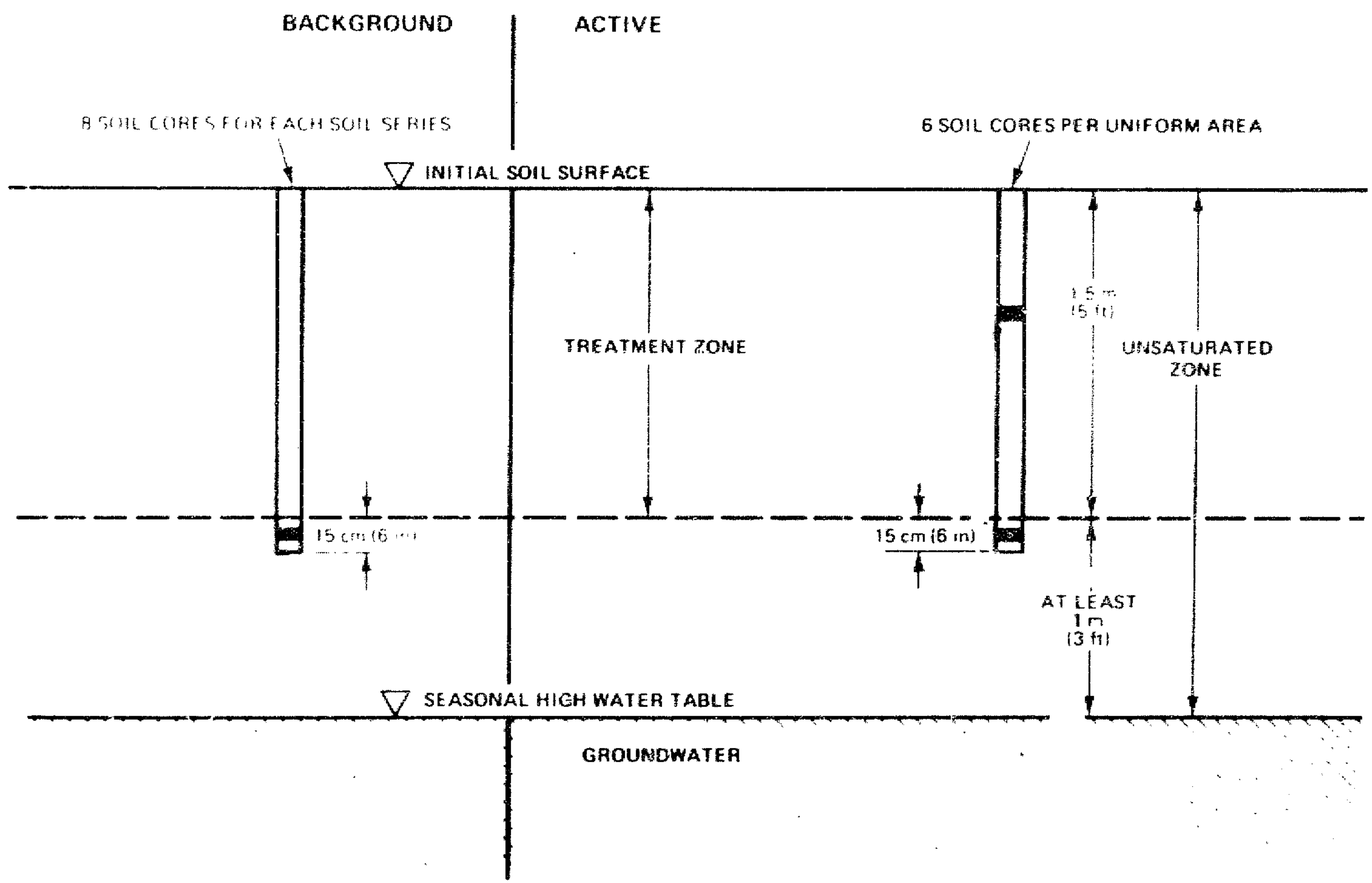

Figure 3-17. Soil core sampling depths

The active portion of a land treatment unit can be sampled according to the following procedures:

(1) The owner or operator should take at least six randomly selected soil cores per uniform area, semi-annually. However, if a uniform area is greater than 5 hectares (12 acres), at least two randomly selected soil cores per 1.5 hectares (4 acres) should be taken semi-annually. The cores should penetrate to a depth below the treatment zone but no greater than 15 centimeters (6 inches) below the treatment zone (Figure 3-17).

(2) The pH sample from the treatment zone in each uniform area should be obtained using the following procedure:

   a. Select one representative sample from each soil-core portion taken within the treatment zone.

(3) The concentrations of hazardous constituents below the treatment zone in each uniform area should be determined using the following procedure :

   a. Obtain one sample from each soil-core portion taken below the treatment zone (Figure 3-17).

3.4.1 Compositing Samples

While the RCRA Guidance Document: Land Treatment Units (EPA, 1983b) does not recommend compositing of samples, under very uniform conditions compositing may be considered. The soil samples collected by the techniques described in the previous sections will be used for the composites.

For some of the sampling tools, such as soil probes and Veihmeyer tubes, the sample size is generally small enough that the overall size of the composite is not cumbersome. Other techniques, such as barrel augers, will provide so much sample that a composite will be of much larger mass than required for analysis. In this case the sample size should be reduced to a manageable volume. A simple method is to mix the samples thoroughly by shovel, divide the mixed soil into quarters, and place a sample from each quarter into a sample container. Mechanical sample splitters are also available. EPA (1982b) recommends using the riffle technique. A riffle is a sample splitting device consisting of a hopper and series of chutes. Materials poured into the hopper are divided into equal positions by the chutes which discharge alternately in opposite directions into separate pans (Soiltest Inc., 1976). A modification of the basic riffle design allows for quartering of the samples.

3.4.1.1 Compositing with a Mixing Cloth--

A large plastic or canvas sheet is often used for compositing samples in the field (Mason, 1982). This method works reasonably well for dry soils but has the potential for cross contamination problems. Organic chemicals can create further problems by reacting with the plastic sheet. Plastic sheeting, however, is inexpensive and can therefore be discarded after each sampling site.

This method is difficult to describe. It can be visualized if the reader will think of this page as a plastic sheet. Powder placed in the center of the sheet can be made to roll over on itself if one corner is carefully pulled up and toward the diagonally opposite corner. This process is done from each corner. The plastic sheet acts the same way on the soil as the paper would on the powder. The soil can be mixed quite well if it is loose. The method does not work on wet or heavy plastic soils. Clods must be broken up before attempting to mix the soil.

After the soil is mixed, it is again spread out on the cloth to a relatively flat pile. The pile is quartered. A small scoop, spoon or spatula is used to collect small samples from each quarter until the desired amount of soil is acquired (this usually is about 250 to 500 grams of soil but can be less if the laboratory desires a smaller sample). This is mixed and placed in the sample container for shipment to the laboratory. The site material not used in the sample should be disposed by simply depositing them back on the treatment zone.

3.4.1.2 Compositing with a Mixing Bowl--

An effective field compositing method has been to use large stainless steel mixing bowls. These can be obtained from scientific, restaurant, or hotel supply houses. They can be decontaminated and are able to stand rough handling in the field. Subsamples are placed in the bowls, broken up, then mixed using a large stainless steel scoop. The rounded bottom of the mixing bowl was designed to create a mixing action when the material in it is turned with the scoop. Careful observance of the soil will indicate the completeness of the mixing.

The soil is spread evenly in the bottom of the bowl after the mixing is complete. The soil is quartered and a small sample taken from each quarter. The subsamples are mixed together to become the sample sent to the laboratory. The excess soil is disposed of as waste.

An alternative method of compositing is to collect measured quantities of subsamples from individual core segments. This eliminates the possibility of disproportionately sampling individual cores, and gives each core roughly equivalent weight in the composite sample. A plastic or stainless steel measuring cup is recommended to collect equal volumes from each core.

3.5 SAMPLING PROCEDURE

It is assumed that the number and location of sampling locations within the background area and active portion of the land treatment unit have been selected in accordance with the random selection procedure described above. This section describes the following elements of a sampling procedure: (1) preliminary site preparation, and (2) soil sample collection.

3.5.1 Preliminary Activities

In preparation for sample collection, it is strongly suggested that a checklist (See Table 3-3 for a typical checklist) be prepared itemizing all of the equipment necessary, both for sampling and for maintaining quality assurance. Thus all of the tools needed for sampling should be itemized and located

TABLE 3-3. EXAMPLE CHECKLIST OF MATERIALS AND SUPPLIES

- Borebrush for cleaning.
- 10 to 12 ten-quart stainless steel mixing bowls.
- Safety equipment as specified by safety officer.
- One-quart Mason type canning jars with Teflon liners (order 1.5 times the number of samples. Excess is for breakage and contamination losses.).
- A large supply of heavy-duty plastic trash bags.
- Sample tags.
- Chain-of-custody forms.
- Site description forms.
- Logbook.
- Camera with black-and-white film.
- Stainless steel spatulas.
- Stainless steel scoops.
- Stainless steel tablespoons.
- Caps for density sampling tubes.
- Case of duct tape.
- 100-foot steel tape.
- 2 chain surveyor's tape.
- Tape measure
- Noncontaminating sealant for volatile sample tubes.
- Supply of survey stakes.
- Compass.
- Maps.
- Plot Plan.
- Trowels.
- Shovel.
- Sledge Hammer.
- Ice chests with locks.
- Dry ice.
- Communication equipment.
- Large supply of small plastic bags for samples.
- Large supply of paper towels or lint-free rags.
- Large supply of distilled water.
- Work gloves.

in the transporting vehicle: Similarly, all of the documentation accessories, such as field book, maps labels, etc., should be checked off. A few minutes of preliminary preparation will ensure that all equipment is on hand and that time will not be wasted in returning to the operations base for forgotten items.

Careful site preparation will also take a few minutes but is absolutely necessary to ensure that the samples are representative of in-situ conditions. Specifically, a severe problem with some of the sampling methods described elsewhere in this chapter is that "contamination" of the sample may occur by soil falling in the cavity either from the land surface or from the walls of the borehole. Thus to minimize contamination from surface soils, loose soils and clods should be thoroughly scraped away from each site prior to sampling. A shovel or rake will facilitate this operation. Under some geologic circumstances with some hand-operated drilling methods, perfect site preparation will not eliminate downward transport of contaminants.

It is recommended that a soil profile description be taken with each soil core sampling event. The profile description will provide information on the spatial variable properties important to both land treatment functioning and will assist in the interpretation of monitoring results. For instance, it is quite possible that sandy conduits (e.g., stumpholes or root channels) may contain different levels of a hazardous constituent than surrounding soil.

3.5.2 Sample Collection with Multipurpose Drill Rigs

There are three principal ad ntages in using multipurpose auger-core-rotary drill rigs for unsaturated . ne sampling: (1) the work can be performed rapidly in the most adverse environments such as extremely hot or extremely cold and wet weather, (2) borings can be readily made in the densest or hardest soil conditions, and (3) there is the greater capability of preventing downward movement of contaminants during drilling and sampling. Also, with some samplers the sample is encased as it is taken in a protective enclosure with minimal atmospheric contamination or loss of volatile constituents. The only disadvantage is the cost of decontamination of the drill and the tools.

It is suggested the Drilling Safety Guide (no date) published by the National Drilling Federation (NDF) be read and studied in depth by all drilling and sampling personnel before using auger-core-rotary drills.

3.5.2.1 Hollow-Stem Auger Drilling and Sampling--

The general process of using hollow-stem augers to simultaneously advance and case a borehole was previously presented (Refer to Figures 3-1 and 3-2). The following is a detailed yet generalized procedure:

(1) The outer and inner hollow-auger components (Figure 3-2A) are assembled and connected by the shank on top of the drive cap to the rotary drive of the drill rig.

(2) This assembly is advanced to the desired sampling depth using the rotary action and ram forces of the drill rig. The auger head cuts into the soil at the bottom of the hole and directs the cuttings to the spiral flights which convey the cuttings to the surface (Figure 3-2A).

(3) The drive cap is disconnected from the auger column assembly. The pilot assembly with the center rod column is then removed, usually with a hoist line (Figure 3-2B).

(4) A sampling device attached to a sampling rod column is inserted and lowered within the hollow axis of the auger column to rest on the soil at the bottom of the hole. The sampling device is then pushed with the hydraulic feed system of the drill or driven with a hammer assembly into the relatively undisturbed soil below the auger head (Figure 3-2C).

(5) The sampler is then retracted from the hollow axis of the auger column. The sampler is either retracted with a hoist line or by connecting the sampling rod column to the hydraulic feed (retract) system of the drill rig. "Back-driving" may be required to remove some samplers that are driven to obtain a sample. In some soils, back-driving will cause some or even all of the sample to be released from the sampler and remain in the bottom of the borehole. Back-driving should not be used when a hoist or the hydraulic feed of the drill can be used to retract the sampler.

(6) The pilot assembly and center rod column is reinserted, the drive cap is reconnected to the auger column and the rotary drive of the drill rig. The hollow auger column is then advanced to the next sampling depth.

(7) If sampling is required at depths greater than about 4.5 ft plus the length of the sampler below the auger head, additional 5 ft hollow auger sections and center rod sections are added. The flights are timed and mated at the coupling to provide a continuous conveyance of cuttings.

(8) Fill in the cavity with soil, tamping to increase the bulk density of the added soil. Fill the hole to ground surface.

For some types of samplers, it is difficult to retain the sample in the sampler because of the "vacuum" within (or apparent tensile strength of) the soil at the bottom of the sample. After the sampler is pushed or driven, the hollow augers can be advanced downward to the bottom of the sampler to "break" the vacuum.

3.5.2.2 Continuous Flight Auger Drilling and Sampling--

Continuous flight augers have hexagonal shank and socket connections which prevent sampling through the usually small diameter axial tubing; consequently, the complete auger column must be retracted and reinserted for each sampling increment.

(1) The continuous flight auger assembly, i.e, auger head and 5 ft flight auger section is connected by the top shank of the auger to the rotary drive of the drill.

(2) The auger assembly is advanced to the desired sampling depth using the rotary action and ram forces of the drill rig (Figure 3-3A).

(3) After rotation is stopped and the rotary power train of the drill is placed in neutral, all cuttings are carefully removed from the zone adjacent to the borehole. This will minimize the amount of material that will fall to the bottom of the borehole when the augers are removed.

(4) The auger column is then removed from the borehole without further rotation (Figure 3-3B). The augers should be immediately removed from the area of drilling to prevent cuttings from the auger flights falling into the borehole, and it may be necessary to remove cuttings from the area adjacent to the borehole as the auger column is retracted.

(5) The sampling device on a sampling rod column is inserted and lowered into the open borehole to rest on the soil at the bottom. Care should be taken to minimize the contact of the sampler and sampling rod column with the side of the open borehole. The sampler is then pushed with the hydraulic feed system of the drill or driven with a hammer assembly through whatever cuttings that may have accumulated at the bottom of the borehole into the undisturbed soil (Figure 3-3C).

(6) The sampler is then retracted from the borehole using the same procedures and care described above for hollow auger drilling.

(7) If additional samples are required, the auger column assembly is reinserted and the drilling and sampling sequence is continued (Figure 3-3D).

(8) If sampling is required at depths greater than about 4.5 ft plus the length of the sampler, additional 5 ft auger sections are added.

(9) Usually the top of the sample should be "discarded" to assure that cuttings that fall into the borehole do not provide false data or contaminate the remainder of the sample.

(10) Fill in the cavity with soil, tamping to increase the bulk density of the added soil. Fill the hole to ground surface.

3.5.2.3 Samplers--

Various types of samplers and complete sampling systems are available for use with hollow auger, continuous flight auger and other appropriate drilling methods. The sampler used will depend upon economic availability, the type of drill rig being used, the general nature of the project and specific sampling requirements. The following are some of the common samplers and related procedures commonly used in North America.

3.5.2.3.1 Thin-walled volumetric tube samplers--Thin-walled volumetric tube samplers are commonly called Shelby tubes (from the original manufacturer's nomenclature). Shelby tube samplers are described in 3.2.2.5.1. Shelby tube samplers can be used in most soft to stiff fine grained soils and in some granular soils. The Shelby tube is a rather ideal sampler in that the soil can remain in the sample tube for transportation to a testing facility. Also, Shelby tubes can be predrilled with smaller circular "sampling ports" that are "taped over" during sampling and transportation to a test facility. At the testing facility the sealing tape can be removed as required to obtain a small cylindrical "plug sample" from the side of the larger sample. The procedure for general use of Shelby tubes follows:

(1) The borehole is advanced to the sampling depth by the selected method. When hollow-stem augers are used, the auger I.D. should be at least 0.20 in. greater than the Shelby tube O.D. When an open hole drilling method is used, the diameter of the drilled hole should be at least 1.00 in. greater than the Shelby tube O.D.

(2) The Shelby tube sampler is attached to the sampler head which in turn is connected to a sampling rod column.

(3) The Shelby tube sampler assembly is lowered within the hollow auger axis or open borehole to rest on the bottom.

(4) The sampling rod column is extended upward to contact the retracted base of the drill rig rotary box.

(5) The sampler is then pushed into the soil at the bottom of the borehole by using the hydraulic feed of the drill. The Shelby tube should be pushed at a rate of about 3 to 6 inches per second. Care should be taken to assure that the top of the sampling rod column is squarely against a flat surface of the rotary box and that there are no loose tool joints in the sampling rod column. All members of the drilling and sampling crew should stand away from the sampling rod as the sampler is being pushed.

(6) The sampler should be allowed to "rest" within the soil for at least one minute to allow the soil to expand laterally against the inside of the Shelby tube. This surface contact will improve sample recovery.

(7) The sampler is then pulled upward with a hoist line and hoisting swivel or by connecting to and using the hydraulic feed system of the drill rig. In some cases sample recovery may be improved by rotating the sampler after it has been pushed and allowed to expand against the inside of the Shelby tube.

(8) The Shelby tube with sample enclosed is detached from the sampler head.

(9) Any loose material on the "top" of the sample should be removed with a large spoon, a putty knife or a similar tool.

(10) If the sample is to be shipped to a testing facility within the tube, the tube ends should be sealed immediately. Sealing is best accomplished by using expanding soil seals (Figure 3-6A, 3-6B) and then capping the ends of the tubes with "plastic" caps and sealing tape.

(11) It may be appropriate to extrude the samples in the field, in which case a hydraulic extruder (Figure 3-18) is used. Following extrusions, the samples are then placed in large, wide-mouthed jars or other sealable containers.

(12) Fill in the cavity with soil, tamping to increase the bulk density of the added soil. Fill the hole to ground surface.

3.5.2.3.2 Piston samplers--Piston samplers usually consist of a Shelby tube sampler with a sampling head that contains a piston follower. The piston follower rests on the soil surface within the Shelby tube prior to and during pushing of the tube into the soil. The piston is then "locked" in position to provide a vacuum on top of the sample to react against the vacuum at the bottom of the sample which develops as the tube and soil sample is pulled out of the soil. Sampling procedures for piston samplers are identical to those for common Shelby tube samplers except for the activities involving the locking of the piston and the breaking of the piston vacuum to remove the sample tube and sample from the sampler head. There are different types of piston sampler heads according to the piston locking mechanism. Generally, it is only advantageous to use a piston sampler over a common Shelby tube sampler in soft, wet soils. Piston samplers will often provide optimum sample recovery in soft, wet organic soils.

3.5.2.3.3 Split barrel drive samplers--The split barrel drive sampler assembly consists of a drive shoe, two split barrel halves and a sampler head as described in 3.2.2.5.2. Split barrel samplers are used with the same procedures as thin-walled volumetric samplers as described above in 3.5.2.2.1 except that in almost all cases the sampler is driven into the soil using a hammer assembly. The common 2-in. O.D. Sampler is typically driven with 140 lb drive weight. Larger samplers are often driven with 300 lb, 340 lb or 350 lb drive weights. Granular samples are often retained with the aid of various spring and flap-valve retainers (Figure 3-19).

3.5.2.3.4 Continuous sample tube systems--The "continuous sample tube system" is a patented sampling system which consists of a 5 ft long sample barrel as described in 3.1.1.5.3 (Figure 3-7). The continuous sample tube system works best in fine grained soils but has been used in granular soils with success. The sample barrel is used in conjunction with hollow-stem augers as follows:

(1) The sample barrel assembly is inserted within the first hollow auger to be advanced and connected to a hexagonal extension that passes through the drill spindle with bearing assembly to a stabilizer plate above the rotary box.

(2) The hollow auger is coupled to a flightless auger section that is connected to the drill spindle. The cutting shoe of the auger barrel will extend a short distance in front of the auger head when the assembly is completed.

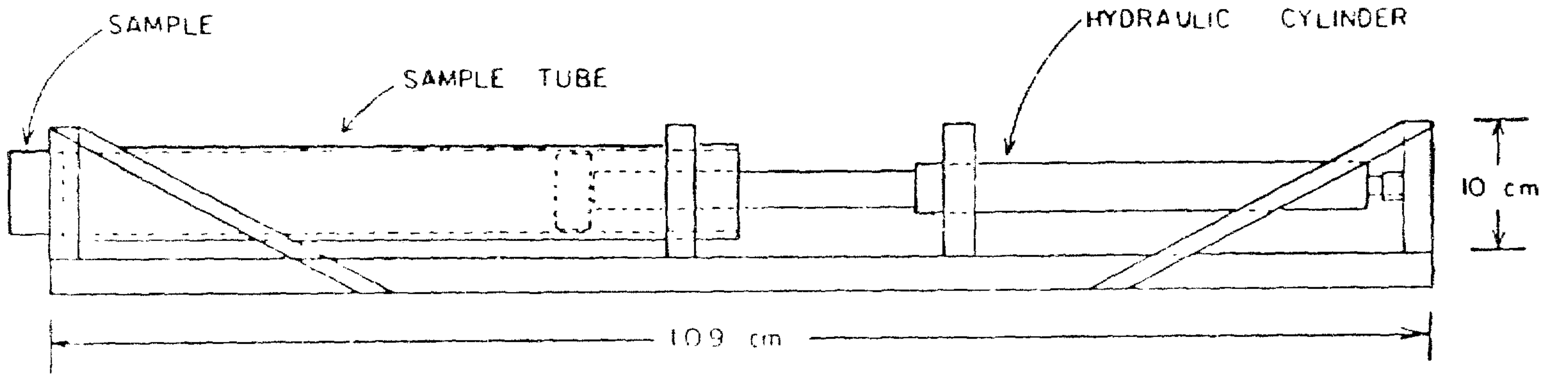

Figure 3-18. Core sample extruding device

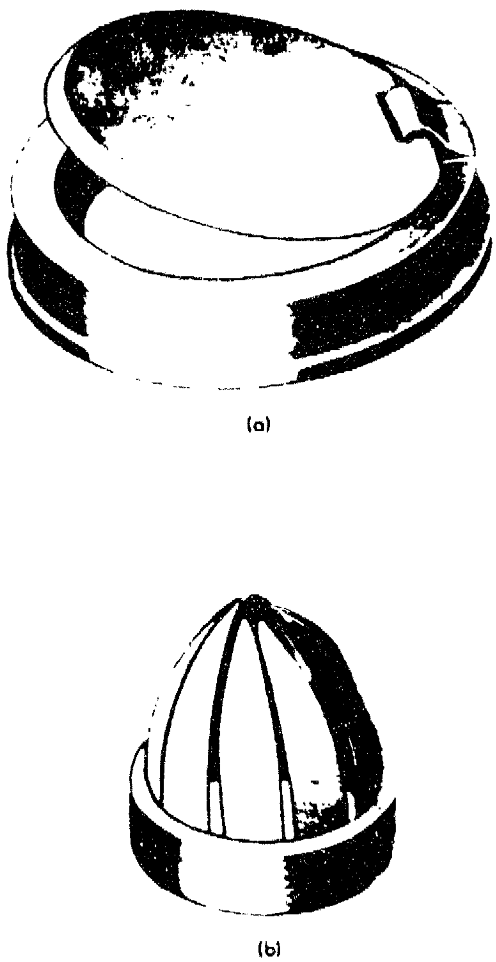

Figure 3-19. Soil core retainers for sampling in very wet soils and cohensionless soils. (a) One-way solid flap valve,' (b) Spring-type, segmented basket retainer

(3) The cutting shoe advances into the soil as the augers are rotated and advanced into the soil.

(4) The hollow augers and sampler assembly is usually advanced until the drill spindle "bottoms out."

(5) The auger is then disconnected at the top from the flightless auger section.

(6) The sample barrel is then hoisted upward, leaving the hollow auger in place.

(7) The sample is then removed from the sample barrel. Treatment of the sample will be generally like the treatment of Shelby tube samples but will depend specifically on whether or not a "split" or "solid" outer barrel is used or whether or not liners are used. Typically clear "plastic" liners are used within a split outer barrel for efficient processing of samples. These liners with soil can be processed for transportation using the same procedures that are used for Shelby tube samples.

(8) When greater sampling depths are required additional 5 ft auger sections and hexagonal drill stem extensions are used. Obtaining optimum recovery with the continuous sample tube system requires some trial-and-error adjustments by the driller. Generally, recovery approaching 100 percent is readily obtainable in fine grained soils. In some angular granular soils it is advisable to only advance the system in 2.5 ft increments to obtain optimum recovery.

(9) Fill in the cavity with soil, tamping to increase the bulk density of the added soil. Fill the hole to ground surface.

3.5.2.3.5 Peat sampler--The peat sampler is seldom used. However, under some circumstances it may provide the optimum sampling method.

(1) Place the sampler tip on the soil surface at the exact sampling location.

(2) With the tube in an exactly vertical position, force the sampler into the soil to the desired depth of sampling. (Note: during this step, the internal plunger is held in place within the sampling cylinder by a piston attached to the end of the push rods).

(3) Jerk up on the actuating rod to allow the plunger to move upward in the cylinder. (The snap catch will prevent the plunger from moving back downward in cylinder).

(4) Push the assembly downward to force the cylinder into undisturbed soil.

(5) Extrude the sample into a clean sample container. Label the container.

(7) Fill in the cavity with soil, tamping to increase the bulk density of the added soil. Fill the hole to ground surface.

3.5.3 Sample Collection with Hand-Operated Equipment

In the following section, step-by-step sample collection procedures are described for each of the major soil-sampling devices.

3.5.3.1 Screw-Type Augers--

(1) Locate tip of auger on the soil surface at exact sampling location.

(2) With the auger and drill stem in an exactly vertical position, turn and pull down on the handle.

(3) When the auger has reached a depth equivalent to the length of the auger head, pull the tool out of the cavity.

(4) Gently tap the end of the auger on the ground or on a wooden board to remove soil from the auger flights. For very wet, sticky soils it may be necessary to remove the soil using a spatula or by hand. In the latter instance, the operator is advised to wear disposable rubber gloves for protection from organic contaminants.

(5) Clean loose soil away from the auger flights and soil opening.

(6) Insert the auger in the cavity and repeat steps (ii) through (v). Keep track of the sampling depth using the marks on the drill rod or by inserting a steel tape in the hole.

(7) When the auger has reached a depth just above the sampling depth, run the auger in and out of the hole several times to remove loose material from the sides and bottom of the hole.

(8) Advance the auger into the soil depth to be sampled.

(9) Remove the auger from the cavity and gently place the head on a clean board or other support. Remove soil from the upper flight (to minimize contamination). Using a clean spatula or other tool, scrape off soil from the other flights into the sample container. Label the sample container pursuant to information presented in Appendix B.

(10) Pour soil back into the cavity. Periodically use a rod to tamp the soil to increase the bulk density. Fill the hole to land surface.

3.5.3.2 Barrel Augers--

The sampling procedures for each of the barrel augers are basically the same with minor variations. Only the procedure for the post-hole auger is presented in detail.

(1) Locate auger bit on soil surface at exact sampling location.

(2) With the auger and extension rod in an exactly vertical position, turn and pull down on the handle (see Figure 3-20).

(3) When the auger has reached a depth equivalent to the length of the auger head, pull the assembly out of the cavity.

(4) Gently tap the auger head on the ground or on a wooden board to remove the soil from the auger. For very wet and sticky soils, it may be necessary to remove the soil using a spatula or rod or by hand. In the latter instance, the operator is advised to wear disposable rubber gloves for protection from organic contaminants.

(5) Remove all loose soil from the interior of the auger and from the soil opening.

(6) Insert the auger back into the cavity and repeat steps (ii) through (v). Keep track of the sampling depth using the marks on the extension rod or by extending a steel tape in the hole.

(7) When the auger has reached a depth just above the sampling depth, run the auger in and out of the hole several times to remove loose material.

(8) Advance the auger into the soil depth to be sampled.

(9) Careful . remove the auger from the cavity and gently place the barrel head on a clean board or other support. Using a clean spatula or other tool, scrape the soil from the control part of the head into the sample container. Discard remaining soil. Label the sample container pursuant to the information presented in the section entitled "Sampling Protocol".

(10) Pour soil back into the cavity. Periodically use a rod to tamp the soil to increase the bulk density. Fill hole to land surface.

3.5.3.3 Tube-Type Samplers: Soil Probe--

The general procedure for soil sampling using soil probes is presented, together with the modified approach when a "backsaver" attachment is used. The basic technique is described first.

(1) Place the sampler tip on the soil surface at the exact sampling location.

(2) With the sampling point and extension rod in an exactly vertical position, push or pull down on the handle to force the sampler into the soil.

(3) When the auger has reached a depth equivalent to the length of the sampling tube, twist the handle to shear off the soil. Pull the tube out of the soil.

Figure 3-20. Barrel auger sampling method (Clements Associates, Inc., 1983)

(4) Gently remove the soil from the tube using a spatula or rod or by hand. If the tool is cleaned by hand, the operator should wear rubber gloves for protection from organic contaminants.

(5) Remove loose soil and soil stuck to the walls of the tool. Similarly, gently remove loose soil around the soil opening.

(6) Insert the probe back into the cavity and repeat steps (ii) through (v). Keep track of the sampling depth using the marks on the rod or by extending a steel tape in the hole. If necessary, screw on an additional extension rod.

(7) When the auger has reached a depth just above the sampling depth, run the probe in and out of the hole several times to remove loose material from the cavity walls.

(8) Advance the auger into the soil depth to be sampled.

(9) Carefully remove the unit from the hole and gently place the tube on a clean board. Scrape the soil out of the tube or force the sample out of the tube by pushing down on the top of the sample. Again, rubber gloves should be used. Using a clean spatula, gently place soil samples into sample containers. Label the sample container pursuant to information presented in the section entitled "Sampling Protocol".

(10) Pour soil back into the cavity, periedically tamping to increase the bulk density. Fill the hole back to land surface.

A modified version of the basic sampling procedure for tube samplers provided with a so-called "back saver" handle is described in Figure 3-21.

3.5.3.4 Tube Type Samplers: Veihmeyer Tubes--

(1) Place the sampler tip on the soil surface at the exact sampling location. Position the tube in an exactly vertical position.

(2) Place the tapered end of the drive hammer into the tube. Place one hand around the tube and the other around the hand grip of the drive hammer. While steadying the tube with one hand, raise and lower the hammer with the other. Eventually a depth will be reached where both hands can be used to control the handle.

(3) Drive the sampler to the desired depth of penetration. For some soils, the tube may be extremely difficult to remove because of wall friction. In such a case, the operator may choose to reduce the depth of penetration during advance of the hol

HOW DOES THE BACKSAVER HANDLE WORK

Procedure used to pull a soil core with a sampling tube equipped with the "Backsaver Handle" or the "Backsaver N-3 Handle."

1) Steady the soil probe in a nearly vertical position by grasping the handgrip with both hands. Force the sampling tube into the soil by stepping firmly on the footstep.

2) Remove the first section of the core by pulling upward on the handgrip. Empty the sampling tube and clean. (see "cleaning of the soil sampling tube")

3) Place the sampling tube in the original hole and push into the soil until the footstep is within an inch or two of the surface of the ground.

4) While maintaining a slight pressure on the footstep pull upward on the handgrip until the footstep has been elevated 6 to 8 inches above the surface of the ground.

5) Maintain a slight upward pressure on the handgrip and step downward on the footstep. The footstep now grips the rod and the sampling tube can be pushed into the soil until the footstep is within 1 or 2 inches above the ground.

6) Steps 4 and 5 are repeated until the sampling tube is full. The depth of penetration can be determined by the position of the rod end which can be seen through the viewing holes in the side of the square portion of the Backsaver Handle. It is important not to push the sampling tube into the soil to a depth that exceeds the holding capacity of the tube as this jams the sample and can make removal from the ground extremely difficult.

(7) Remove the full sampling tube by lifting upward on the handgrip. After the sampling tube has been elevated 6 to 8 inches, push downward on the handgrip returning the footstep to within 1 to 2 inches of the surface of the ground.

(8) Empty the sampling tube and clean.

9) Steps 3 through 8 are repeated until the desired depth is reached.

Procedure used to pull a soil core with a sampling tube equipped with the "Backsaver N-2 Handle."

Same as steps 1 and 2 above.

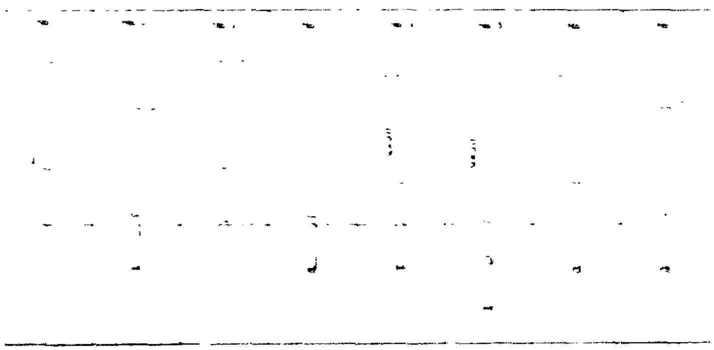

Figure 3-21. Operation of "backsaver" handle with soil sampling tube (Clements Associates, Inc., 1983)

(4) Remove the drive hammer from the tool and place the opening in the hammer above the tube head. Rotate the hammer as required to allow the slots in the opening to pass through the ears on the head. Drop the hammer past the ears and rotate the hammer so that the unslotted opening rests against the ears. Pull the hammer upward to force the tube out of the ground. (In some cases it may be necessary to jar the hammer head against the ears, or have another person pull up on the hammer).

(5) Gently place the side of the tube against a hard surface to remove soil from the tube. If this procedure does not work, it may be necessary to insert a long rod inside the tube to force out the soil.

(6) Scrape off the side of the tube to remove loose soil. Similarly, remove loose soil from the soil cavity.

(7) Insert the tube back into the soil cavity and repeat stops (1) through (6). Keep track of the sampling depth by the marks on the tube or by extending a steel tape in the hole.

(8) When the tip has reached a depth just above the sampling depth, gently run the tube in and out of the hole several times to remove loose material from the cavity walls.

(9) Drive the tube to the depth required for sampling.

(10) Carefully remove the unit from the hole and gently place the tip on a clean board. Force the sample out of the tube using a clean rod or extraction tool. Using a clean spatula, spoon the soil sample into a sample container. As a matter of precaution, the uppermost one or two inches of soil should be discarded on the chance that this segment has been contaminated by soil originating from above the sampling depth. Label the sample container pursuant to information presented in Appendix B.

(11) Pore soil back into the cavity, periodically tamping to increase the bulk density. Fill the hole back to ground surface.

Since the augers, probes and tubes must pass through contaminated surface soils before reaching the sampling depth (1.5 m (5 ft)) cross contamination is a real possibility. Soil is compacted into the threads of the auger and must be extracted with a stainless steel spatula. Probes and tubes are difficult to decontaminate without long bore brushes and some kind of washing facility. One possible way to minimize the cross contamination is to use the auger, probe, or tube to open up a bore hole to the desired depth, clean the bore hole out by repeatedly inserting the auger, probe or tube and finally using a separate, decontaminated auger, probe or tube to take a soil sample through the existing open bore hole.

3.5.4 Miscellaneous Tools

Hand tools such as shovels, trowels, spatulas, scoops and pry bars are helpful for handling a number of the sampling situations. Many of these can be obtained in stainless steel for use in sampling hazardous contaminants. A set of tools should be available for each sampling site where cross contamination is a potential problem. These tool sets can be decontaminated on some type of schedule in order to avoid having to purchase an excessive number of these items.

A hammer, screwdriver and wire brushes are helpful when working with the split spoon samplers. The threads on the connectors often get jammed because of soil in them. This soil can be removed with the wire brush. Pipe wrenches are also a necessity as is a pipe vise or a plumbers vise.

3.6 DECONTAMINATION

One of the major difficulties with soil sampling arises in the area of cross contamination of samples. The most reliable methods are those that completely isolate one sample from the next. Freshly cleaned or disposable sampling tools, mixing bowls, sample containers, etc. are the only way to insure the integrity of the data.

Field decontamination is quite difficult to carry out, but it can be done. Hazardous chemical sampling adds another layer of aggravation to the decontamination procedures. With the exception of highly volatile solvents, washing solutions can be safely disposed at the land treatment facility being sampled.

3.6.1 Laboratory Cleanup of Sample Containers

One of the best containers for soil is the glass canning jar fitted with Teflon or aluminum foil liners placed between the lid and the top of the jar. These items are cleaned in the laboratory prior to taking them into the field. All containers, liners and small tools should be washed with an appropriate laboratory detergent, rinsed in tap water, rinsed in distilled water and dried in an oven. They are then rinsed in spectrographic grade solvents if the containers are to be used for organic chemical analysis. Those containers used for volatile organics analysis must be baked in a convection oven at 105°C in order to drive off the rinse solvents.

The Teflon or aluminum foil used for the lid liners is treated in the same fashion as the jars. These liners must not be backed with paper or adhesive.

3.6.2 Field Decontamination

Sample collection tools are cleaned according to the following procedure (Mason, 1982).

- Washed and scrubbed with tap water using a pressure hose or pressurized stainless steel, fruit tree sprayer.

- Check for adhered organics with a clean laboratory tissue.

- If organics are present, rinse with the waste solvents from below. Discard contaminated solvent by pouring into a waste container for later disposal.

- Air dry the equipment.

- Double rinse with deionized, distilled water.

- Where organic pollutants are of concern, rinse with spectrographic grade acetone saving the solvent for use in step 3 above.

- Rinse twice in spectrographic grade methylene chloride or hexane, saving the solvent for use in step 3.

- Air dry the equipment.

- Package in plastic bags and/or pre-cleaned aluminum foil.

The distilled water and solvents are flowed over the surfaces of all the tools, bowls, etc. The solvent should be collected in some container for disposal. One technique that has proven to be quite effective is to use a large glass or stainless steel funnel as the collector below the tools during flushing. The waste then flows into liter bottles for later disposal (use the empty solvent bottles for this). A mixing bowl can be used as a collection vessel. It is then the last item cleaned in the sequence of operations.

The solvents used are not readily available. Planning is necessary to insure an adequate supply. The waste rinse solvent can be used to remove organics stuck to the tools. The acetone is used as a drying agent prior to use of the methylene chloride or hexane.

Steam cleaning might prove to be useful in some cases but extreme care must be taken to insure public and worker safety by collecting the wastes. Steam alone will not provide assurance of decontamination. The solvents will still have to be used.

3.7 SAFETY PRECAUTIONS

Safety problems may arise when operating power equipment and when obtaining soil cores at sites used to dispose of particularly toxic or combustible wastes.

The problem of operator contact with hazardous wastes and the possibility of fires and explosions are not factors of concern when soil-sampling at background sites. However, these items may be of very real concern when sampling active areas. EPA (1983a) review elements of personnel health safety at land treatment areas from the viewpoint of the disposal operators. However, many of these concerns also apply to workers obtaining soil-core samples during a monitoring program. For example, many wastes emit toxic vapors even following land disposal (EPA, 1983a). Such vapors may cause short or prolonged illness in unprotected workers. Long-term direct contact with wastes (e.g., during handling of soil samples) may be considered to be a carcinogenic risk.

Explosive gases may be given off from land treatment areas used to dispose of combustible wastes (EPA, 1983a). For such wastes, extreme caution must be taken when sampling to avoid creating sparks or the presence of open flames. Sparks will be of particular concern when sampling with power-driven equipment. Workers should not be permitted to smoke.

Protective clothing that should be worn during sample collection must be decided on a case-by-case basis. As a guide, the alternative levels of protective equipment recommended by Zirshky and Harris (1982) for use during remedial actions at hazardous waste sites could be employed at land treatment sites used to dispose of highly toxic wastes. Specific items for each level are itemized in Table 3-4. Level 1 equipment is recommended for workers coming into contact with extremely toxic wastes. Such equipment items offer the maximum in protection. Level 2 equipment can be used by supervising personnel who do not directly contact the waste. Level 3 equipment applies primarily to sampling on background areas or on treatment sites used to dispose of fairly innocuous wastes. Level 4 equipment could be used during an emergency situation such as a fire.

OSHA is the principal Federal agency responsible for worker safety. This agency should be contacted for information on safety training procedures and operational safety standards (EPA, 1983a).

3.8 DATA ANALYSIS AND EVALUATION

A critical step in any monitoring program is the proper analysis and evaluation of the data collected. Input from the field scientist is important in this data interpretation. The field scientist should have made observations of field conditions (e.g., weather, unusual waste distribution patterns, soil conditions, etc.) when the samples were taken and noted these in the field log book (see Appendix B). This information will assist in explaining the sampling data and provide insight into potential remedial actions that may be taken in the event they are necessary.

Appendix C provides example sheets for summarizing the analytical and statistical analysis results from unsaturated zone monitoring. Summary sheets, such as these, and the chain of custody documentation described in Appendix B, should be included in the operating record of the facility.

The land treatment regulations (see 40 CFR Part 264) require that the owner or operator determine if hazardous constituents have migrated below the treatment zone at levels that are statistically increased over background levels. The following analysis can be used to make this determination. This analysis can be done on a calculator.

The mean (Eq. 3-1), variance (Eq. 3-2), and a two-sided ($100(1-\alpha)\%$) confidence interval (Eq. 3-3) are first calculated by the following equations:

$$\bar{y} = \sum_{i=1}^{n} y_i/n \qquad (3\text{-}1)$$

TABLE 3-4. PERSONNEL PROTECTIVE EQUIPMENT
(Zirshky and Harris, 1982)

Level	Equipment
1	3-M White Cap with air-line respiration PVC chemical suit Chemical gloves taped to suit, leather gloves as needed Work boots with neoprene overshoes taped to chemical suit Cotton coveralls, underclothing/socks (washed daily) Cotton glove liners Walkie-talkies for communications Safety glasses or face shield
2	Hard hat Air purifying respirator with chemical cartridges PVC chemical suit and chemical gloves Work boots with neoprene overshoes taped to chemical suit Cotton coveralls/underclothing/socks (washed daily) Cotton glove liners Walkie-talkies for communications Safety glasses or face shield
3	Hard hat Disposable overalls and boot covers Lightweight gloves Safety shoes Cotton coveralls/underclothing/socks (washed daily) Safety glasses or face shield
4	Positive pressure self-contained breathing apparatus PVC chemical suit Chemical gloves, leather gloves, as needed Neoprene safety boots Cotton coveralls/underclothing/socks (washed daily) Walkie-talkie for communications Safety glasses or face shield

$$s^2 = \sum_{i=1}^{n} (y_i - \bar{y})^2/(n-1) \qquad (3-2)$$

where y_i = ith sample

n = number of samples

$\bar{y}$ = sample mean

s^2 = estimated variance of the mean

$$L = \bar{y} \pm t_{\alpha/2} \cdot \frac{s}{\sqrt{n}} \qquad (3-3)$$

where L = 100 (1 - α) % confidence level

$t_{\alpha/2}$ = the $\alpha/2$ percentage value from a one-sided t-distribution with (n - 1) degrees of freedom

s = standard deviation

The data for each hazardous constituent or "principal hazardous constituent" (if identified in permit) from the background area can be statistically compared to the data from the appropriate uniform area in the active portion using the Student's t-test. The t-test given in equation 3-4 below (Li, 1959) is used to determine if the mean of the hazardous constituents in the uniform area is greater than that in the appropriate background area. This equation assumes homogeneity of variances which is most often the case in soils work.

For testing if the uniform area (active portion) mean is greater than the background mean (i.e., one-tailed test), compare the calculated t-value (t_c) with the critical value t_α, where t_α is the upper tail value from the t-distribution with $n_1 + n_2 - 2$ degrees of freedom at the α significance level. If $t_c > t_\alpha$, there is a statistically significant increase in the uniform area (active portion) mean over the background area mean.

$$t_c = (\bar{y}_1 - \bar{y}_2) \Big/ \sqrt{s_p^2(1/n_1 + 1/n_2)} \qquad (3-4)$$

where t_c = calculated t-value

$\bar{y}_k$ = mean for area k

k = 1 for uniform area (active portion)

k = 2 for background area

SECTION 4

SOIL PORE-LIQUID MONITORING

The sampling of soil pore-liquid was reported in the literature in the early 1900's when Briggs and McCall (1904) described a porous ceramic cup which they termed an "artificial root". The sampling of soil pore-liquid has received increasing attention in more recent years as concern over migration of pollutants in soil has increased. As shown in Figure 4-1, different soils are capable of yielding different levels of water. The unsaturated zone, as described in Section 2, is the layer of soil between the land surface and the groundwater table. At saturation the volumetric water content is equivalent to the soil porosity (see Figure 4-1). In contrast the unsaturated zone is usually found to have a soil moisture content less than saturation. For example, the specific retention curve on Figure 4-1 depicts the percentage of water retained in previously saturated soils of varying texture after gravity drainage has occurred. Suction-cup lysimeters are used to sample pore-liquids in unsaturated media because pore-liquid will not readily enter an open cavity at pressures less than atmospheric (The Richard's outflow principle).

Suction-cup lysimeters are made up of a body tube and a porous cup. When placed in the soil, the pores in these cups become an extension of the pore space of the soil. Consequently, the water content of the soil and cup become equilibrated at the existing soil-water pressure. By applying a vacuum to the interior of the cup such that the pressure is slightly less inside the cup than in the soil solution, flow occurs into the cup. The sample is pumped to the surface, permitting laboratory determination of the quality of the soil pore-liquids.

Although a number of techniques are available for indirectly monitoring the movement of pollutants beneath waste disposal facilities, soil core sampling and suction-cup lysimeters, remain the principal methods for directly sampling pore-liquids in unsaturated media. The main disadvantages of soil core sampling are that it is a destructive technique (i.e., the same sample location cannot be used again) and it may miss fast-moving constituents. Lysimeters have been used for many years by agriculturists for monitoring the flux of solutes beneath irrigated fields (Biggar and Nielsen, 1976). Similarly, they have been used to detect the deep movement of pollutants beneath land treatment units (Parizek and Lane, 1970). Inasmuch as lysimeters are the primary tools for soil pore-liquid monitoring at land treatment units, understanding the basic principles of lysimeter operation and their limitations is important to owners and operators of such units, as well as those charged with permitting land treatment units. This section will discuss soil moisture/tension relationships, soil pore-liquid sampling equipment, site selection, sampling frequency and depths, installation and operation of the available devices, and sample collection, preservation, storage, and shipping.

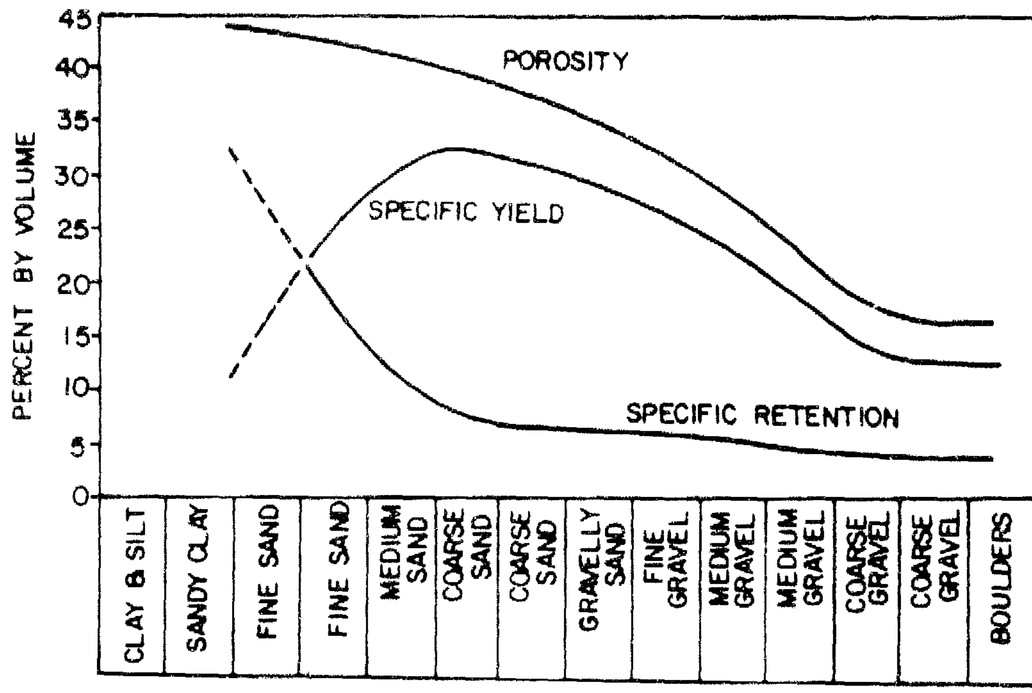

Figure 4-1. Variation of porosity, specific yield, and specific retention with grain size (Scott and Scalmanini, 1978)

It should be recognized, however, that situations may occur where the flow velocities in the unsaturated zone are higher than empirically demonstrated by Darcy's Law. As a result, the wetting front will not be uniform and most of the flow will occur through macropores. This type of gravity flow in highly structured soils will not be sampled effectively by suction lysimeters. The most promising technique for sampling soil pore-liquid in highly structured soils is pan lysimeters (e.g., free drainage glass block samplers). This kind of sampling probably will have its most utility in the treatment demonstration phase of a permit application because structured soils that permit gravity flow may not have sufficient treatment capabilities to satisfy the treatment demonstration. If the treatment demonstration is successfully completed, pan lysimeters may be an important element in the soil pore-liquid monitoring program for the full-scale facility.

4.1 SOIL MOISTURE/TENSION RELATIONSHIPS

Unlike water in a bucket, free, unlimited access to water does not exist in the soil. Soil water or, as it is frequently called, "soil moisture", is stored in the small "capillary" spaces between the soil particles and on the surfaces of the soil particles. The water is attracted to the soil particles, and tends to adhere to the soil. The smaller the capillary spaces between the particles, the greater the sticking force. For this reason, it is harder to get moisture out of fine clay soils than it is from the larger pores in sandy soils, even if the percent of moisture in the soil, by weight, is the same.

Figure 4-2 shows the results of careful research work done with special extractors. As described by the Soilmoisture Equipment Corporation (1983), the graph shows the relationship of the percent of moisture in a soil to the pressure required to remove the moisture from the soil. These are called Moisture Retention Curves. The pressure is measured in bars* which is a unit of pressure in the metric system. Figure 4-2 clearly points out that two factors are involved in determining ease of water sampling: 1) moisture content, and 2) soil type.

Moisture in unsaturated soil is always held at suctions or pressures below atmospheric pressure. To remove the moisture, one must be able to develop a negative pressure or vacuum to pull the moisture away from around the soil particles. For this reason we speak of "Soil Suction". In wet soils the soil suction is low, and the soil moisture can be removed rather easily. In dry soils the Soil Suction is high, and it is difficult to remove the soil moisture.

Given two soils (one clay and one sand) with identical moisture contents, it will be more difficult to extract water from the finer soil (clay) because water is held more strongly in very small capillary spaces in clays.

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*By definition a bar is a unit of pressure equal to 10^6 dyne/cm^2. It is equivalent to 100 kPa (kilopascals), or 14.5 psi, or approximately 1 atmosphere, or 750 mm of mercury, or 29.6 inches of mercury, or 1,020 cm of water, or 33.5 feet of water.

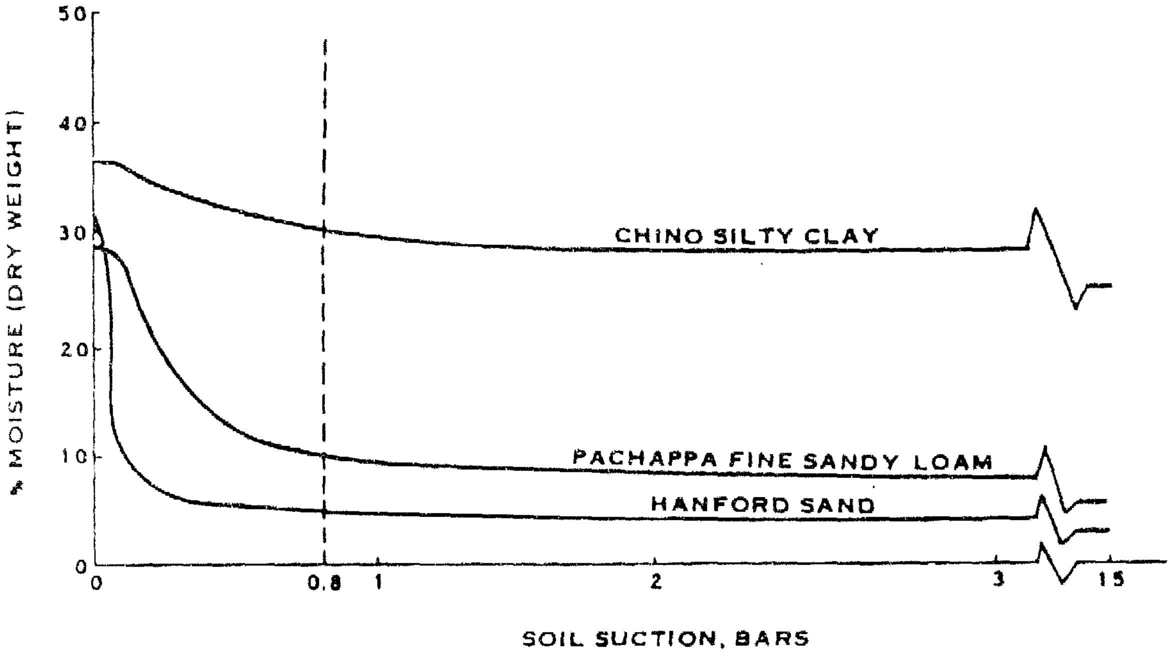

Figure 4-2. Moisture retention curves - three soil types (Soilmoisture Equipment Corp., 1983)

Another fact, brought out by the graphs on Figure 4-2, is that silty clay soil with 30 percent moisture, if placed in contact with a sandy soil with only 10 percent moisture will actually suck moisture out of the sandy soil until the moisture content in the sandy soil is only 5 percent. This is due to the greater soil tension in the fine clay texture.

4.2 PORE-LIQUID SAMPLING EQUIPMENT

Well and open cavities cannot be used to collect solution flowing in the unsaturated zone under suction (negative pressures). The sampling devices for such unsaturated media are thus called suction samplers or lysimeters. Everett et al. (1983) provides an in depth evaluation of the majority of unsaturated zone monitoring equipment. Law Engineering and Testing Company (1982) provides a description of some of the available suction lysimeters (Appendix D). Three types of suction lysimeters are (1) ceramic-type samplers, (2) hollow fiber samplers, and (3) membrane filter samplers.

Because of the potential for macropore flow, pan lysimetry should be employed for soil-pore liquid monitoring in addition to suction lysimetry during the treatment demonstration. While pan lysimeters (e.g., glass block samplers) are not at present commercially available, they are relatively easy to construct and instrument (R.R. Parizek, personal communication, 1984). However, installation will require more skill and effort than suction lysimeters (K. Shaffer, personal communication, 1984).

4.2.1 Ceramic-Type Samplers

Two types of samplers are constructed from ceramic material: the suction cup and the filter candle. Both operate in the same manner. Basically, ceramic-type samplers comprise the same type of ceramic cups used in tensiometers. When placed in the soil, the pores in these cups become an extension of the pore space of the soil. Although cups have limitations, at the present time they appear to be the best tool available for sampling unsaturated media, particularly in the field. The use of teflon for the body tube parts and the porous segment (instead of a porous ceramic) may reduce the chemical interaction between the sampler and the hazardous waste.

Suction cups may be subdivided into three categories: (1) vacuum operated soil-water samplers, (2) vacuum-pressure samplers, and (3) vacuum-pressure samplers with check valves. Soil-water samplers generally consist of a ceramic cup mounted on the end of a small-diameter PVC tube, similar to a tensiometer (see Figure 4-3). The upper end of the PVC tubing projects above the soil surface. A rubber stopper and outlet tubing are inserted into the upper end. Vacuum is applied to the system and soil water moves into the cup. To extract a sample, a small-diameter tube is inserted within the outlet tubing and extended to the base of the cup. The small-diameter tubing is connected to a sample-collection flask. A vacuum is applied via a hand vacuum-pressure pump and the sample is sucked into the collection flask. These units are generally used to sample to depths up to 6 feet from the land surface. Consequently, they are used primarily to monitor the near-surface movement of pollutants from land disposal facilities or from irrigation return flow.

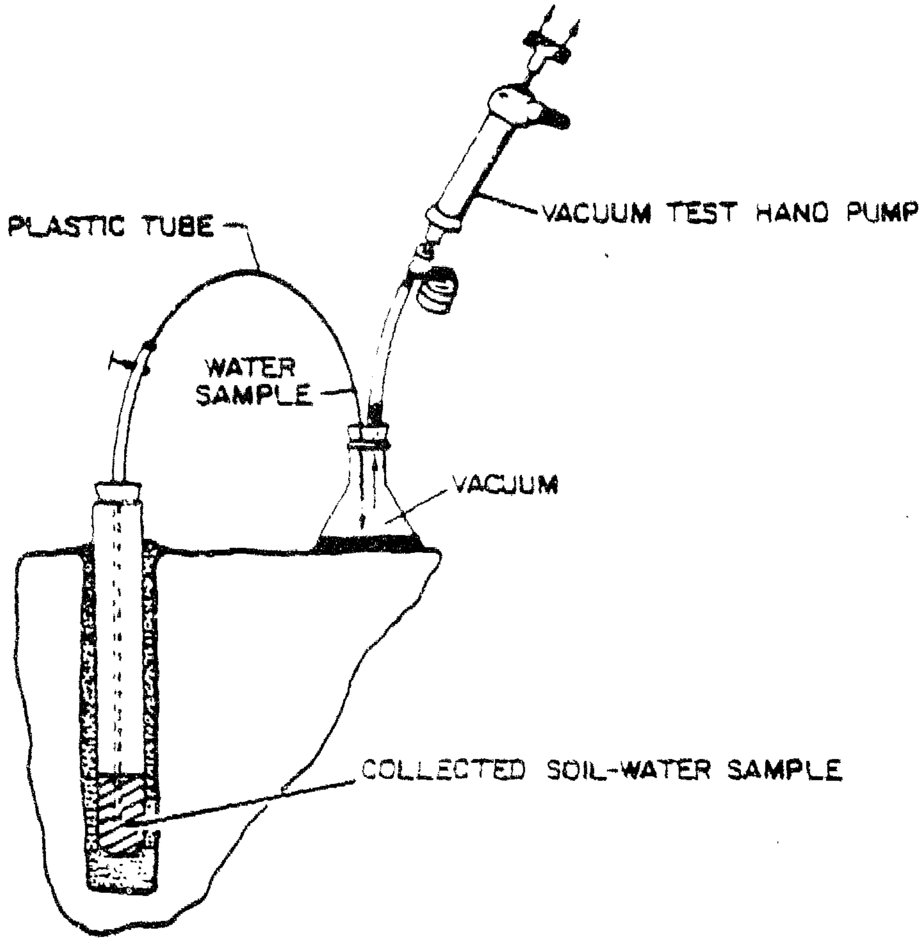

Figure 4-3. Soil-water sampler (Courtesy Soilmoisture Equipment Corp., 1978)

To extract samples from depths greater than the suction lift of water (about 25 feet), a second type of unit is available, the so-called vacuum-pressure lysimeter. These units were developed by Parizek and Lane (1970) for sampling the deep movement of pollutants from a land disposal project in Pennsylvania. The design of the Parizek and Lane sampler is shown in Figure 4-4. The body tube of the unit is about 2 feet long, holding about 1 liter of sample. Two copper lines are forced through a two-hole rubber stopper sealed into a body tube. One copper line extends to the base of the ceramic cup as shown and the other terminates a short distance below the rubber stopper. The longer line connects to a sample bottle and the shorter line connects to a vacuum-pressure pump. All lines and connections are sealed. At land treatment units, however, polyethylene or teflon tubing is recommended.

In operation, a vacuum is applied to the system (the longer tube to the sample bottle is clamped shut at this time). When sufficient time has been allowed for the unit to fill with solution, the vacuum is released and the clamp on the outlet line is opened. Air pressure is then applied to the system, forcing the sample into the collection flask. A basic problem with this unit is that when air pressure is applied, some of the solution in the cup may be forced back through the cup into the surrounding pore-water system. Consequently, this type of pressure-vacuum system is recommended for depths only up to about 50 feet below land surface. In addition to the monitoring effort of Parizek and Lane, these units were used by Apgar and Langmuir (1971) to sample leachate movement in the vadose zone underlying a sanitary landfill.

Morrison and Tsai (1981) proposed a modified lysimeter design with the porous material located midway up the sampling chamber instead of at the bottom (see Figure 4-5, Morrison and Tsai, 1981). This mitigated the basic problem of sample solution being forced back through the cup when air pressure is applied. The dead space below the porous section, however, will result in potential cross contamination.

Wood (1973) reported on a modified version of the design of Parizek and Lane. Wood's design is the third suction sampler discussed in this subsection. Wood's design overcomes the main problem of the simple pressure-vacuum system; namely, that solution is forced out of the cup during application of pressure. A sketch of the sampler is shown in Figure 4-6. The cup ensemble is divided into lower and upper chambers. The two chambers are isolated except for a connecting tube with a check valve. A sample delivery tube extends from the base of the upper chamber to the surface. This tube also contains a check valve. A second shorter tube terminating at the top of the sampler is used to deliver vacuum or pressure. In operation, when a vacuum is applied to the system, it extends to the cup through the open one-way check valve. The second check valve in the delivery tube is shut. The sample is delivered into the upper chamber, which is about 1 liter (0.26 gallon) in capacity. To deliver the sample to the surface, the vacuum is released and pressure (generally of nitrogen gas) is applied to the shorter tube. The one-way valve to the cup is shut and the one-way valve in the delivery tube is opened. Sample is then forced to the surface. High pressures can be applied with this unit without danger of damaging the cup. Consequently, this sampler can be used to depths of about 150 feet below land surface (Soilmoisture Equipment Corporation, 1978). Wood and Signor (1975) used this sampler to examine geochemical changes in water during flow in the vadose zone underlying recharge basins in Texas.

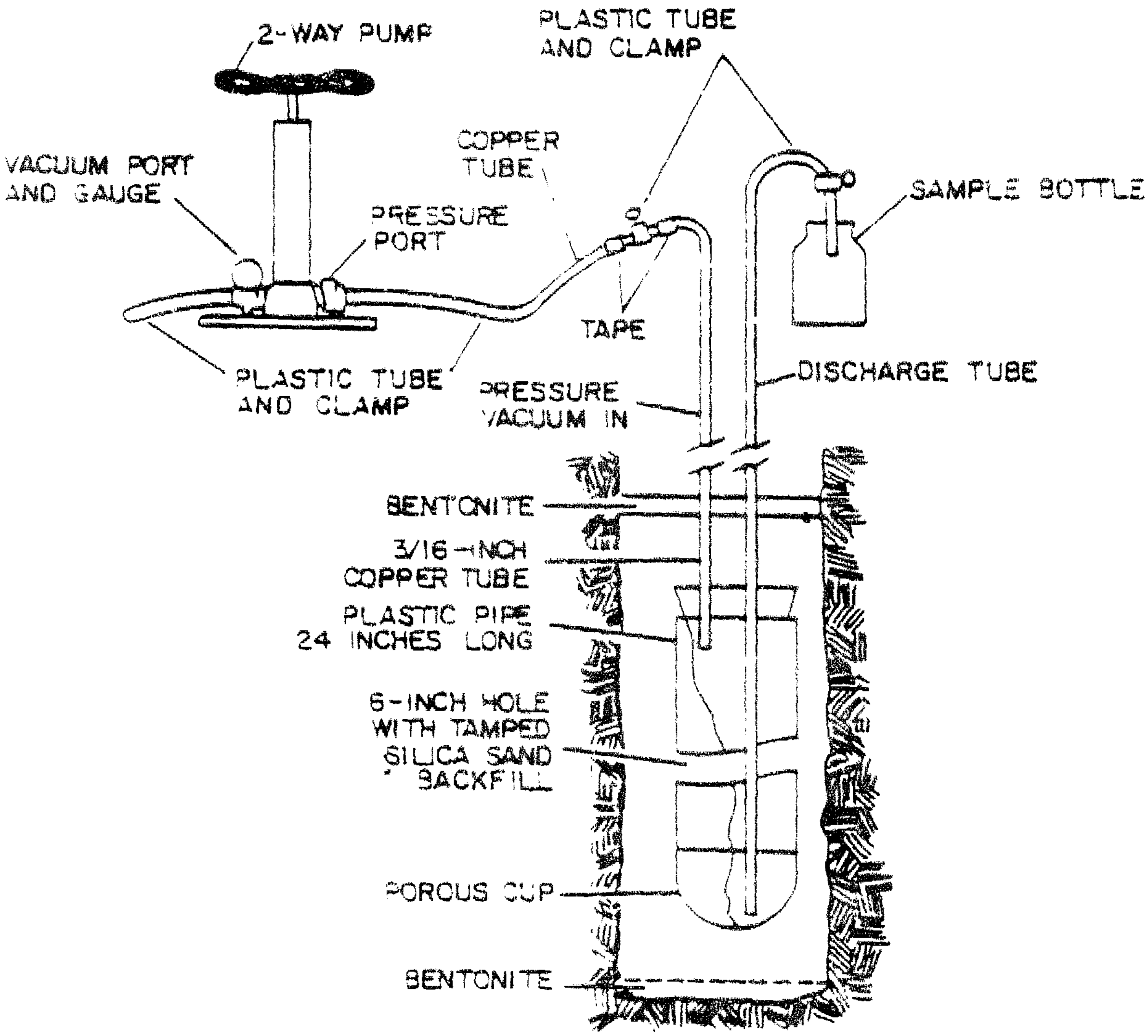

Figure 4-4. Vacuum-pressure sampler (Parizek and Lane, 1970)

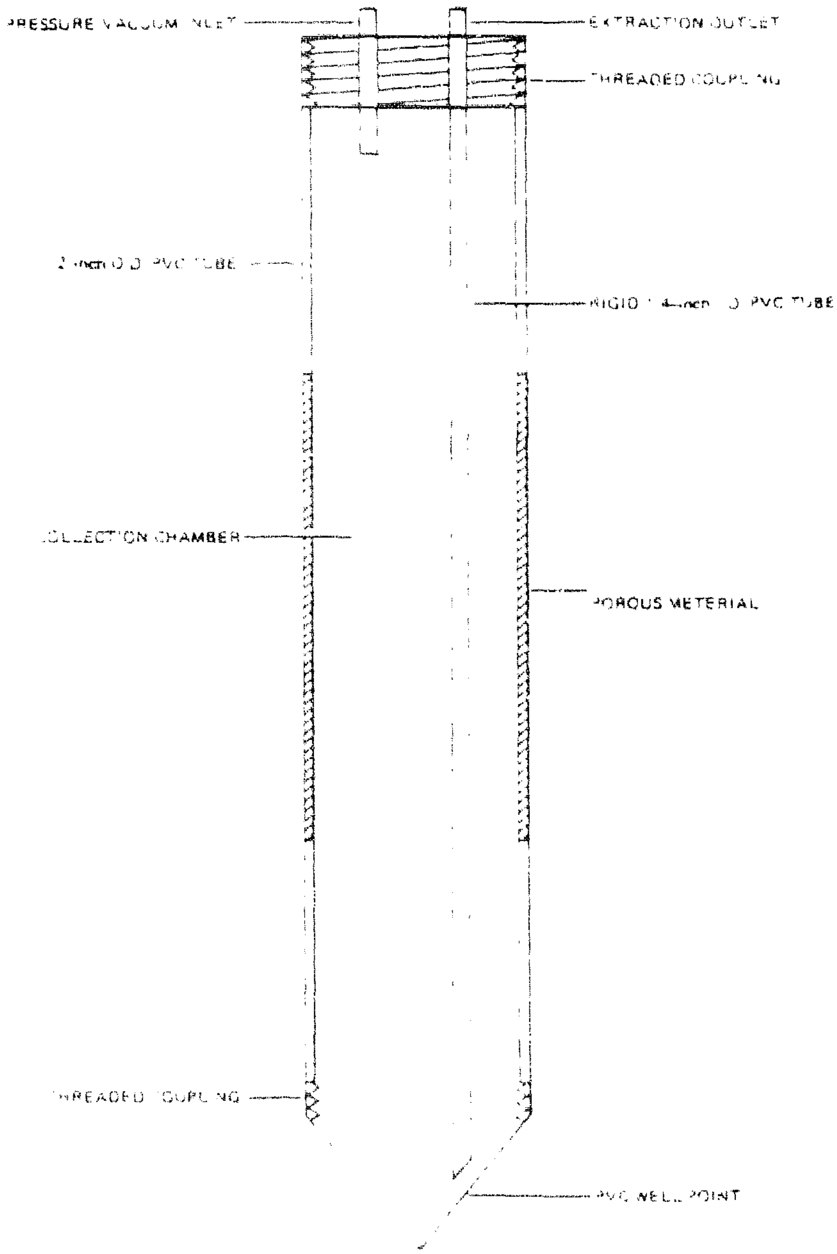

Figure 8 - Modified pressure-vacuum lysimeter (Morrison and Tsai, 1981)

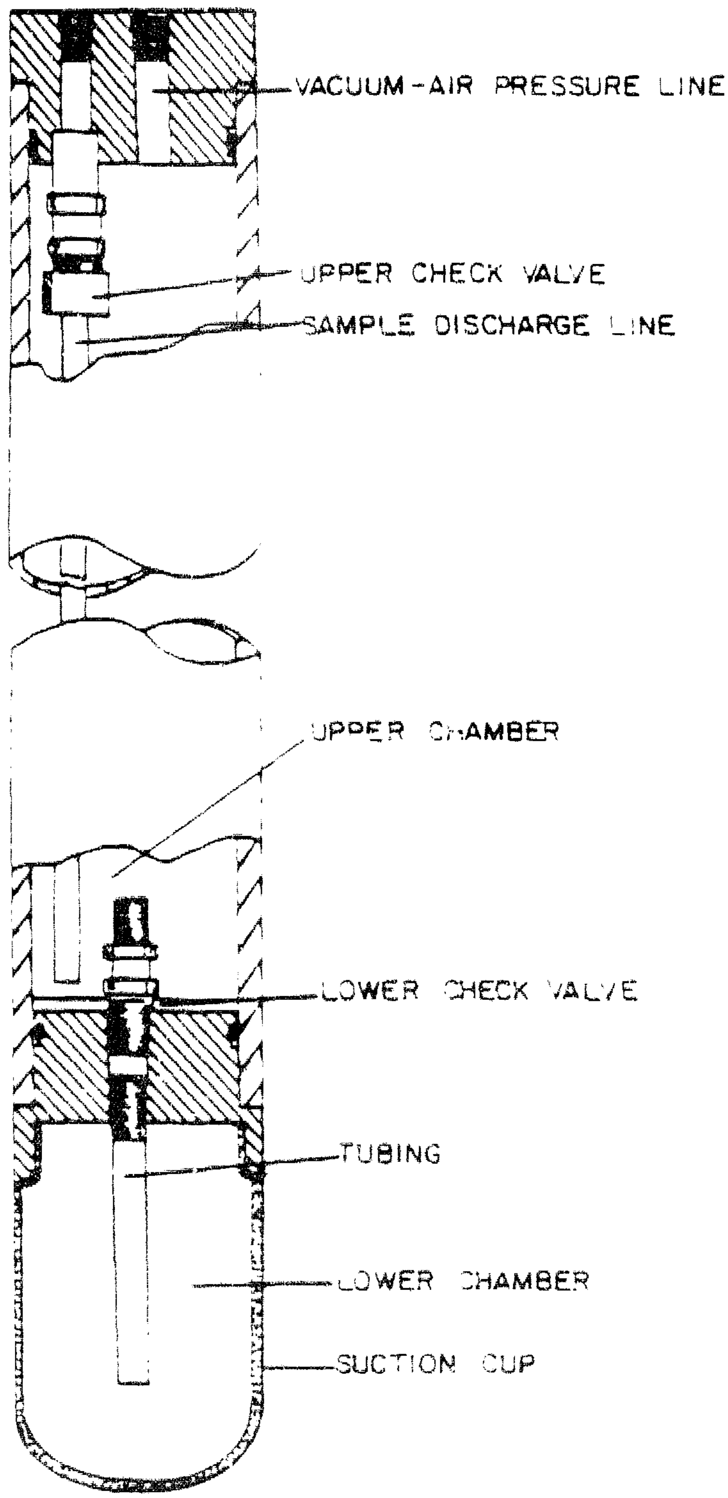

Figure [illegible]. "Hi[illegible] pressure vacuum soil-water sampler" (Courtesy Soilmoisture Equipment Corp., [illegible])

A sampling unit employing a filter candle is described by Duke and Haise (1973). The unit, described as a "vacuum extractor," is installed below plant roots. Figure 4-7 shows an illustrative installation. The unit consists of a galvanized sheet metal trough open at the top. A porous ceramic candle (12 inches long and 1.27 inches in diameter) is placed into the base of the trough. A plastic pipe sealed into one end of the candle is connected to a sample bottle located in a nearby manhole or trench. A small-diameter tube attached to the other end of the candle is used to rewet the candle as necessary. The trough is filled with soil and placed within a horizontal cavity of the same dimensions as the trough. The trough and enclosed filter candle are pressed up against the soil via an air pillow or mechanical jack. In operation, vacuum is applied to the system to induce soil-water flow into the trough and candle at the same rate as in the surrounding soil. The amount of vacuum is determined from tensiometers. Hoffman et al. (1978) used this type of sampler to collect samples of irrigation water leaching beneath the roots of orange trees during return flow studies at Tacna, Arizona.

4.2.2 Cellulose-Acetate Hollow Fiber Samplers

Jackson, Brinkley, and Bondietti (1976) described a suction sampler constructed of cellulose-acetate hollow fibers. These semipermeable fibers have been used for dialysis of aqueous solutions, functioning as molecular sieves. Soil column studies using a bundle of fibers to extract soil solution showed that the fibers were sufficiently permeable to permit rapid extraction of solution for analysis. Soil solution was extracted at soil-water contents ranging from 50 to 20 percent.

Levin and Jackson (1977) compare ceramic cup samplers and hollow fiber samplers for collecting soil solution samples from intact soil cores. Their conclusion is: "... porous cup lysimeters and hollow fibers are viable extraction devices for obtaining soil solution samples for determining EC, Ca, Mg, and PO_4-P. Their suitability for NO_3-N is questionable." They also conclude that hollow fiber samplers are more suited to laboratory studies, where ceramic samplers are more useful for field sampling. Because of the high potential to alter sample quality, further research is required on these types of samplers before they can be recommended.

4.2.3 Membrane Filter Samplers

Stevenson (1978) presents the design of a suction sampler using a membrane filter and a glass fiber prefilter mounted in a "Swinnex" type filter holder. Figure 4-8 shows the construction of the unit. The membrane filters are composed of polycarbonate or cellulose-acetate. The "Swinnex" filter holders are manufactured by the Millipore Corporation for filtration of fluids delivered by syringe. A flexible tube is attached to the filter holder to permit applying a vacuum to the system and for delivering the sample to a bottle.

The sampler is placed in a hole dug to a selected depth. Sheets of glass fiber "collectors" are placed in the bottom of the hole. Next, two or three smaller glass fiber "wick" discs that fit within the filter holder are placed in the hole. Subsequently, the filter holder is placed in the hole with the glass fiber prefilter in the holder contacting the "wick" discs. The hole is then backfilled.

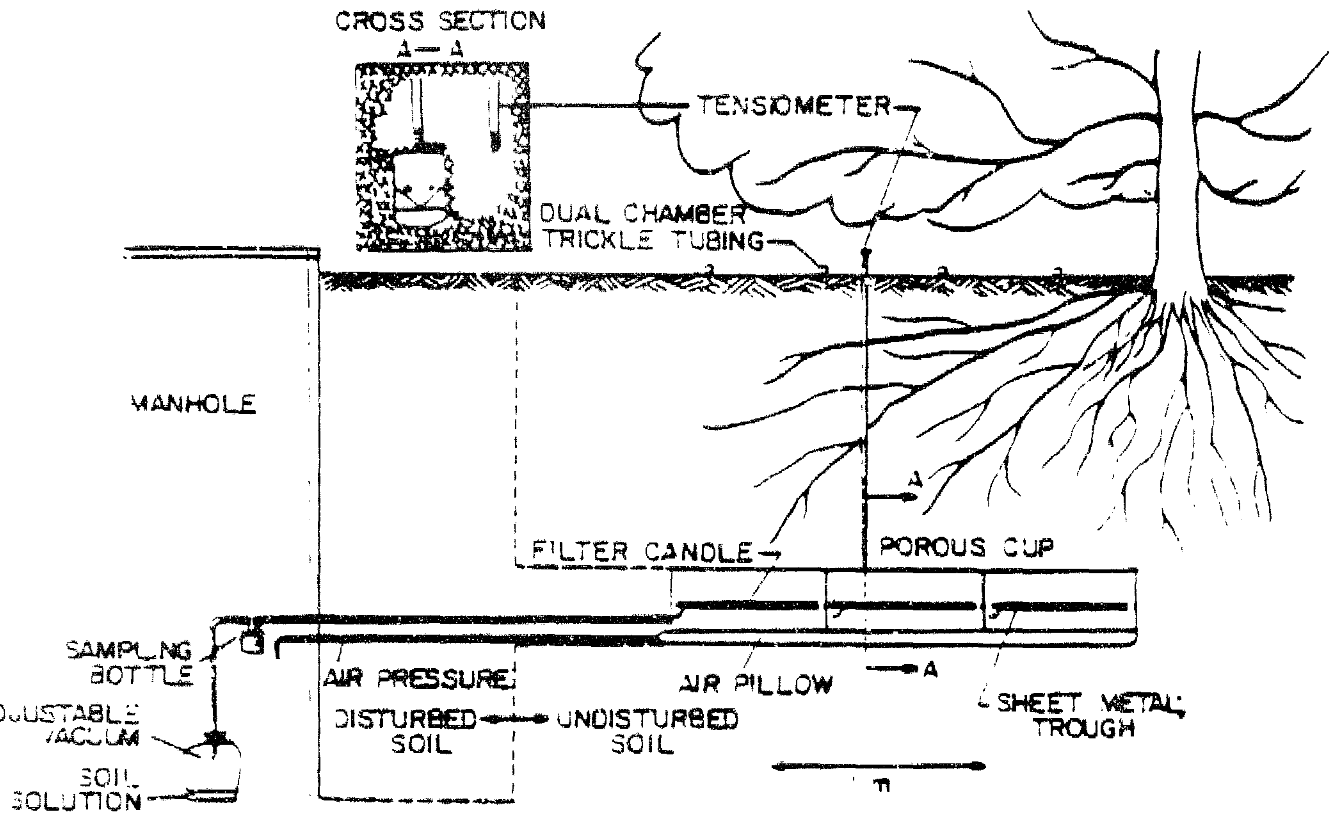

Figure 4-7. Facilities for sampling irrigation return flow via filter candles, for research project at Tacna, Arizona (Hoffman et al., 1978)

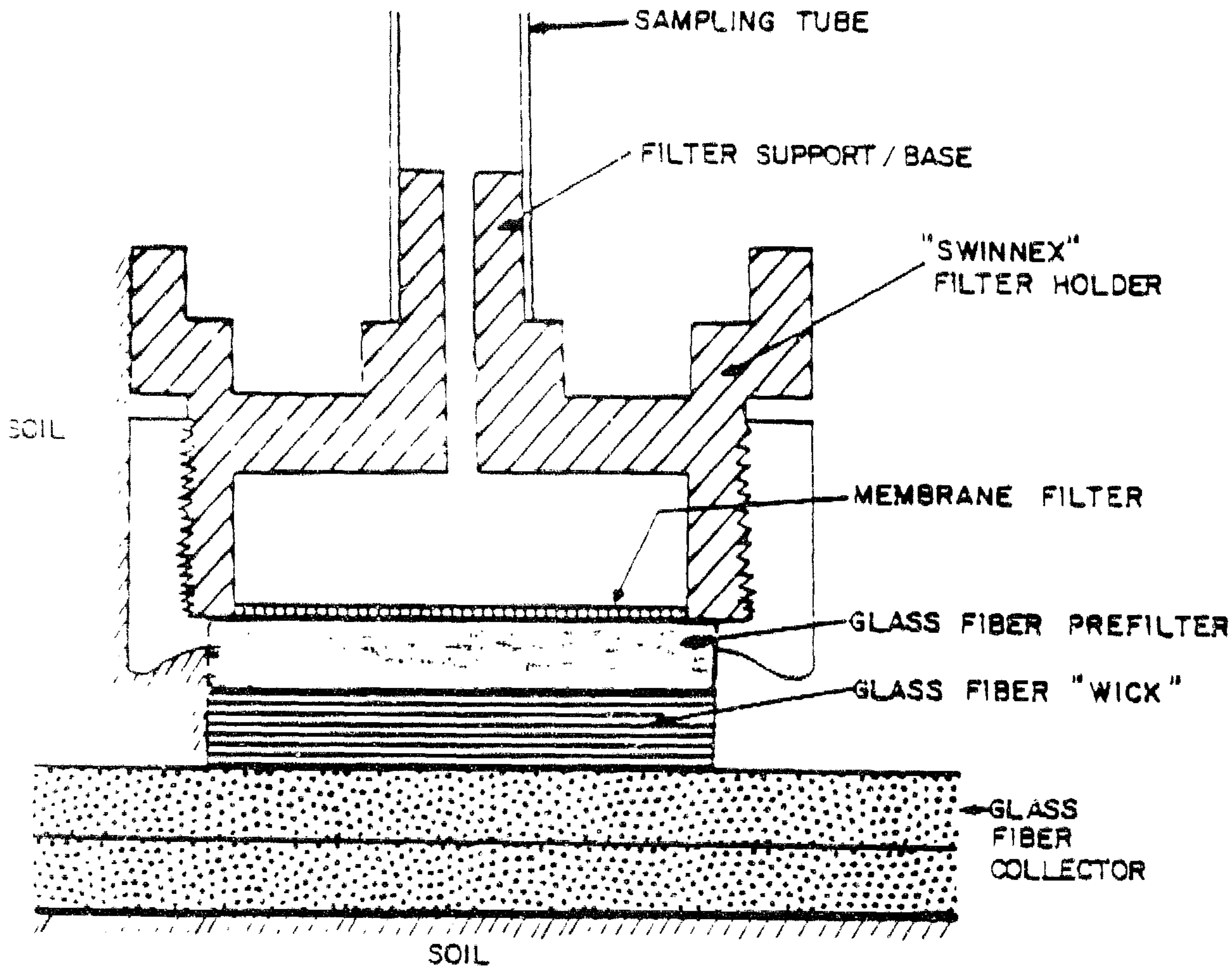

Figure 4-8. Membrane filter sampler (Stevenson, 1978)

In operation, soil water is drawn into the collector system by capillarity. Subsequently, water flows in the collector sheets toward the glass fiber wicks as a result of the suction applied to the filter holder assembly. The glass fiber prefilter minimizes clogging of the membrane filter by fine material in the soil solution.

During field tests with the sampler, it was observed that sampling rates decreased with decreasing soil-water content. The "wick and collector" system provided contact with a relatively large area of the soil and a favorable sampling rate was maintained even when the "collector" became blocked with fine soil. The basic sampling unit can be used to depths of 4 meters.

4.2.4 Pan Lysimeters

The presence of macropore or fracture flow should be determined during the treatment demonstration phase for land treatment units located in highly structured soils. It is important to acknowledge the occurrence of macropore flow under certain soil conditions and its significant potential to contaminate groundwater. The pan lysimeter, which is a free drainage type lysimeter is suited for sampling macropore or fracture flow.

There are a number of designs for pan-type lysimeters. Parizek and Lane (1970) constructed a 12x15 inch pan lysimeter (Figure 4-9) from 16 gauge sheet metal. Barbee (1983) employed a perforated 12x12 inch glass brick, the kind used in masonry construction, as a pan lysimeter (Figure 4-10). Shaffer et al. (1979) devised a 20 cm diameter pan lysimeter with a tension plate capable of pulling 6 centibars of tension. A pan lysimeter can be constructed of any non-porous material provided a leachate-pan interaction will not jeopardize the validity of the monitoring objectives. The pan itself may be thought of as a shallow draft funnel. Water draining freely through the macropores will collect in the soil just above the pan cavity. When the tension in the collecting water reaches zero, dripping will initiate and the pan will funnel the leachate into a sampling bottle. The use of a tension plate or a fine sand packing reduces the extent of capillary perching at the cavity face and promotes free water flow into the pan.

4.3 CRITERIA FOR SELECTING SOIL-PORE LIQUID SAMPLERS

In selecting soil-pore liquid sampling equipment, the following criteria should be considered: cost, commercial availability, installation requirements, hazardous waste interaction, vacuum requirements, soil moisture content, soil characteristics and moisture regimes, durability, sample volume, and sampling depth. Fritted glass samplers, for example, are too fragile for field application. Plastic lysimeters require a continuous vacuum and high soil moisture levels. The vacuum extractor is expensive, requires intensive installation procedures and a continuous vacuum. The "Swinnex" sampler has difficult installation procedures and produces too small a sample. Some samplers, such as the aluminum oxide porous cup sampler, are not commercially available. All teflon samplers are more expensive than PVC body parts and ceramic cups. The high pressure-vacuum samplers are not required for the shallow sampling depths at land treatment units. The sample vacuum lysimeter cannot be used in situ with the sampler totally covered by soil.

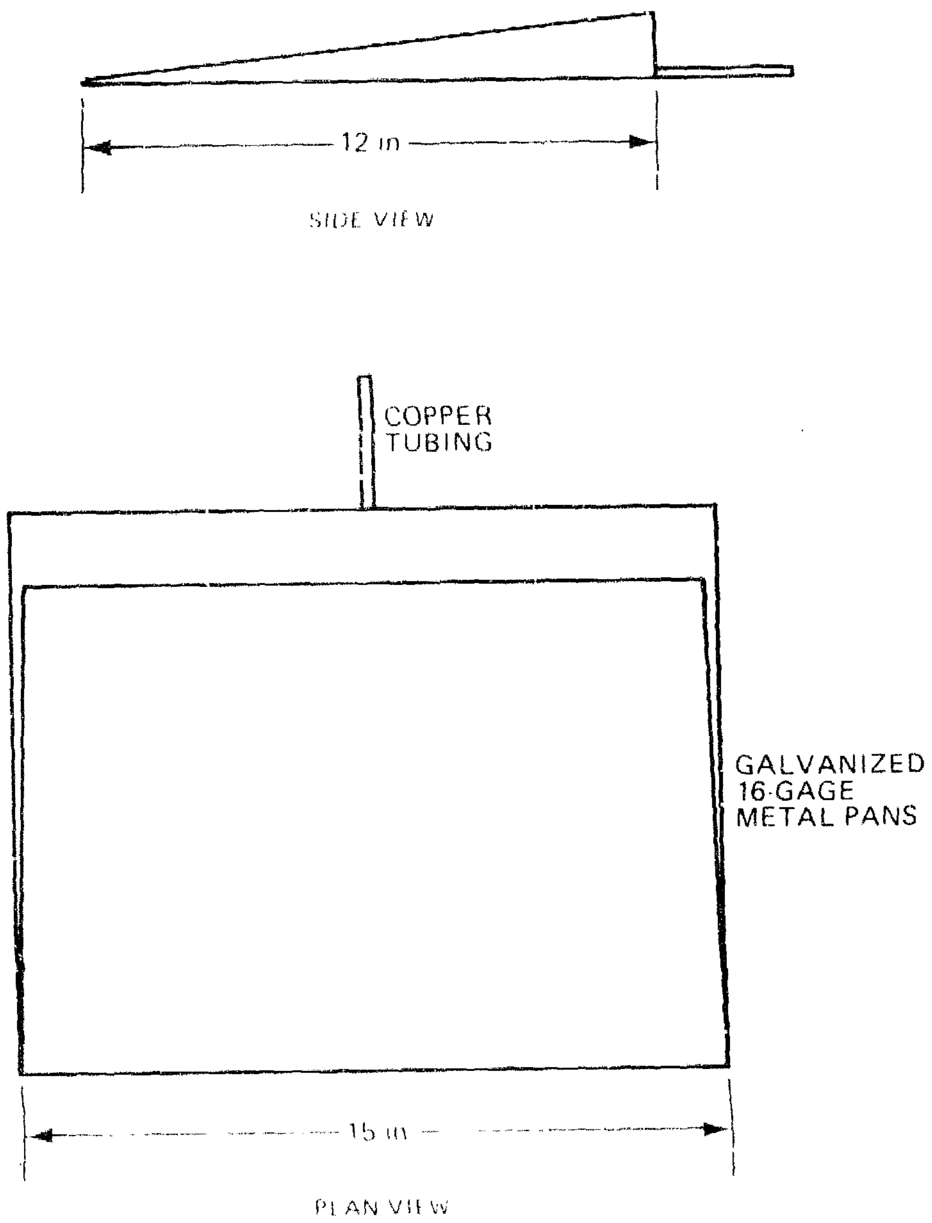

Figure 4-9. Example of a pan lysimeter

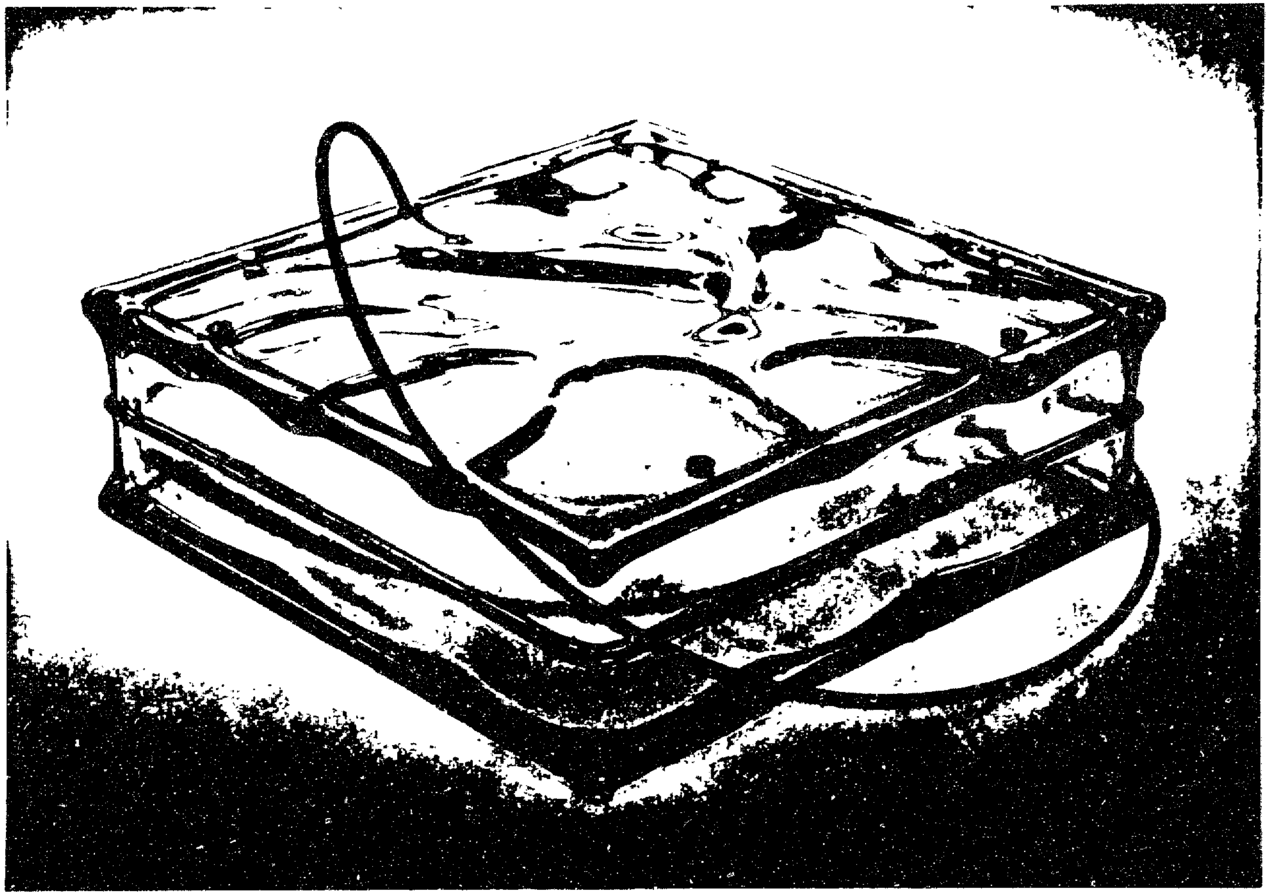

Figure 4-10. Free drainage glass block sampler

In most cases, the lysimeter of choice at land treatment units will be pressure-vacuum ceramic lysimeters. Teflon models have certain limitations which preclude their use at soil suction conditions recommended for land treatment units (Everett et. al., 1986) Most pressure-vacuum lysimeters are reasonably priced, commercially available, and easy to install. In addition, a constant vacuum apparatus is not required. They can be used in situ at depths well within the requirements of land treatment units and can produce a large sample volume. Body tubes of various lengths are available to compliment the volume and sample depth requirements.

Free drainage lysimeters can only sample and thus monitor the movement of gravitational water when precipitation is equal to or greater than field capacity requirements or when there is a large water input into the soil (Parizek and Lane, 1970; Tadros and McGarity, 1976; Fenn et al., 1977). However, in the unsaturated zone of soils, most water movement is in the wet moisture range (0 to -50 kPa soil moisture tensions, Reeve and Doering, 1965), and in well structured soils through macropores (Shaffer et al., 1979), which accounts for the vast majority of the water and chemical constituents that can be lost from the soil by leaching. Free drainage samplers have the following characteristics:

1) It is a continuously sampling "collection" system without the need for externally applied vacuum.

2) Because vacuum is only used to pull the sample to the surface, there is less potential for losing volatile compounds in the sample obtained.

3) Its defined surface area may allow quantitative estimates of leachate.

4) The method of installation allows monitoring the natural percolation of liquids through the unsaturated zone without alteration of flow.

5) If made of chemically inert materials (i.e., glass), it has less potential for altering the chemical composition of a sample obtained by it.

6) Since the inside of the glass block type is uneven, the potential exists for cross contamination from residual samples.

7) If the glass blocks are not installed perfectly level, a sump or collection area can result in dead space where the sample cannot be removed.

8) Pan lysimeters require trenching to be installed. At land treatment sites where the treatment zone includes 1.5 m (5 ft) plus some build up of the land surface, the trenches may require "shoring up."

4.3.1 Preparation of the Samplers

A decision must be made on the size of pressure-vacuum lysimeters to be installed at the site, and the composition of the pressure-vacuum tubing. According to data by Silkworth and Grigal (1981), the larger commercially available units with a 4.8 cm diameter are more reliable than the 2.2 cm diameter units, influence water quality less, and yield a larger volume of sample for analysis. Although various materials have been used for conducting tubing (e.g., polypropylene and copper tubing), it is advisable to select teflon tubing to minimize contamination and interference with the sample.

In order to avoid interferences from chemical substances attached to porous sampling points, it is recommended advisable to prepare each unit using the following procedure described by Wood (1973). Clean the cups by letting approximately 1 liter of 8N HCl seep through them, and rinse thoroughly by allowing 15 to 20 liters of distilled water to seep through. This cleaning process can be accelerated by placing the distilled water inside the lysimeter and developing 20-30 psi of pressure to drive the water through the porous material. The cups are adequately rinsed when there is less than a 2 percent difference between the specific conductance of the distilled water input and the output from the cup.

Prior to taking the suction lysimeters in the field, each lysimeter should be checked for its bubbling pressure and for leaks. Complete procedures for testing for leaks and air entry values are given in Everett et. al (1986).

4.4 RANDOM PORE-LIQUID MONITORING SITE SELECTION

The RCRA Guidance Document: Land Treatment Units (EPA, 1983b) includes recommendations on the numbers and locations of pore-liquid samplers for both background and active portions, as well as the specifications for sampling frequency. These specifications are summarized on Table 4-1.

The RCRA guidance document suggests that the pore-liquid monitoring sites be randomly selected. In practice, each site is selected separately, randomly, and independently of any sites previously drawn. For pore-liquid monitoring, each site to be included in the "sample" is a volume of liquid (soil-pore liquid).

The field location for soil-pore liquid devices is obtained by selecting random distances on a coordinate system and using the intersection of the two random distances on a coordinate system as the location at which a soil-pore liquid monitoring device should be installed.

The location, within a given uniform area of a land treatment unit (i.e., active portion monitoring), at which a soil-pore liquid monitoring device should be installed is determined using the following procedure (EPA, 1983b):

(1) Divide the land treatment unit into uniform areas (see Figure 3-16). A qualified soil scientist should be consulted in completing this step.

TABLE 4-1. SUMMARY OF GUIDANCE ON PORE-LIQUID SAMPLING

Location	Number of Units	Location of Sampling Portion of Unit	Frequency
Background	2 each on similar soils found on treatment area	With 12 inch depth below treatment zone	Quarterly. If samples cannot be obtained quarterly, they should be timed to follow a rainfall event.
Active	a. Uniform area less than 12 acres: 6 units b. Uniform area greater than 12 acres: 2 per 4 acres	With 12 inch depth below treatment zone	Quarterly. Samples should be obtained 24 hours after waste application events.

(2) Map each uniform area by establishing two base lines at right angle to each other which intersect at an arbitrarily selected origin, for example, the southwest corner. Each baseline should extend to the boundary of the uniform area.

(3) Establish a scale interval along each base line. The units of this scale may be feet, yards, miles, or other units depending on the size of the uniform area. Both base lines must have the same scale.

(4) Draw two random numbers from a random numbers table (usually available in any basic statistics book, see Appendix A). Use these numbers to locate one point along each of the base lines.

(5) Locate the intersection of two lines drawn perpendicular to these two base line points. This intersection represents one randomly selected location for installation of one soil-pore liquid device. If this location at the intersection is outside the uniform area or is within 10 m of another location, disregard and repeat the above procedure.

(6) For soil-pore liquid monitoring, repeat the above procedure as many times as necessary to obtain six locations for installation of a soil-pore liquid monitoring device (location) per uniform area, but no less than two devices per 1.5 hectares (4 acres). Monitoring at these same randomly selected locations will continue throughout the land treatment unit life (i.e., devices do not have to be relocated at every sampling event).

(7) If the device must be replaced for some reason, go through the procedure again to get a new location.

One point should be made regarding randomly locating soil-pore liquid monitoring devices in the active portion according to the procedure specified above. In order to prevent operational inconvenience and sampling bias, the monitoring system should be designed and installed so that the above-ground portion of the device is located at least 10 meters (30 feet) from the sampling location. If the above-ground portion of the device is located immediately above the sampling device, the sampling location will often be avoided because of operational difficulties. Thus, samples collected at this location will be biased and not representative of the treated area. The distance may be shorter than 10 m (30 ft) if the operator can ensure no sampling bias (i.e., hazardous waste treatment practices above the sampler will be the same as the rest of the uniform area) due to operational practices.

Locations for monitoring on background areas should be randomly determined using the following procedure:

(1) Consult a qualified soil scientist in determining an acceptable background area. The background area must have characteristics (i.e., at least soil series classification) similar to those present in the uniform area of the land treatment unit it is representing.

(2) Map an arbitrarily selected portion of the background area (preferably the same size as the uniform area) by establishing two base lines at right angles to each other which intersect at an arbitrarily selected origin.

(3) Complete steps 3, 4, and ˉ as defined above.

(4) For soil-pore liquid monitoring, repeat this procedure as necessary to obtain two locations for soil-pore liquid monitoring devices within each background area.

4.4.1 Surveying in the Locations of Sites and Site Designations

The exact location of each sampler on the active and background areas should be designated on a detailed map of the treatment area. Subsequently, a surveying crew should be sent into the field to precisely locate the coordinates of the sites in reference to a permanent marker. This step is important to facilitate future recovery of any failed samplers.

For convenience, each sampler location should be given a descriptive designation to facilitate all future activities at the site. For example, this designation should be posted at the sampling station (which will be off the active portion) and should be marked on all collection flasks to facilitate differentiating between samples. Examples of site designations are shown in Figure 4-11. The selection of a designation is purely arbitrary and any convenient or easily recalled symbol could be used.

4.5 SAMPLE NUMBER, SIZE, FREQUENCY AND DEPTHS

Background concentrations of hazardous constituents can be established using the following procedures.

(1) For each soil series present (see Figure 3-16) in the treatment zone, install two soil-pore liquid monitoring devices at randomly selected locations in similar soils (Figure 4-12) where waste has not been applied. The sample collecting portions of the monitoring devices should be placed at a depth no greater than 30 centimeters (12 inches) below the actual treatment zone used at the unit (Figure 4-13).

(2) Collect a sample from each of the soil-pore liquid monitoring devices on at least a quarterly basis for at least one year. If liquid is not present at a regularly scheduled sampling event, a sample should be collected after a rainfall has occurred.

The active portion of a land treatment unit can be sampled using the following procedures:

(1) The owner or operator should install six soil-pore liquid monitoring devices at randomly selected locations per uniform area, but no less than two devices per 1.5 hectares (4 acres). A uniform area is an area of the active portion of a land treatment unit which is composed of soils of the same soil

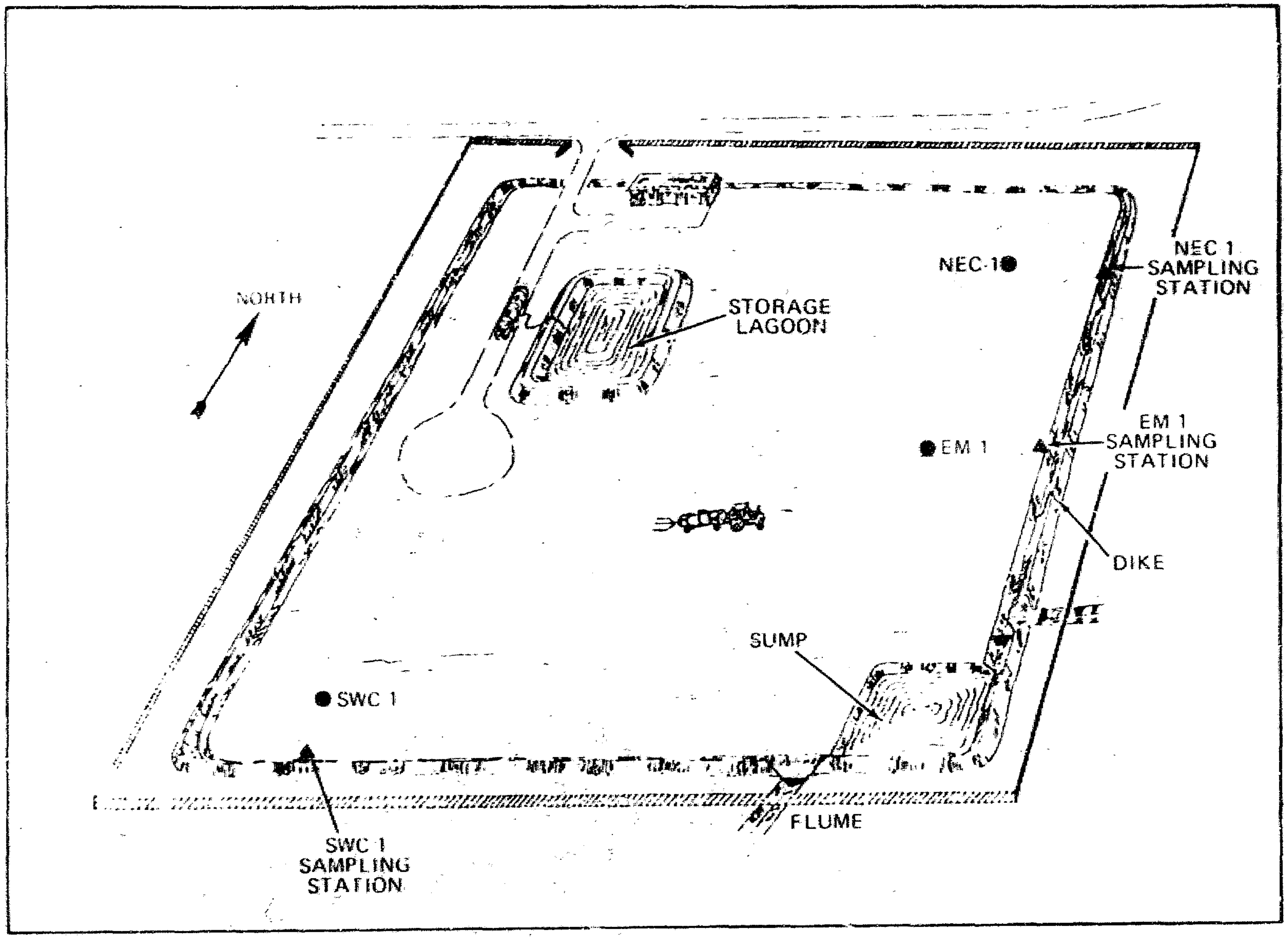

Figure 4-11. Sketch of land treatment site showing designations at pore-liquid sampling sites (SWC1 = southwest corner; NE1 = northeast corner; EM1 = east-middle of field)

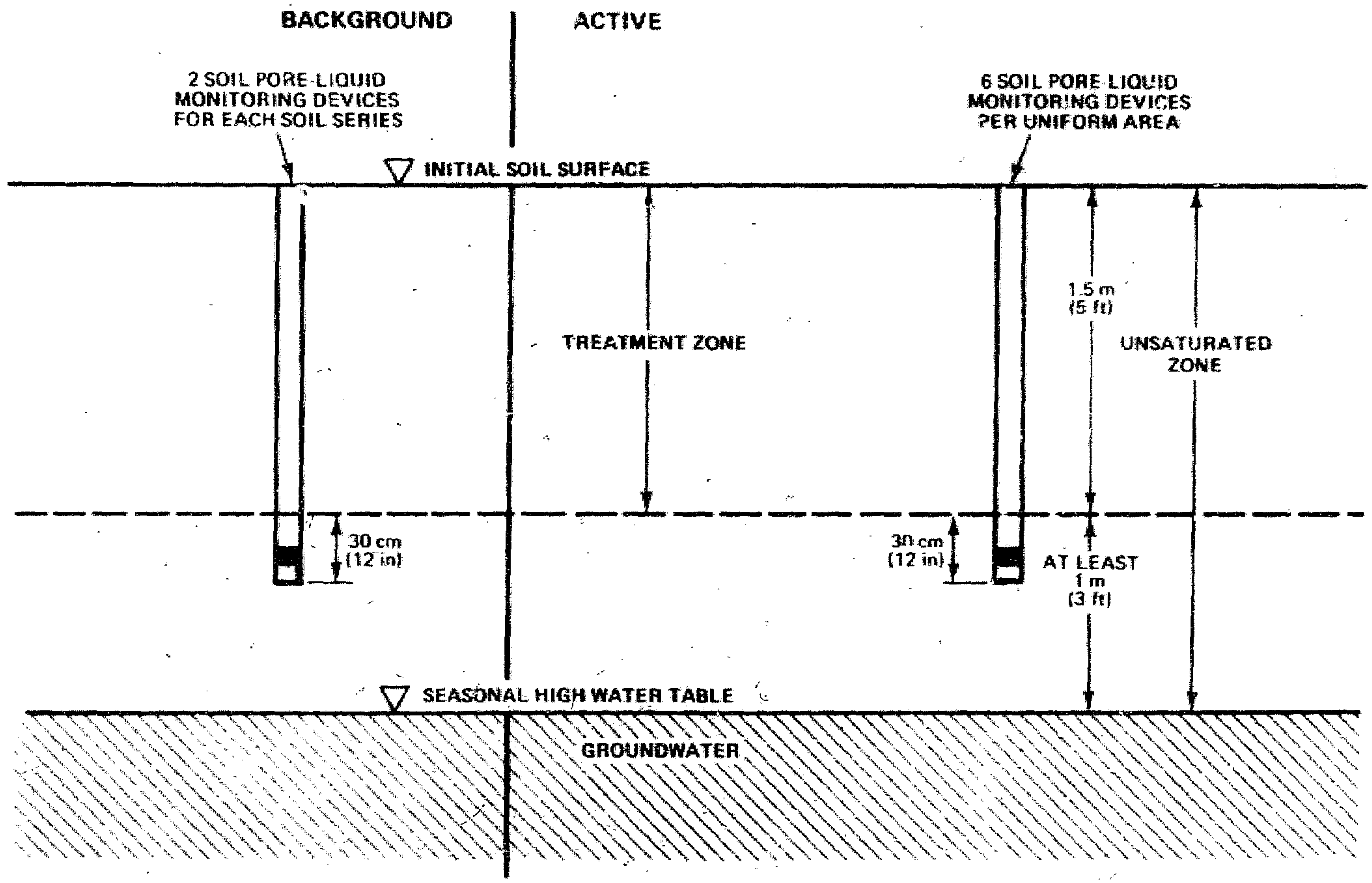

Figure 4-12. Pore liquid sampling depths

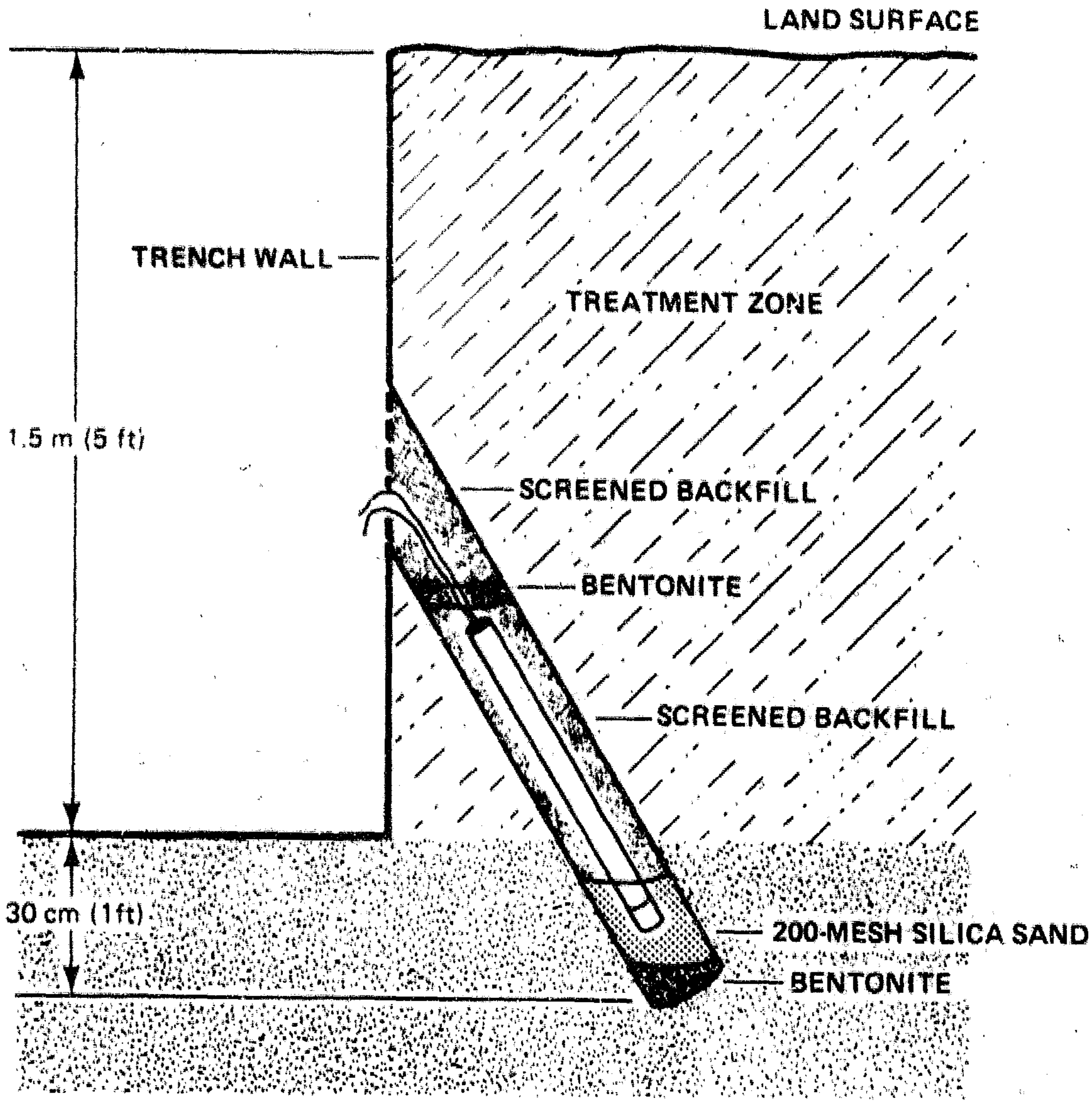

Figure 4-13. Location of suction lysimeters