Characterization of Soil Cover and Estimation of Water Infiltration at Central Facilities Area Landfill II, Idaho National Engineering Laboratory (INEL)

Prepared for

Geosciences Unit
EG&G Idaho, Inc.
Idaho National Engineering Laboratory
Idaho Falls, Idaho 83415

Under Research Subcontract No. C85-110544

By

S.M. Miller
J.E. Hammel
L.F. Hall

The University of Idaho
Idaho Water Resources Research Institute and the
Department of Geology and Geological Engineering
Moscow, Idaho 83843

May 30, 1990

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

To assist the Geosciences Unit of E G & G Idaho, Inc. with hydrogelogic characterization of Central Facilities Area (CFA) Landfill II, researchers at the University of Idaho have completed a project aimed at characterizing the soil cover and estimating the annual water infiltration through the cover.

Based on historical evidence of landfill operations and on the results of particle size analyses with depth, it is reasonable to divide the soil cover into two layers: 1) an upper surface layer approximately 1-ft thick consisting of more sand than gravel, and 2) a lower layer at depths greater than 1 ft consisting of more gravel than sand.

The overall thickness of the soil cover was measured with a hand auger at 60 locations across the landfill. The sample mean was 1.5 ft, with a minimum and maximum of 0.33 and 3.17 ft, respectively. Several of the auger holes caved or were blocked, so maximum thickness of the soil cover at a few locations may be greater than 3.17 ft.

A field procedure using cheese-cloth and resin was successfully used to collect large, undisturbed specimens of coarse-grained soils. In the laboratory these blocks were trimmed to fit 8-in. diameter sections of PVC pipe for subsequent hydraulic testing. Measured saturated hydraulic conductivities ranged from 0.0020 to 0.0025 cm/sec.

Water retention tests of the large cores and of smaller specimens comprised of the fine fraction (particles smaller than 2.0 mm) provided relationships of capillary pressures vs. water content. Results from these tests and from mass-volume calculations indicated that water storage in the soil cover effectively occurs in the volume occupied by the fine fraction and is approximately equal to 0.097 and 0.062 cm of water per cm of soil thickness for Layers 1 and 2, respectively.

Historical meteorological data from a 31-year record was used to estimate the amount of water available for annual infiltration through the soil cover (i.e., recharge). The median value of annual (PPT-ETA) was combined with block-kriged maps of cover thickness, percent-fines in Layer 1, and percent-fines in Layer 2 to generate maps depicting the estimated annual infiltration through the cover (in 50 x 50 ft cells) for a "median" year. The cell values range from 0.99 to 2.05 inches, and indicate the annual recharge to the waste. The analysis was repeated for a "dry" (0.10 quantile of PPT-ETA) year and for a "wet" (0.90 quantile of PPT-ETA) year. The former indicates annual cell recharge values of 0.00 to 0.73 inches. The latter indicates annual cell recharge values of 3.50 to 4.56 inches.

Based on the above results, regulatory closure of CFA Landfill II will require the design and construction of a soil cap. Soil materials that contain more silt and clay than Layer 1 material will be required to economically construct a cap. In addition, ground surface sloping and a properly selected cover crop of grasses should be incorporated into any prudent design of the soil cap.

2. PROJECT OVERVIEW

2.1 Introduction

Landfill II at the Central Facilities Area (CFA) of the Idaho National Engineering Laboratory (INEL) has been identified as a Land Disposal Unit under jurisdiction of the Resource Conservation and Recovery Act (RCRA). This inactive sanitary landfill currently is under investigation by EG&G Idaho, Inc., a process that includes testing and evaluation leading to compliance with regulations outlined in 40 CFR 265.90. These regulatory guidelines require all Land Disposal Units operational after 1980 to have a ground-water monitoring system to detect any possible release of hazardous constituents into the environment.

The current phase of the EG&G program, known as Phase II, is being conducted primarily by the Geosciences Unit of EG&G. To help achieve compliance with RCRA ground water monitoring guidelines, this phase addresses the hydrogeologic characteristics of the landfill site. As part of this effort, EG&G has contracted with the University of Idaho to provide technical expertise in the specific areas of characterizing the physical properties of the existing soil cover at CFA Landfill II and estimating the annual water infiltration through the cover. Water that passes through the cover is recharge for the ground water system, which will react with the waste to generate and transport leachate.

2.2 Statement of Problem

Prior to June, 1989, little geotechnical information was available for the soil cover at CFA Landfill II. It was believed to be 2 to 6 ft. thick and generally comprised of a gravelly sand with some silt (Ansley, et al., 1988). Major questions concerned the spatial variability of the cover thickness, the homogeneity of the soil material within the cover, and the water storage characteristics of the cover soil. In using the term "soil" in this context, we recognize that the landfill cover "material" is not a natural, geologic soil because it has been excavated, transported, and emplaced at the site. However, we have adopted a more engineering viewpoint of a soil, defining it as the unconsolidated, particulate material that overlies bedrock and contains mineral and/or organic compounds.

To estimate expected annual infiltration of natural water (i.e., precipitation in the form of rain, hail, or snowmelt) through the soil cover, the following information for soil-water balance computations is required:

1) Annual precipitation,
2) Estimate of evapotranspiration,
3) Thickness of the soil cover,
4) Percent by volume of the fines (i.e., particles less than 2 mm in diameter), assuming that the fines store all or practically all the soil water, and
5) Estimates of the water retention capability of the cover soil.

Such computations should be based on extremely local conditions (when possible) rather than on average values across the study site. This is due to the fact that spatial variability in soil characteristics has been observed even for carefully constructed man-made compacted soil fills (Rogowski and Simmons, 1988).

2.3 Project Objectives

The primary objective of this project was to spatially characterize the soil cover at CFA Landfill II and then use this characterization in conjunction with historical weather data to spatially estimate the annual water infiltration through the soil cover. To achieve this ultimate goal, the following objectives also were defined:

1) Collect and summarize available historical, operational, and geologic information pertaining to the site;

2) Make in-situ measurements of soil properties, collect soil specimens for later laboratory testing, and estimate hydraulic properties using laboratory tests on undisturbed cores;

3) Evaluate methods for collecting undisturbed specimens of cohesionless, granular soils for subsequent laboratory tests;

4) Produce spatial estimates of cover thickness, surface topography, and percent finer than 2 mm using geostatistical interpolations;

5) Collect, evaluate, and analyze available meteorological data to provide input to soil-water balance computations leading to estimates of water storage in the soil cover; and

6) Produce spatial estimates of annual infiltration through the soil cover based on several different assumptions for annual precipitation.

Spatial estimates of the annual water infiltration then can be used in subsequent studies to predict leachate formation and movement, leading to the design of a ground water monitoring network appropriate for prudent closure of this Land Disposal Unit.

2.4 Project Scope and Personnel

The University of Idaho submitted a proposal to the EG&G Geosciences Unit in early June, 1989, outlining this work plan. The initial contact with EG&G was established by Mr. L.F. Hall, who had been a summer employee for the Geosciences Unit and was concurrently pursuing a Master of Science degree in geology at the University of Idaho. The proposal was submitted jointly by the Idaho Water Resources Research Institute and the Department of Geology and Geological Engineering.

Principal investigators for the project were Dr. Stan Miller, Associate Professor of Geological Engineering, and Dr. John Hammel, Associate Professor of Soil Physics. They were assisted by L. Flint Hall, M.S. Geology candidate, and Dr. Dale Ralston, Professor of Hydrogeology. Profs. Miller and Hammel made an initial site visit to INEL in late June, 1989, to discuss and refine the project proposal with EG&G personnel. Technical specialists from the EG&G Geosciences Unit involved with this project included: Martin Doornbos, Shannon Ansley, Larry Hull, and Buck Sisson. A contract was issued by EG&G to the University on July 24, 1989 (Task Order No. 51, Special Research Contract No. C85-110544), to authorize and fund this project.

Work completed under the contract included the following: review and evaluation of available information about the site (July - December, 1989); field measurements and sample collection (summer, 1989); analysis of field data (September, 1989 - February, 1990); laboratory testing of soil specimens (October, 1989 - May, 1990); analysis and interpretation of soil-cover testing results and meteorological data (December, 1989 - May, 1990); computation of water storage and infiltration through the soil cover (April - May, 1990); report preparation (May, 1990). Although the contract period terminated on May 30, 1990, a final project meeting and discussion of results has been scheduled for early June, 1990, in Idaho Falls.

3. SITE DESCRIPTION

3.1 History of Landfill Operation

CFA Landfill II is located in the southwest corner of an abandoned gravel pit, northeast of the Lincoln Boulevard and Portland Avenue intersection, and north of the Central Facilities Area (Figure 3.1). This region of the gravel pit was originally opened in the late 1940's or early 1950's. Waste disposal began in early 1970 at the far southwest corner of the pit, progressing west to east across the southern pit boundary to a service road approximately 900 ft east of Lincoln Boulevard. Operations progressed northward to eventually cover an area of about 12 acres when the facility closed in September, 1982.

It was standard practice for a single equipment operator to be assigned to the landfill during the day. After refuse was dumped at the edge of the pit, the operator compacted wastes into layers 12 to 24 in. thick which sloped northward into the pit. Compacted waste was covered with at least 6 to 8 in. of soil at the end of the day. Material for intermediate cover was scraped from the pit bottom and a previously unexcavated region beneath power lines just north of the landfill. The texture of cover materials was generally sandy to sandy gravel. After landfill closure finer-grained overburden material, previously stockpiled at the opening of the gravel pit, was used for a finer-grained cap having a thickness of between several inches and several feet.

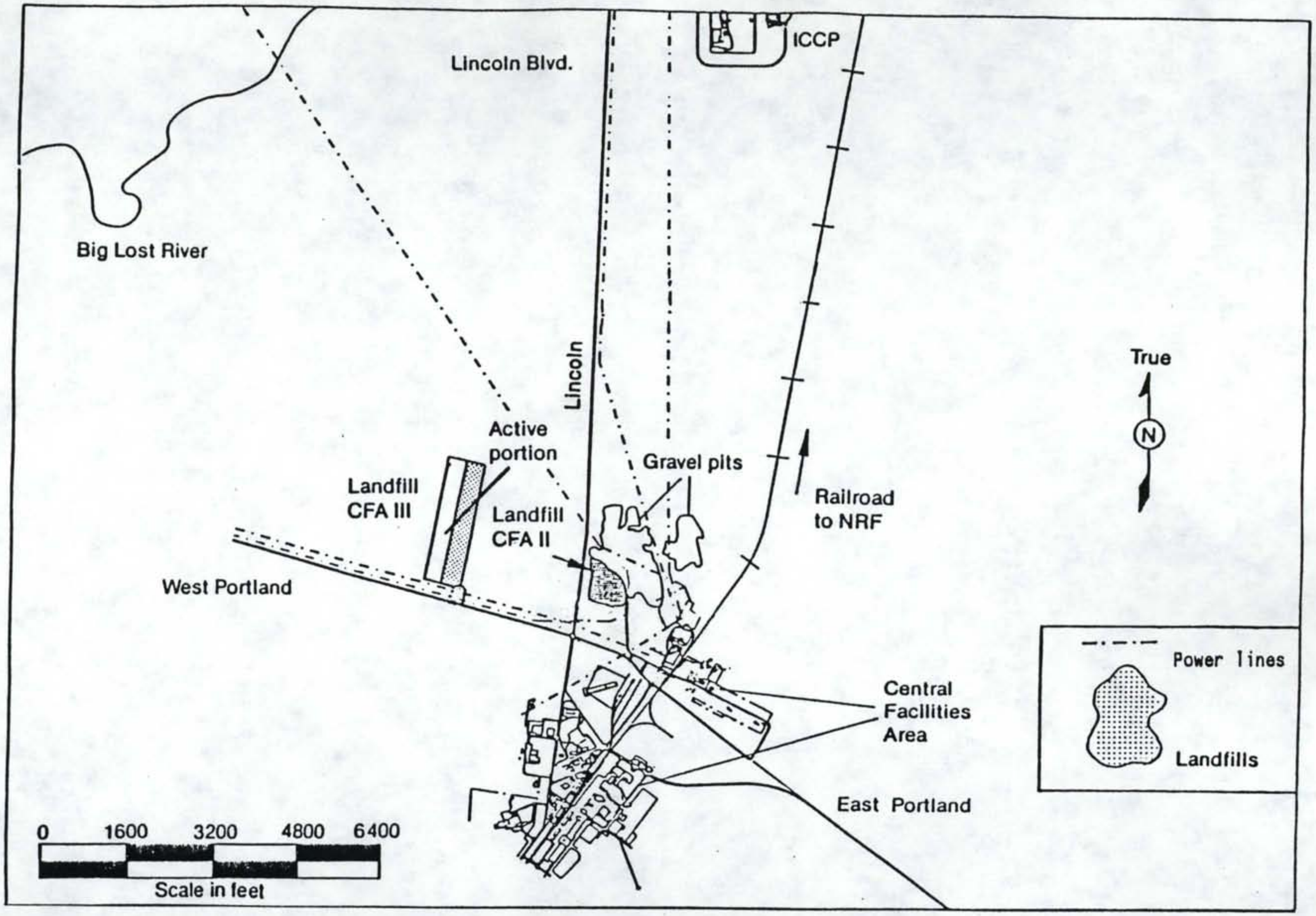

Figure 3.1 Map showing INEL Central Facilities Area and CFA Landfill II.

The disposal area is bordered on the south and west by a system of grid markers used by equipment operators to identify locations when logging the wastes received. Depth to the bottom of the landfill is estimated to be 12 to 14 ft in the south, and slightly deeper towards the north. The pit probably was not excavated beyond the base of the gravel-bearing unit. An equipment operator, periodically assigned to CFA Landfill II throughout its operation, suggested that gravelly or sandy materials are likely present beneath the wastes (Olsen, 1989). This conflicts with an assumption drawn from a previous interview with an equipment operator (Peterson, 1989, cited by Wood, et al., 1989), indicating that landfill waste material rests directly on basalt in some locations beneath the landfill.

The major gravel-bearing unit extends to depths of 15 to 18 ft below the surface, based on lithologic logs for wells LF2-1, 2, 8, 9, 10 (Ansley, et al., 1988) located along the southern and western margins of the landfill (Figure 3.2). A fine to medium sand and sandy-clay or silt unit is logged beneath the gravel in wells LF2-1, and 2. All wells showed a clay unit overlying the basalt. For example, well LF2-8 showed about 1-2 ft of clay resting on basalt, overlaid by 10 ft of silty-sand. Logs for wells LF2-8, 9, and 10 only differentiate between the clay and gravel units. It can be assumed that the fine to medium sand and sandy-clay unit also is present in wells LF2-8, 9, and 10, and can be extrapolated as at least partially intact beneath the entire landfill.

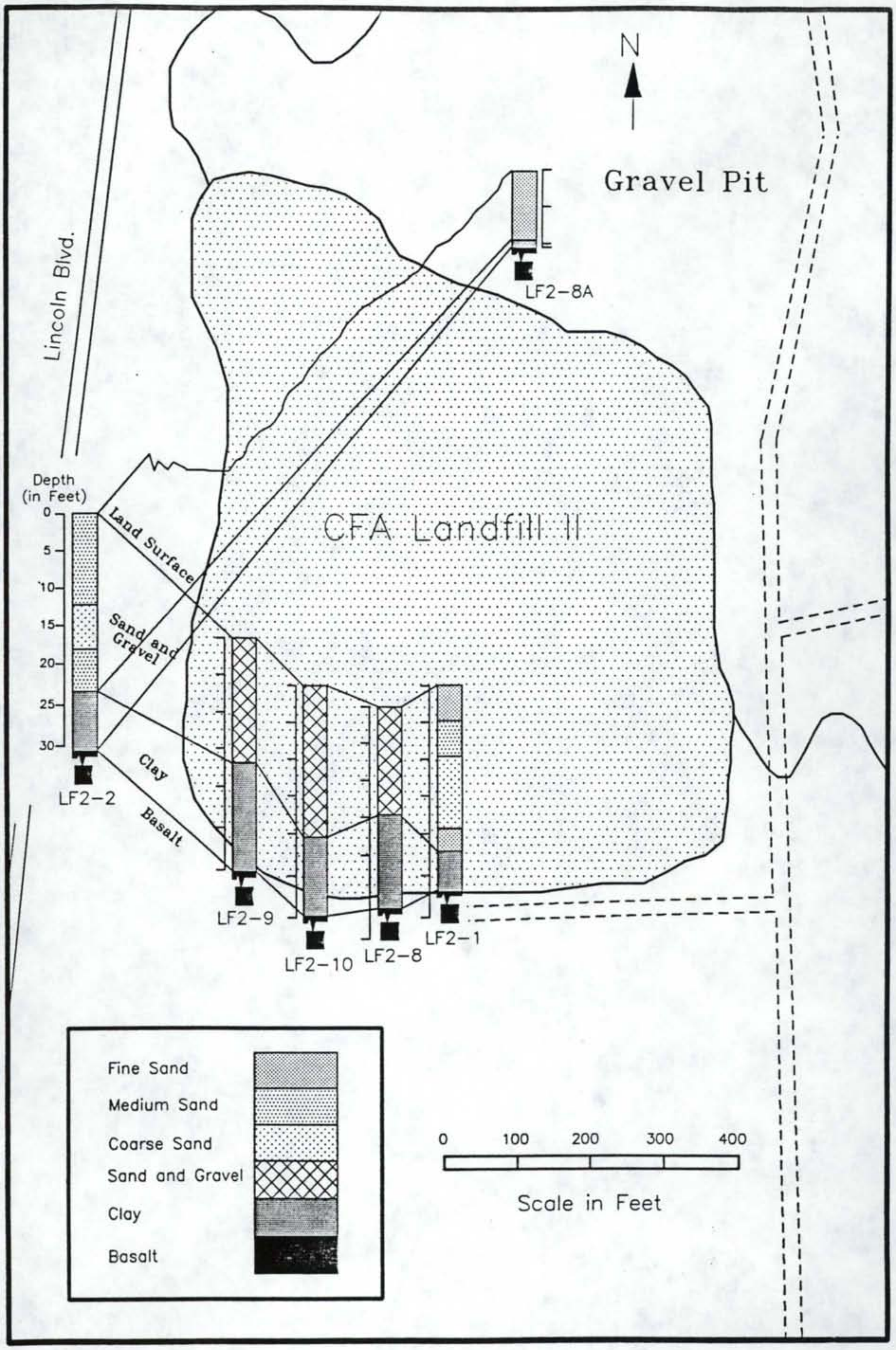

Figure 3.2 Summary of borehole geologic logs (from Ansley, et al., 1988).

3.2 Regional Geology

The INEL is located on the eastern portion of the Snake River Plain, an anomalous physiographic depression extending across Southern Idaho from the Oregon border to the Yellowstone Plateau. The Eastern Snake River Plain (ESRP) is described by Maybey (1982) as a crustal downwarp with minor faulting along the margins. The ESRP is a bimodal volcanic province characterized by voluminous rhyolite tuffs and lavas with associated caldera collapse, overlain by basalts and interbedded sediments. Material is dominated volumetrically by rhyolites, which are present in thicknesses greater than 8200 ft. The basalts and interbedded sediments form a veneer generally 2000 to 3000 ft thick over the earlier rhyolites (Ansley, et al., 1988).

The surface of the Eastern Snake River Plain is composed largely of Pleistocene and Neocene basalt, commonly blanketed with 1.5 to 3.3 ft of Pleistocene loess (Lewis and Fosberg, 1982). Basalt in the vicinity of the INEL appears to have erupted from numerous vents displaying two general trends. The first is a northwest-southeast alignment roughly perpendicular to the trend of the Snake River Plain and in general alignment with active basin and range normal faulting. The second is parallel to a topographic high forming a divide along the axis of the plain, paralleling the overall northeast trend of the Snake River Plain-Yellowstone Plateau volcanic province (Spear and King, 1982). Basalt flows on the INEL reveal eruption ages between 12,000 and 400,000 years before present (b.p.). The Hell's Half Acre flow immediately south of the INEL has been dated at 4100 years b.p. The most recent Eastern Snake River Plain volcanism occurred approximately 2100 years b.p. at the craters of the Moon National Monument, about 25 km southwest of the INEL.

Fluvial and lacustrine sediments associated with flood plains and playa lakes of the Big Lost River, Little Lost River, and Birch Creek drainages are present on the portion of the Eastern Snake River Plain occupied by the INEL. These sediments consist of sands, silts, clays, and gravels derived from source areas in the White Knob, Lost River, Lemhi, and Beaverhead ranges, and local basalts of the SRP. Clasts are composed of sedimentary materials, volcanics, intrusives, and limestones. These deposits formed during the period of much greater discharge associated with late Pleistocene glaciation (Pierce and Scott, 1982).

Alluvium in the area of CFA Landfill II can be divided into two stratigraphic units. The uppermost unit is a poorly sorted sand and gravel with little silt or clay-sized material in the matrix, approximately 15-20 ft thick. This unit represents outwash and main stream gravel deposits of the Big Lost River. Beneath this is a discontinuous clay to silty clay, 1-6 ft thick, interpreted as loess (Wood, et al., 1989). Depths to basalt in the area are generally 25 to 35 ft (Ansley, et al., 1988; Wood, et al., 1989), as shown in Figure 3.2. Alluvium rests on a jointed, vesicular basalt.

The material used for cover at Landfill II was derived primarily from gravelly deposits of the Big Lost River. The particle size, lithology, bulk mineralogy, and cation exchange properties of Big Lost River deposits have been addressed by numerous authors. Studies conducted by the United States Geological Survey are summarized by Bartholomay, et al. (1989). These investigators determined bulk mineralogy by x-ray diffraction for a suite of 11 samples of Big Lost River channel deposits. Minerals present in order of decreasing abundance were, quartz, plagioclase and potassium feldspar, pyroxene, detrital mica, calcite, and dolomite. Clay minerals, smectite, kaolinite, and illite were detected in three of eleven samples. Table 3.1 summarizes the bulk mineralogy of the samples analyzed. Additional geologic information was presented by Bartholomay (1990).

Table 3.1 Summary of statistical measures of bulk mineralogy of Big Lost River channel deposits (after Bartholomay, et al., 1989).

Mineral:	Minimum % by weight	Maximum	Median	Mean
Quartz	32	45	38	38
Plagioclase feldspar	16	30	23	24
Potassium feldspar	6	18	12	13
Calcite	0	6	3	3
Pyroxene	8	14	12	11
Dolomite	0	3	0	0
Detrital micas and total clays	8	14	10	10

The cation exchange capacity of soils in the vicinity of CFA Landfill II has been quantified by Nace, et al. (1956). Their findings suggest that CFA area soils have an extremely low exchange capacity, reflecting the coarse-grained nature of the sediments. The ability of a soil to retain or exchange ions with soil water is quantified by its cation exchange capacity. The affinity of a soil for various cations is limited by its surface area and dnesity (Bohn, et al., 1979).

3.3 Regional Climate

The regional climatology for the INEL, and specifically the CFA location, has been summarized by Clawson, et al. (1989). Briefly, Landfill II is located near the CFA, which is the location of a meteorological station designated as NCDC Idaho Falls 46 W. The elevation of CFA is 4938 ft (1506 m). Based on average data from the 30-year period of 1951-1980 for this site (Clawson, et al., 1989), the mean annual temperature for the location is 42.0 F (5.6 C) and the mean annual precipitation is 8.62 in. (21.9 cm). Approximately 70 percent of the annual precipitation occurs from October through May. Peak precipitation occurs in May and June, which is due primarily to regional major synoptic conditions. Average precipitation for each of these months is approximately 1.2 in. (3.0 cm).

3.4 Previous EG&G Work

Recent investigations by the Geosciences Unit of EG&G pertaining to CFA Landfill II have been summarized primarily in two reports: Ansley, et al. (1988) and Wood, et al. (1989). Various references to these two documents have already been made in this text. The latter report briefly discusses the operational history of the landfill and the local stratigraphy, but it primarily addresses concerns and requirements for a ground water monitoring system. The first report focused on a shallow drilling program consisting of boreholes located adjacent to the backfilled CFA Landfill II pit. The holes were equipped with access ports and instrumented with moisture and contaminant sensing probes. Subsequent data collection in 1988 from the neutron moisture probes indicated that no significant water movement occurred through the surficial sediments below a depth of 6 ft. In addition, chemical analyses of soil specimens showed significant amounts of acetone and methylene chloride, suggesting that some leachate possibly is being generated in the landfill. Gas sampling also showed positive results for several contaminants, but not enough evidence was available to conclusively indicate leachate migration.

Materials testing of the surficial soils reported by Ansley, et al. (1988), included particle size analyses for specimens collected at various depths in six of the boreholes at Landfill II. Specimens collected at depths of 5 ft or less had D50 sizes from 0.20 to 9.00 mm, and values of percent-by-weight finer than 2.0 mm that ranged from 22 to 85 percent. Other material properties for sediments at similar depths are summarized as follows: moisture content--1.93 to 13.2 percent; bulk density--1.54 to 2.05 Mg/m^3; saturated hydraulic conductivity--0.237 to 0.029 cm/sec.

As part of an innovative technology demonstration at INEL, a geophysical investigation recently was conducted by ICF Technology, Inc., at CFA Landfill II (ICF Technology, Inc., 1989). Terrain conductivity, time-domain electromagnetic induction, ground penetrating radar, and soil gas measurements were the geophysical methods applied in this study. Results of the investigations provided information about the boundaries of the landfill (depth and areal), locations of contaminant "hot spots" and buried metal objects (such as drums containing chemical wastes), and geologic stratigraphy beneath the landfill. The average thickness of the landfill was reported as 14 ft over an estimated total area of 14.9 acres. No significant information was reported for characteristics of the soil cover.

4. FIELD INVESTIGATIONS

4.1 Measurements of the Soil Cover

A total of 61 sampling sites were selected across CFA Landfill II using a regular hexagonal grid supplemental with several randomly placed sites (Figure 4.1). Each sample site was located to within 2 ft of its intended grid location and then identified with a survey marker. Physical properties that influence the water storage capacity of the landfill cover were estimated at these locations. Field measurements of the soil cover included the following:

1. In-situ density and moisture content at all sample locations using a nuclear density gauge (neutron densometer).
2. Cover thickness by augering.

A total of 118 in-situ density and moisture content measurements were taken at 61 sample sites across the study area with a Troxler 3400 nuclear density gauge. A standard count was performed prior to entering the field each day at the EG&G Materials Testing Laboratory, adjacent to the landfill site. Sampling procedures are summarized below:

1. Each site was prepared for use of a surface nuclear/density/moisture gauge following ASTM D-2922, and ASTM D-3017.
2 Measurements were taken at 4 and 8 in. depth, within 3 ft of the sample location marker. In the event that conditions prevented a measurement at 8 in. depth, readings at 6 in. were obtained.

A portable, two-person, gasoline-powered posthole auger with a 4-in. diameter bit, and a 3.5-in. diameter hand-auger were used

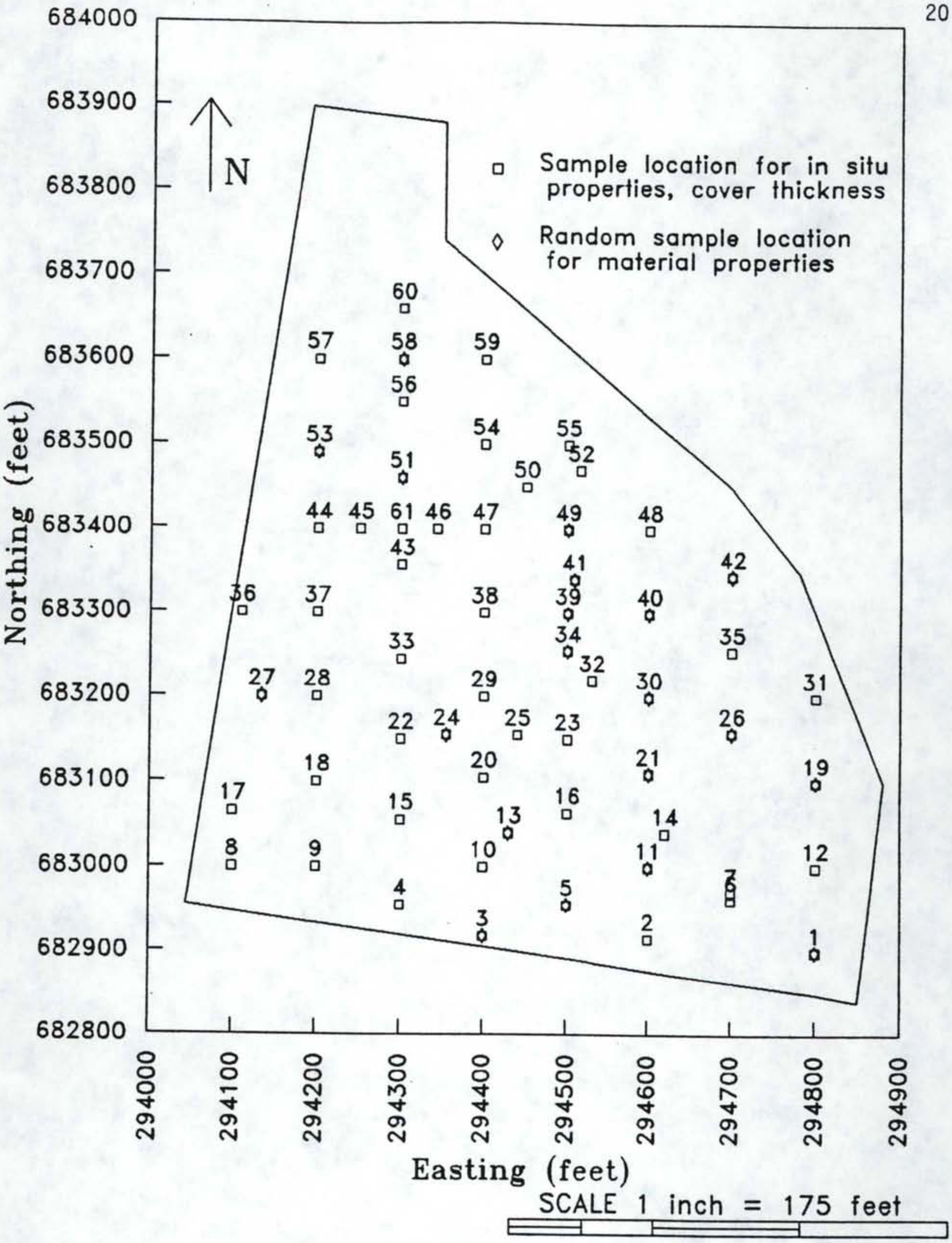

Figure 4.1 Sampling sites for measuring soil cover properties at CFA Landfill II.

to determine cover thickness at sample locations numbered 1 through 60 (Figure 4.1). Augering continued until waste was encountered or the auger would not advance. The hole and the removed material were surveyed periodically by a health physicist (HP) and an industrial hygienist (IH) for radioactive and organic vapor hazards. Wastes that were encountered were not removed from the hole. Material samples were collected with the hand auger from 19 of the holes (noted on Figure 4.1) for subsequent laboratory analysis.

Procedures to measure the cover thickness are summarized below:

1. The power auger was used to open a hole into the surface of the cover. A new location was chosen within 3 ft of the sample location marker if concrete, asphalt, or rocks were struck at a relatively shallow depth and prevented further auger advance.
2. The hand auger then was used to clean the hole and auger deeper until waste was encountered or the hole was blocked.
3. The hole was back-filled with a mixture of native soil and bentonite.

4.2 Collection of Soil Specimens

The field sampling program to collect soil specimens for subsequent laboratory testing consisted of two parts: 1) collection of specimens for moisture content and particle size analysis, and 2) collection of undisturbed, intact specimens for mass-volume calculations and hydraulic testing.

Soil specimens used for measuring gravimetric moisture content and for particle size analyses were collected at 19 sites randomly selected from the 60 auger sites. Initially, specimens from 20 sites were planned, but one was not sampled due to the detection of unidentified vapors. Cover material was hand augered with a 3.5-in. bucket auger, and specimens were collected andbagged at approximately 1-ft increments. Augering continued until waste was encountered or the hand auger could no longer be advanced. Soil material removed from each augered hole was surveyed by an HP and an IH for radioactive and organic vapor hazards. Material was inspected for waste prior to being transferred to the sample bag. The auger sample was returned to the hole if wastes were encountered. Sampling procedures are summarized below:

1. Augering was initiated at the center of the small, flat pad, which had been constructed and used for the nuclear gauge readings. Material recovered in the auger was transferred to a plastic sample bag. The top of the bag was closed during periods when additional materials were being augered to reduce evaporation losses.

2. At the completion of each 1-ft interval, the sample volume was mixed and a random 300-500 g subsample was collected in a metal can. The can was sealed with tape, bagged, and placed in a portable cooler for gravimetric water content analysis in accordance with Geoscience standard G-103 (EG&G) and ASTM D-2216. The remaining sample was sealed and double-bagged for later particle size analysis.

3. The depth was recorded at which wastes were encountered or at which augering could not continue.

4. The hole was backfilled with a mixture of native soil and bentonite.

The collection of intact soil specimens included both driven cores and trimmed block samples. Eight casted soil blocks and four driven, thin-walled tube soil cores were collected. A trial casted soil block was taken from the bottom of the gravel pit directly north of the landfill in order to test proposed methods for sampling and handling undistributed soil materials. After the procedures were proven, the eight casted blocks were collected at locations where in-situ drainage tests were conducted (see Section 4.3). Driven cores were taken adjacent to four of the casted blocks.

The goal in preparing a casted block was to secure the soil in such a fashion that an intact specimen representing the cover material in an undisturbed state could be transported to the laboratory for estimation of volume-density relationships and hydraulic properties. The outer boundaries of the casted and driven specimens were surveyed by the HP and IH. Sampling procedures are summarized below:

A. Casted blocks

1. A small trench, 12 to 16 in. deep, was excavated completely around a square zone approximately 2 ft on a side. The upper 3 to 4 in. of dry, cohesionless soil were removed. The region was carved into a uniform, free-standing column with a circular cross-section and sides perpendicular to the ground surface. Column dimensions varied from 10 to 12 in. in diameter and 8 to 10 in. high.

2. Cheese-cloth and/or gauze was draped over the soil column and secured by strips of gauze wrapped around the sample perimeter. The top and sides of the wrapped column were coated liberally with a cellulose-acetate resin until the cloth was saturated. The column was allowed to dry overnight and then another wrapping of cheese-cloth and coat of resin was applied. The second wrapping was allowed to dry.

3. The excess wrapping was trimmed from the margin of the column with a shovel and pocketknife. The intact specimem was removed by forcing a shovel into the base of the column approximately 1 to 2 in. below the wrapped portion and then gently prying up. The column generally fractured clean, parallel to the bottom of the cast. The specimen then was placed on its top outside the excavation.

4. Cheese-cloth and resin then were applied to the bottom of the cylindrical block and allowed to dry.

5. The resulting hole, approximately 3 ft on a side and 16 in. deep, was backfilled with native soil and bentonite.

B. Driven cores

1. Driven cores were collected with 6-in. O.D. carbon-steel, thin-walled tubing, in accordance with ASTM D-1587. The upper 3 to 4 in. of loose, cohesionless soil were removed and the tubing was driven 8 in. into the ground with a modified post pounder. The sampling was done within a lateral distance of 2 ft from where the casted block was obtained.

2. The tube with its soil specimen was removed by excavating around the tube and prying with a shovel. The specimen was secured by packing foam and cardboard on both ends of the tubing.

3. The specimens were sealed with filament tape, then carefully packed for transport.

4.3 In-situ Drainage Tests

To estimate the total in-situ capacity of the cover soils, several in-situ drainage tests were conducted. The goal was to provide an upper limit on the amount of water stored in the soil after saturation and a subsequent drainage period.

These drainage tests were conducted at eight locations and were based on methods for determining field capacity described by Cassel and Nielsen (1986). Sites were chosen to represent various types of cover materials observed at the 19 sites where gravimetric water content and cover thickness had been measured. Each test was conducted by adding a volume of water sufficient to wet the cover material to a desired depth, approximately 1 to 2 ft. Then, sufficient time (3 to 4 days) was allowed for gravitational drainage.

Cover material then was hand-augered with a 3.5-in. bucket auger, and samples were collected and bagged at approximately 1-ft increments through the wetted depth. Samples were surveyed by the HP and the IH for radioactive and organic vapor hazards. Sampling procedures are summarized below:

1. A site within 3 ft of the previous augering was cleared of plants, debris and the upper 3 to 4 in. of soil. A 5-gal. bucket with the bottom removed was seated into the soil cover and loose soil material was piled around the base. The bucket then was filled with water and monitored for seepage, with more material added around the base (if necessary) to prevent water leakage. The water was allowed to infiltrate for 1 to 1.5 hrs, after which the bucket was refilled and its top covered with plastic to prevent evaporative losses.
2. After 3 to 4 days, the bucket was removed and the cover material was hand augered to provide samples bagged by 1-ft increments. The top of the bag was closed during periods when additional materials were being augered to reduce evaporative losses.
3. The sample was double-bagged at the completion of each 1-ft interval and placed in a portable cooler for gravimetric water content analysis in accordance with Geoscience standard G-103 (EG&G) and ASTM D-2216.
4. The augered hole was backfilled with a mixture of native soil and bentonite.

4.4 Meteorological Observations at the Site

Acquisition of meteorological data for soil-water balance estimations, specifically evapotranspiration, required a meteorological data base commonly maintained by NCDC sites, one of which is located at CFA (Idaho Falls 46 W). A temporary weather station at CFA Landfill II was erected for purposes of comparison of meteorological parameters between Landfill II and Idaho Falls 46 W. Meteorological parameters measured were total irradiance (solar radiation), wind speed, and air temperature. Hourly mean temperature, irradiance, and wind speed were measured along with daily values for mean, minimum, and maximum air temperature and wind speed. These parameters were recorded for the period from Julian day 182 through Julian day 206, 1989. A meteorological data base was obtained from NCDC Idaho Falls 46 W for the same period. Total irradiance data, which was not recorded in this data base, was obtained from USGS-RWMC for the same period.

5. LABORATORY TESTING

5.1 Soil Density and Moisture Content

Laboratory testing to measure density and moisture was conducted primarily at the EG&G INEL laboratories.

The specimens obtained by hand augering at the 19 sites mentioned in Section 4.2 were analyzed for moisture content at EG&G facilities immediately after returning from the field each day. The specimens were processed according to Geoscience procedure G-103 (EG&G) and ASTM D-2216. Laboratory procedures are summarized below:

1. The weight of the metal sample can plus moist soil was recorded.
2. The can and its soil were placed in an oven and allowed to dry for 24 hours at 103 °C.
3. The weight of the can plus dry soil was recorded, the soil was discarded, and the weight of the empty can was recorded. The weight of solids is the difference between these two weights.
4. The gravimetric water content was estimated as:
   $W = (\text{weight of water})/(\text{weight of solids})$.

The gravimetric water content of specimens obtained as part of the field drainage test also were processed at EG&G facilities immediately after returning from the field each day. Laboratory procedures are summarized below:

1. The entire soil sample of 2000 to 5000 g was transferred to a shallow metal pan.
2. The weight of the pan plus moist soil was recorded.
3. The pan and its soil were placed in an oven and allowed to dry for 24 hours at 103 °C.

4. The weight of the pan plus dry soil was recorded, the soil was rebagged for later analyses, and the weight of the empty pan was recorded. The weight of solids is the difference between these two weights.

5. The gravimetric moisture content was estimated as:
   W = (weight of water)/(weight of solids)

The bulk density and mass-volume relationships for the cover soils were obtained by laboratory measurements of the driven cores (see Section 4.2). These specimens were processed to measure the total volume, percent of total volume occupied by the sample fraction <2.0 mm, percent by mass <2.0 mm, and the relationship between percent-by-mass and percent-by-volume for sample fractions <2.0 mm.

Laboratory procedures are summarized below:

1. The soil volume within the steel tube was estimated using calipers to record the size and shape of the soil core.

2. After removing the specimen from the tube, the soil was oven-dried and processed for bulk density estimates (see below) and for particle size analyses (see Section 5.2).

3. The volume of the sample fraction ≥ 2.0 mm was measured by water displacement. The specimen was placed in a calibrated beaker and a known volume of water was added. Sample volume was estimated by the difference between the total volume and this added volume of water. Because of the size of the sample, this procedure was repeated for smaller subsamples until all of the original sample had been processed.

$$\text{Volume}_{\geq 2.0\text{ mm}} = \Sigma \text{ volumes displaced}$$

$$\text{Volume}_{< 2.0\text{ mm}} \text{ (incl. pores)} = \text{Volume}_{\text{Total}} - V_{\geq 2.0\text{ mm}}$$

$$\text{Bulk density}_{\text{Total}} = \text{Mass}_{\text{Total}} / \text{Volume}_{\text{Total}}$$

$$\text{Bulk density}_{< 2.0\text{ mm}} = \text{Mass}_{< 2.0\text{ mm}} / \text{Volume}_{< 2.0\text{ mm}}$$

$$\text{Percent by volume} < 2.0\text{ mm} = \text{Volume}_{< 2.0\text{ mm}} / \text{Volume}_{\text{Total}}$$

$$\text{Percent by mass} < 2.0\text{ mm} = \text{Mass}_{< 2.0\text{ mm}} / \text{Mass}_{\text{Total}}$$

Ratio of percent by volume to percent by mass <2.0 mm =

(% Volume < 2.0 mm) / (% Mass < 2.0 mm)

5.2 Particle Size Analyses

Excess soil material remaining after the moisture content tests on specimens collected at the drainage test sites was transported to the University of Idaho Soil Physics laboratory. Particle size analysis according to Geoscience procedure G-105 (EG&G) and ASTM D-421 was conducted from October, 1989, through January, 1990. Pipette or hydrometer procedures were not used due to the very small fraction of silt sized and smaller material. Laboratory procedures are summarized below:

1. A soil sample of 1500 to 4000 g remained after the moisture content tests of the drainage site samples. This entire sample was allowed to air-dry overnight.
2. The sample was transferred to a tray, the weight was recorded, and then the entire sample was transferred to a stack of sieves.
3. Soil was passed through 25.4, 19.1, 9.5, 4.75, 2.00, 1.19, 1.00, 0.595, 0.500, 0.250, 0.150, 0.106, and 0.063 mm standard sieves. Each sample was shaken mechanically for seven minutes isomg a Ro-tap shaker in two stages, with sieves >1.0 mm processed first. The portion passing the 1.0 mm sieve and retained in the pan then was transferred to the remaining sieves and shaken for an additional seven minutes.
4. The soil particles retained on each sieve were transferred to a tray to be weighed. Particles lodged in the sieve screens were removed by tapping the sides, brushing with a paint brush, or using a metal probe.
5. The sample was divided into ≥2.0 mm, and <2.0 mm fractions and rebagged.

5.3 Lithology of Clasts

The general lithology of clasts retained on the 25.4, 19.1, and 4.75 mm sieves was identified in soil material from sampling sites 5, 19, 27, and 58. Clasts were grouped into three distinct categories (calcareous sediments, non-calcareous sediments, and igneous rocks) based on hand-lens identification and reaction to dilute HCL. Laboratory procedures are summarized below:

1. Samples were washed with distilled water and examined with a hand lens. Clasts of apparent sedimentary origin were isolated from the igneous clasts.
2. Apparent sedimentary clasts reacting to dilute HCL were isolated from the other sedimentary clasts.
3. The clast groups were air-dried and then weighed to estimate percentages of each group contained in the sample.

Results from these studies are included with the results of the particle size analyses reported in Section 6.4.

5.4 Saturated Hydraulic Conductivity

The intact, undisturbed soil blocks were packed securely and then transported to the University of Idaho Soil Physics laboratory. These blocks were used to estimate saturated hydraulic conductivity. Sample preparation and handling methods were developed during preparation of the test specimens. Laboratory procedures are summarized below:

1. The intact specimens were removed from the packing material and approximately 500 to 600 ml deionized water was poured through holes punched in the casting material in the top of the intact block. The water was allowed to redistribute overnight.
2. The block was placed back inside the transport box and frozen at -40 °F for 24 hours.

3. The block was removed from the freezer and placed on its top. The bottom 1 to 2 in. was removed to produce a flat surface perpendicular to the original ground surface.

4. The intact specimen was inverted and placed on a linoleum board approximately 1-ft square. It then was trimmed carefully with a fine instrument to a uniform cylindrical shape with a final diameter of 6 to 6.5 in. Protruding rocks and loose material were removed to allow a section of schedule-40 PVC casing with an 8-in. I.D. and 7-in. length to fit over the trimmed core with 0.5 to 1 in. of annular space.

5. The casing was positioned to include the most uniform section of the core and to make sure the core was centered inside the casing. Paraffin heated to approximately 50 °C was poured into the annular space to form an initial seal at the base of the casing. After a sufficient seal had been formed, the annulus was filled to approximately two-thirds of the core length and allowed to cool. The remaining space was filled to the top of the casing and allowed to cool for about 20 minutes.

6. The paraffin was trimmed to expose the entire upper surface of the soil volume. Material passing 1.0 mm sieve was placed on the base of the core to ensure good contact with a screen to be added later. A disk of filter paper and a piece of nylon mesh were cut and placed over the core. A stainless-steel screen designed to fit snugly inside the casing was forced into the wax and secured to the casing by three rivets. Additional paraffin was added to seal between the screen and annular space. The core was allowed to cool several hours.

7. The casing containing the trimmed, intact core was inverted, and the top of the core was trimmed smooth. All cores were refrigerated until use.

8. Saturated hydraulic conductivity was measured for the cores by constant-head permeability techniques in accordance with Geoscience procedure G-107 (EG&G), and ASTM D-2434. Tests were run at 10, 20, and 30 cm heads.

5.5 Water Retention

Samples from the four drive-core sites were selected for estimating the capillary pressure-moisture content relationships according to ASTM D-2325. Materials <2.0 mm were packed to a density of 1.55 g/cm^3 into retaining rings with a 2-in. diameter and height of 1.5 in. and then saturated overnight.

Moisture contents were measured at capillary pressures of 100, 300, 500, 1000, 3000, 5000, and 15,000 cm-water (0.1, 0.3, 0.5, 1, 3, 5, and 15 bars). Laboratory procedures are summarized below:

1. Specimens were prepared and placed within a pressure-plate apparatus.
2. Sample repetitions for the 100 to 1000 cm-water range were allowed 48 hours to come to equilibrium. At equilibrium for each pressure the specimens were removed from the porous plate, weighed, and returned to the plate. At the 1000 cm-water pressure, the repetitions were weighed and removed from their retaining rings and transferred to metal cans to be oven dried for 24 hrs.
3. Sample repetitions for 3000 and 5000 cm-water pressures were prepared and conducted on the same plates. Repetitions for 3000 cm-water were allowed five days to come to equilibrium and then removed. The remaining repetitions were taken to 5000 cm-water and allowed an additional five days to come to equilibrium. Samples were removed from the apparatus and weighed, then transferred to metal cans to be oven dried for 24 hrs.
4. Sample repetitions for 15,000 cm-water pressures were allowed 10 days to reach equilibrium, after which they were removed, weighed and transferred to tared metal cans to be dried.
5. Weights of the empty retaining rings and the dry weights of sample repetitions were measured. The gravimetric moisture content of the soil, was calculated as:

   $$W = (\text{weight of water})/(\text{weight of solids})$$

Similar procedures were applied to the large intact cores which had been used for saturated hydraulic conductivity tests. Moisture contents were measured at capillary pressures of 100, 300, 500, and 100 cm-water. Soil removed from the intact cores was separated into fractions retained on and passing the 2.0-mm sieve. Volume of the sample ≥2.0 mm was estimated by water displacement. Total volume occupied by the core was estimated by filling the casing with a known volume of dry sand packed to a uniform density. Bulk density and volume relationships then were developed.

6. DATA ANALYSIS AND INTERPRETATION

6.1 Detailed Topography of the Soil Cover

Topographic data of the landfill soil cover were obtained by an EG&G contracted survey in the spring of 1989. The original data file provided by EG&G on a PC-compatible diskette contained 344 observation points but was culled to 191 points, which were located in the immediate area identified as Landfill II (Figure 6.1). The slope along the northeast boundary of the landfill was ignored to avoid problems associated with discontinuities in the spatial elevation data and to focus on the relatively flat surface of the landfill where subsequent soil sampling for landfill cover characterization would be conducted. The culled elevation data were approximately normally distributed with a slight negative skew. The mean elevation was 4931.4 ft and the standard deviation was 1.85 ft.

Geostatistical methods were used to interpolate elevation values to a finer grid than that used in the field survey. This finer grid would facilitate contouring of the ground surface and provide enhanced detail. Geostatistics is a branch of applied statistics that focuses on the characterization of spatial dependence in attributes and the use of that dependence to predict values of the attributes at unsampled locations. Spatial dependence implies that two data values from nearby locations are more alike than two values from distant locations. The typical function used to model spatial dependence is the variogram (or

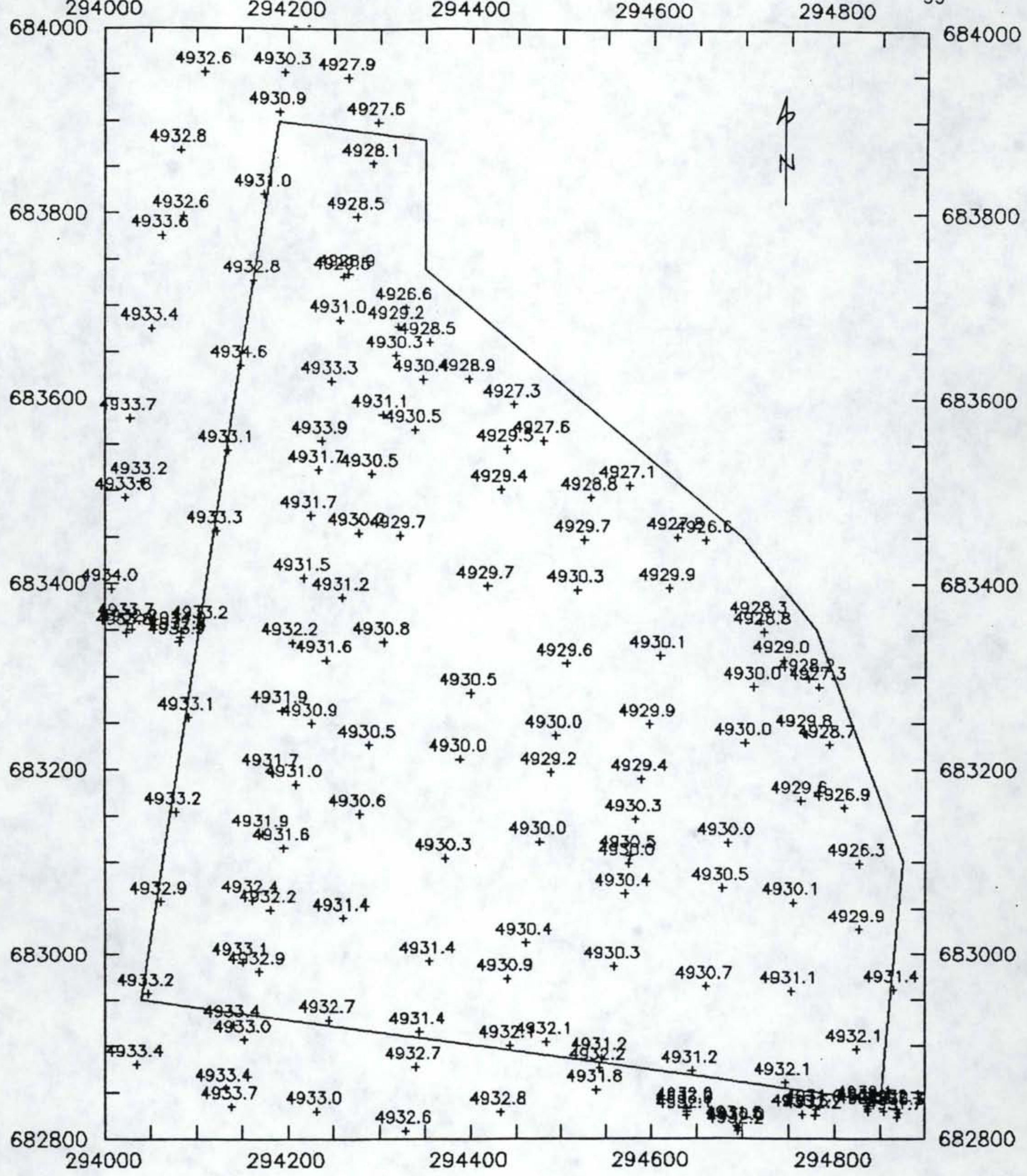

Figure 6.1 Measured ground surface elevations at CFA Landfill II from EG&G topographic survey of May, 1989.

more precisely, the "semivariogram"), whose values at various separation distances, h, can be estimated from a data set by computing one-half the average squared difference in paired sample values having an h separation distance. A plot of the semivariance as a function of h then can be generated. An acceptable variogram model is fitted to this plot and then used in a kriging system of equations to solve for an optimal set of sample weights to be used in interpolating values at unsampled locations. Excellent discussions of variograms and kriging interpolation methods have been given by Isaaks and Srivastava (1989).

Spatial dependence modeling and kriging estimation were accomplished using GeoEAS, a public-domain software package available from the U.S. EPA (Englund and Sparks, 1988). The elevation showed an anisotropic spatial dependency with a long range of influence (750 ft) in the N30W direction and a shorter range of influence (360 ft) in the N60E direction. Estimated variograms are shown in Appendix A. The GeoEAS ordinary point kriging routine was used to estimate elevation values on a 25 x 25 ft regular grid across the site. These grid points then were contoured to produce the topographic map shown in Figure 6.2. The ground-surface depressions in the central portion of the landfill initially were targeted for the installation of survey markers to monitor any settlement that may be occurring. However, after the field measurements of cover thickness showed many values less than 2 ft, the idea of installing markers was

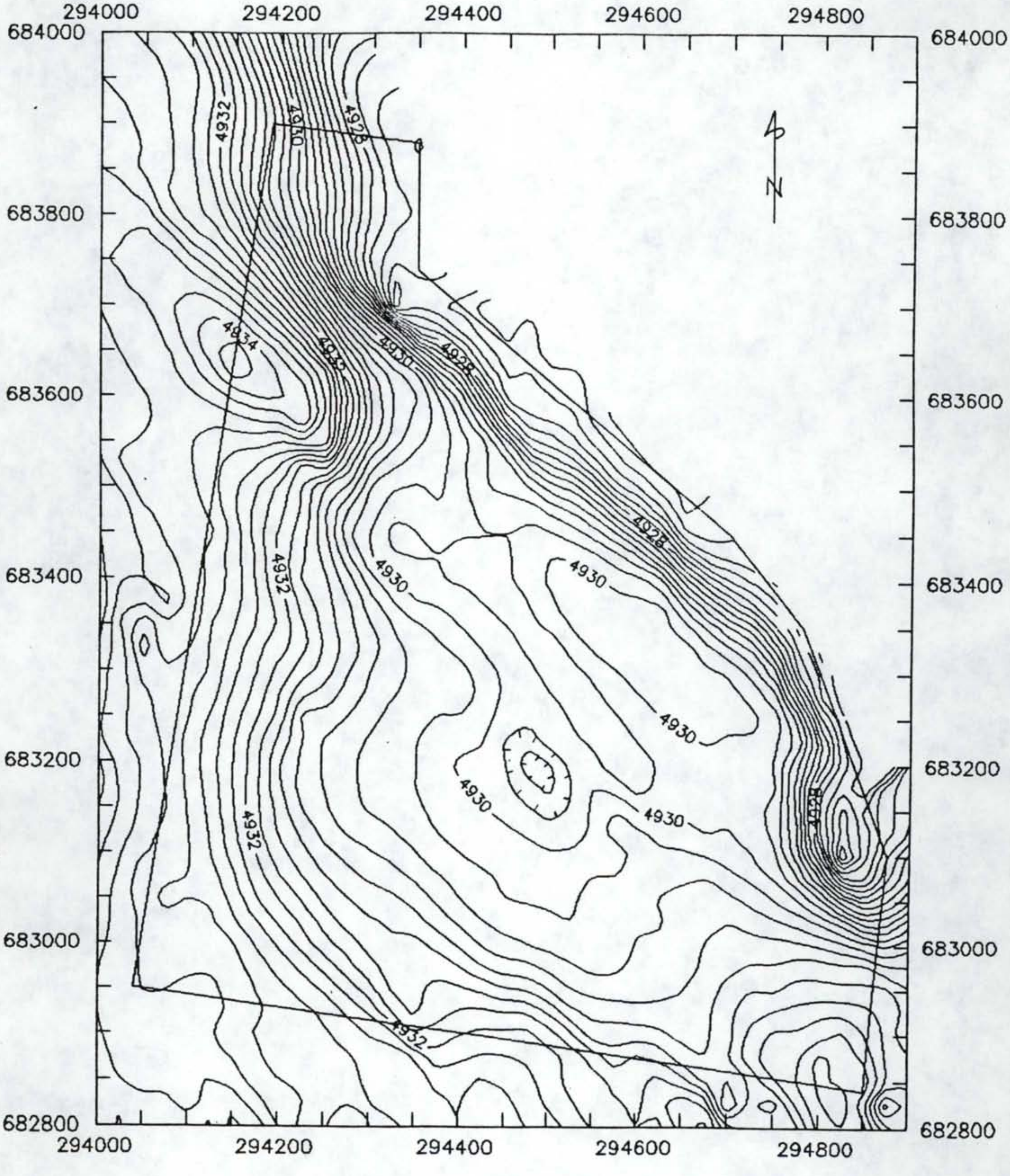

Figure 6.2 CFA Landfill II topography estimated by ordinary point kriging.

abandoned because the base of such installations would have penetrated into waste material.

6.2 Soil Density and Moisture Content

A summary of the 61 field-measured values of dry density and moisture content (obtained from neutron densometer) is presented in Table 6.1. The mean values agree well with those reported earlier by Ansley, et al. (1988).

A series of hypothesis tests was conducted to compare population means of these measurements at the various depth intervals. The results imply that 1) the dry density data reasonably can be grouped according to depth into a 4-in. population and a 6 to 8 in. population, and 2) the moisture content data are more difficult to interpret, but in general, the measurements at 4-in. depth are significantly different from those at 6 to 8-in. depths. A standard z-test or t-test was used where samples were large enough and/or where variances were similar; otherwise, a two sample, Smith-Satterthwaite t-test was conducted (Devore, 1987). Results of the hypothesis tests are summarized below:

Comparison	Type of Test	Results for Significance Level of 0.05
Dens. 4 vs. 6 in.	t-test	means signif. different
Dens. 6 vs. 8 in.	S-S t-test	means not signif.different
Dens. 4 vs. 8 in.	z-test	means signif. different
Mois. 4 vs. 6 in.	S-S t-test	means signif. different
Mois. 6 vs. 8 in.	S-S t-test	means not signif. different

Thus it is reasonable to group the measurements into two populations: one pertaining to a 4-in. depth interval and one to an 8-in. depth interval (combined 6 and 8 in. measurements). Figures 6.3 - 6.6 show the measured values of dry density and moisture content separated according to these two categories.

Gravimetric moisture contents were measured in the laboratory for those specimens collected at the 19 sites used for more detailed study (Figure 4.1). A total of 42 measurements were made, because several sites were represented by multiple specimens at various depths. A summary of these data is given in Table 6.2. The minimum and maximum values were 1.2 percent and 4.6 percent, respectively, with a mean of 2.55 percent and a standard deviation of 0.84 percent. These measured values agree well with those obtained in the field with the neutron densometer.

Table 6.1 Summary of insitu dry density and moisture content measured by neutron densometer in the soil cover at CFA Landfill II.

	Number of	Dry Density (Mg/m^3)				Moisture Content (%)			
Depth (in.)	Observations	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
4	61	1.81	0.12	1.51	2.02	3.1	0.64	2.0	5.1
6	14	1.91	0.13	1.71	2.11	2.7	0.39	2.2	3.5
8	41	1.98	0.09	1.76	2.14	2.9	0.66	1.8	4.8

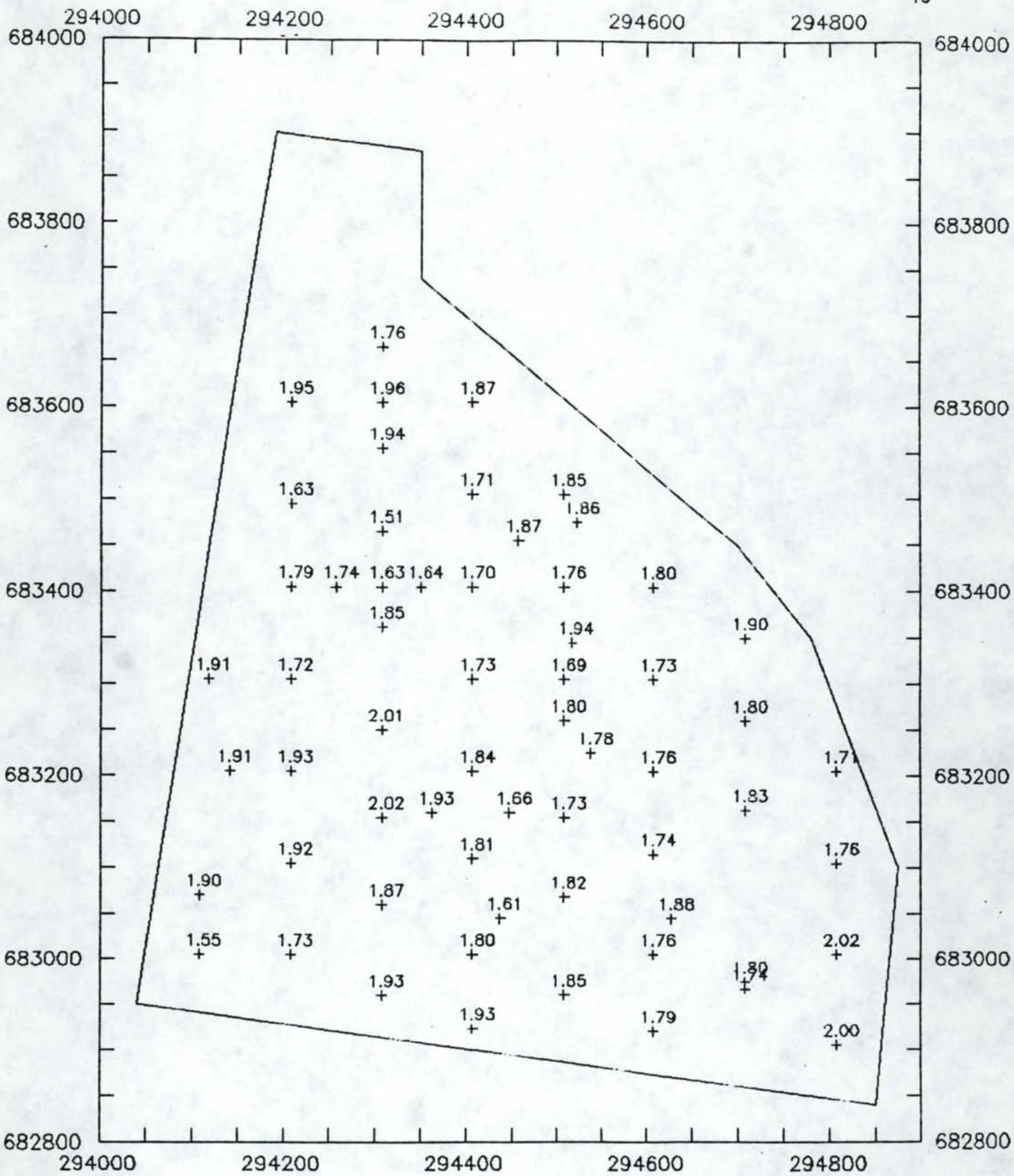

Figure 6.3 In-situ measurements of dry density (g/cc) at a depth of four inches.

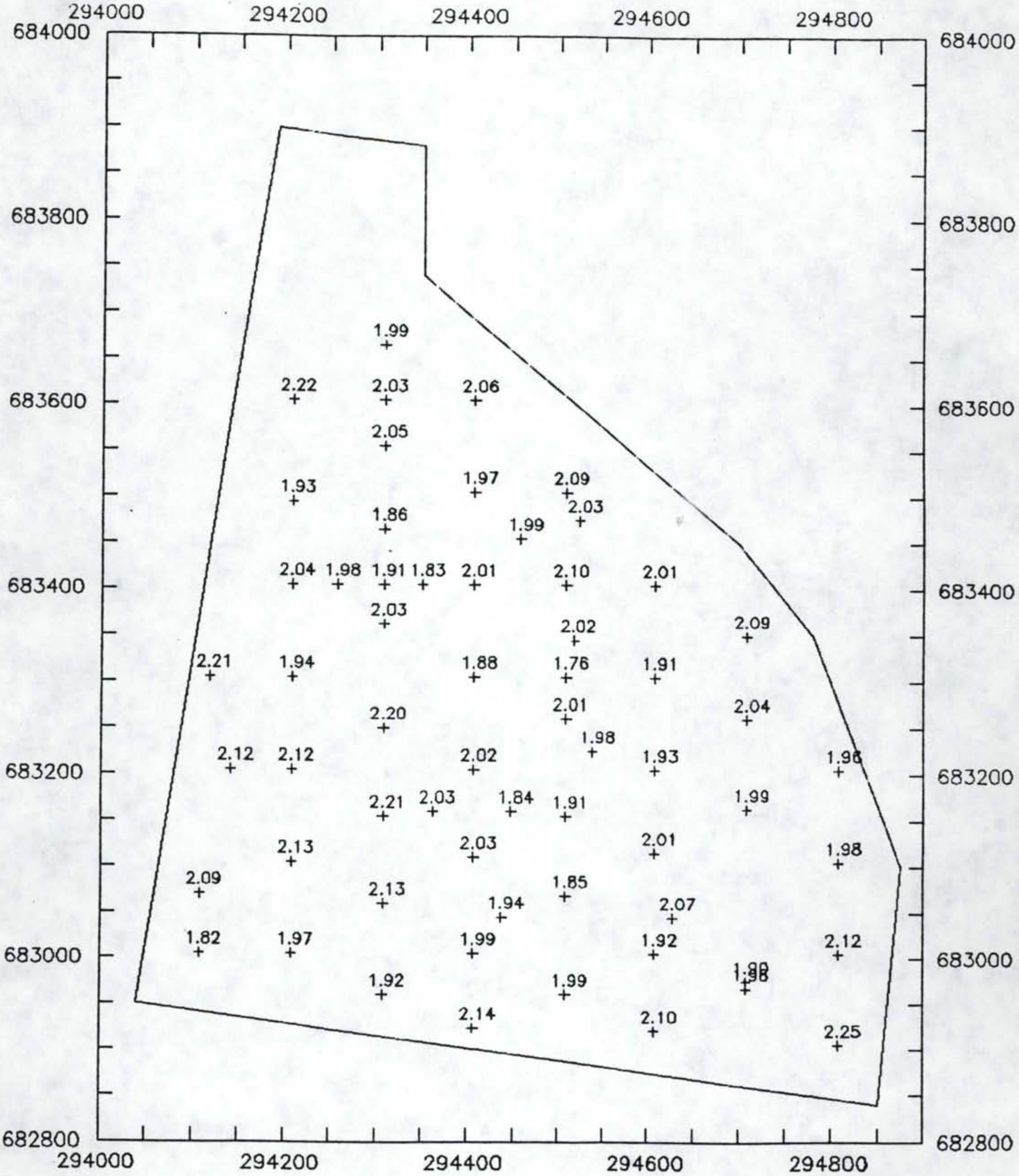

Figure 6.4 In-situ measurements of dry density (g/cc) at a depth of eight inches.

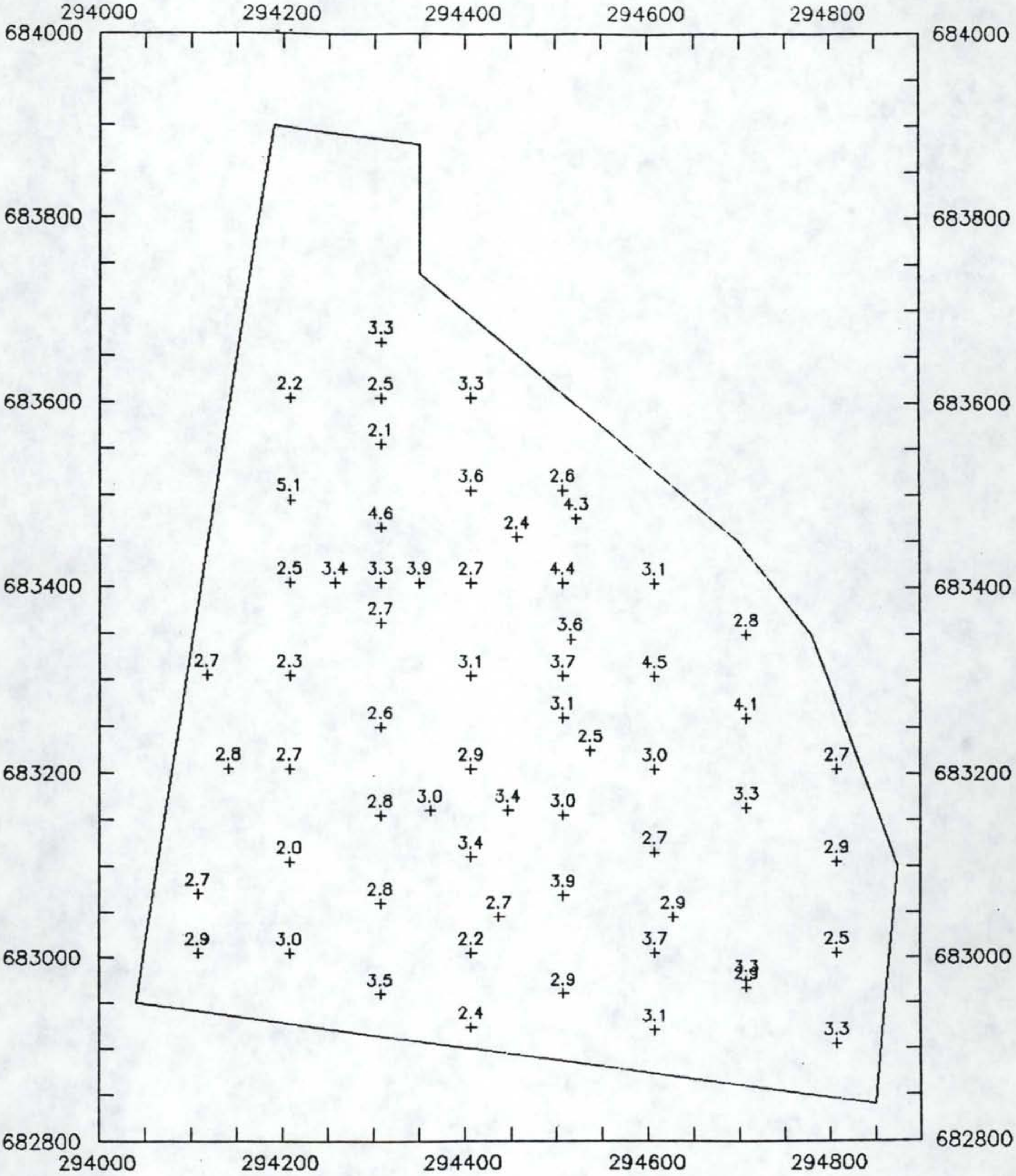

Figure 6.5 In-situ measurements of moisture content (percent) at a depth of four inches.

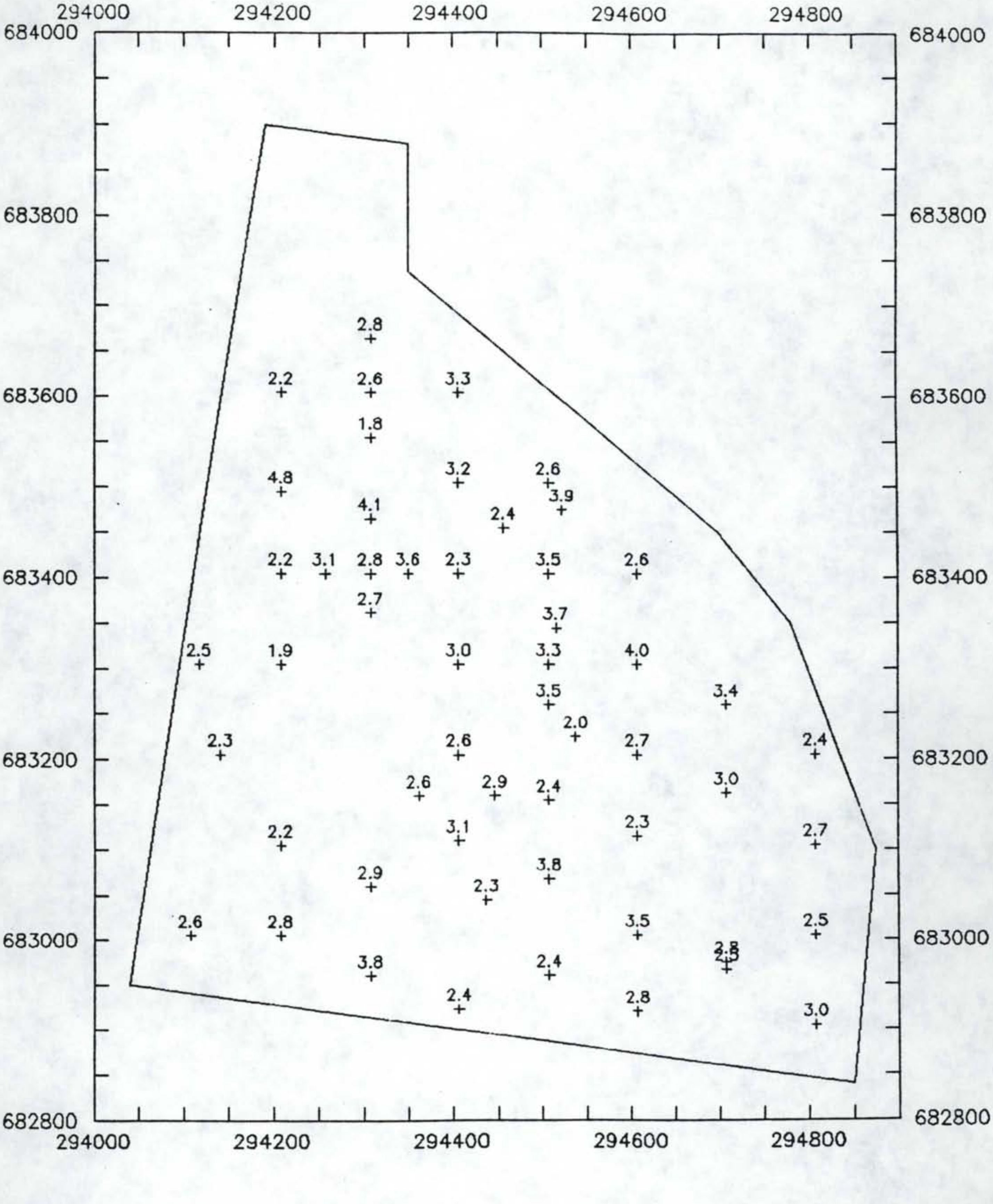

Figure 6.6 In-situ measurements of moisture content (percent) at a depth of eight inches.

Table 6.2 Summary of gravimetric moisture content measurements of soil cover at CFA Landfill II.

Sample	Number of Observations	Moisture Content (percent) mean	standard dev.	min.	max.
Layer 1 0 - 1 ft. depth	19	2.10	0.07	1.2	3.4
Layer 2 1 - 3 ft. depth	23	2.90	0.83	1.8	4.6
Overall	42	2.55	0.84	1.2	4.6

6.3 Thickness of Soil Cover

The thickness of the soil cover was estimated in the field using hand augers at 60 sampling sites (Figure 6.7). These measured thicknesses had a distribution positively skewed with a sample mean of 1.50 ft and a standard deviation of 0.69 ft. The minimum and maximum values were 0.33 ft and 3.17 ft, respectively. The variogram estimated for the thickness data indicates isotropic spatial dependence and a range of influence of 160 ft (Appendix A).

The block kriging routine in GeoEAS was used to estimate the average cover thickness in 50 x 50 ft cells across the site. We

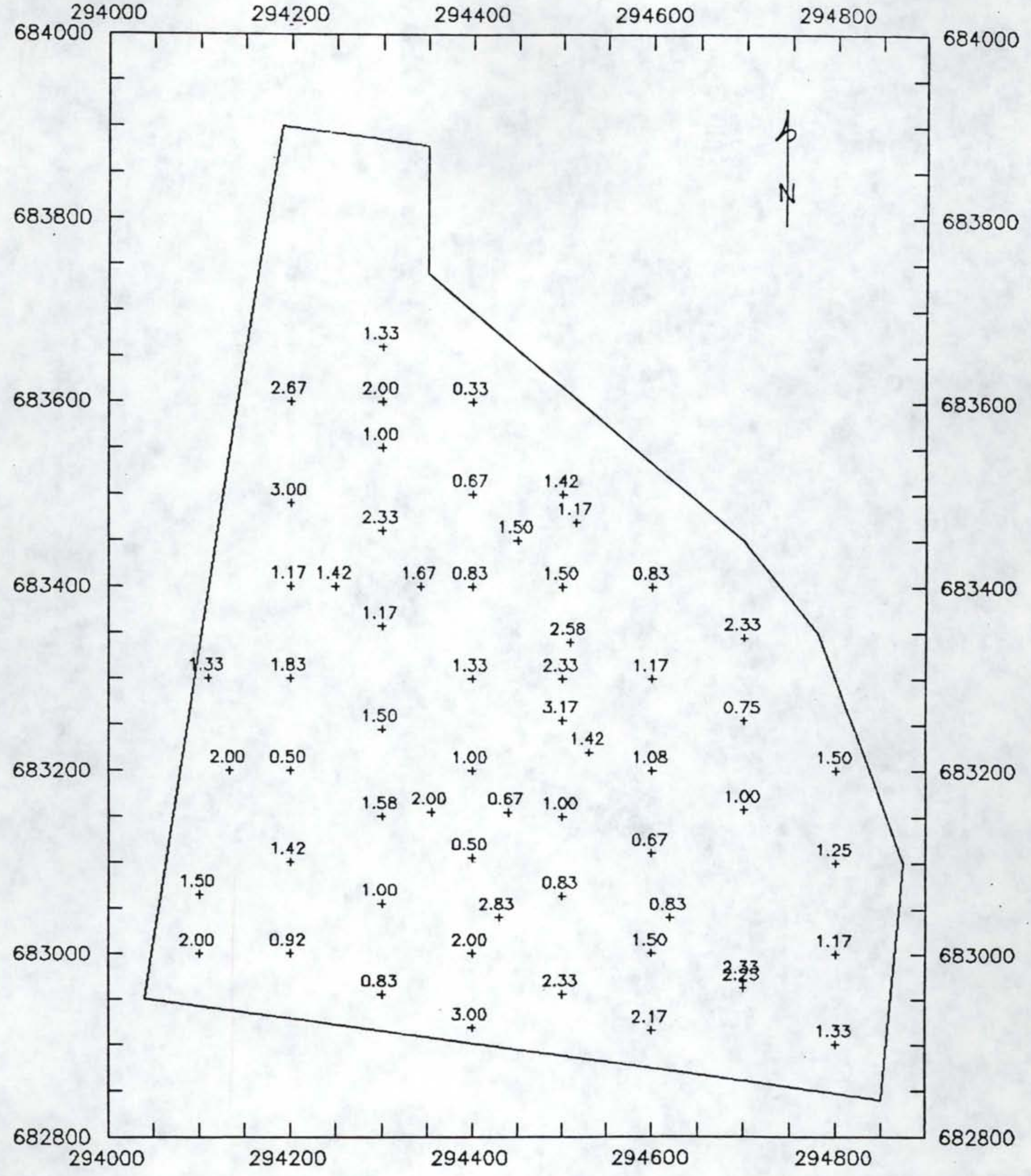

Figure 6.7 Measured thickness (ft) of soil cover at CFA Landfill II.

selected this cell size (which will be used for water infiltration estimates) because it provided sufficient resolution of the cover but not an unmanageable number of grids to analyze. Figure 6.8 shows an overlay of the 229 cells on the sampling locations. The block-kriged estimates of cover thickness are presented in Figure 6.9, where each plotted value is located in the center of a cell. This type of kriging tends to "smooth" the spatial attribute of interest, as can be seen in a comparison of Figures 6.7 and 6.9.

6.4 Particle Size Analyses

Distributions of particle sizes were estimated for 42 specimens collected from 19 specified locations (Figure 4.1). The specimens represent continuous sampling at 1-ft increments for the entire thickness of the cover at any given sample location. Statistical analyses of the particle size data suggests that gravel content of the cover material increases with depth. The cover can be subdivided crudely into an upper and a lower unit, based on percentages of sand and gravel present. Layer 1 is defined as the 0-1 ft depth, and Layer 2 as the depths greater than 1 ft. A summary of the particle size distributions is presented in Figure 6.10, with individual plots given in Appendix B. Table 6.3 summarizes the particle size distributions for the cover soils at CFA Landfill II. These distributions are comparable with mean values reported by Bartholomay, et al. (1989), for Big Lost River channel deposits. According to soil

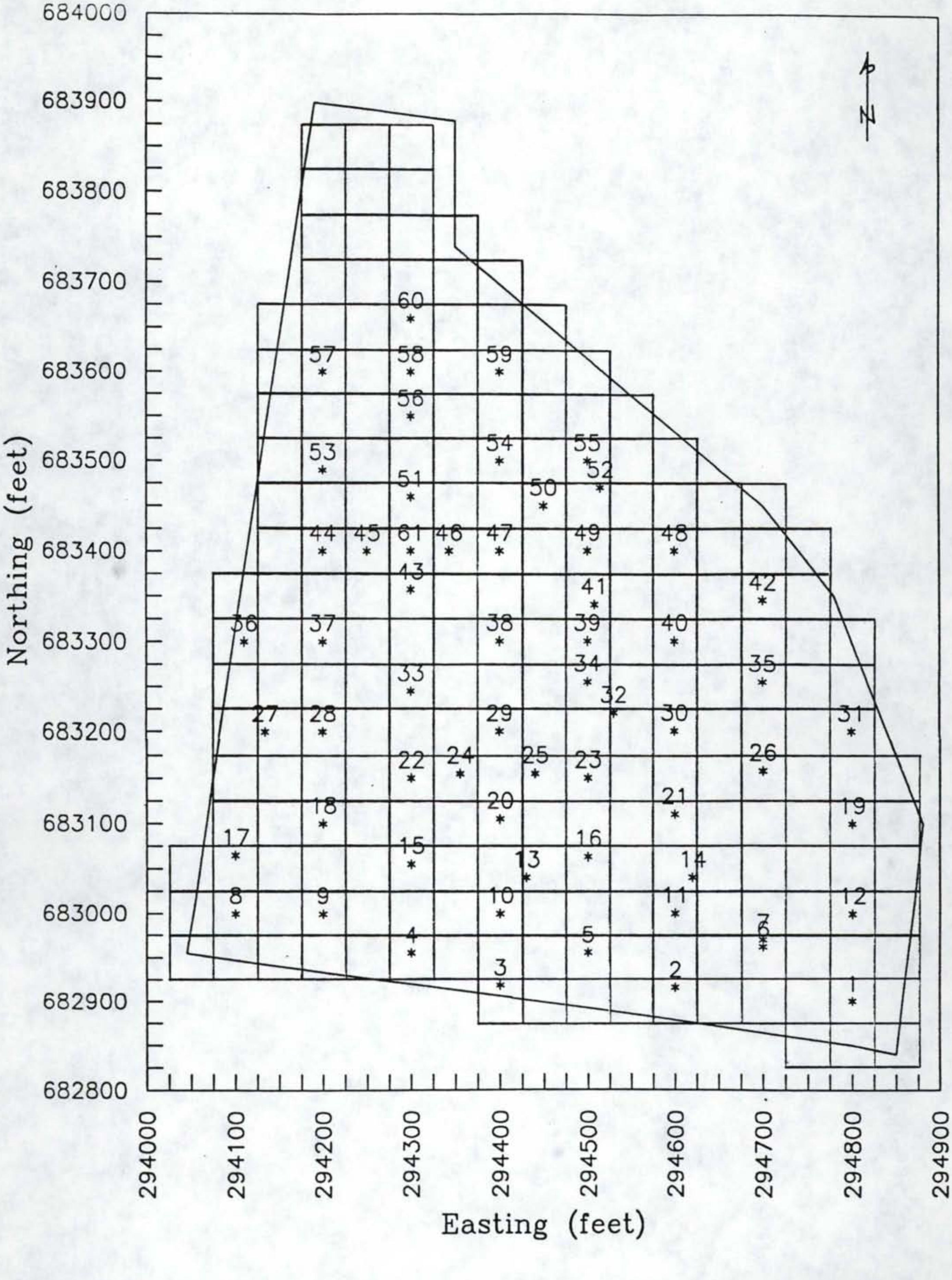

Figure 6.8 A grid consisting of 50 x 50 ft cells overlain on a map of sampling locations.

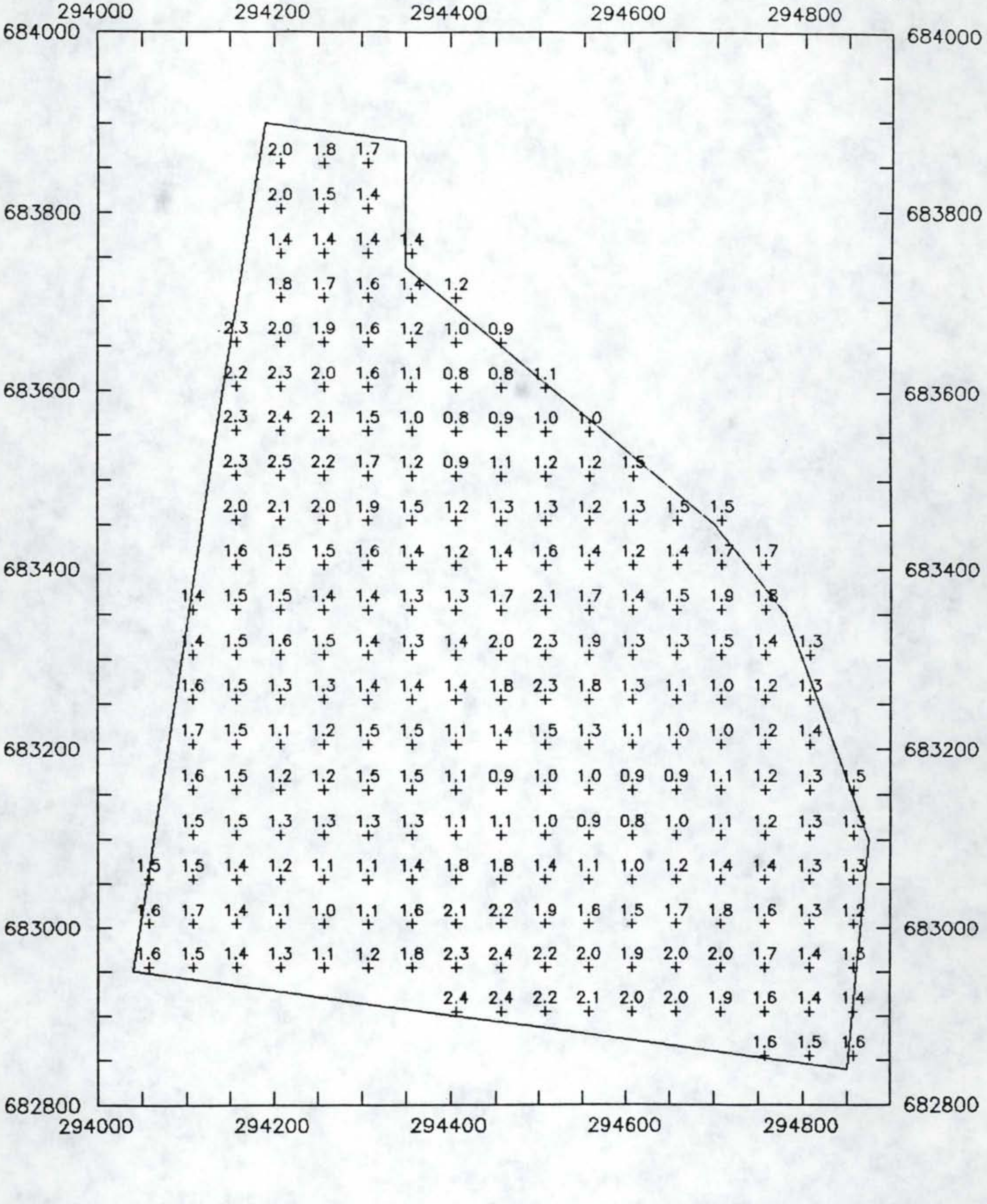

Figure 6.9 Block-kriged estimates of average soil cover thickness (ft) in 50 x 50 ft cells at CFA Landfill II.

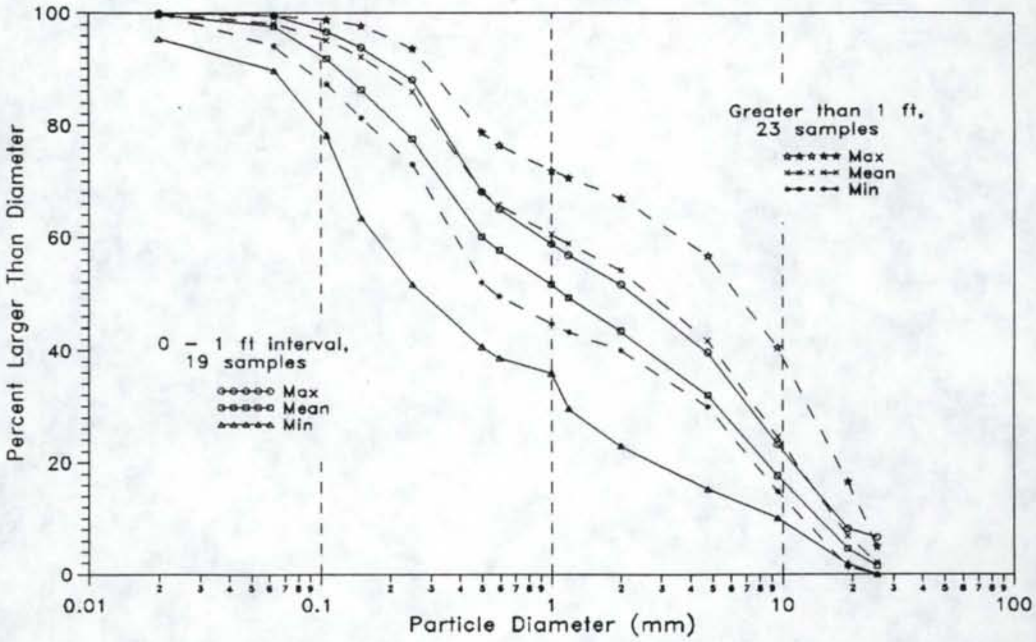

Figure 6.10 Summary of particle size distributions for specimens of the soil cover at CFA Landfill II.

classification guidelines given in ASTM D-2488, the soil cover as a whole is classified as SW, a well-graded sand with gravel. The constituents are: approximately 52 percent subrounded and subangular gravel, 46 percent subrounded sand, and 2 percent silt with low plasticity. The material occasionally has weak to moderate calcium-carbonate cementation.

As a follow-up to the particle size analyses, the petrography of individual clasts was identified in specimens from locations 5, 19, 27, and 58. Clasts retained on the 25.4, 19.1, and 9.5 mm sieves were identified and grouped into three distinct categories: igneous rocks, non-calcareous sediments, and calcareous sediments. Estimated weight percentages for each lithologic group are summarized in Table 6.4. Igneous rocks were dominated by rhyolites and granites, followed by mafic volcanics (basalts and andesites), followed by intermediate composition volcanics. Non-calcareous lithologies were dominated by siltstones, followed by sandstone and conglomerate clasts. Calcareous sediments were primarily silty limestones. Fossil fragments also found. The mean composition considering all locations and size fractions was 38 percent igneous, 42 percent non-calcareous sediments, and 20 percent calcareous sediments.

Table 6.3 Summary of particle size analysis for Layers 1 and 2 of the soil cover at CFA Landfill II.

Sample	Number of Observations	Percent by Weight [mean, min., max.] < 0.063 mm (silt, clay)	0.063 - 2.00 mm (sand)	> 2.00 mm (gravel)
Layer 1 0 - 1 ft. depth	19	[2, 0.4, 10]	[54, 48, 67]	[44, 23, 52]
Layer 2 1 - 3 ft. depth	21	[2, 0.5, 6]	[44, 33, 54]	[54, 40, 67]

Table 6.4 General lithology of soil material in the cover at CFA Landfill II

Particle Size (mm)	Lithology	Percent by Weight for Each Specimen 05	19	27	58
> 25.4	Igneous	72.0	0.0	0.0	29.5
	Non-calcareous	24.4	100.0	0.0	37.7
	Calcareous	3.6	0.0	0.0	32.8
19.1 - 25.4	Igneous	23.9	13.1	83.0	39.9
	Non-calcareous	53.4	51.2	17.0	39.3
	Calcareous	22.7	35.7	0.0	20.8
< 19.1	Igneous	39.8	32.9	37.0	36.3
	Non-calcareous	42.2	19.9	46.3	41.0
	Calcareous	18.0	47.2	16.7	22.7

6.5 Mass-Volume Relationships

Estimation of the water storage and retention characteristics of the landfill cover required the determination of the mass-volume relationships of the different size components (i.e., fractions) of the soil material. Mass-volume relationships were developed for soil specimens obtained using driven steel tubes (locations 5, 19, 27, 58) and on intact soil cores (locations 19, 27, 58) at the completion of hydraulic conductivity and water retention tests. Volume fractions of the particle size classes were estimated using the known bulk volume of each specimen.

The mass-volume relationships determined from the collected driven and intact specimens are given in Table 6.5. The volume fractions of the driven specimens had a greater range compared to the intact cores. This variability occurred from structural disruption during the driving process, which increased the total sample volume. Therefore, estimated values of the volume fraction of fines are low due to this factor. Thus, more reliable values are estimated from the intact cores.

Estimation of the water storage component of each layer of the landfill cover material required that the fraction of fines determined from particle-size analyses be converted from a mass to volume basis. The volume-to-mass ratio was calculated using the mass and volume fractions obtained in the laboratory analyses. These ratios ranged from 1.16 to 1.30, and for subsequent analyses we selected an overall value of 1.25

(emphasizing the results from the undisturbed cores). The estimated bulk density of the fines was required to convert the water contents of laboratory and field analyses from a mass to a volume basis. The bulk density of the fines used was 1.55 Mg/m^3.

Table 6.5 Mass-Volume relationships for Layer 1 (0 - 1 ft.) of the soil cover at CFA Landfill II ("fines" are defined as those soil particles smaller than 2.0 mm).

	Unit Weight (Mg/m^3)		Total : Fines	Mass Frac.	Vol. Frac.	Vol. : Mass
Specimen No.	Total	Fines	Unit Weight	Fines	Fines	Fraction
Driven cores:						
05	1.84	1.51	1.22	0.458	0.556	1.21
19	1.79	1.55	1.16	0.547	0.632	1.16
27	1.80	1.49	1.21	0.580	0.681	1.17
58	1.84	1.51	1.22	0.371	0.470	1.27
Undisturbed:						
19	1.93	1.49	1.30	0.477	0.580	1.30
27	2.11	1.74	1.21	0.450	0.550	1.22
58	2.08	1.64	1.27	0.400	0.510	1.28

6.6 Saturated Hydraulic Conductivity Estimated

Measurements of the saturated hydraulic conductivity (K_{sat}) were made on three of the large intact cores collected at CFA Landfill II (sites 19, 27, 58) using a constant head permeameter. The results of these measurements are given in Table 6.4.

Table 6.6 Saturated hydraulic conductivity of the 0-1 ft depth increment of the CFA Landfill II cover material.

Sample Site	Saturated Conductivity ($\times 10^{-3}$ cm/sec)
19	2.04
27	2.20
58	2.50
Average	2.25

The average K_{SAT} of the landfill cover material estimated from the intact cores was 2.25×10^{-3} cm/sec. The results were not analyzed statistically because of the low number of measurements; however, differences among the sample locations were small.

The large intact samples were obtained from the upper 0-1 ft layer of the landfill cover material, which had a greater percentage of fines than the adjacent underlying layers (Table 6.3). Because of the greater fraction of fines, the unconsolidated, unstructured surface layer would have a lower K_{SAT} value than underlying layers, and thus would control water flux through the cover material. The landfill cover material is considered a stable structure because of its coarse, porous matrix. In stable systems, the K_{SAT} is approximately equal to the steady-state infiltration rate. This rate for the landfill cover material can be classified as moderately rapid.

6.7 Water Retention Estimates

Water retention characteristics of the landfill cover material were estimated using the large intact cores and the fine fractions (<2.0 mm) obtained from Layers 1 and 2 (sites 5, 13, 19, 27, 34, 42, 53, 58). Reformed cores of fines were packed at the estimated bulk density of 1.55 Mg/m^3 (Section 6.5). Water retention characteristics of the fines were evaluated under the assumption that these size fractions form the porous matrix and provide the landfill cover material with its effective water storage properties. Water retention characteristics were measured at capillary pressures of 100, 300, 500, and 1000 cm-water for both the intact specimens and reformed cores of fines, and at additional pressures of 3000, 5000, and 15,000 cm for the fines.

Additional measurements of the upper and lower limits of water storage were made in-situ. Field drainage tests (Section 4.3) were used to estimate the upper limit. Measured moisture contents after cover-crop water extraction (July 1989) were used to estimate the lower limit. Both laboratory and field techniques were used as cross-checks of water storage characteristics of the landfill cover material. The moisture contents at capillary pressures of 100 and 15,000 cm-water were set as the upper (field capacity) and lower (lower limit of plant water extraction) limits of water storage for the landfill cover material, and are accepted values (Hillel, 1982). The water storage capacity (depth water/depth soil) is the difference between the upper and lower limits of water storage.

Based on comparisons among laboratory water retention measurements of the fines, of the intact cores, and of the field samples, use of the estimated water storage of the fines to predict water storage of the landfill cover is justified and can be performed with reasonable confidence. Estimated water storage values for Layers 1 and 2 were 0.097 and 0.062 cm of water/cm of layer thickness (Table 6.7).

Table 6.7 Summary of estimated water storage based on water retention tests of the soil fraction <2.0 mm, CFA Landfill II (pressure range: 100 - 15,000 cm-water).

Soil Specimen	Available Water Storage in Soil (cm H_2O/cm soil depth)
05-1	0.207
19-1	0.135
27-1	0.095
58-1	0.061
Average - Layer 1 (excluding 05-1)	0.097
05-2	0.086
27-2	0.040
58-2	0.060
Average - Layer 2	0.062

Water retention relationships of the fines (reformed cores) for the two layers are shown in Figures 6.11 and 6.12, respectively. Pressure-water content relationships for the intact soil specimens (sites 19 and 58) are included in Figure 6.13. Results from retention tests on the intact core from site 27 were questionable and are not included in Figure 6.13 or in water retention and storage estimates from the intact core data. The variability of retention characteristics among the sites probably resulted from structural (packing) and textural (fractions of various size classes) differences of the fines of each sample tested.

The slope of the capillary pressure-water content relationship is indicative of the rate of water released with increasing pressure. The slopes of these relationships are similar among sites within each layer. Therefore, even though water contents at the 100 and 15,000 cm-water capillary pressures vary between sites within each layer, the differences between the upper and lower storage limits are similar. Because the slope of the water retention relationship from Layer 1 of site 5 differed considerably compared to other site-depth relationships (Figure 6.11), water retention data from site 5 were not included in the estimation of the water storage of the fines in Layer 1.

Comparisons of volumetric water contents for the intact cores, fines, and field measurements at capillary pressures of 100 (upper storage limit), 1000, and 15,000 (lower storage limit) cm-water are presented in Appendix D (Table D1). The volume

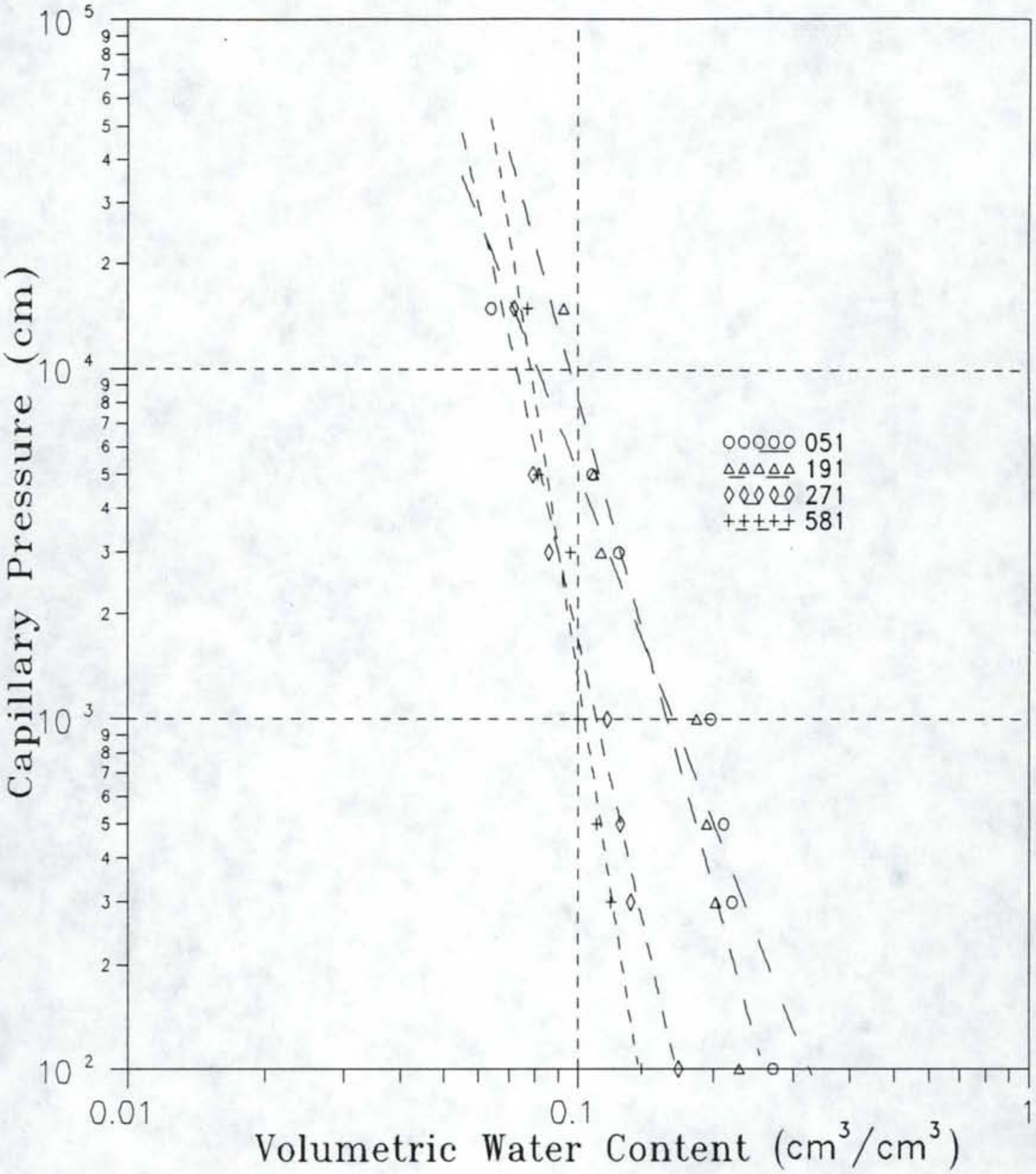

Figure 6.11 Capillary pressure - water content relationships for Landfill cover materials < 2.00 mm, 0 - 1 ft depth, all locations.

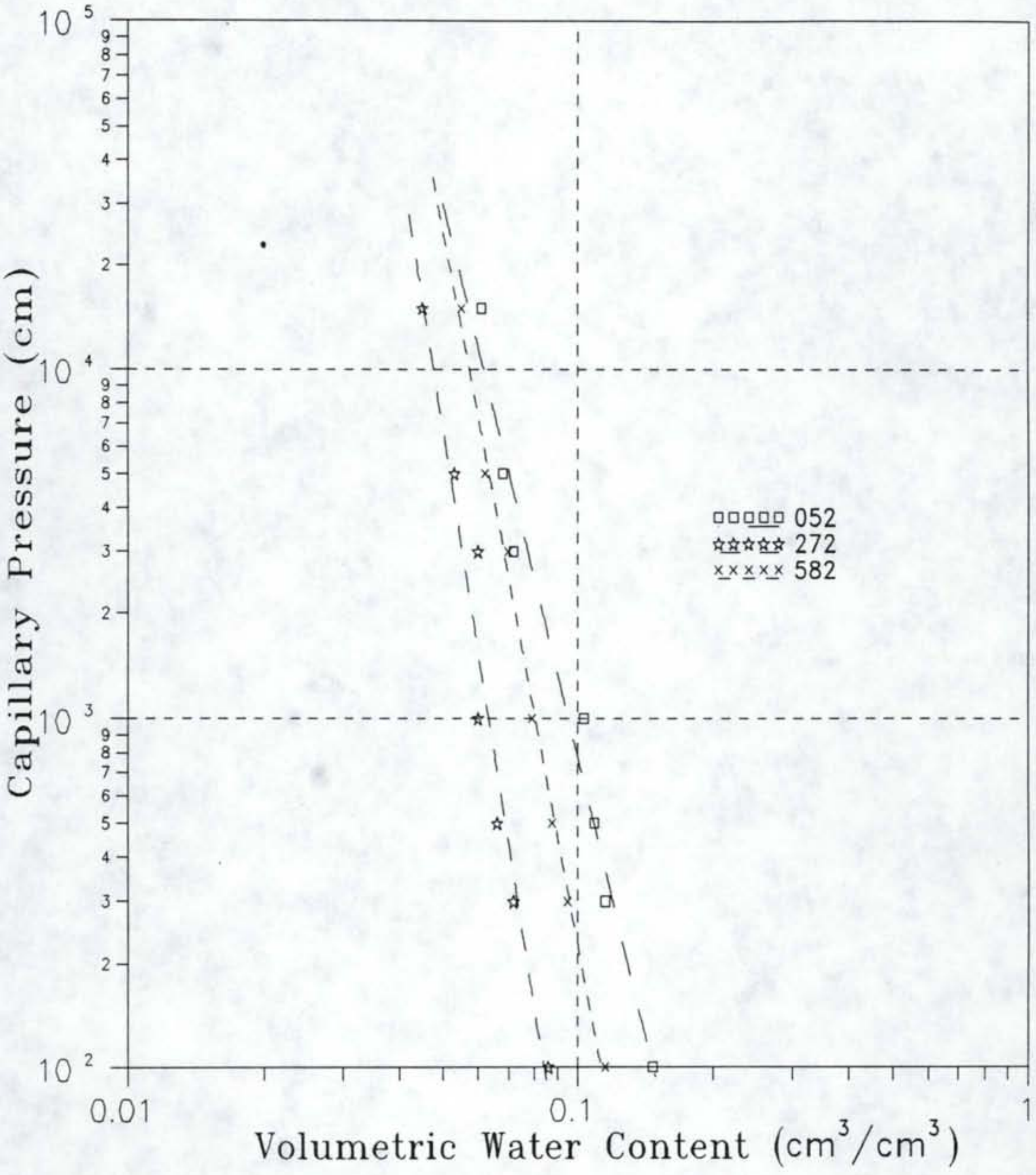

Figure 6.12 Capillary pressure - water content relationships for Landfill cover materials < 2.00 mm, 1 - 2 ft depth, locations 05, 27, and 58.

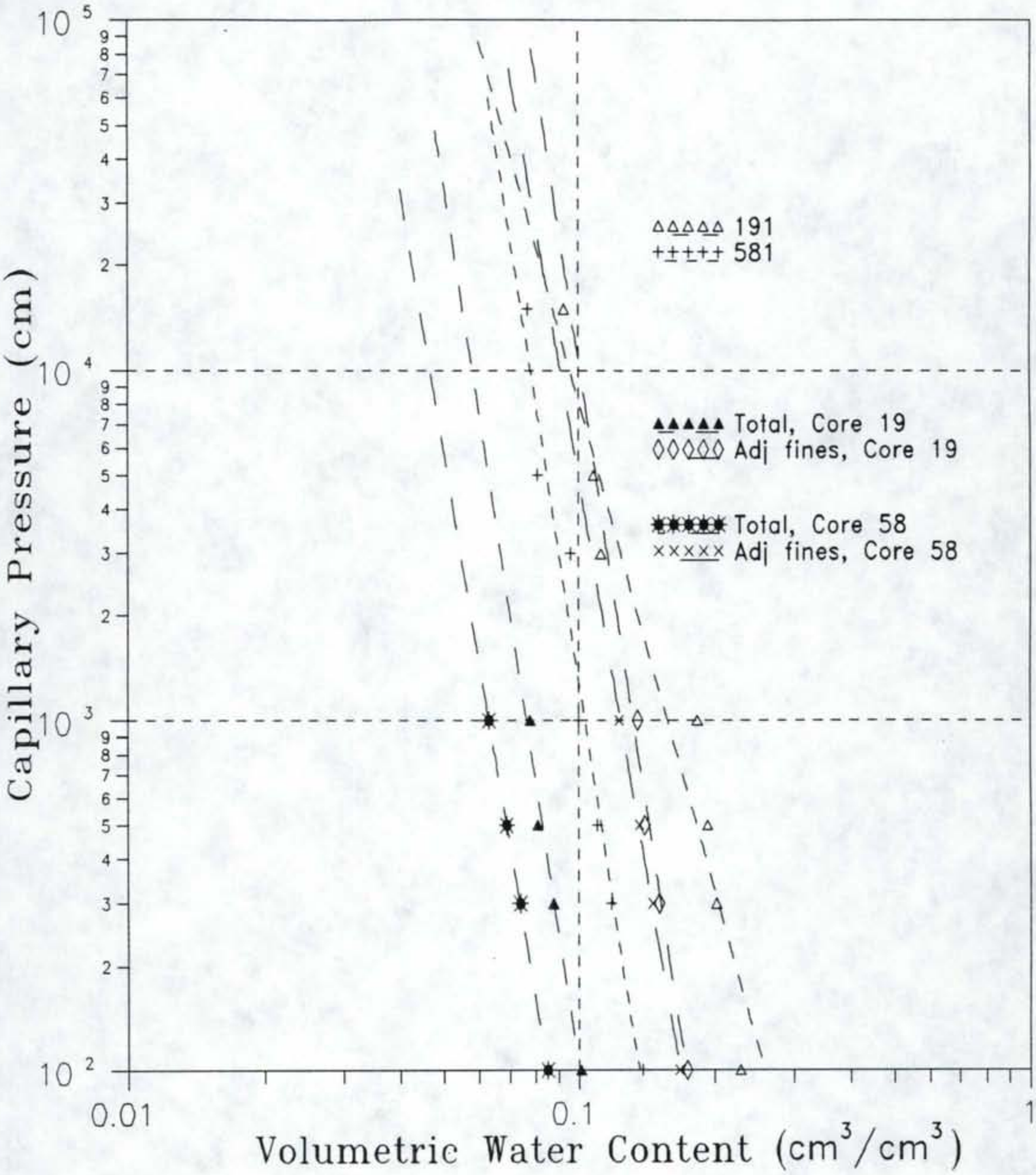

Figure 6.13 Capillary pressure - water content relationships for Landfill cover materials, locations 19 and 58, with fines, intact cores, and adjusted value for core fraction < 2.00 mm.

fractions of water retained by the fines (reformed cores) at each pressure have been adjusted to account for the percent fines by volume (Table 6.5). Therefore, water contents and estimated storage values of the fines can be compared with those of the intact cores and field measurements as shown in Figure 6.13 (see Table D1). There is reasonable agreement among the water contents retained by the fines, intact cores, and field samples at the upper storage limit for both layers. Water contents of the intact cores and field measurements are within the range of adjusted water contents determined at the upper storage limit. At the lower storage limit (15,000 cm-water) differences among adjusted water contents of the fines, intact cores, and field measurements were greater. Two factors could account for these differences: 1) the textural and structural variations among sites were greater than the physical variability of the reformed cores, and 2) capillary pressures of the field samples were greater than 15,000 cm-water due to cover-crop water extraction and surface evaporation, which resulted in lower water contents. However, estimated water storage for the fines (adjusted) and field measurements are in reasonable agreeable (Table D1: 0.057 vs. 0.072 for Layer 1, and 0.031 vs. 0.035 for Layer 2).

7. ESTIMATION OF SOIL WATER STORAGE AND INFILTRATION

7.1 Soil-Water Balance Computations

Hourly mean temperatures recorded at CFA Landfill II and NCDC Idaho Falls 46 W for Julian days 182 through 206 are shown in Figure 7.1. Daily mean, maximum, and minimum temperatures from both stations for the same period are given in Figure 7.2. Variations in hourly means occurred due to locale, but daily mean, minimum, and maximum air temperatures at both locations did not show any substantial differences over the period of comparison. The higher maximum temperature measured at the Landfill II site after Julian day 200 can be attributed to a faulty sensor. Total irradiance at the CFA Landfill II site was slightly greater during peak intensities, but was normally within 5 percent of global radiation measured at USGS-RWMC (Figure 7.3).

Because of small differences in meteorological measurements during the comparison period (2 weeks) and of the close proximity of the two sites, long-term average meteorological records for the two sites would be similar. Therefore, use of meteorological data from Idaho Falls 46 W for water balance estimations is justified. A 32-year record (1954-1986) of daily maximum and minimum temperatures, and daily precipitation from this site was used to obtain the water balance components for CFA Landfill II (i.e., precipitation, evapotranspiration, actual evapotranspiration).

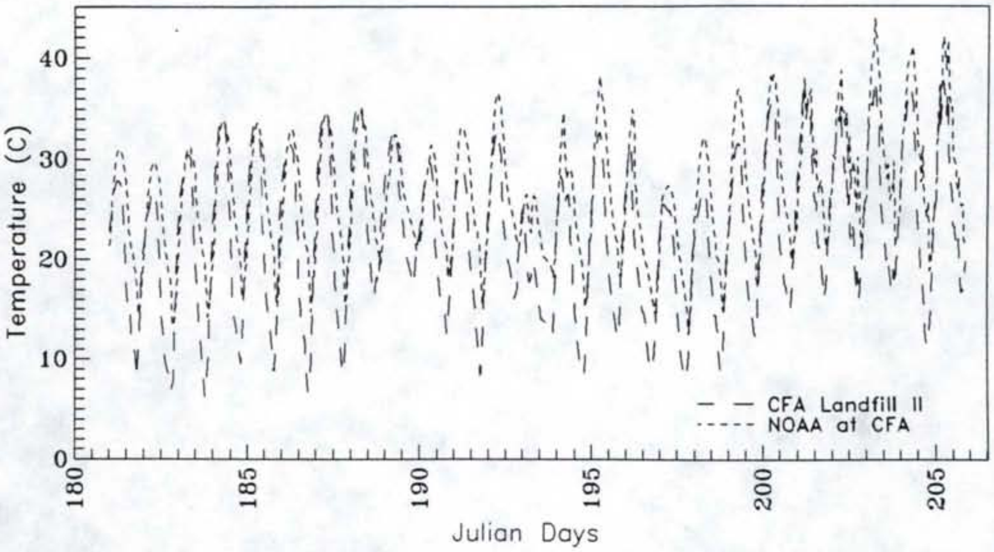

Figure 7.1 Hourly mean temperatures for CFA, recorded at Landfill II temporary weather station, and by NOAA, Julian days 182 - 206.

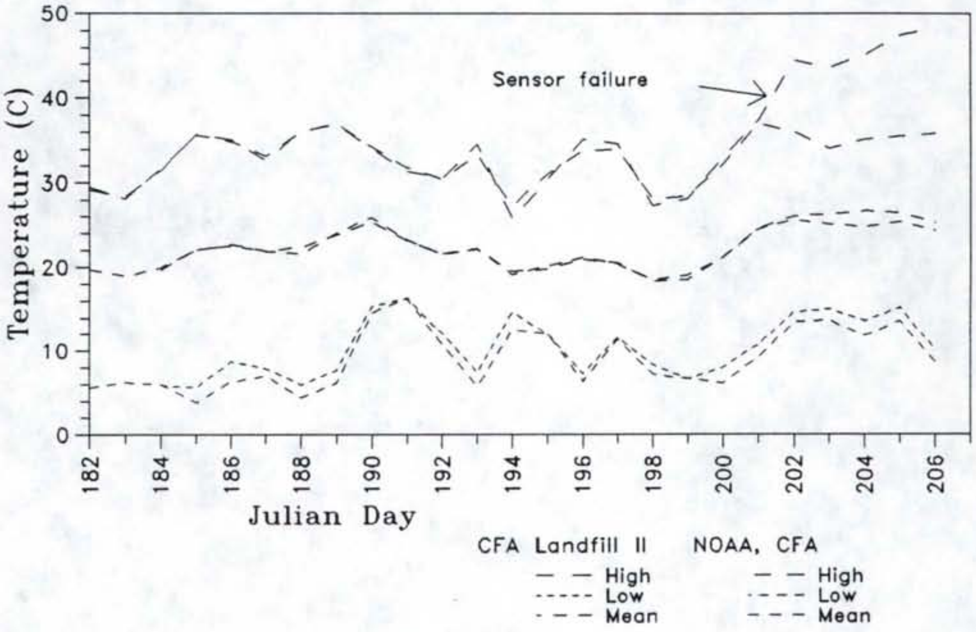

Figure 7.2 Maximum, minimum, and mean daily values for CFA, recorded by Landfill II temporary weather station, and NOAA, Julian Days 182 - 206, 1989.

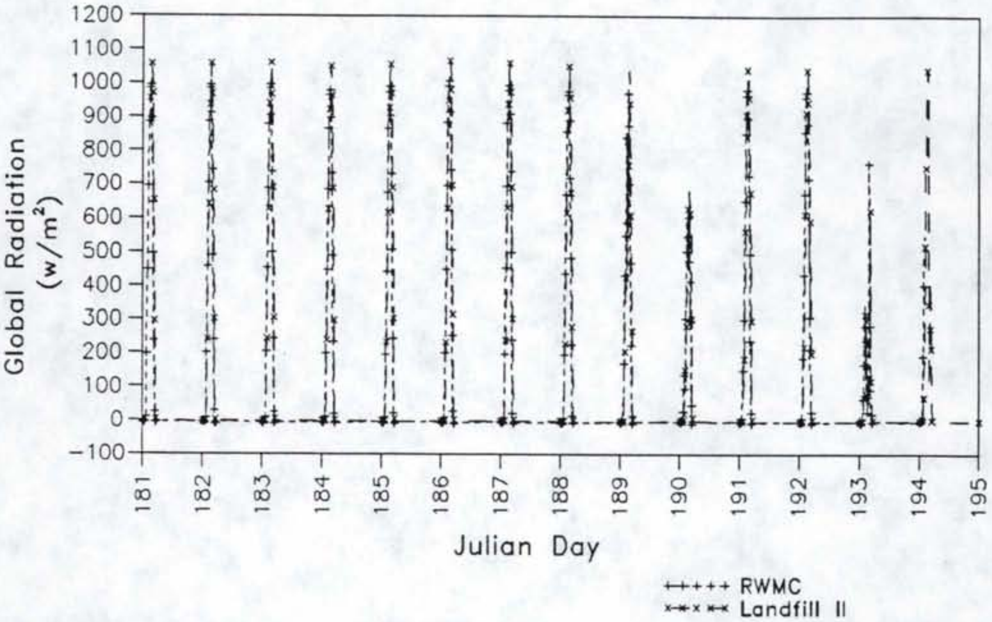

Figure 7.3 Global solar radiation recorded by temporary weather station, CFA Landfill II, and by USGS at RWMC, Julian days 181 - 195, 1989.

In simple terms, the water balance of CFA Landfill II cover material is a function of both the climatic conditions at the site and physical characteristics of the cover material. The water balance for the landfill cover material can be written as:

$$PPT = ETA + D + R + S,$$

where PPT is the precipitation, ET is the sum of the actual evaporation from the soil surface and transpiration by plants, D is the drainage from the landfill cover material, R is the runoff, and S is the cover material water storage. For purposes of this study, the runoff term (R) was considered negligible. The storage term (S) was estimated from both field and laboratory techniques as discussed in Section 6.7. The drainage (D), or infiltration through the soil cover, was estimated by:

$$D = (PPT - ETA) - S.$$

Actual evapotranspiration (ETA) generally is only a fraction of the potential evapotranspiration (PET). The potential evapotranspiration is generally estimated using various empirical or physically based techniques (Thornwaite, 1948; Blaney and Criddle, 1950; Penman, 1948; Jensen and Haise, 1963; Priestly and Taylor, 1972). Reduction in evapotranspiration below PET is the result of cover crop characteristics (e.g., stomatal closure) and soil characteristics. Due to these factors, ETA for an entire year is approximately 60 to 80 percent of PET, and may be considerable lower depending on water supply (Hillel, 1982).

Most relationships (e.g., Penman, Jensen-Haise, Blaney-Criddle) used to estimate PET or ETA have been developed and calibrated for warm weather conditions (May-September) during the active crop growth period. As previously mentioned, approximately 70 percent of the precipitation occurs from October through May at the INEL site, a period of cool temperatures and low evaporative demand. In addition, the CFA Landfill II site has a grass cover crop. To properly compensate for these conditions, a soil-water balance model developed by Campbell and Diaz (1988) based on the Priestly-Taylor method of PET estimation (Priestly and Taylor, 1972) was utilized. The Campbell-Diaz model partitions evaporative water losses between cover crop transpiration and soil evaporation, thus, estimating the effective ETA term.

The Campbell-Diaz model uses daily precipitation, maximum air temperature, and minimum air temperature as inputs. The 32-year weather record for Idaho Falls 46 W includes these parameters. For purposes of this study, the daily weather record was converted from an annual to a water year (October-September) basis. Because 1954 was the start of the record and had numerous missing data, the data for that year were not used. The final data pool consisted of 31 water-year records from September 1955 through October 1986. Daily trace precipitation values were considered negligible and were not included in total precipitation determinations.

The annual precipitation and ETA for the CFA Landfill II site were estimated for each water year using respective daily inputs for each year, soil physical characteristics, and cover crop parameters. Average water-year precipitation during the 31-year period was 8.19 in (20.8 cm). Highest and lowest annual precipitation values on a water-year basis during this period were 12.13 (30.8 cm) and 3.46 in (8.8 cm), respectively. Average annual ETA estimated by the model was 5.75 in (14.6 cm). Highest and lowest estimated annual ETA during this period were 8.43 (21.4 cm) and 3.35 in (8.5 cm), respectively.

The maximum (PPT-ETA) values occurred during May or June in approximately 80 percent of the water years of record. The annual estimates were used to develop a cumulative frequency relationship for the annual maximum (PPT-ETA) values using SAS procedure UNIVARIATE (SAS, 1985). This relationship is shown in Figure 7.4. The 0.5 (median) value (as well as the 0.10 and 0.90 quantile values) was used to estimate annual infiltration through the landfill cover (recharge).

7.2 Spatial Estimation of Effective Water Storage

The average estimated water storage values reported in Table 6.7 provide the basis for predicting the effective water storage in Layer 1 and Layer 2 across the landfill. Because the reported storage values pertain to the fine fraction (less than 2.0-mm size), an in situ estimate of storage at any location of the soil cover also requires the following information:

1. Thicknesses of Layer 1 and Layer 2, and
2. The percent-by-volume fraction of fines in Layer 1 and in Layer 2 (this percentage can by obtained by multiplying the percent-by-weight fraction times 1.25; refer to Table 6.5).

The spatial distribution of cover thickness was presented in Figure 6.9, where the average thickness in 50 x 50 ft cells was

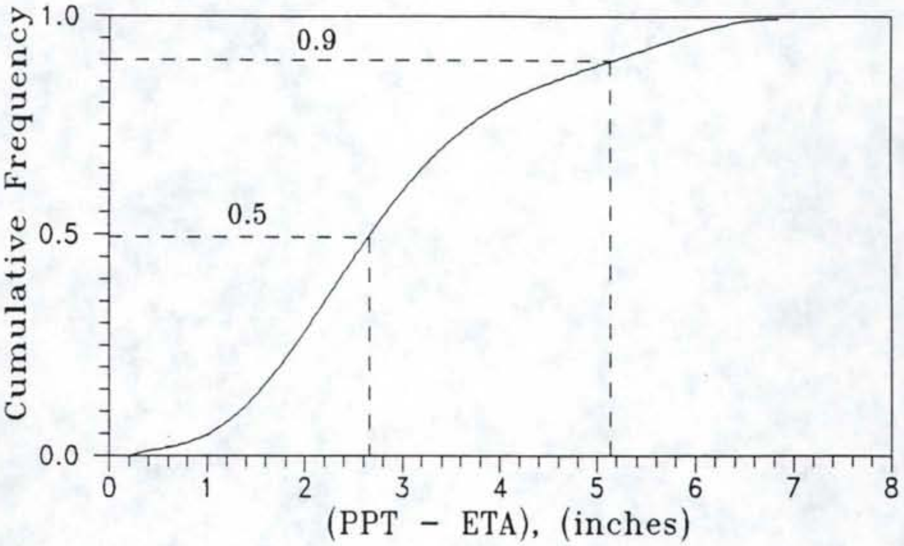

Figure 7.4 Estimated cumulative frequency distribution function of annual amount of water available for infiltration (PPT - ETA).

estimated by block kriging. To meet the objective stated above, we needed similar maps of the percent-by-weight fraction of fines for each of the two layers. Thus, a variogram was generated for these percentages in each of the two layers, given the data from the particle size analyses discussed in Section 6.4. The estimated variograms (shown in Appendix A) were used in the block-kriging routine of GeoEAS to produce average percentages expected in the 50 x 50 ft cells. The results are displayed in Figures 7.5 and 7.6.

The effective water storage in each cell then could be calculated as follows:

$$\begin{aligned}\text{Eff. Storage} &= (\text{Storage of Layer 1}) + (\text{Storage of Layer 2})\\ &= [(\text{Layer 1 thickness})(\%\text{fines by weight})(1.25)(0.097)] +\\ &\quad\ [(\text{Layer 2 thickness})(\%\text{fines by weight})(1.25)(0.062)]\end{aligned}$$

The calculated water storage values for the 50 x 50 ft cells are presented in Figure 7.7.

7.3 Spatial Estimation of Annual Water Infiltration Through the Soil Cover

The annual water available for infiltration through the soil cover (i.e., drainage) at CFA Landfill II is given by the difference between precipitation and evapotranspiration (i.e., PPT-ETA), as discussed in Section 7.1. Not all of this available water will drain through the soil cover to provide the groundwater necessary for leachate generation in the landfill.

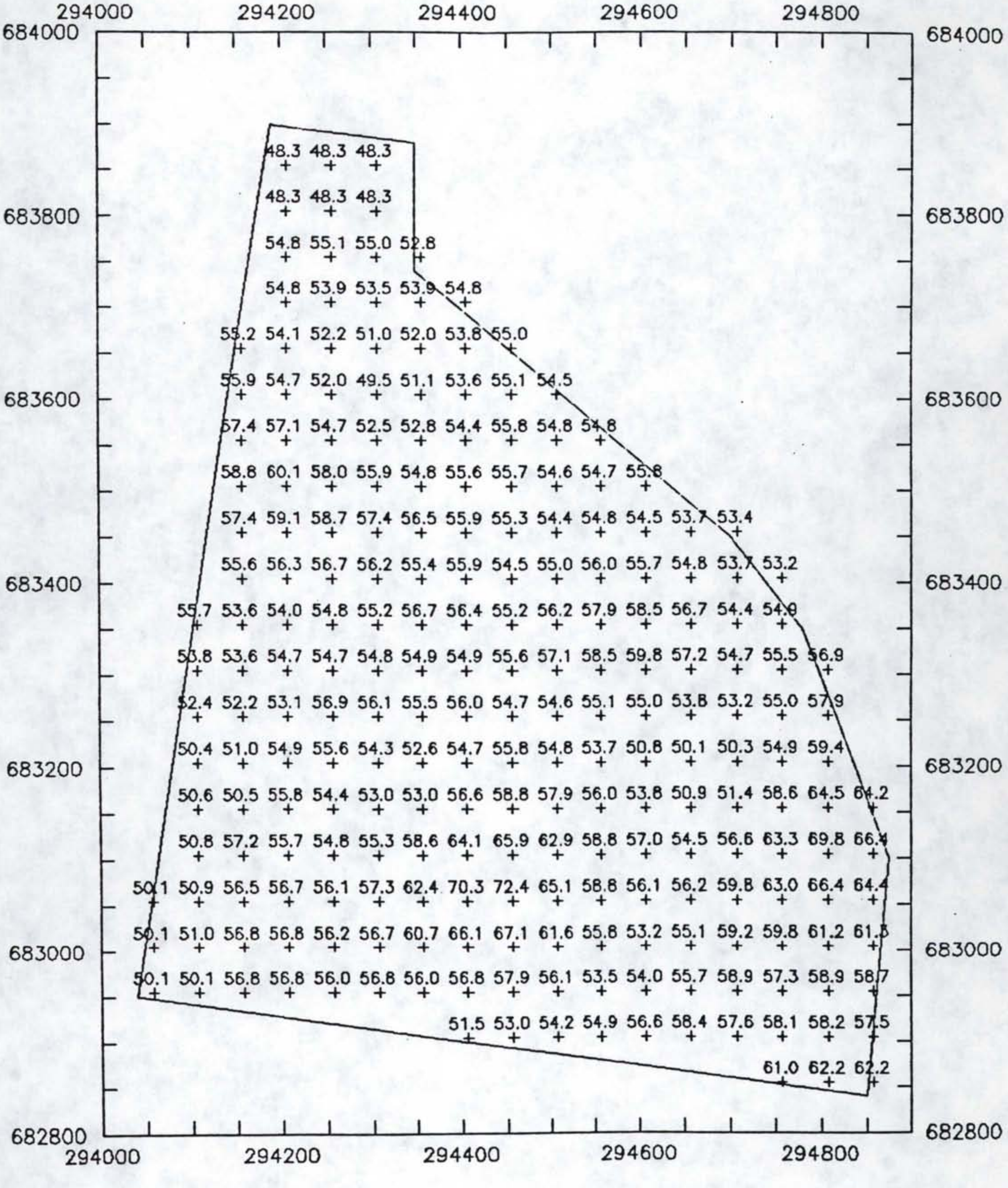

Figure 7.5 Block-kriged estimates of average percent-by-weight fraction of fines (<2.0 mm) in 50 x 50 ft cells, Layer 1, CFA Landfill II.

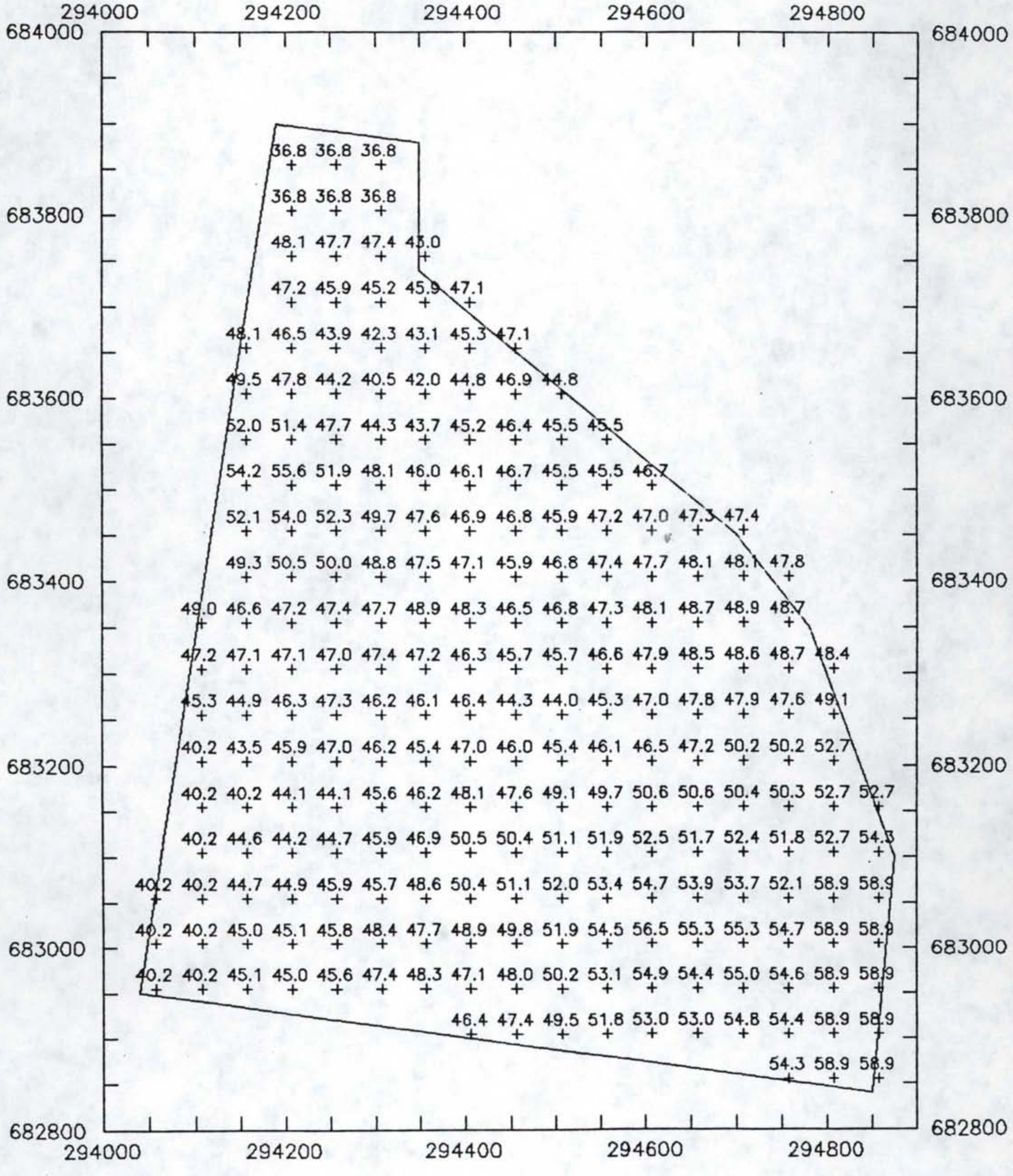

Figure 7.6 Block-kriged estimates of average percent-by-weight fraction of fines (<2.0 mm) in 50 x 50 ft cells, Layer 2, CFA Landfill II.

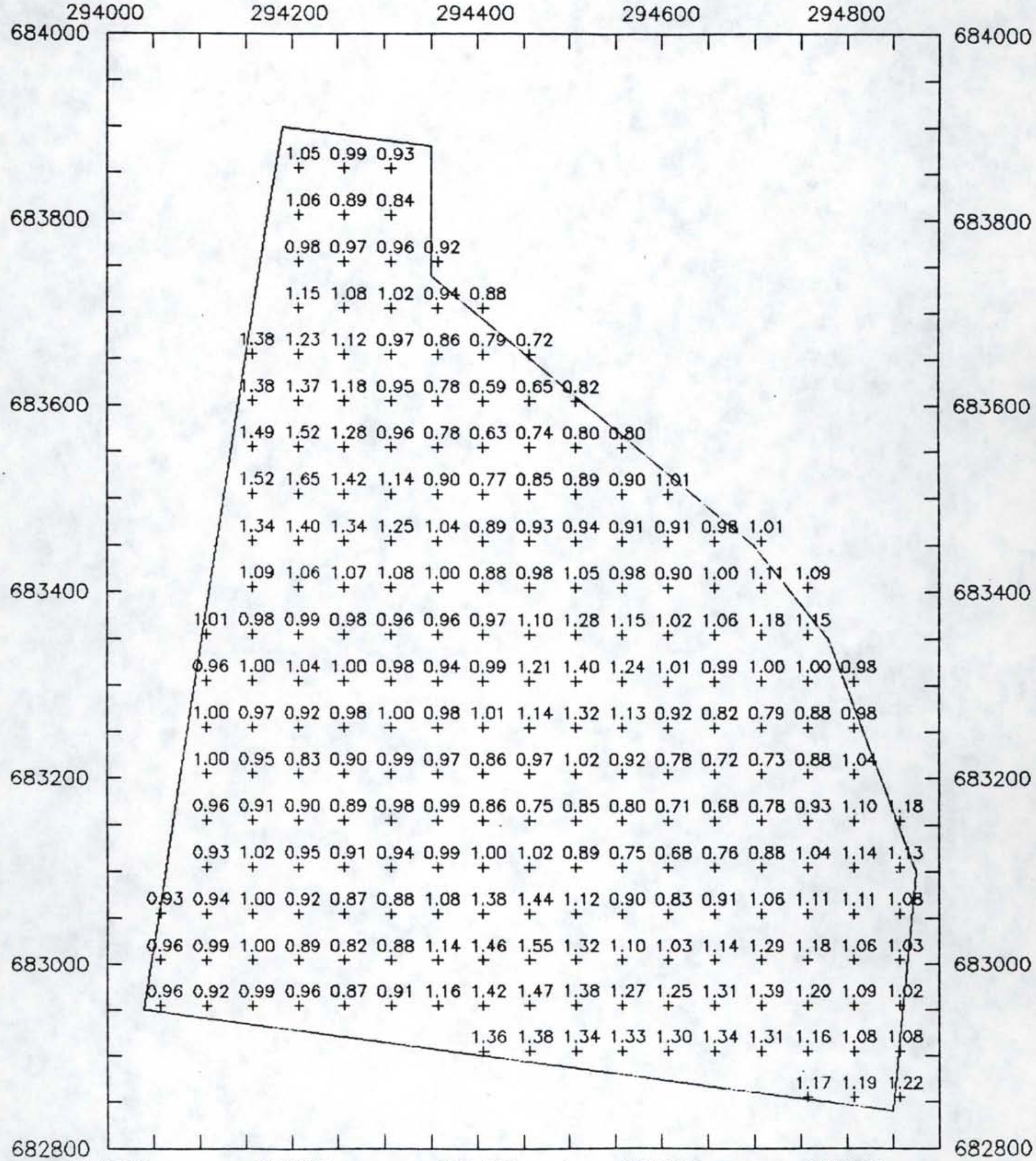

Figure 7.7 Effective water storage of the soil cover at CFA Landfill II.

Some of it will be stored in the soil cover, more specifically in the fine fraction (particles smaller than 2.0 mm) of the cover. Thus, the annual amount of water passing through the soil cover to produce leachate is given by: (PPT-ETA) - STORAGE.

The estimated cumulative distribution function of annual (PPT-ETA) shown in Figure 7.4 allows us to select any particular quantile value and then generate a corresponding map of soil-cover drainage. Of course, the other key input here is the map of estimated water storage values for the soil cover (Figure 7.7). We selected the 0.50 quantile to represent a median (PPT-ETA) year, the 0.10 quantile for a "dry" year, and the 0.90 quantile for a "wet" year. Thus, the storage values in 50 x 50 cells were subtracted from these three quantile values to generate the maps shown in Figures 7.8, 7.9, and 7.10. These spatial estimates of the annual water infiltration through the cover depend heavily on the thicknesses and the percentages of fine fraction of Layers 1 and 2 in the cells.

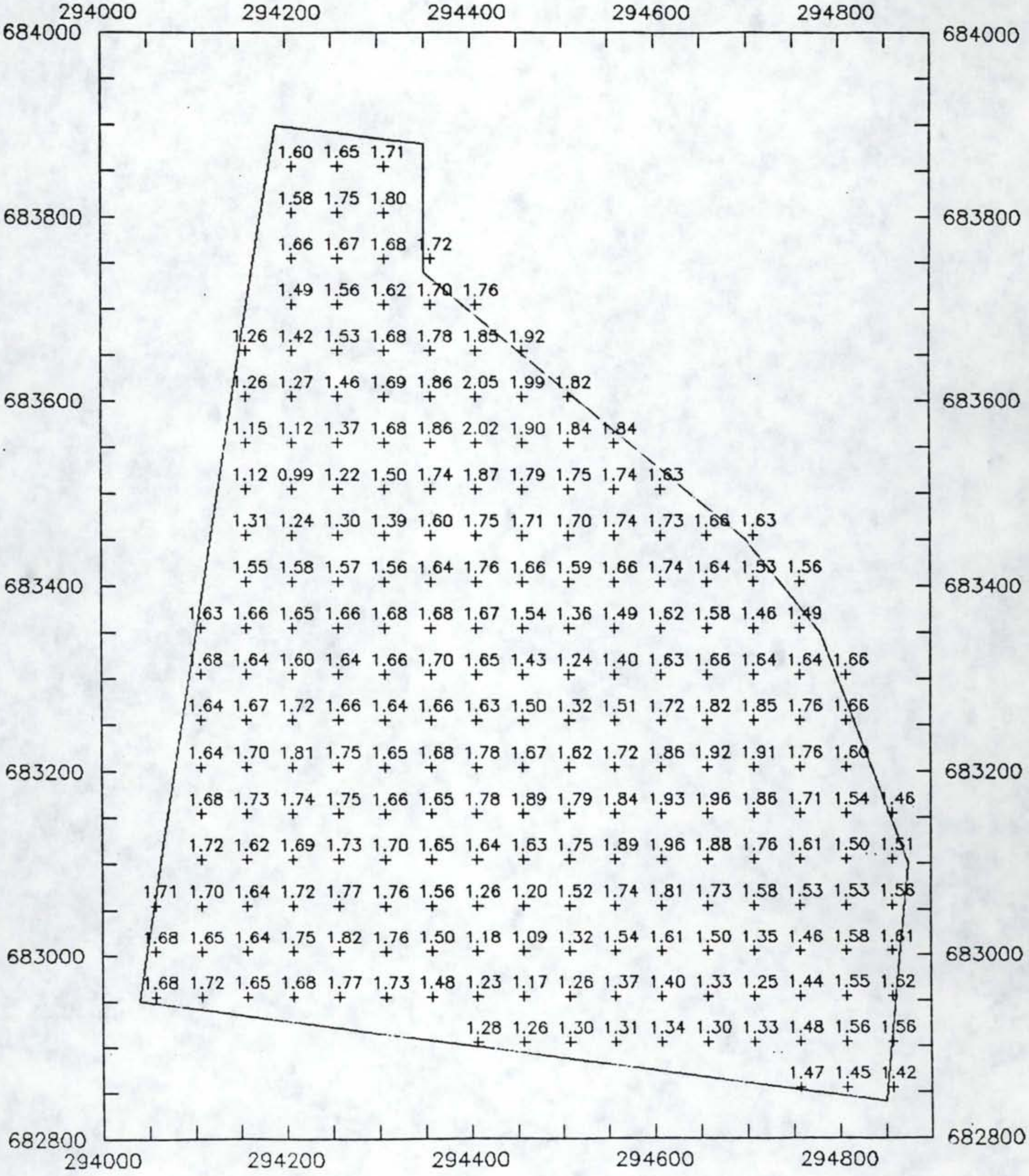

Figure 7.8 Estimated annual infiltration (in.) through the soil cover at CFA Landfill II for a "median" year (0.5 quantile value for: PPT-ETA).

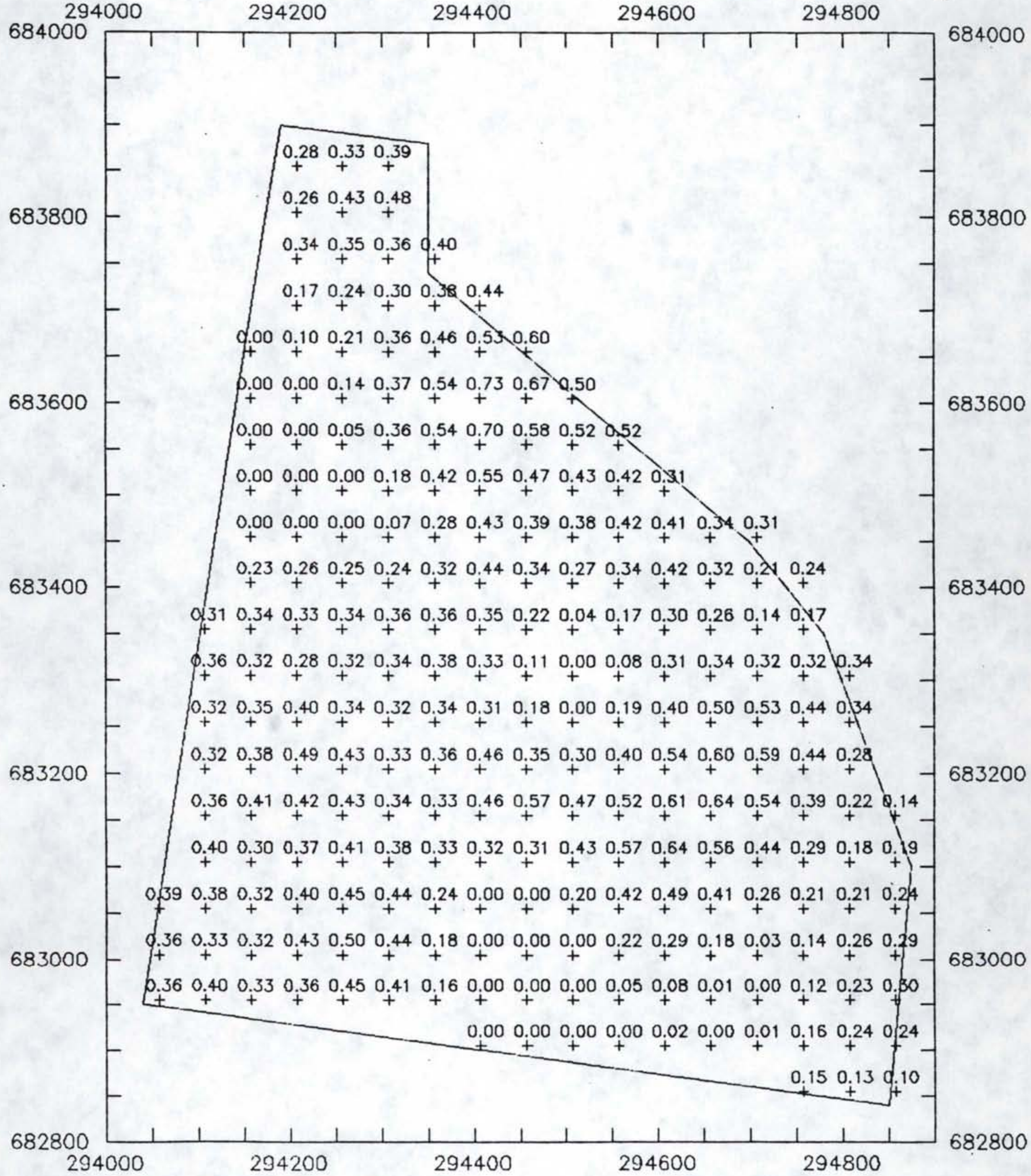

Figure 7.9 Estimated annual infiltration (in.) through the soil cover at CFA Landfill II for a "dry" year (0.1 quantile value for: PPT-ETA).

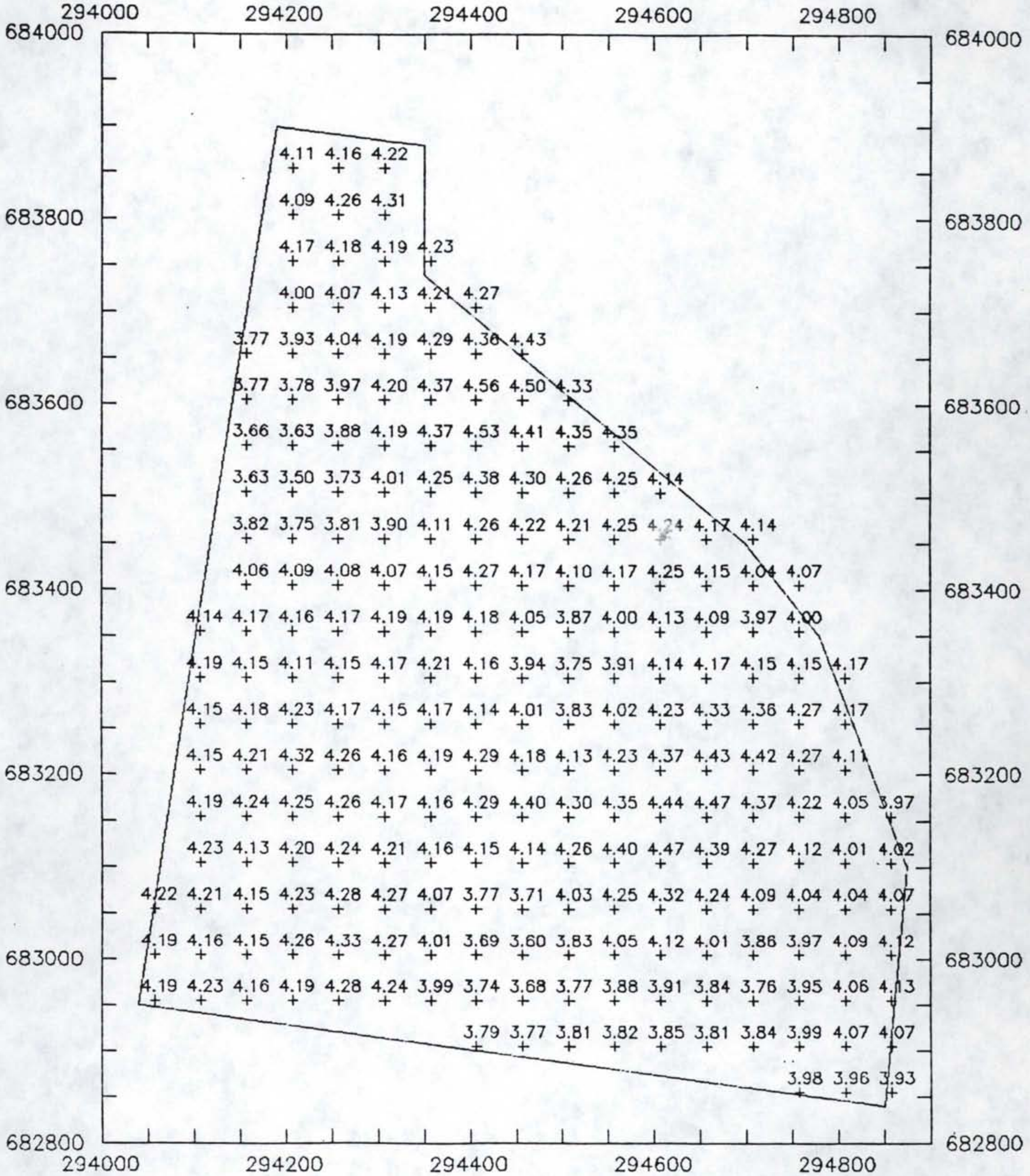

Figure 7.10 Estimated annual infiltration (in.) through the soil cover at CFA Landfill II for a "wet" year (0.9 quantile value for: PPT-ETA).

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Critical Findings

Physical properties of the soil cover at CFA Landfill II have been characterized and soil-water balance computations (based on historical meteorological data) have been completed. Results from these studies have led to spatial estimates of annual water infiltration (i.e., drainage) through the soil cover.

Based on historical evidence of landfill operations and on the results of particle size analyses with depth, it is reasonable to divide the soil cover into two layers: 1) an upper layer at 0 to 1 ft depth consisting of more sand than gravel, and 2) a lower layer at depths greater than 1 ft consisting of more gravel than sand.

The overall thickness of the soil cover was measured with a hand auger at 60 locations across the landfill. The sample mean was 1.5 ft and the standard deviation was 0.69 ft, with a minimum and maximum of 0.33 and 3.17 ft, respectively. Of these 60 measurements, four of them in the 3-ft range (sites numbered 3, 13, 34, and 53) were "inequality" data in that waste was not encountered in these holes, but auger advance was blocked by rocks or caving hole conditions. Thus, the maximum thickness of the soil cover may be greater than 3.17 ft. However, because a majority of the water storage occurs in Layer 1 due to its higher percentage of fines, an additional one or two feet of Layer 2 material in a few areas of the landfill will not cause significantly less infiltration through the soil cover.

A field procedure was developed for collecting large, undisturbed specimens of coarse-grained soils. Cylindrical blocks approximately 12 to 14 inches in diameter were excavated in place, then wrapped with several layers of cheese-cloth and resin. In the laboratory these blocks were trimmed to fit 8-in. diameter sections of PVC pipe. Saturated hydraulic conductivity tests on three of these large, undisturbed cores provided values that ranged from 0.0020 to 0.0025 cm/sec.

Water retention tests of the large cores and of smaller specimens consisting of the fine fraction (particles smaller than 2.0 mm) provided relationships of capillary pressures vs. water content. Results from these tests and from mass-volume calculations indicated that water storage in the soil cover effectively occurs in the volume occupied by the fine fraction and is approximately equal to 0.097 and 0.062 cm/cm-thickness for Layers 1 and 2, respectively.

Historical meteorological data from a 31-year record was used to provide estimates of the water available for annual infiltration through the soil cover (i.e., precipitation minus evapotranspiration). The median value of annual (PPT-ETA) was combined with block-kriged maps of cover thickness, percent-fines in Layer 1, and percent-fines in Layer 2 to generate maps depicting the estimated annual infiltration through the cover (in 50 x 50 ft cells) for a "median" year. The cell values range from 0.99 to 2.05 inches, and indicate the annual recharge to the waste. The analysis was repeated for a "dry" (0.10 quantile of PPT-ETA) year and for a "wet" (0.90 quantile of PPT-ETA) year. The latter indicates cell recharge values of 3.50 to 4.56 inches.

8.2 Limitations of this Study

Although a very thorough study of the landfill cover was conducted in this project, there were some assumptions and analytical limitations that warrant some attention. For example, we have assumed that the soil cover consists of a flat layer with a well-defined planar base at the top of the waste. Such a sharp discontinuity is impossible to achieve with heavy equipment during the emplacement of cover soils over waste materials. However, the cover thickness measurements must be averaged over some defined area in order to produce any reasonable estimates of soil-cover storage and drainage. Block kriging was used to generate these estimates for 50 x 50 ft cells, and even though some spatial smoothing results, the issue of an irregular contact between soil and waste seems minor in light of the fact that kriging provides unbiased, minimum-variance estimates.

Our spatial estimates of annual infiltration through the soil cover rely on the assumption that water is applied uniformly across the site. Field observations during the early springtime of past years have shown that some localized ponding of snowmelt occurs on the landfill cover. We originally proposed making such observations in the spring of 1990 to provide estimates of the location and extent of these temporal ponds. Unfortunately, the late winter of 1990 was quite dry, and EG&G personnel reported that snowmelt was insignificant and no ponding was observed. Existing topographical depressions in the cover do show some buildup of light-colored silty sediment from past years' surface drainage. The effects of such temporal ponding on our spatial estimates of soil-cover storage and drainage are unclear at this time. However, if the ponding areas generally are smaller than the 50 x 50 ft cells and are only a few in number, then the overall effect on infiltration across the landfill may not be significant.

The computer model used to predict (PPT-ETA) relies on the assumption that the crop cover is spring-planted. The crop cover at CFA Landfill II is a perennial grass species and would have an existing root system throughout the cover material for water extraction during the early spring. The model assumes that water is extracted from deeper depths as the crop root system develops. Small differences in ETA estimates based on root growth and root system configuration are predicted by the model. However, a large fraction of the annual precipitation that contributes to drainage (February through April) occurs <u>prior</u> to the beginning of crop growth and transpiration (late May). Therefore, the effects of these assumptions on ETA estimates, and subsequently, leachate generation are not significant.

8.3 Recommendations

Based on the findings of this study, we can make the following recommendations:

1) Additional thickness measurements of the soil cover along the boundries of the landfill would help reduce uncertainties in the block-kriged estimates of cover thickness in the 50 x 50 ft cells in those locations. The greatest errors in the estimated thickness, and thus, the recharge values, occur along the boundaries.

2) Design of an additional soil cap overlying the current cover material would require the measurement of the water storage capacity of the borrow material selected. The water storage capacity (depth of water/depth of material thickness) would determine the required soil cap thickness to prevent infiltration through the landfill cover. For example, a selected silt loam material (with fractions of clay and silt greater than those of the existing cover) with an effective water storage capacity of 0.17 in, of water/in. of soil thickness would need to be at least 27 in. thick to store the estimated 0.90-quantile cell recharge values, which range between 3.5 to 4.6 inches.

3) In addition to the required soil cap thickness, complete design of the landfill cover should include cover crop selection and surface sloping. The selected cover crop should have an effective rooting depth equal to the soil cover thickness. Water extraction by the cover crop during the late spring and summer months would deplete the water stored within the cover and restore soil cap storage capacity prior to the wet recharge season. Surface sloping would induce adequate runoff and eliminate ponding, thus

preventing water recharge from exceeding the effective storage capacity at any location on the soil cover.

REFERENCES

Ansley, S.L., L.C. Hull, and S.M. Burns, 1988, Shallow Drilling Report for CFA Landfills II and III (FY-1988): Characterization of Surficial Sediments; Report No. EGG-ER-8291, EG&G, Idaho, Inc., Idaho Falls, ID.

Bartholomay, R.C., 1990, Minerology, Petrology, and Grain Size of Surficial Sediment from the Big and Little Lost Rivers and Birch Creek Drainages, at the Idaho National Engineering Laboratory, Idaho; M.S. Thesis, Idaho State University, Pocatello, Idaho.

Bartholomay, R.C., L.L. Knoble, and L.C. Davis, 1989, Mineralogy and grain size of surficial sediment from the Big Lost River drainage and vicinity, with chemical and physical characteristics of geologic materials from selected sites at the Idaho National Engineering Laboratory, Idaho; USGS Open File Report 89-384, 74 p.

Blaney, H.F. and W.D. Criddle, 1950, Determining water requirements in irrigated areas from climatological and irrigation data, U.S. Soil Cons. Serv, Tech. Publ. 96.

Campbell, G.S. and R. Diaz, 1988, Simplified soil-water balance models to predict crop transpiration; <u>In</u> F.R. Bidinger and C. Johnson (eds.) Drought research priorities for the dryland tropics; ICRISAT, Parancheru, India, p. 15-26.

Cassel, D.K., and Nielsen, D.R., Field Capacity and Available Water Capacity; Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods- Agronomy.

Clawson, K.L., G.E. Start, and N.R. Ricks, 1989, Climatography of the Idaho National Engineering Laboratory; U.S, Department of Commerce, NOAA Environmental Research Laboratories, Field Research Division, Idaho Falls, ID, 2nd Ed.

Devore, J.L., 1987, Probability and Statistics for Engineering and the Sciences; 2nd Ed., Brooks/Cole Publ. Co., Monterey, CA, 672 p.

Englund, E. and A. Sparks, 1988, GeoEAS User's Guide; USEPA-EMSL, Las Vegas, NV.

Hillel, D., 1982, Introduction to soil physics; Academic Press, Inc., San Diego, CA.

ICF Technology, Inc., 1989, Innovative Technology Demonstration, Idaho National Engineering Laboratory, CFA Landfill II, Idaho Falls, ID; unpubl. report submitted to EG&G Idaho, Inc., November.

Isaaks, E.H. and Srivastava, R.M., 1989, An Introduction to Applied Geostatistics; Oxford Univ. Press, New York, NY, 561 p.

Jensen, M.E. and H.R. Haise, 1963, Estimating evapotranspiration from solar radiation; J. Irrig. Drain. Div., Am. Soc. Div. Engr. v. 89, p. 15-41.

Lewis, G.C. and M.A. Fosberg, 1982, Distribution and character of loess and loess soils in southeastern Idaho, in Bill Bonnichsen and R.M. Breckenridge, editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 705-716.

Maybey, D.R., 1982, Geophysics and tectonics of the Snake River Plain, Idaho, in Bill Bonnichsen and R.M. Breckenridge, editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 139-153.

Olsen, J.F., 1989, Personal communication; Equipment Operator, Central Facilities Area, EG&G Idaho, Inc.

Penman, H.L., 1948, Natural evaporation from open water, bare soil, and grass; Proc. R. Soc. London Ser. A, 193:120-146

Pierce, K.L. and W.E. Scott, 1982, Pleistocene episodes of alluvial-gravel deposition, southeastern Idaho, in Bill Bonnichsen and R.M. Breckenridge, editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 685-702.

Priestly, C.H.B. and R.J. Taylor, 1972, On the assessment of surface hear flux and evaporation using large-scale parameters; Mon. Weather Rev., v. 100, p. 81-92.

Rogowski, A.S., and D.E. Simmons, 1988, Geostatistical Analysis of Field Hydraulic Conductivity in Compacted Clay; Math. Geology, v. 20, p. 423-446.

SAS Institute, Inc., 1985, SAS Procedure Guide for Personal Computers, Cary, NC, 6th Ed.

Spear, D.B. and King, 1982, The geology of the Big Southern Butte, Idaho, in Bill Bonnichsen and R.M. Breckenridge, editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 395-403.

Thornwaite, C.W., 1948, An approach toward a rational classification of climate; Geograph. Rev., v. 38, p. 55-94.

Wood, T.R., L.C. Hull, and M.H. Doornbos, 1989, Informal Report: Groundwater Monitoring Plan and Interim Status Report for Central Facilities Landfill II; Report No. EGG-ER-8496, EG&G Idaho, Inc., Idaho Falls, ID.

APPENDIX A

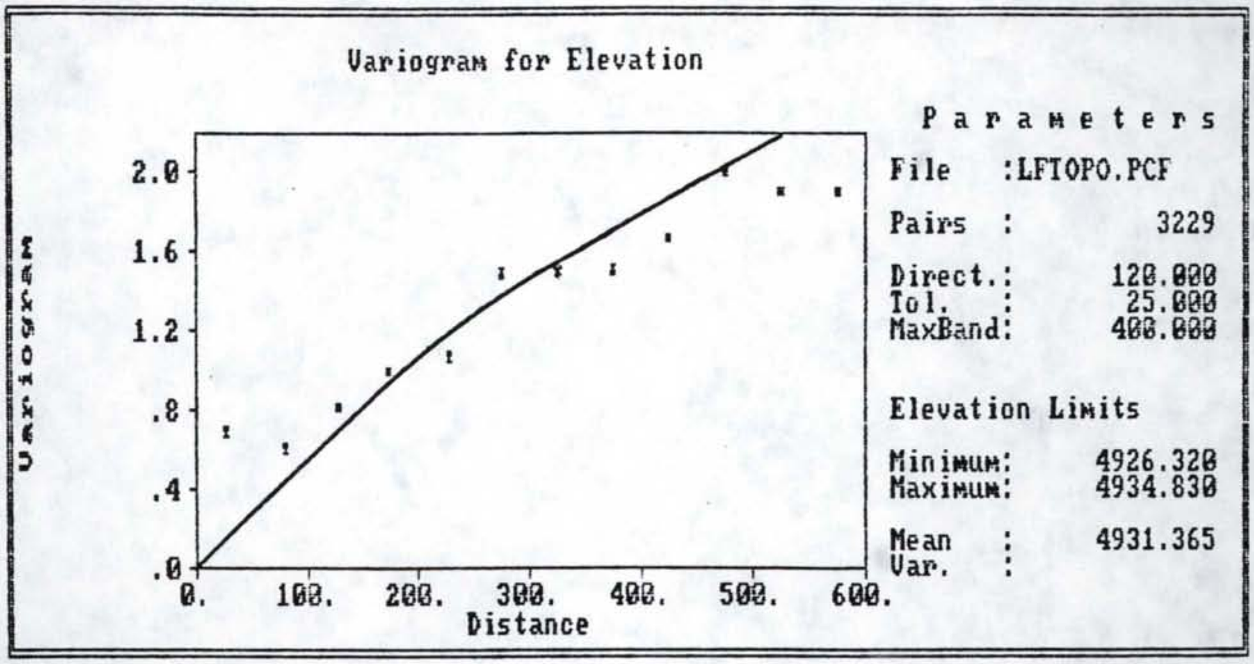

Figure A1. Estimated N30W variogram for elevation of ground surface at CFA Landfill II; spherical model with var. = 3.42, intercept = 0.0, and range = 750 ft.

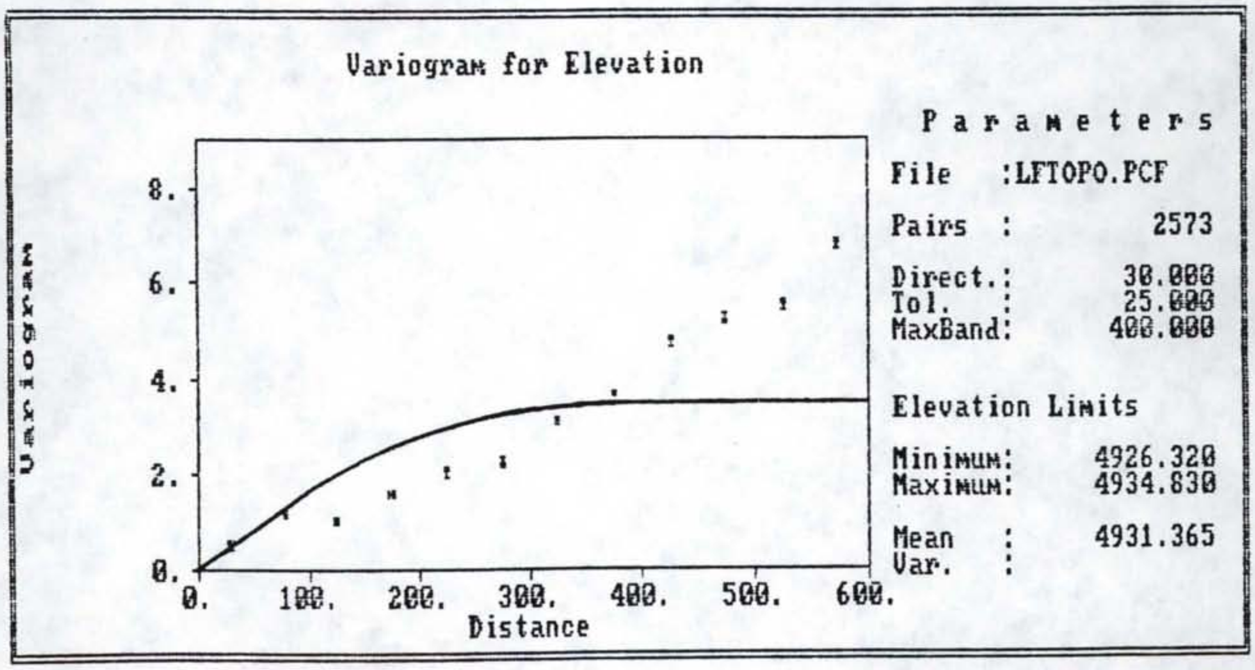

Figure A2. Estimated N60E variogram for elevations of ground surface at CFA Landfill II; spherical model with var. = 3.42, intercept = 0.0, and range = 360 ft.

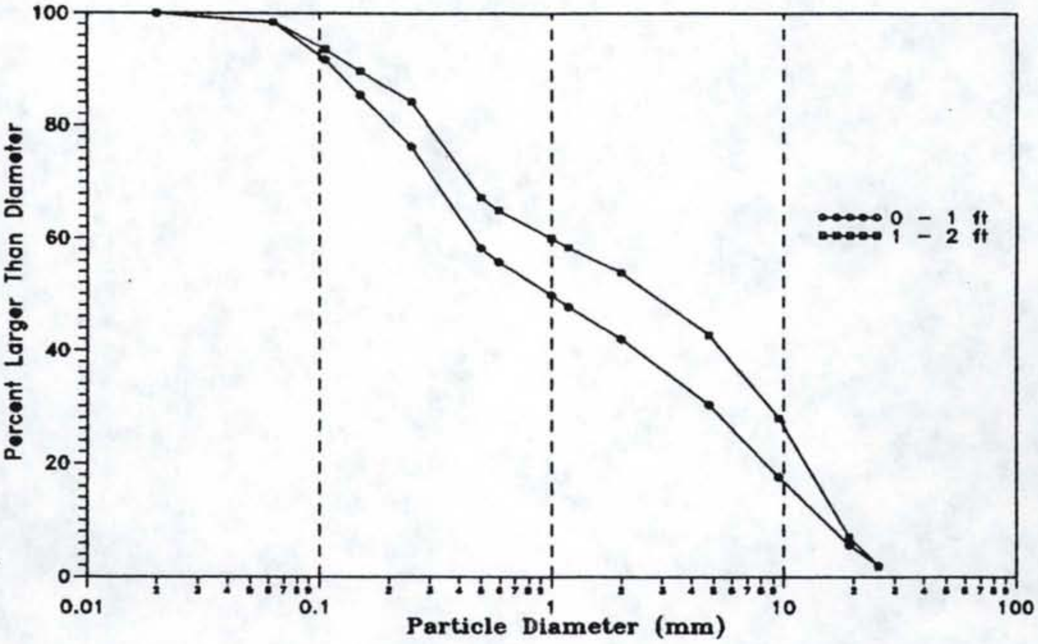

Figure B7. Particle size distribution for sample location 39, CFA Landfill II.

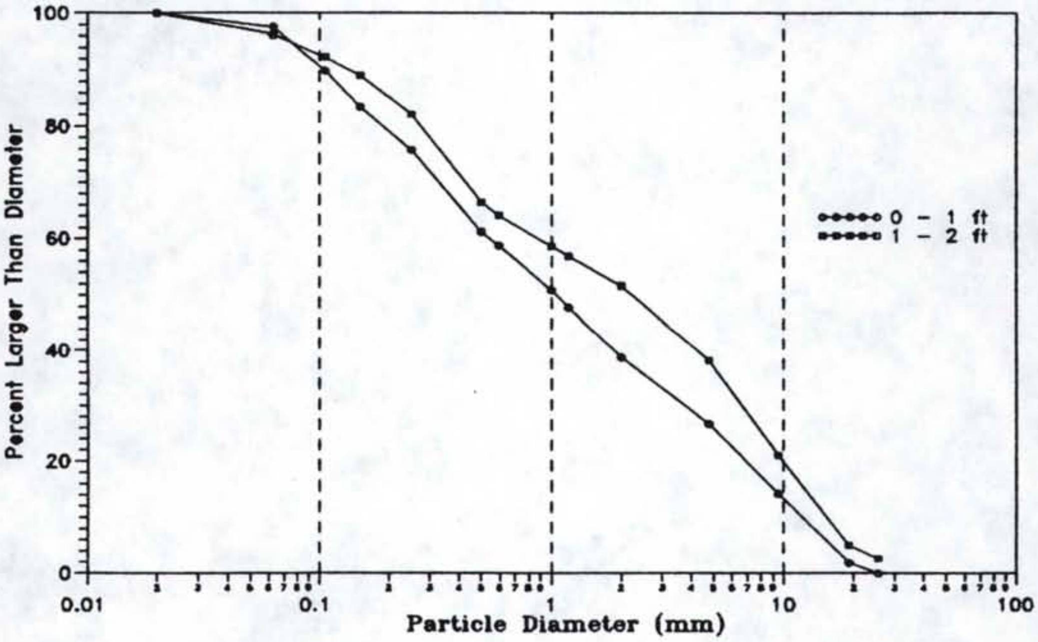

Figure B8. Particle size distribution for sample location 40, CFA Landfill II.

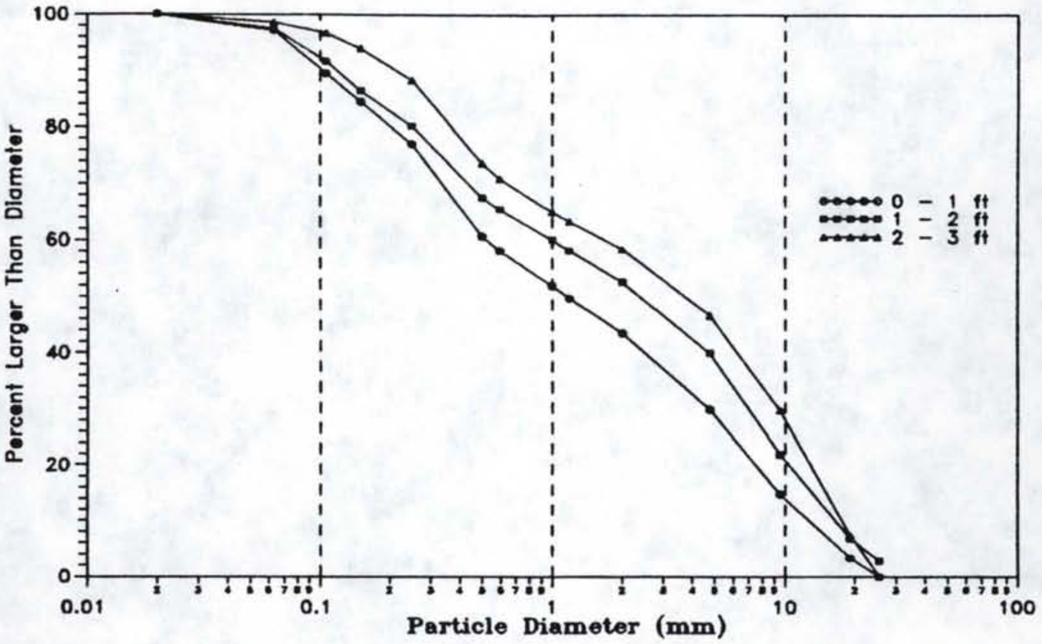

Figure B9. Particle size distribution for sample location 41, CFA Landfill II.

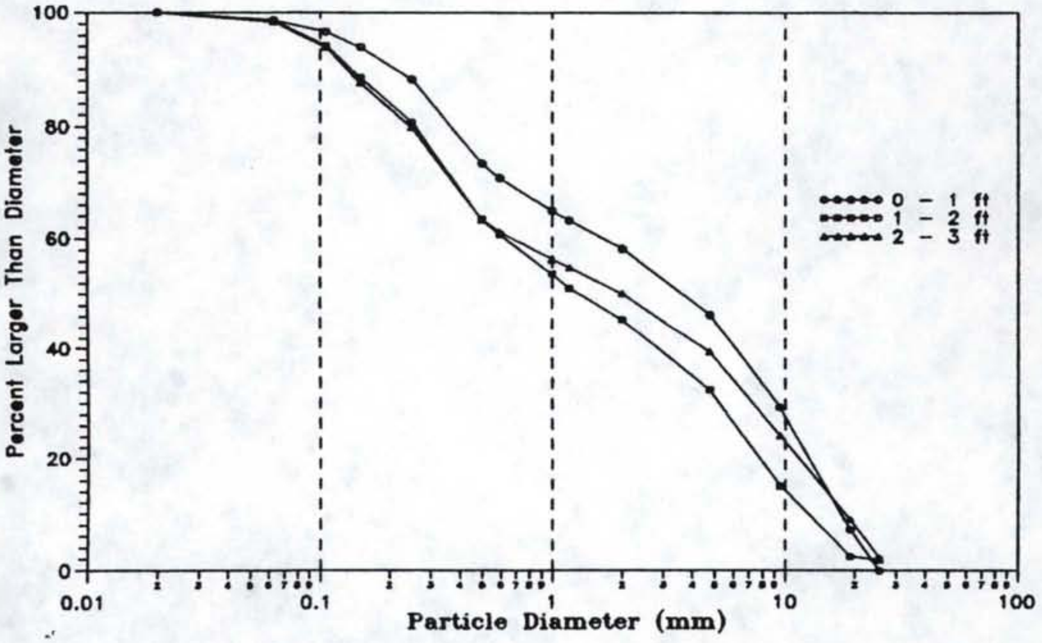

Figure B10. Particle size distribution for sample location 42, CFA Landfill II.

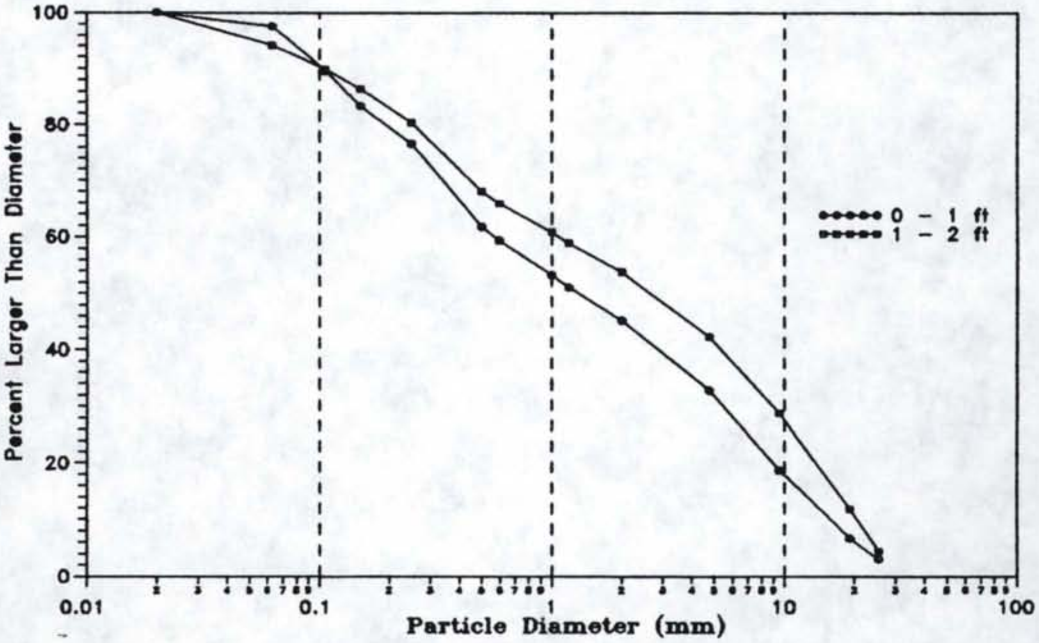

Figure B11. Particle size distribution for sample location 49, CFA Landfill II.

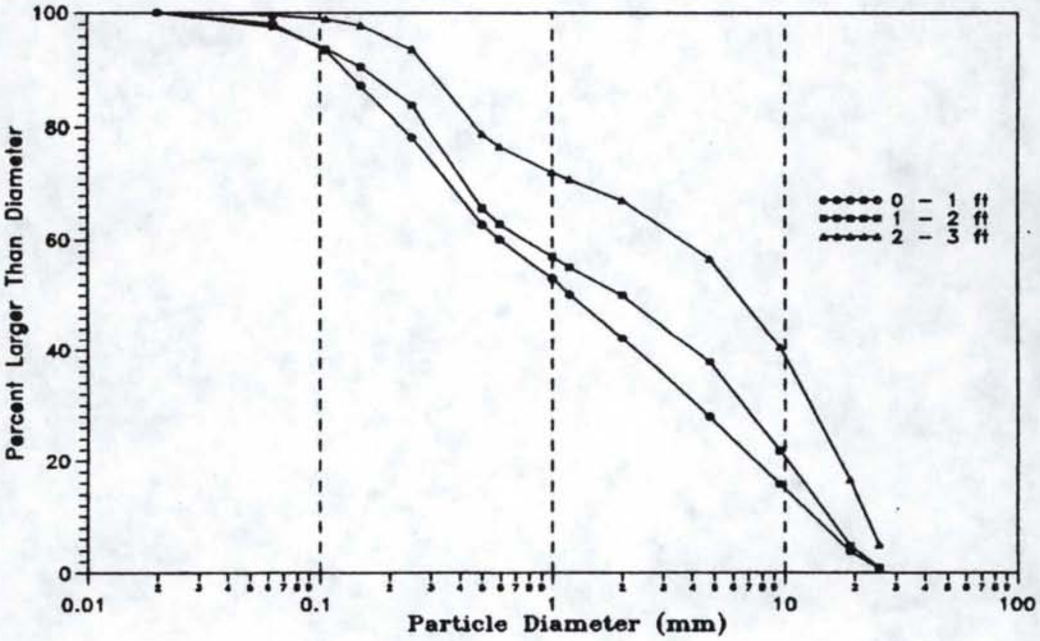

Figure B12. Particle size distribution for sample location 51, CFA Landfill II.

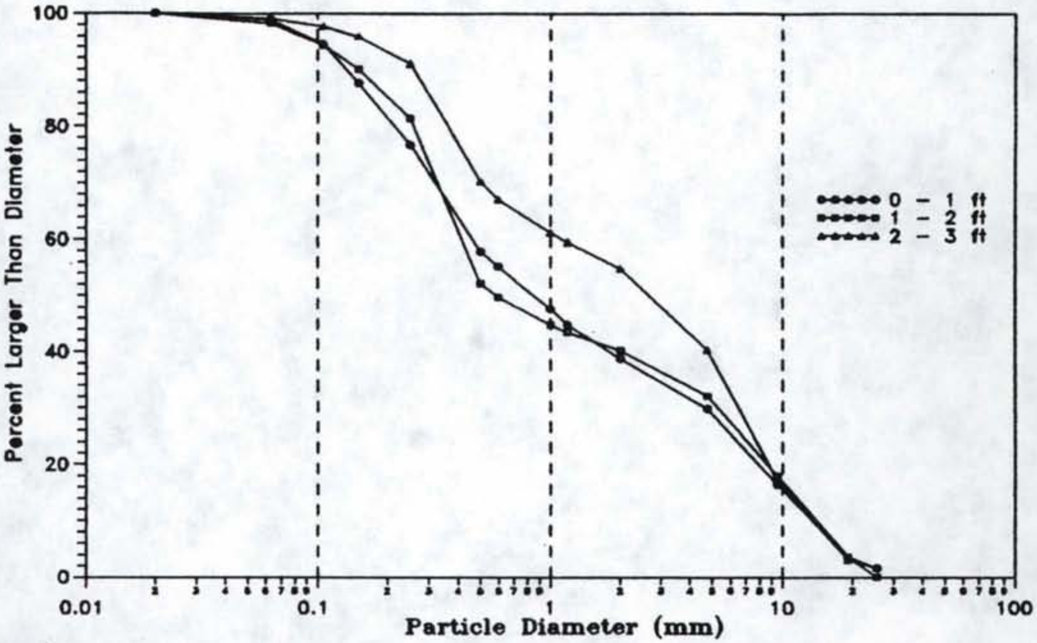

Figure B14. Particle size distribution for sample location 58, CFA Landfill II.

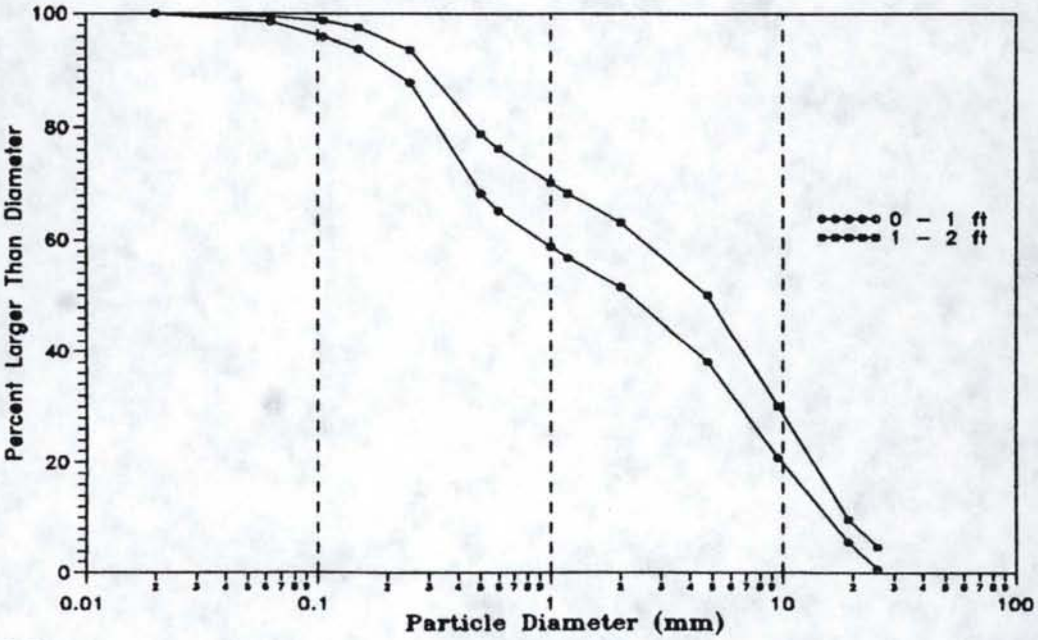

Figure B13. Particle size distribution for sample location 53, CFA Landfill II.

APPENDIX C

Constant head permeability: CPA Landfill II

Sample Nunber: 58

Sample length 15 cm
Sample diameter 17.7 cm
Cross-sectional area 246.1 cm^2

Test	Water	Volume	Collection time:		Collection rate	Elevation: inlet	outlet	Head	K sat
no.	temp	(cm^3)	min	sec	(cm/sec)	(cm)	(cm)	(cm)	(cm/sec)
1.	25	500	6	58	1.196	63	34.5	28.5	2.6E-03
2	24.5	500	7	3	1.182	63	34.5	28.5	2.5E-03
3	24	500	7	6	1.174	63	34.5	28.5	2.5E-03
4	24	500	7	8	1.168	63	34.5	28.5	2.5E-03
5	24	500	7	10	1.163	63.5	34.5	29	2.4E-03
6	24	500	10	36	0.786	59.5	39.5	20	2.4E-03
7	24	500	10	39	0.782	59.5	39.5	20	2.4E-03
8	24	500	10	41	0.780	59.5	39.5	20	2.4E-03
9	24.5	500	21	2	0.396	55.5	45.5	10	2.4E-03
10	25	500	21	2	0.396	55.5	45.5	10	2.4E-03
11	25	500	21	1	0.397	55.5	45.5	10	2.4E-03

Sample Nunber: 19

Sample length 16.5 cm
Sample diameter 18 cm
Cross-sectional area 254.5 cm^2

Test	Water	Volume	Collection time:		Collection rate	Elevation: inlet	outlet	Head	K sat
no.	temp	(cm^3)	min	sec	(cm/sec)	(cm)	(cm)	(cm)	(cm/sec)
1	25.5	500	8	59	0.928	63.5	34.5	29	2.1E-03
2	25	500	9	4	0.919	63.5	34.5	29	2.1E-03
3	25	500	9	9	0.911	63.5	34.5	29	2.0E-03
4	25	500	9	15	0.901	63.5	34.5	29	2.0E-03
5	24.5	500	9	20	0.893	63.5	34.5	29	2.0E-03
6	25	500	13	51	0.602	57.5	37.5	20	2.0E-03
7	24.5	500	13	54	0.600	57.5	37.5	20	1.9E-03
8	24.5	500	13	58	0.597	57.5	37.5	20	1.9E-03
9	25	500	27	0	0.309	52.5	42.5	10	2.0E-03
10	25	500	27	2	0.308	52.5	42.5	10	2.0E-03
11	25	500	26	57	0.309	52.5	42.5	10	2.0E-03

Sample Number: 27

Sample length 16.5 cm
Sample diameter 17.2 cm
Cross-sectional area 232.4 cm^2

			Collection			Elevation:			
Test no.	Water temp	Volume (cm^3)	time: min	sec	rate (cm/sec)	inlet (cm)	outlet (cm)	Head (cm)	K sat (cm/sec)
1	25	500	8	5	1.031	61.5	31.5	30	2.2E-03
2	25	500	8	3	1.035	61.5	31.5	30	2.2E-03
3	25.5	500	7	55	1.053	61.5	31.5	30	2.3E-03
4.	25.5	500	8	7	1.027	61.5	31.5	30	2.2E-03
5	25.5	500	8	28	0.984	61.5	31.5	30	2.1E-03
6	25.5	500	13	28	0.606	53.5	33.5	20	2.0E-03
7	25.5	500	14	2	0.594	53.5	33.5	20	1.9E-03
8	25.5	500	14	23	0.579	53.5	33.5	20	1.9E-03
9	25.5	500	30	53	0.270	44.5	34.5	10	1.7E-03
10	25.5	500	31	28	0.265	44.5	34.5	10	1.7E-03
11	25.5	500	31	59	0.261	44.5	34.5	10	1.7E-03

APPENDIX D

Table D1. Volumetric water content at the upper and lower limits of water storage and estimated water storage of field and laboratory specimens.

	Capillary Pressure (cm)			Water Storage (cm/cm)	
Layer	10^2 (Upper)	10^3	1.5×10^4 (Lower)	(10^2-10^3)	(Upper-Lower)
Reformed cores of fines					
0-1 ft	0.178	0.133	0.081	0.045	0.097
Range	(.138-.228)	(.100-.183)	(.072-.093)	(.038-.045)	(.066-.133)
%Fines Adj.	0.104	0.078	0.047	0.026	0.057*
Adj. Range	(.081-.133)	(.058-.107)	(.042-.054)	(.022-.026)	(.039-.078)
>1 ft	0.116	0.081	0.054	0.035	0.062
Range	(.086-.147)	(.060-.103)	(.045-.061)	(.026-.044)	(.041-.086)
%Fines Adj.	0.058	0.041	0.027	0.018	0.031**
Adj. Range	(.043-.074)	(.030-.052)	(.023-.031)	(.013-.022)	(.021-.043)
Large intact cores (19,58)					
0-1 ft	0.093	0.071		0.022	
Gravimetric field samples (05,13,19,27,34,42,53,58)					
0-1 ft	0.110	--	0.038		0.072
Range	(.077-.191)		(.026-.048)		(.051-.143)
>1 ft	0.084	--	0.049		0.035
Range	(.069-.094)		(.037-.060)		(.032-.034)

* Water content values and storage adjusted for volume fraction of fines of 0.585.

**Water content values and storage adjusted for volume fraction of fines of 0.500.

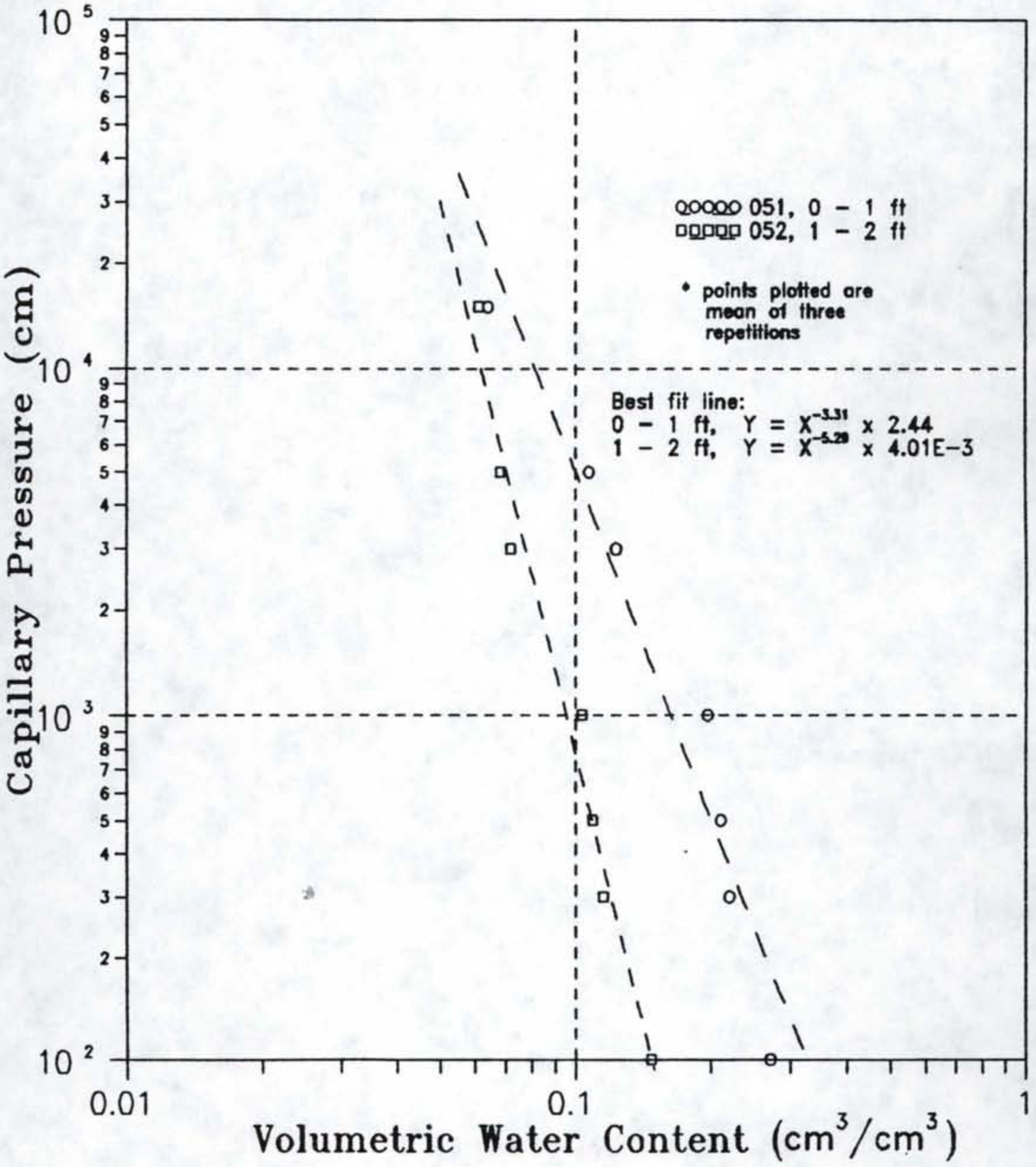

Figure D1. Capillary pressure - water content relationships for soil fractions < 2.00 mm, CFA Landfill II, location 05.

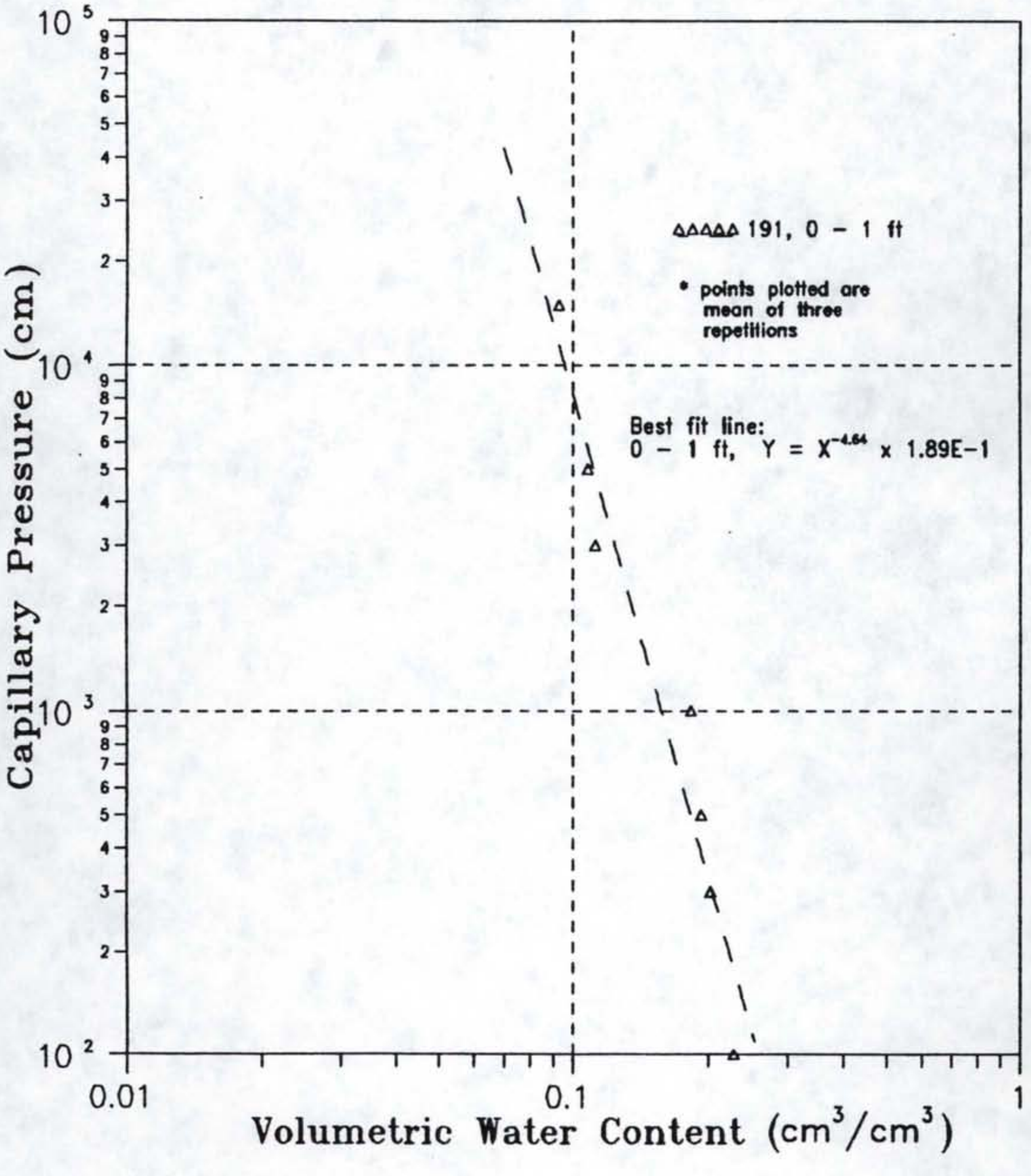

Figure D2. Capillary pressure - water content relationships for soil fractions < 2.00 mm, CFA Landfill II, location 19.

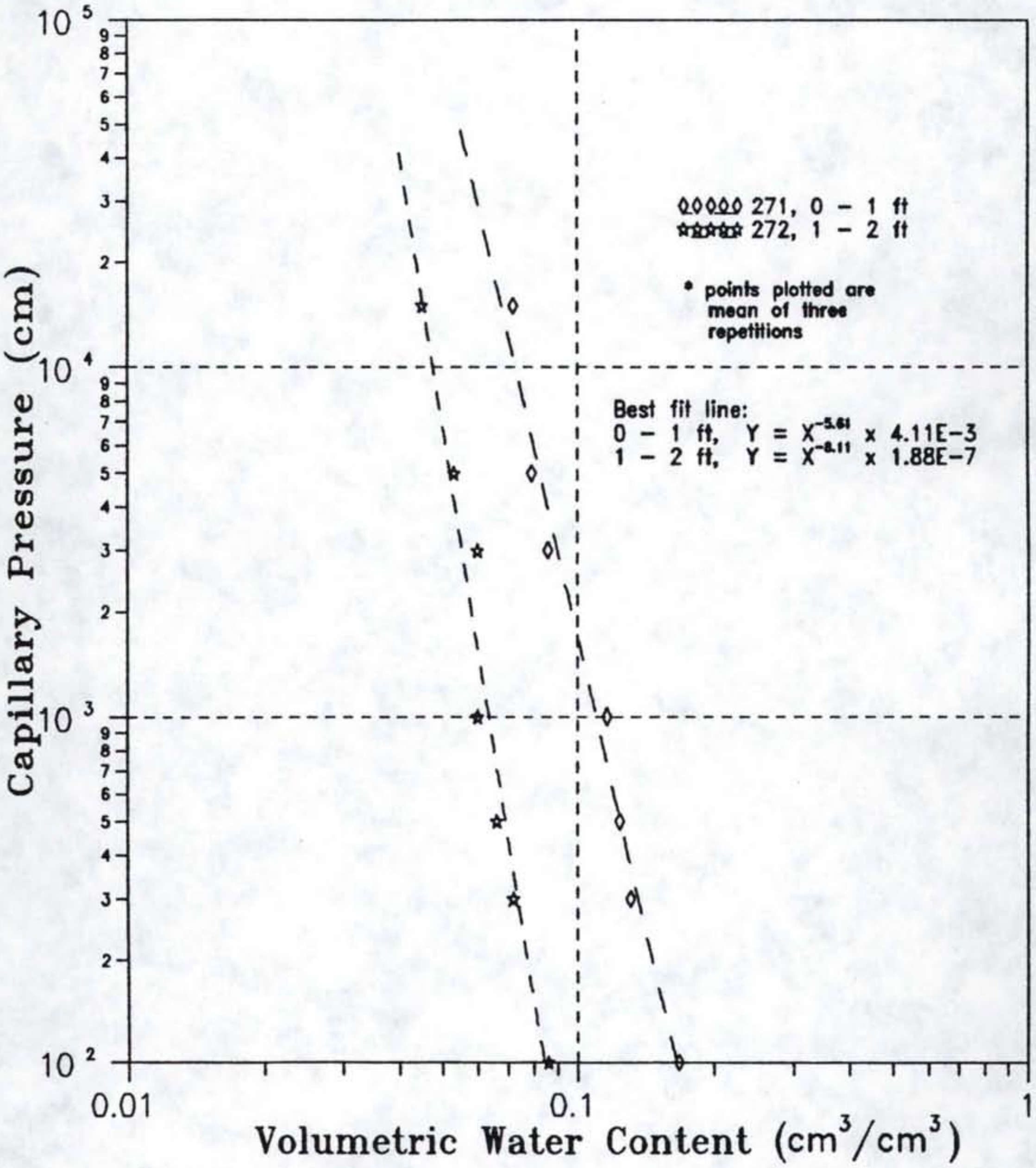

Figure D3. Capillary pressure - water content relationships for soil fractions < 2.00 mm, CFA Landfill II, location 27.

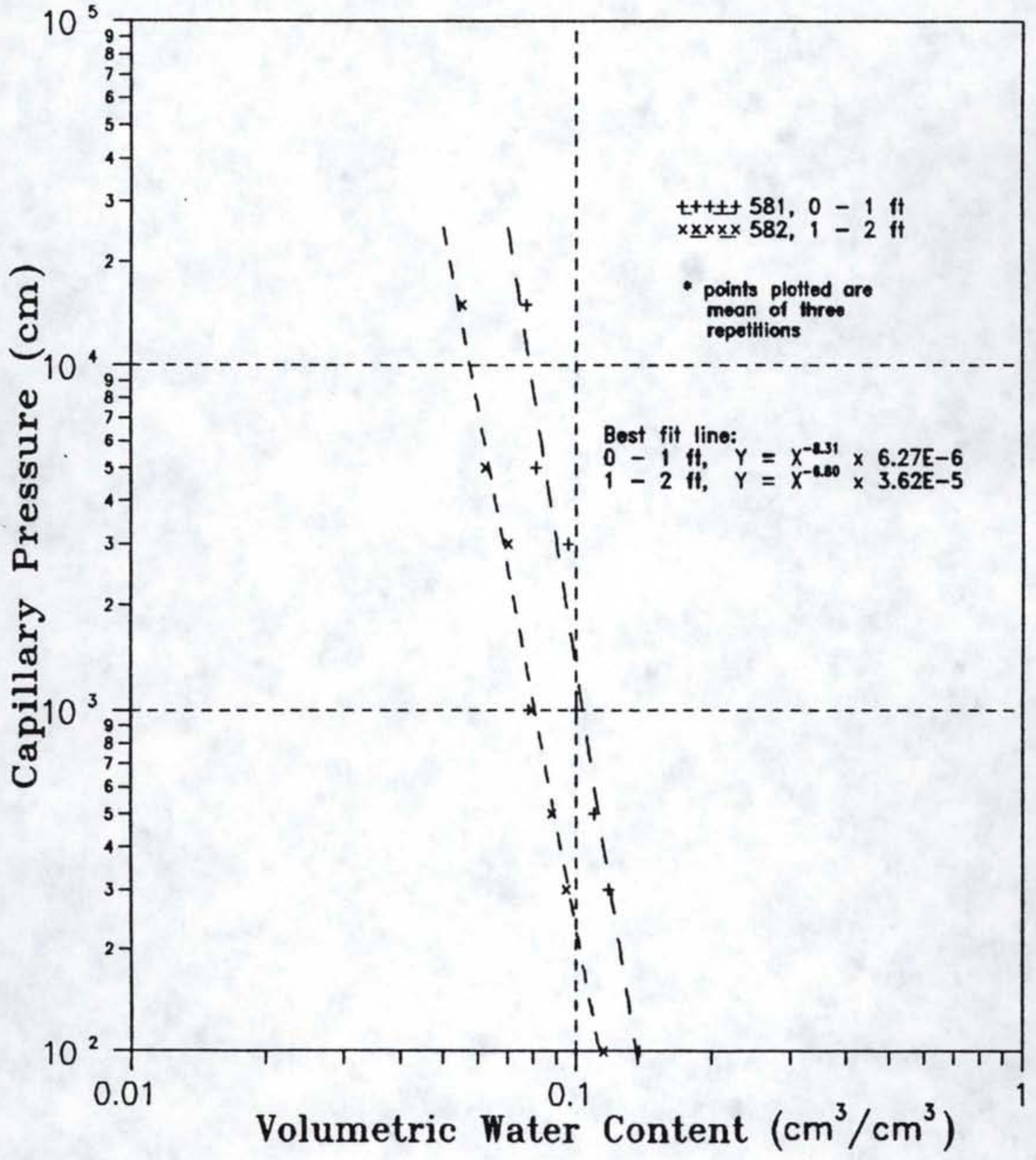

Figure D4. Capillary pressure - water content relationships for soil fractions < 2.00 mm, CFA Landfill II, location 58.

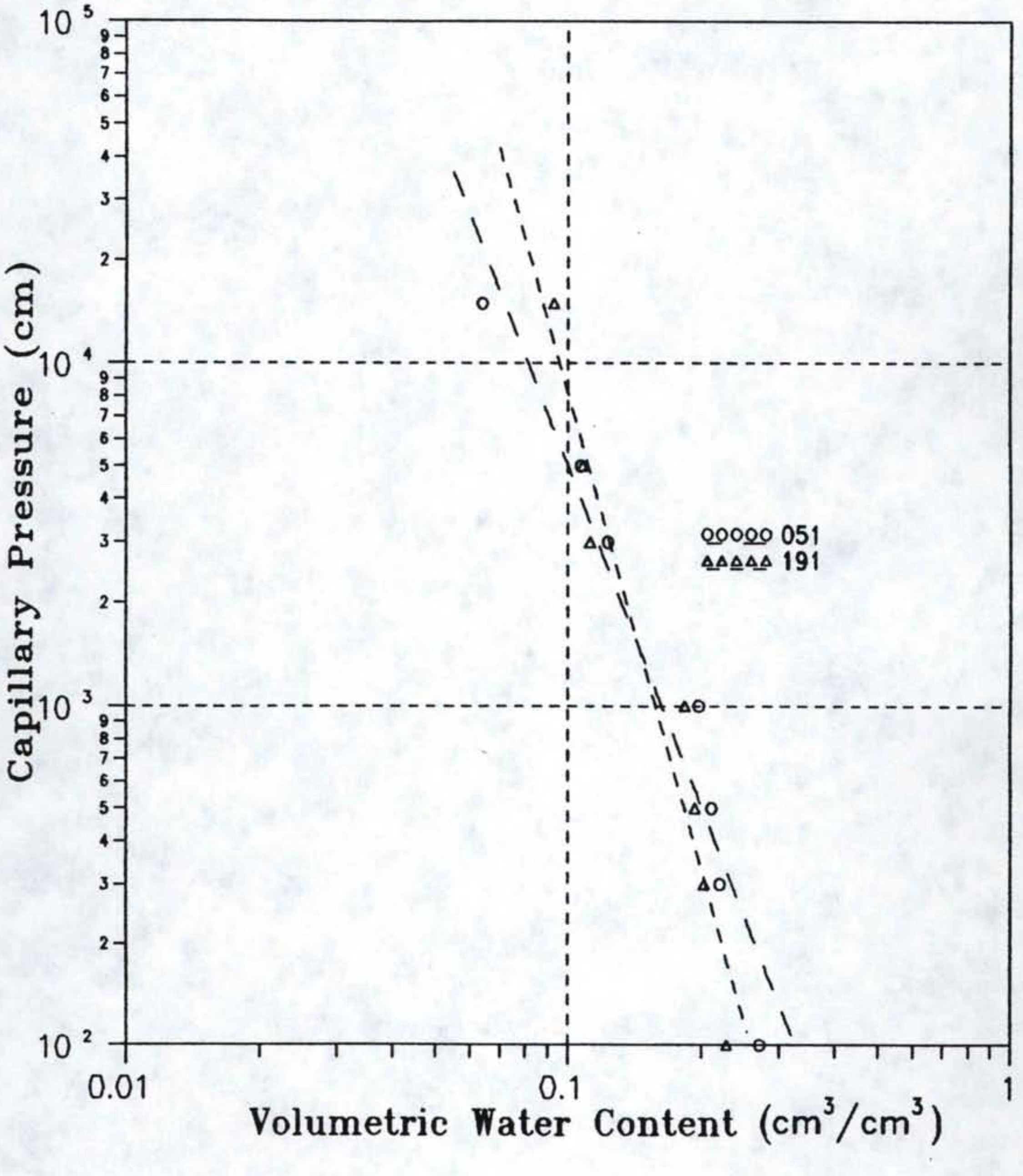

Figure D5. Capillary pressure - water content relationships for soil fractions < 2.00 mm, CFA Landfill II, silty locations, 0 - 1 ft interval.

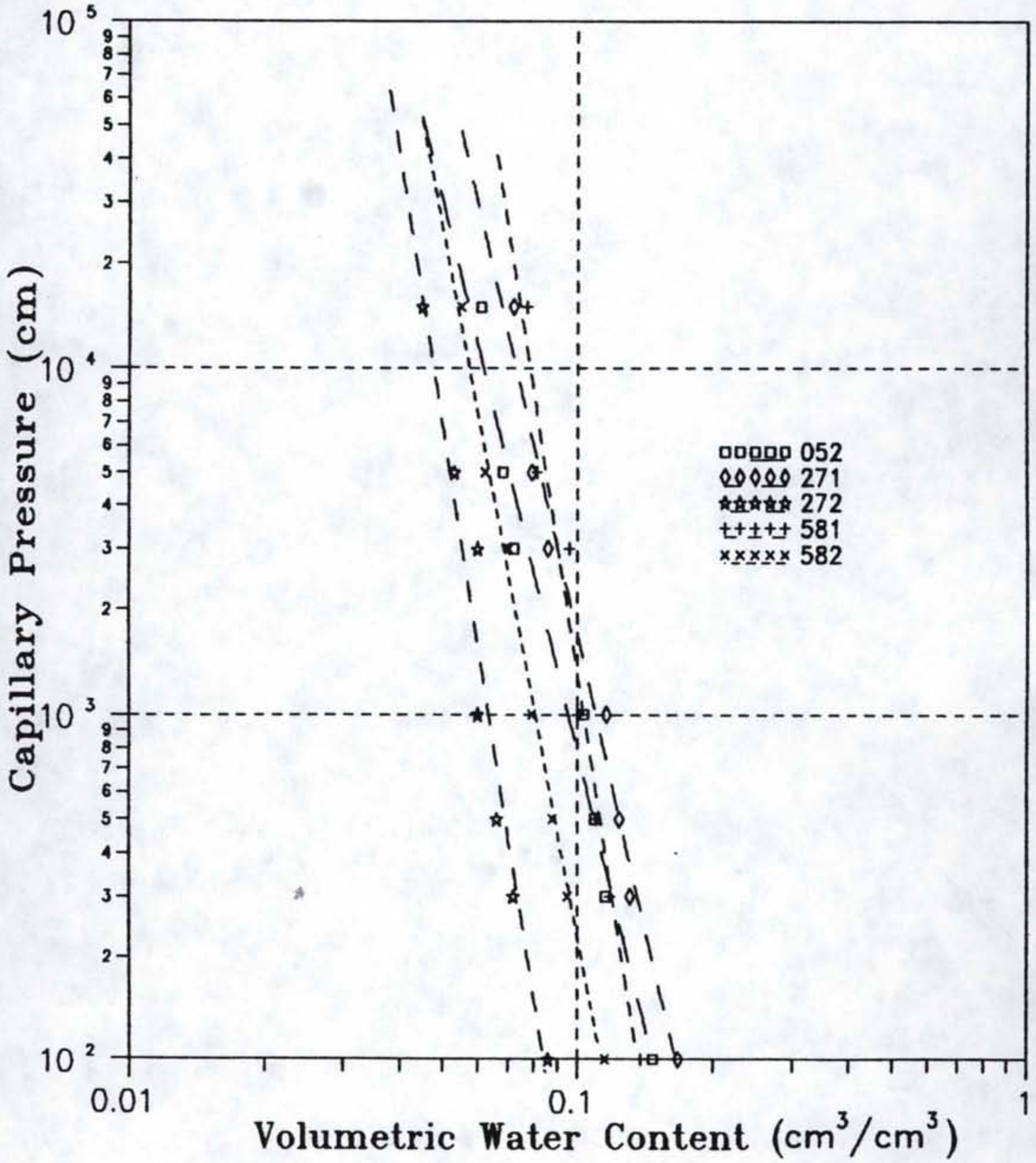

Figure D6. Capillary pressure - water content relationships for soil fractions < 2.00 mm, CFA Landfill II, sandy locations, 1 - 2 ft interval.

APPENDIX E

Hourly mean solar radiation (watts/meter^2), air and soil temperatures (°C) and wind speed (meter/second), CFA Landfill II, INEL, Julian days 181 - 206, 1989. (from temporary weather station)

Julian Day	Hour	Global Radiation (watts/meter^2)	Temperature: Air (°C)	Soil: 5 cm (°C)	20 cm (°C)	40 cm (°C)	Wind Speed (meters/second)
181	1200	954	22.91	21.33	18.74	18.9	5.851
	1300	1027	24.63	23.94	19.62	19.49	5.753
	1400	1057	25.96	26.31	20.32	19.79	6.396
	1500	1038	26.65	27.85	20.72	19.69	6.127
	1600	969	27.36	29.37	21.5	19.86	6.124
	1700	871	27.87	30.48	22.39	20.16	6.243
	1800	653.6	27.84	31.09	23.34	20.56	5.349
	1900	495.6	27.75	30.94	23.94	20.73	5.216
	2000	294.8	27.22	30.66	24.73	21.21	5.148
	2100	102	25.48	29.94	25.43	21.74	4.372
	2200	2.855	22.2	29.03	26.18	22.47	2.122
	2300	-1.184	18.57	27.89	26.68	23.11	2.001
182	0	-3.713	15.86	25.96	26.12	22.88	2.327
	100	-4.336	14.97	23.89	25.11	22.31	2.387
	200	-5.518	15.27	22.19	24.16	21.82	2.395
	300	-0.025	12.8	21.08	23.55	21.66	2.116
	400	-3.636	10.95	21.02	23.92	22.41	1.81
	500	-2.956	11.06	19.65	22.92	21.84	2.081
	600	-1.408	10.29	18.81	22.36	21.65	2.611
	700	62.08	8.04	17.63	21.39	21.05	1.998
	800	239.5	11.27	14.51	18.26	18.33	2.947
	900	445.4	14.77	15.23	18.4	18.73	4.065
	1000	640.2	18.95	16.82	18.51	19.06	4.877
	1100	804	20.57	18.95	18.67	19.27	5.21
	1200	937	21.94	21.27	19.01	19.47	5.75
	1300	1026	23.22	23.59	19.56	19.71	6.528
	1400	1058	24.42	25.54	20.1	19.81	6.93
	1500	1039	25.14	27.21	20.74	19.93	7.49
	1600	968	26.04	28.48	21.46	20.09	7.4
	1700	831	26.63	29.2	22.07	20.16	7.04
	1800	681.7	26.97	29.65	22.73	20.34	6.661
	1900	465.6	26.71	29.85	23.56	20.76	6.337
	2000	300.6	26.59	29.49	24.23	21.14	5.653
	2100	107.5	25.04	28.81	24.78	21.54	3.537
	2200	2.952	21.45	28.35	25.87	22.58	1.846
	2300	-1.386	18.01	27.14	26.29	23.14	2.369
183	0	-1.461	14.25	25.38	25.85	22.99	1.825
	100	-2.65	12.52	23.63	25.14	22.69	1.93
	200	-2.948	10.29	22.18	24.5	22.47	1.829
	300	-3.127	9.53	20.69	23.63	22.06	1.891
	400	-3.671	8.75	19.6	23.02	21.87	2.286
	500	-2.184	8.37	18.51	22.29	21.56	2.642
	600	-1.454	7.29	18.05	22.12	21.73	1.599
	700	66.82	6.828	16.09	20.28	20.32	1.695
	800	242.6	7.89	13.3	17.46	17.86	1.352
	900	440.2	12.33	13.63	17.2	17.88	0.964
	1000	627.4	17.4	15.71	17.65	18.55	0.922
	1100	802	21.82	18.18	17.79	18.74	1.981
	1200	940	24.59	20.97	18.21	18.98	4.202
	1300	1028	26.41	23.79	19	19.38	5.354
	1400	1060	27.72	26.17	19.81	19.67	5.693
	1500	1042	28.86	27.98	20.5	19.75	5.77
	1600	968	29.74	29.62	21.48	20.07	6.574
	1700	849	30.24	30.55	22.32	20.28	6.384
	1800	688.9	30.51	30.98	22.99	20.4	5.646
	1900	503.8	30.38	31.31	23.9	20.85	5.46
	2000	304.3	30.07	31.13	24.73	21.33	5.098
	2100	114.8	28.21	30.36	25.3	21.7	3.398
	2200	4.481	23.23	30.03	26.62	22.91	2.118
	2300	-2.709	20.5	28.64	26.96	23.4	2.478
184	0	-2.423	18.21	26.3	26	22.76	2.72
	100	-3.268	16.81	24.52	25.24	22.39	2.532

Hourly mean solar radiation, air and soil temperatures and wind speed, CFA Landfill II, INEL, Continued

Julian Day	Hour	Solar Radiation	Temp: Air	Soil, 5 cm	20 cm	40 cm	Wind Speed
184	200	-1.366	13.37	23.67	25.14	22.68	1.771
	300	-3.148	12.21	22.65	24.8	22.77	1.802
	400	-2.005	10.12	21.33	24.07	22.46	1.288
	500	-2.336	8.72	20.43	23.63	22.42	0.8
	600	-0.581	6.196	19.66	23.27	22.44	1.149
	700	60.25	6.681	17.27	21.09	20.73	1.001
	800	237.2	9.4	14.19	18.04	18.08	2.048
	900	439.5	14.37	15.21	18.47	18.79	3.294
	1000	626	18.3	17.29	18.94	19.47	3.245
	1100	794	21.9	18.99	18.41	19.06	2.606
	1200	923	25.15	20.9	17.83	18.37	1.728
	1300	1011	28.01	23.77	18.28	18.47	1.77
	1400	1050	30.55	27.13	19.61	19.23	2.92
	1500	1032	32.29	30.02	21.09	20.01	3.983
	1600	965	33.53	32.11	22.44	20.59	4.39
	1700	836	34.15	33.22	23.4	20.84	4.506
	1800	687.5	34.34	33.88	24.45	21.24	5.091
	1900	500.3	34.02	34.04	25.41	21.68	4.745
	2000	296.8	33.52	33.55	26.09	21.99	3.476
	2100	105.2	31.35	32.59	26.57	22.24	1.255
	2200	0.812	28.72	32.25	27.97	23.53	1.189
	2300	-1.286	24.92	30.93	28.48	24.2	1.663
185	0	-2.203	21.13	28.79	27.8	23.84	0.818
	100	-1.668	17.13	27.08	27.21	23.65	1.37
	200	-2.32	14.04	25.64	26.69	23.58	1.254
	300	-4.323	14.07	23.86	25.67	23.06	1.101
	400	-3.545	12.85	22.52	24.9	22.75	1.445
	500	-2.543	11.87	21.52	24.35	22.63	1.582
	600	-2.3	10.62	21.07	24.26	22.92	1.283
	700	59.12	9.47	19.15	22.56	21.68	1.251
	800	231.1	11.45	16.18	19.63	19.16	1.644
	900	430.5	15.64	16.6	19.5	19.32	1.784
	1000	616.4	20.28	18.48	19.8	19.88	1.587
	1100	787	24.02	20.12	19.13	19.34	1.428
	1200	928	26.79	22.92	19.57	19.62	3.389
	1300	1015	29.95	25.97	20.57	20.27	4.513
	1400	1056	31.8	28.32	21.28	20.48	5.29
	1500	1042	32.87	30.5	22.34	20.93	6.174
	1600	969	33.49	32.17	23.41	21.36	6.774
	1700	847	33.58	33.15	24.35	21.69	6.776
	1800	689.7	33.4	33.62	25.21	22.01	6.975
	1900	511.5	32.9	33.58	25.93	22.3	6.44
	2000	303.9	32.25	33.1	26.54	22.62	5.141
	2100	111.7	30.43	32.23	27.03	22.95	3.456
	2200	4.957	24.66	31.83	28.29	24.14	1.854
	2300	-3.439	22.21	30.46	28.64	24.68	2.359
186	0	-2.236	18.86	28.19	27.77	24.12	2.328
	100	-1.723	16.6	26.45	27.08	23.84	2.01
	200	-3.169	15.01	25.17	26.63	23.82	1.561
	300	-3.762	13.65	23.9	26.03	23.66	1.451
	400	-3.095	12.98	22.73	25.41	23.49	1.601
	500	-2.012	10.98	21.68	24.81	23.31	1.996
	600	-0.299	8.88	21.06	24.57	23.43	1.558
	700	58.68	8.88	19.06	22.78	22.1	1.503
	800	231.6	11.37	15.29	18.95	18.7	0.887
	900	436.3	16.11	15.34	18.46	18.51	0.849
	1000	629.4	21.29	18.35	19.88	20.13	1.138
	1100	809	25.46	20.92	20.15	20.47	3.671
	1200	950	27.62	23.79	20.79	20.96	5.69
	1300	1035	28.93	26.03	21.17	21.01	5.93
	1400	1066	29.9	28.18	21.78	21.16	5.797
	1500	1053	30.62	30.19	22.65	21.47	6.418
	1600	981	31.26	31.59	23.43	21.66	6.368

Hourly mean solar radiation, air and soil temperatures and wind speed (meter/second), CFA Landfill II, INEL, Continued

Julian Day	Hour	Solar Radiation	Temp: Air	Soil, 5 cm	20 cm	40 cm	Wind Speed
189	1000	427.5	24.98	21.01	21.5	21.27	5.482
	1100	478.8	26.7	23.28	22.43	22.21	5.478
	1200	830	29.04	23.97	21.75	21.5	7.24
	1300	606.6	29.47	26.37	22.66	22.16	7.6
	1400	758	30.35	27.71	23.17	22.4	7.63
	1500	1038	31.57	28.6	23.14	22.05	8.27
	1600	941	32.13	30.46	23.88	22.41	8.26
	1700	816	32.89	31.71	24.59	22.71	8.03
	1800	609.5	32.93	32.33	25.21	22.91	6.251
	1900	467.9	32.82	32.59	25.92	23.24	6.206
	2000	267.2	32.33	32.38	26.5	23.54	5.056
	2100	76.2	30.45	31.92	27.17	24.01	2.911
	2200	1.474	26.77	31.51	28.18	24.91	2.046
	2300	-4.912	25.46	30.05	28.2	25.05	2.57
190	0	-2.187	24.17	27.72	26.97	24.08	3.436
	100	-1.879	23.13	26.65	26.51	23.88	3.503
	200	-1.702	21.59	26.17	26.48	24.13	2.982
	300	-0.851	20.47	25.52	26.24	24.18	2.496
	400	-2.364	19.77	24.97	26.01	24.21	0.912
	500	-1.912	19.14	24.27	25.55	24.03	1.495
	600	-1.229	18.48	23.66	25.14	23.86	1.73
	700	4.517	17.62	23.34	24.99	23.93	1.611
	800	20.34	17.43	22.87	24.62	23.76	2.886
	900	85.4	19.57	21.86	23.7	23.09	3.71
	1000	150.3	21.16	20.92	22.45	22.04	3.971
	1100	94.4	21.09	21.91	22.82	22.5	5.157
	1200	282	22.08	22.62	23.15	22.9	3.873
	1300	615.7	23.87	21.7	21.19	21.06	4.18
	1400	629.8	25.61	23.65	21.29	21.1	3.718
	1500	573.8	26.9	26.27	22.35	21.94	4.609
	1600	520	28	27.85	23.22	22.5	3.329
	1700	580.6	28.39	28.29	23.25	22.21	4.031
	1800	616.5	29.08	29.24	23.69	22.33	3.736
	1900	576.8	29.69	30.39	24.4	22.68	5.105
	2000	303.3	29.44	31.53	25.7	23.62	5.625
	2100	149.1	28.42	30.99	26.11	23.76	4.653
	2200	7.24	24.86	30.64	27.12	24.55	2.203
	2300	-2.354	21.61	29.78	27.93	25.32	2.162
191	0	-2.987	19.18	27.72	27.34	24.88	1.77
	100	-4.018	19.09	25.62	26.23	24.05	2.091
	200	-1.776	16.97	24.6	25.83	23.94	1.136
	300	-2.448	15.68	23.98	25.81	24.23	1.761
	400	-2.197	15.15	22.79	25.02	23.76	1.461
	500	-1.752	14.76	22.11	24.51	23.56	1.211
	600	-1.312	14.55	21.69	24.2	23.52	1.045
	700	39.44	12.63	21.45	24.15	23.7	1.094
	800	182.6	14.06	18.22	20.94	20.83	1.195
	900	197.6	16.53	19.56	22.03	22.04	1.378
	1000	561.5	18.88	19.8	21.32	21.56	1.548
	1100	762	21.3	20.99	20.49	20.85	1.516
	1200	909	23.86	23.58	20.59	20.86	3.416
	1300	1004	26.12	26.89	21.79	21.75	5.173
	1400	1042	27.36	29.12	22.46	22	5.908
	1500	1030	28.11	30.95	23.19	22.2	6.496
	1600	959	28.73	32.4	24.07	22.51	7.06
	1700	838	29.07	33.22	24.91	22.8	7.78
	1800	677.2	29.2	33.32	25.51	22.93	7.27
	1900	497.2	28.8	33.17	26.15	23.19	7.23
	2000	296.7	28.2	32.7	26.8	23.58	6.287
	2100	110.5	26.64	31.73	27.25	23.9	4.138
	2200	1.572	23.36	30.94	28.14	24.76	3.057
	2300	-3.163	20.84	29.48	28.38	25.15	2.295
192	0	-4.454	18.5	27.57	27.86	24.93	2.879
	100	-2.933	17.32	25.64	26.94	24.41	3.287

Hourly mean solar radiation, air and soil temperatures and wind speed (meter/second), CFA Landfill II, INEL, Continued

Julian Day	Hour	Solar Radiation	Temp: Air	Soil, 5 cm	20 cm	40 cm	Wind Speed
192	200	-3.476	16.27	24.33	26.34	24.21	3.012
	300	-1.541	15.2	23.39	25.92	24.19	2.063
	400	-2.817	12.52	23.26	26.3	24.89	1.742
	500	-2.035	10.74	22.24	25.8	24.77	1.243
	600	-1.864	8.49	21.21	25.23	24.55	1.683
	700	48.22	8.62	19.14	23.42	23.17	1.212
	800	219.2	11.47	15.75	20.03	20.19	2.053
	900	424.4	15.77	16.67	20.32	20.73	2.962
	1000	614.5	19.49	18.93	20.85	21.46	3.322
	1100	784	22.09	21.23	20.81	21.52	3.224
	1200	916	24.62	23.36	20.37	20.99	2.383
	1300	1005	26.66	25.92	20.39	20.72	1.819
	1400	1041	28.59	29.19	21.52	21.32	2.184
	1500	1026	30.26	32.09	22.8	21.96	3.034
	1600	946	31.81	34.01	23.76	22.23	2.3
	1700	829	32.59	35.54	24.85	22.6	2.581
	1800	592.3	33.04	36.65	26.2	23.28	2.44
	1900	415.7	32.85	36.52	27.13	23.66	1.848
	2000	197.4	31.89	35.9	27.89	24.01	3.099
	2100	89.8	30.47	34.99	28.79	24.68	2.36
	2200	2.065	26.21	33.82	29.55	25.38	1.304
	2300	-3.096	23.55	31.98	29.58	25.58	0.97
193	0	-4.655	22.02	29.66	28.72	25.03	2.096
	100	-1.694	20.7	27.56	27.59	24.31	2.736
	200	-2.625	19.79	26.64	27.34	24.46	2.853
	300	-1.796	19.4	25.63	26.72	24.26	2.624
	400	-2.096	18.63	25.12	26.52	24.41	2.933
	500	-1.909	17.66	24.57	26.38	24.6	3.566
	600	-2.008	16.19	24	26.24	24.76	2.853
	700	22.96	16.51	22.9	25.38	24.24	1.978
	800	68.03	17.18	21.92	24.39	23.55	2.795
	900	132.7	19.24	21.46	23.54	22.98	3.37
	1000	316.7	21.49	21.23	22.5	22.16	5.18
	1100	237.4	23.3	22.5	22.61	22.36	4.2
	1200	299.4	25.09	23.38	22.51	22.28	3.34
	1300	150.9	24.65	25.19	23.58	23.19	3.853
	1400	71.7	23.66	26.13	24.64	24.07	5.009
	1500	90.2	20.18	26.64	25.81	25.05	3.732
	1600	88.5	18.47	25.18	25.29	24.51	4.598
	1700	531.1	17.84	23.65	24.38	23.68	3.62
	1800	623.6	18.43	22.75	22.34	21.8	2.277
	1900	440.7	19.8	24.82	23.07	22.53	3.17
	2000	116.9	19.95	26.47	24.23	23.53	2.995
	2100	35.86	19.01	26.31	24.91	24.05	2.89
	2200	0.705	18.07	25.25	25.02	24.08	1.957
	2300	-1.847	16.92	24.11	24.88	23.97	1.273
194	0	-1.908	15.35	23.19	24.79	23.98	1.015
	100	-1.815	14.14	22.27	24.58	23.95	0.587
	200	-1.868	11.08	21.12	23.91	23.53	1.317
	300	4.119	14.03	20.37	23.23	23.1	1.351
	400	3.521	13.78	20.26	23.03	23.1	1.011
	500	1.986	13.93	20.04	22.75	23	1.589
	600	2.835	13.85	19.88	22.52	22.91	0.9
	700	17.29	13.47	19.84	22.41	22.91	1.102
	800	68.81	12.79	19.76	22.25	22.85	1.305
	900	276.3	12.6	18.93	21.1	21.83	2.025
	1000	518.5	14.71	18.29	19.39	20.25	2.192
	1100	742	19.07	20.2	19.27	20.12	2.383
	1200	751	22.32	23.11	19.91	20.6	2.714
	1300	1007	24.78	25.24	19.94	20.34	2.769
	1400	1041	26.83	28.38	20.87	20.8	3.581
	1500	1024	28.5	31.04	21.9	21.24	3.152
	1600	346.2	28	33.45	23.58	22.18	5.298
	1700	95.8	26.29	34.74	26.88	24.7	8.74

Hourly mean solar radiation, air and soil temperatures and wind speed, CFA Landfill II, INEL, Continued

Julian Day	Hour	Solar Radiation	Temp: Air	Soil, 5 cm	20 cm	40 cm	Wind Speed
194	1800	274.8	25.49	30.61	25.6	23.11	4.454
	1900	425	26.46	28.16	24.05	21.46	3.324
	2000	213.6	26.63	28.98	24.94	22.29	3.04
	2100	81.9	25.22	29.1	25.71	23.07	1.84
	2200	0.488	21.92	29.19	27.04	24.38	1.029
	2300	-1.976	19.87	27.89	27.23	24.71	1.101
195	0	-2.063	16.04	26.36	26.94	24.66	1.727
	100	-2.033	14.7	24.64	26.19	24.25	2.145
	200	-2.315	12.95	23.35	25.62	24.02	1.221
	300	-1.749	11.41	22.39	25.23	23.99	1.154
	400	-2.099	10.01	21.45	24.77	23.88	0.801
	500	-2.729	9.03	20.61	24.34	23.78	0.79
	600	-2.837	8.54	19.7	23.77	23.54	1.34
	700	41.9	8.39	18.16	22.41	22.53	0.872
	800	201.8	10.44	15.3	19.47	19.95	1.67
	900	400.2	14.44	16.36	19.9	20.58	2.832
	1000	589.1	18.29	18.48	20.24	21.1	3.707
	1100	759	21.38	20.67	20.05	20.97	3.885
	1200	893	24.07	22.89	19.59	20.41	2.765
	1300	982	26.37	25.78	19.8	20.28	2.111
	1400	1045	29.26	29.63	21.3	21.19	2.235
	1500	1052	30.27	32.04	21.82	21.08	2.606
	1600	971	31.14	34.02	22.64	21.19	2.263
	1700	887	32.3	35.98	24.09	21.85	2.38
	1800	449.2	32.86	38.3	26.57	23.51	2.579
	1900	492	32.36	37.25	27.13	23.53	3.162
	2000	191.5	30.73	36.02	27.46	23.4	3.533
	2100	48.46	28.49	35.06	28.62	24.31	2.716
	2200	0.069	24.53	33.54	29.37	25.04	1.515
	2300	-3.748	21.99	31.58	29.4	25.24	1.392
196	0	2.263	19.89	29.31	28.69	24.9	1.481
	100	3.242	17.95	27.42	27.96	24.61	1.387
	200	2.757	16.77	25.94	27.32	24.44	1.083
	300	2.729	15.29	24.79	26.86	24.43	2.157
	400	3.806	15.09	23.58	26.18	24.21	3.07
	500	2.44	14.05	22.77	25.76	24.19	2
	600	1.01	12.86	22.21	25.52	24.32	2.215
	700	39.81	12.28	21.1	24.64	23.82	1.38
	800	198.9	13.68	18.6	22.17	21.74	3.006
	900	395	17.6	18.45	21.4	21.27	3.196
	1000	542.4	21.86	20.15	21.43	21.52	4.541
	1100	771	24.31	22.3	21.38	21.56	4.147
	1200	889	26.27	24.88	21.4	21.49	3.336
	1300	893	28.85	27.68	21.61	21.44	3.004
	1400	746	30.43	30.31	22.3	21.66	4.178
	1500	857	31.82	32.55	23.95	22.69	6.089
	1600	576.3	31.36	33.51	24.85	22.97	4.968
	1700	63.08	28.31	35.08	27.2	24.67	5.646
	1800	11.13	23.48	34.1	29.99	27	5.805
	1900	110.7	21.76	27.91	27.32	24.42	2.669
	2000	137.2	19.73	25.85	26.46	23.77	3.936
	2100	50.38	19.11	24.97	26.38	24.03	3.126
	2200	1.913	17.75	24.03	26.31	24.32	2.312
	2300	2.239	16.68	22.97	26.03	24.44	2.236
197	0	2.046	14.86	21.93	25.66	24.46	2.298
	100	3.188	14.87	20.72	24.97	24.18	2.545
	200	2.1	13.66	19.92	24.48	24.06	1.592
	300	1.209	11.72	19.51	24.37	24.27	1.284
	400	2.545	10.28	18.97	24.15	24.37	0.839
	500	2.432	9.23	18.03	23.52	24.05	1.101
	600	3.001	9.01	17.16	22.81	23.65	1.149
	700	16.82	9.74	16.14	21.78	22.92	1.114
	800	86.1	10.84	15.44	20.69	22.1	1.184
	900	318.5	12.79	14.63	18.91	20.58	1.502

Hourly mean solar radiation, air and soil temperatures and wind speed, CFA Landfill II, INEL, Continued

Julian Day	Hour	Solar Radiation	Temp: Air	Soil, 5 cm	20 cm	40 cm	Wind Speed
197	1000	457.2	16.44	16.18	18.76	20.54	1.333
	1100	530.2	19.53	18.01	18.46	20.23	2.323
	1200	748	22.33	20.44	18.69	20.31	2.635
	1300	577.8	24.41	24.07	19.9	21.13	4.891
	1400	526.7	25.64	26.07	21.07	21.81	6.237
	1500	348	25.59	26.68	21.74	21.95	5.803
	1600	539	25.45	26.88	22.34	22.08	7.52
	1700	465.4	25.22	27.32	22.54	21.9	6.774
	1800	326.7	24.98	27.54	23.18	22.22	7.22
	1900	358.9	25.04	26.96	23.27	22.09	5.935
	2000	176.4	24.62	26.97	23.65	22.28	7.13
	2100	90.9	23.82	26.36	24.22	22.74	5.776
	2200	0.059	21.01	25.73	24.99	23.45	2.893
	2300	1.404	19.04	24.36	25.05	23.62	2.936
198	0	2	16.14	23.17	25	23.76	1.544
	100	2.242	13.74	22.01	24.75	23.78	1.806
	200	1.813	11.46	20.72	24.22	23.58	1.5
	300	2.39	9.96	19.67	23.78	23.47	1.318
	400	3.618	9.13	18.49	23.1	23.14	1.364
	500	2.676	8.98	17.42	22.38	22.76	1.211
	600	2.815	8.14	16.62	21.86	22.55	1.866
	700	38.58	8.17	15.31	20.68	21.71	1.31
	800	213.6	10.62	12.56	17.72	19.09	2.918
	900	431.1	14.52	13.97	17.96	19.54	3.35
	1000	593.1	17.94	16.7	18.37	20.06	3.608
	1100	763	20.31	19.65	18.66	20.33	4
	1200	851	21.77	22.55	18.95	20.37	5.056
	1300	550.4	22.47	25.25	19.62	20.6	5.612
	1400	848	24.05	26.47	20.58	21	6.221
	1500	1062	24.67	27.55	20.22	20.13	6.788
	1600	933	25.74	30.16	21.42	20.74	7.25
	1700	788	26.47	31.31	22.25	20.97	6.236
	1800	683	26.87	31.94	23.05	21.2	5.248
	1900	505.6	27.09	32.34	24.01	21.65	5.46
	2000	281.1	26.99	32.05	25.02	22.25	4.731
	2100	94.3	25.65	30.87	25.69	22.67	4.002
	2200	1.066	22.47	29.65	26.61	23.49	2.59
	2300	2.211	20.06	27.85	26.76	23.77	2.361
199	0	2.88	18.05	25.86	26.23	23.54	2.257
	100	2.577	16.1	24.36	25.79	23.46	1.076
	200	2.938	14.55	23.19	25.44	23.52	1.084
	300	4.549	14.55	21.85	24.78	23.29	1.238
	400	2.581	13.21	20.48	23.89	22.82	1.504
	500	1.093	10.75	20.16	23.97	23.24	1.31
	600	1.652	9.05	19.74	23.98	23.58	1.377
	700	46.22	9.33	17.82	22.35	22.36	1.399
	800	182.2	11.02	15.01	19.46	19.85	2.678
	900	380.8	15.3	16.37	19.99	20.65	4.332
	1000	561.9	18.42	17.89	19.67	20.53	4.977
	1100	738	20.87	20.34	19.68	20.59	5.121
	1200	898	22.63	22.93	19.59	20.38	3.817
	1300	985	24.39	26.03	19.89	20.34	3.002
	1400	1017	26.52	29.05	20.38	20.31	2.403
	1500	998	28.43	31.87	21.3	20.55	2.296
	1600	929	30.04	34.4	22.7	21.15	2.712
	1700	811	31.04	35.6	23.62	21.29	2.247
	1800	652.3	31.64	36.76	25.17	22.07	2.299
	1900	472.2	31.76	37.01	26.42	22.69	2.156
	2000	277.3	31.55	36.4	27.35	23.16	2.485
	2100	87.3	30.01	35.23	28.2	23.74	1.813
	2200	0.605	25.63	34.05	29.4	24.83	1.56
	2300	2.674	22.9	31.92	29.52	25.14	1.489
200	0	2.343	20.05	29.24	28.55	24.55	1.638
	100	3.523	18.43	27.25	27.79	24.25	1.41
	200	2.31	16.48	25.84	27.3	24.24	1.601

Hourly mean solar radiation, air and soil temperatures and wind speed, CFA Landfill II, INEL, Continued

Julian Day	Hour	Solar Radiation	Temp: Air	Soil, 5 cm	20 cm	40 cm	Wind Speed
200	300	2.68	14.77	24.7	26.88	24.3	1.251
	400	4.815	14.8	23.42	26.18	24.09	2.094
	500	1.553	13.77	22.18	25.36	23.73	2.071
	600	1.571	12.6	21.75	25.27	24.03	1.803
	700	37.31	12.43	20.37	24.13	23.3	1.106
	800	197.8	13.03	17.33	21.07	20.66	1.613
	900	396.1	17.77	17.97	21.06	20.94	2.029
	1000	587	22.27	20.03	21.22	21.34	3.158
	1100	760	25.43	22.52	21.11	21.32	3.721
	1200	898	27.93	25.22	21.06	21.15	3.642
	1300	986	30.16	28.13	21.33	21.08	2.613
	1400	1023	31.85	31.21	22.11	21.33	2.631
	1500	1003	33.63	34.31	23.51	22.03	2.412
	1600	879	34.91	36.54	24.65	22.42	2.498
	1700	635.9	35.53	38.25	26.46	23.42	2.549
	1800	671.4	35.54	37.52	26.47	22.81	2.184
	1900	472.4	35.59	38.35	27.92	23.69	3.064
	2000	271.4	35.31	38.01	28.74	23.96	3.136
	2100	82	33.28	36.93	29.84	24.98	2.739
	2200	-0.433	28.68	35.66	30.85	25.92	1.295
	2300	-2.016	25.02	33.57	30.89	26.16	1.046
201	0	-2.399	21.17	31.32	30.33	25.95	1.475
	100	-3.754	20.58	28.74	29	25.12	1.75
	200	-4.049	19.67	27.1	28.26	24.87	2.393
	300	-2.482	17.76	26.11	27.91	24.99	2.101
	400	-2.4	17.48	25.02	27.32	24.89	2.867
	500	-2.419	16.45	24.25	26.96	24.95	2.244
	600	-2.364	15.25	23.64	26.68	25.05	2.178
	700	44.83	15.16	22.22	25.47	24.26	1.713
	800	180.6	16.49	20.13	23.3	22.48	2.379
	900	235.7	19.26	20.71	23.15	22.58	3.75
	1000	204.4	21.75	22.38	23.68	23.32	2.874
	1100	642	25.2	22.32	22.31	22.13	3.999
	1200	947	28.11	23.82	21.27	21.12	2.964
	1300	372.8	29.23	27.74	22.33	21.87	2.109
	1400	424.7	31.79	29.31	23.31	22.38	2.354
	1500	833	34.79	30.7	23.9	22.55	1.817
	1600	498.2	38.25	36.94	28.14	26.07	4.871
	1700	704	37.33	36.39	28.3	25.94	6.102
	1800	524.2	34.2	34.07	26.56	24.03	4.805
	1900	523.7	36.02	35.78	28.01	24.98	4.731
	2000	200.3	34.06	36.29	29.13	25.76	6.207
	2100	49.89	34.31	36.97	31.17	27.33	5.643
	2200	-0.24	30.26	33.48	29.84	26.22	4.55
	2300	-1.727	27.85	30.99	28.86	25.45	3.875
202	0	-2.278	25.92	29.73	28.63	25.45	2.231
	100	-1.27	25.87	31.06	30.72	27.41	1.566
	200	-1.735	22.9	28.05	28.33	25.67	0.864
	300	-2.454	21.25	26.76	27.54	25.24	1.507
	400	-2.159	21.41	28.02	29.62	27.39	2.307
	500	-2.535	19.74	27.56	29.75	27.77	1.208
	600	-1.723	17.89	25.67	28.18	26.65	1.155
	700	51.08	16.21	23.41	26.11	24.99	1.806
	800	152.8	17.45	21.34	24.03	23.24	2.759
	900	383.9	21.16	22.21	24.33	23.8	4.262
	1000	466	22.81	22.15	22.65	22.33	3.703
	1100	816	27.19	25.66	24.06	23.8	2.307
	1200	384.9	26.95	27.03	23.14	22.76	1.629
	1300	667.7	31.03	30.58	25.13	24.37	3.713
	1400	958	30.57	30.15	24.07	23.09	4.036
	1500	941	34.37	34.88	25.81	24.19	4.145
	1600	691	34.23	36.35	26.79	24.75	4.129
	1700	413	33.84	36.92	27.89	25.32	4.598
	1800	295.5	35.72	38.8	30.17	26.74	5.356
	1900	241	30.73	34.91	28.79	25.5	7.34

Hourly mean solar radiation, air and soil temperatures and wind speed, CFA Landfill II, INEL, Continued

Julian Day	Hour	Solar Radiation	Temp: Air	Soil, 5 cm	20 cm	40 cm	Wind Speed
202	2000	78.6	30.48	34.84	29.76	26.08	6.512
	2100	24.7	28.71	33.38	29.68	25.68	4.69
	2200	-0.183	29.49	34.71	32.28	28.28	3.621
	2300	-2.071	24.9	29.71	28.83	25.69	3.38
203	0	-2.549	26.56	32.32	32.35	28.87	3.059
	100	-1.666	22.19	27.1	27.67	25.21	2.261
	200	-2.493	23.92	29.24	30.44	27.89	1.841
	300	-1.663	22.94	29.92	31.79	29.44	1.567
	400	-2.196	20.77	27.78	29.97	28.1	1.896
	500	-1.567	16.93	24.63	26.86	25.52	0.826
	600	-1.894	18.93	30.31	34.2	32.75	1.191
	700	22.56	16.08	26.09	29.84	28.93	1.315
	800	198.7	17.67	23.33	27.36	26.86	1.143
	900	417.6	19.85	20.55	23.61	23.38	1.974
	1000	617.7	23.83	23.32	24.43	24.38	2.741
	1100	798	26.5	25.66	23.89	23.94	1.767
	1200	899	26.48	26.4	21.45	21.31	2.048
	1300	1126	32.59	33.75	25.07	24.5	2.446
	1400	1128	33.95	36.53	26.09	25	2.705
	1500	994	35.58	39.95	27.36	25.41	3.189
	1600	1015	35.37	40.11	27.03	24.33	3.998
	1700	785	37.98	43.77	30.38	26.79	4.085
	1800	544.9	36.98	42.02	30.42	26.46	4.499
	1900	305.6	34.95	39.82	30.42	26.26	5.19
	2000	113.5	34.06	38.6	31.12	26.56	3.581
	2100	22.45	30.46	37.94	32.49	27.74	5.098
	2200	-0.591	25.71	33.7	30.52	26.39	2.946
	2300	-2.268	24.46	32.63	30.89	26.74	1.351
204	0	-2.484	22.78	30.52	29.93	26.2	1.465
	100	-1.63	22.2	30.26	30.45	26.93	1.498
	200	-2.026	20.05	28.18	29	26.06	0.874
	300	-2.488	20.83	29.6	31.09	28.28	1.712
	400	-1.877	18.76	26.08	27.74	25.63	1.531
	500	-1.332	17.69	26.76	29	27.06	1.291
	600	-2.06	16.93	26.78	29.56	27.95	1.199
	700	27.52	19.16	29.88	33.85	32.32	1.786
	800	164.5	17.39	21.3	24.12	23.3	2.261
	900	321.2	20.03	22.34	24.78	24.19	1.977
	1000	578.6	22.42	22.07	22.79	22.47	1.19
	1100	670.8	25.43	25.1	23.43	23.14	1.673
	1200	598.9	28.39	28.77	24.73	24.31	1.593
	1300	993	32.48	32.21	25.94	25.18	2.617
	1400	1041	32.82	33.98	25.84	24.72	3.308
	1500	1004	33.67	36.01	26.36	24.74	4.298
	1600	999	36.12	39.21	27.97	25.61	5.296
	1700	781	35.79	39.66	28.77	25.86	5.621
	1800	707	35.86	40	29.52	25.98	5.99
	1900	483.5	36.77	41.17	31.44	27.36	5.719
	2000	229.4	35.27	39.61	31.64	27.31	4.568
	2100	76.7	32.36	37.5	31.54	27.16	3.916
	2200	-0.078	27.49	37.15	33.21	28.77	5.782
	2300	-2.777	24.45	32.74	30.94	26.99	6.044
205	0	-1.971	22.94	31.24	30.91	27.13	3.077
	100	-3.138	21.37	30.07	30.8	27.36	2.396
	200	-1.95	19.25	27.8	29.28	26.42	1.725
	300	-2.321	19.35	31.42	34.11	31.16	1.021
	400	-2.613	16.24	26.01	28.7	26.65	1.351
	500	-1.875	13.11	25.26	28.51	26.8	1.671
	600	-1.82	11.52	24.26	28.04	26.71	0.946
	700	29.6	12.34	25.87	30.86	29.84	1.312
	800	181.1	12.97	19	23.23	22.75	1.101
	900	387.7	16.73	19.44	23.2	23	2.047
	1000	597.2	21.29	22.31	24.5	24.55	2.889
	1100	810	24.54	25.3	24.64	24.86	2.451

Hourly mean solar radiation, air and soil temperatures and wind speed, CFA Landfill II, INEL, Continued

Julian Day	Hour	Solar Radiation	Temp: Air	Soil, 5 cm	20 cm	40 cm	Wind Speed
205	1200	885	26.07	26.13	22.77	22.94	1.781
	1300	1022	29.79	30.23	23.68	23.54	2.235
	1400	1154	36.19	37.45	27.46	26.66	3.745
	1500	1007	32.89	35.02	25.33	24.13	3.974
	1600	1058	37.66	40.97	28.93	26.79	4.843
	1700	818	37.72	42	30.09	27.24	4.022
	1800	635.6	36.59	40.73	29.93	26.62	4.48
	1900	376.8	34.31	38.76	29.47	25.79	4.674
	2000	176	36.76	41.7	33.41	28.97	4.31
	2100	33.41	31.06	37.35	31.82	27.43	2.983
	2200	-2.036	27.73	35.05	31.8	27.64	2.398
	2300	-3.396	26.93	35.23	33.61	29.22	1.839
206	0	-3.774	23.5	30.43	30.31	26.78	1.315
	100	-2.923	23.38	29.8	30.61	27.32	2.009
	200	-1.565	21.91	29.51	31.11	28.06	2.112
	300	-6.51	21.93	26.78	28.67	26.36	2.488
	400	-0.869	22.9	28.32	30.93	28.71	2.313
	500	-1.639	18.51	25.94	28.45	26.8	1.611
	600	-2.991	16.86	25.4	28.34	27	1.483
	700	29.35	17.19	25.63	29.32	28.23	2.056
	800	164	17.04	21.79	25.19	24.53	2.509
	900	323	19.95	22.11	25.15	24.74	

Summary of daily mean, maximum, and minimum air and soil temperatures, and wind speed, CFA Landfill II, INEL, ID, Julian days 181 - 206, 1989. (from temporary weather station)

	Mean					Maximum				
	Temperature:					Temperature:				
Julian Day	Air (°C)	Soil; 5 cm (°C)	20 cm (°C)	40 cm (°C)	Wind Speed (m/s)	Air (°C)	Soil: 5 cm (°C)	20 cm (°C)	40 cm (°C)	Wind Speed (m/s)
182	24.66	28.15	23.11	20.84	4.835	29.17	31.23	26.81	23.18	10.13
183	18.97	23.49	22.23	20.82	4.245	28.3	30.03	26.44	23.18	11.97
184	19.65	23.64	22.04	20.72	3.333	31.43	31.41	27.27	23.6	10.69
185	22.07	25.35	22.94	21.15	2.461	35.67	34.14	28.76	24.36	10.61
186	22.69	26.18	23.94	21.88	3.217	35.14	33.73	29.07	24.98	11.41
187	21.93	25.9	24.06	22.25	3.561	32.71	33.18	28.39	24.96	11.73
188	22.41	26.16	24.03	22.34	2.912	36.16	34.73	29.11	25.1	10.21
189	23.83	26.95	24.67	22.77	3.028	36.97	35.05	29.84	25.75	12.45
190	25.36	26.7	24.87	23.11	4.676	34.17	32.66	28.56	25.35	12.69
191	23.19	25.95	24.64	23.27	3.31	31.39	31.73	28.11	25.48	10.61
192	21.6	26.5	24.48	23.03	3.517	30.52	33.41	28.6	25.27	11.65
193	22.19	27.14	24.73	23.15	2.259	34.59	36.98	29.86	25.76	6.447
194	19.48	24.44	24.78	23.7	3.117	25.79	28.19	27.81	25.24	8.37
195	19.78	24.88	23.29	22.54	2.439	30.39	35.7	27.48	24.96	14.69
196	20.99	26.77	24.1	22.69	2.131	35.17	39.43	29.54	25.33	6.767
197	20.51	25.55	25	23.48	3.241	34.65	36.84	30.47	27.5	13.25
198	18.39	21.97	22.44	22.51	3.469	27.36	27.83	25.52	24.51	11.65
199	18.56	23.62	22.25	21.77	3.67	28.22	32.44	26.96	23.89	11.01
200	21.24	26.57	23.8	22.25	2.334	33.05	37.1	29.88	25.36	7.09
201	24.6	28.68	25.48	23.21	2.214	37.5	38.54	31.11	26.22	6.687
202	26.13	28.53	26.4	24.32	3.355	44.55	44.1	37.09	32.29	10.21
203	26.31	29.85	27.5	25.4	3.319	43.67	47.2	38.21	35.97	10.45
204	26.71	31.82	28.47	26.25	2.547	45.1	50.54	41.02	37.84	10.93
205	26.47	31.57	28.53	26.19	3.117	47.55	50.88	42.35	38.94	10.37
206	25.25	31.16	28.52	26.41	2.563	48.36	51.74	47.8	46.22	10.53

Summary of daily mean, maximum, and minimum air and soil temperatures, and wind speed, CFA Landfill II, INEL, Julian days 181 - 206, 1989. Continued

Minimum

	Temperature:				
Julian Day	Air (°C)	Soil; 5 cm (°C)	20 cm (°C)	40 cm (°C)	Wind Speed (m/s)
182	15.14	20.04	18.18	18.48	0.847
183	7.58	13.93	17.66	17.81	0.847
184	5.922	12.93	16.9	17.5	0.447
185	5.59	13.98	17.66	17.92	0.447
186	8.65	15.94	18.85	18.97	0.447
187	7.86	14.58	18.06	18	0.447
188	5.938	14.31	18.52	18.53	0.447
189	7.67	15.05	18.79	18.67	0.447
190	15.34	19.45	20.99	20.78	0.687
191	16.36	20.75	20.75	20.63	0.447
192	12.11	17.33	20.04	19.97	0.447
193	7.38	15.43	19.72	19.93	0.447
194	14.72	21.03	22.18	21.63	0.447
195	12.13	18.03	19.05	19.93	0.447
196	7.19	15.03	19.23	19.74	0.447
197	11.66	18.16	21.27	21.18	0.447
198	8.32	13.97	18.17	19.9	0.447
199	6.623	12.15	17.36	18.72	0.447
200	7.99	14.56	19.08	19.45	0.447
201	10.8	16.97	20.75	20.34	0.447
202	14.69	19.51	20.84	20.64	0.447
203	15.1	20.74	19.49	17.16	0.447
204	13.69	18.67	19.39	16.96	0.447
205	15.27	20.72	20.77	18.29	0.447
206	10.15	18.22	19.8	18.11	0.447