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April 14, 2000
In reply refer to 2000RC1672

BOEING

Mr. Gerard Abrams
California Environmental Protection Agency
Department of Toxic Substances Control, Region 1
10151 Croydon Way, Suite 3
Sacramento, CA 95827-2106

Subject: Infiltration Monitoring Workplan, Former Sodium Disposal Facility
Santa Susana Field Laboratory, Ventura County, California

Dear Mr. Abrams:

The Boeing Company, Rocketdyne (Rocketdyne) has completed the Infiltration Monitoring Workplan for the Former Sodium Disposal Facility and is being submitted, by The IT Group, under separate cover today.

If you have any questions please do not hesitate to call me at (818) 586-4347.

Sincerely,

David H. Chung, P. E.
Environmental Remediation

DHC:bjc
Attachment

cc with attachment: Richard McJunkin/DTSC
Mike Lopez/DOE
R. Marshall/CSUN Urban Archives
J. Metzler/Platt Branch Library
J. Weaver/Simi Valley Library

(SHEA-089764)

# INFILTRATION MONITORING WORKPLAN
# FORMER SODIUM DISPOSAL FACILITY

# SANTA SUSANA FIELD LABORATORY

Prepared for

Rocketdyne Propulsion and Power
The Boeing Company
6633 Canoga Avenue
Canoga Park, California 91309

April 14, 2000

Prepared by

IT CORPORATION
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Project 881344

# INFILTRATION MONITORING WORKPLAN
# FORMER SODIUM FACILITY
# SANTA SUSANA FIELD LABORATORY

The material and data in this report were prepared under the supervision and direction of the undersigned. This report was prepared consistent with current and generally accepted geologic and environmental consulting principles and practices that are within the limitations provided herein.

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# CONTENTS

# CONTENTS (Continued)

# TABLES AND ILLUSTRATIONS

## Tables



## Figures

# ACRONYMS

| | |
|---|---|
| bgs | below ground surface |
| Cal/EPA | California Environmental Protection Agency |
| CEQA | California Environmental Quality Act |
| COPC | Constituents of potential concern |
| cy | cubic yards |
| DHS | California Department of Health Services |
| DOE | Department of Energy |
| DTSC | Department of Toxic Substances Control |
| ESI | Environmental Sensors, Inc. |
| ETEC | Energy Technology Engineering Center |
| FSDF | Former Sodium Disposal Facility |
| HSP | Health and Safety Plan |
| IM | Interim Measures |
| IMWP | Interim Measures Workplan |
| mg/kg | Milligrams (1 x $10^{-3}$ gram) per Kilograms |
| PCB | Polychlorinated Biphenyl's |
| PVC | Polyvinyl Chloride |
| SBA | Soil Borrow Area |
| SHEA | Safety Health and Environmental Affairs |
| SSFL | Santa Susana Field Laboratory |
| TDR | Time Domain Reflectometry |
| VLDPE | Very Low Density Polyethylene |
| VOCs | Volatile Organic Compounds |

# 1 INTRODUCTION

The Boeing Company, Rocketdyne Propulsion and Power (Rocketdyne) is implementing Interim Measures for soil removal at the Former Sodium Disposal Facility (FSDF) near the western end of its Santa Susana Field Laboratory (SSFL). The main excavations will be backfilled with on-site borrow soil. This workplan presents a field program to monitor infiltration through the FSDF fill section. The monitoring program will be implemented for 5 years, or until the final corrective action for the FSDF is in place, whichever is sooner.

## 1.1 Overview

On December 14, 1999, the California Department of Toxic Substance Control (DTSC) approved, with several stipulations, the draft final Interim Measures Workplan for Soil Cleanup at the Former Sodium Disposal Facility, Santa Susana Field Laboratory dated July 9, 1999. The Interim Measures Workplan (IMWP) specifies the Interim Measures (IM) for soil and sediment cleanup at the FSDF. The IM is being performed to reduce the potential for soil and sediment containing Constituents of Potential Concern (COPC) to migrate from the FSDF and drainage channels offsite.

The SSFL is operated by Rocketdyne and is located in the Simi Hills of Eastern Ventura County (Figure 1). The FSDF is located at the western end of the SSFL (Figure 2) in Area IV, in which energy-related research was conducted by the Energy Technology and Engineering Center (ETEC) on behalf of Department of Energy (DOE).

Extensive remedial excavations of the Upper Pond, Lower Pond and Western Area of the FSDF have produced a substantial depressed area which is currently tarped to protect surface water. The Interim Measures in the FSDF area will include:

- Excavation of an additional approximately 3000 cy of soil from the Upper Pond, Western Area and upper (i.e., southern) portion of Channel B (Figure 3),
- Backfilling of the excavation with clean soil taken from an on-site Soil Borrow Area (Figure 2),
- And, removal of sediments from about 1500 feet of the drainages leading from the north side of the FSDF (i.e., Channels A and C )

In the Upper Pond, Lower Pond, and Western Area, the excavation will extend to the top of the underlying sandstone bedrock. As part of the excavation work, the top of the rock will be mapped and scarified prior to placement of the backfill.

## 1.2 Project Background

The FSDF was used to clean non-radioactive metallic sodium and NaK (a mixture of sodium and potassium) from various test components (e.g., pumps, valves, etc.) before they were discarded. The area was used to treat non-radioactive sodium and NaK and to burn non-radioactive waste organic liquids. The facility ceased operations in the 1970's.

The facility consisted of a rectangular, concrete-lined pit filled with water, two water-filled basins (Upper and Lower Ponds), a small building (Building 886), and a steam lance. Components were cleaned by being placed on a concrete slab and opened to expose the sodium or NaK, and then washed with water. The washed items were often placed into the water-filled ponds where they remained until any residual sodium and/or NaK was reacted. The items were then retrieved and disposed off-site. Some components containing small amounts of radioactive material were inadvertently placed in the FSDF, although the facility was not intended for handling such materials.

The FSDF has undergone extensive remedial excavation previously. Debris and soils were removed from the area adjacent to the concrete pool in 1980-81. The RWQCB served Rocketdyne with a TPCA-authorized Cleanup and Abatement Order for the Lower Pond on April 30, 1991. In the Lower Pond, all soil was removed down to the bedrock and the concrete pool area was demolished and decontaminated. The Lower Pond was closed by the RWQCB under TPCA on December 29, 1992. Altogether, 12,000 cubic yards of soil were excavated and removed from the FSDF area, leaving about three feet of overburden (i.e., soil over the bedrock) in the area of the Upper Pond and Western Area. The Upper Pond, Lower Pond, and Western Area are current tarped to protect surface water.

In 1995 through 1997, supplemental chemical and radiological investigation work for the FSDF was performed, the results of which are summarized in the IMWP (ICF KE, 1999b). Radiological issues for the FSDF are overseen by California Department of Health Services (DHS). Based on the results of the supplemental investigations, and confirmation samples taken by DHS, the DHS issued a radiological release for unrestricted use for the FSDF site in May 1998. Regarding chemicals in the subsurface, a risk assessment of the FSDF was performed (IT, 1999a) which identified PCBs and dioxin/furans as the Chemical of Potential Concern (COPCs) for the Interim Measures remediation work. As mercury concentrations may affect the disposal classification of some excavated soil and the selection of personal protective equipment, it too is considered a COPC for the IM. The IMWP describes in detail the further soil and sediment removal to be performed, and the backfilling of the FSDF excavations. Soil to backfill the FSDF excavations is to be taken from an on-site Soil Borrow Area (SBA) (Figure 2). The properties of this backfill soil are described in Section 2.0 of this report.

During excavation of soil from the area of Lower Pond in 1992, substantial concentration of chlorinated solvents were encountered. Detectable concentrations of chlorinated solvents are observed in the shallow groundwater from monitoring well RS-54 in the Lower Pond. This well is screened in shallow bedrock. Consequently, there is concern that residual chlorinated solvents may reside in the shallow bedrock, and that these solvents may migrate to groundwater under the influence of infiltrating water.

## 1.3 Project Objectives

Modeling studies of the vertical infiltration of surface water through the planned FSDF backfill section have been performed (IT, 2000). These studies suggest that only negligible quantities of water will infiltrate through the fill section to the bedrock below in the first four to five years following fill placement. Five years is thought to be a reasonable duration for the Interim Measures (i.e., time until a permanent remedy is implemented). Lateral migration of water to the uphill side of the fill section along the top of bedrock may contribute to the water content conditions of the FSDF fill section, but lateral migration is not taken into account by vertical infiltration models. Consequently, the purposes of this monitoring program are to (1) monitor moisture content changes in the soil column of the FSDF fill to allow a comparison to model-predicted behavior, and (2) to assess the possible contribution of the lateral migration of water along the rock contact to the moisture conditions within the fill.

# 2 DESCRIPTION OF FSDF BACKFILL

The soil properties and infiltration behavior of the proposed FSDF backfill is best considered relative to the existing soil and rock conditions at the FSDF. The FSDF site soil and bedrock conditions and the properties of the fill soil to be obtained from the SBA are discussed in this section.

## 2.1 FSDF Soil and Bedrock Properties

FSDF site soil conditions were characterized as part of a 1996 soil and bedrock sampling program (ICF KE, 1997). Undisturbed surface soils were generally micaceous silts and clays, with some fine-grained sands and traces of coarse-grained sand and fine gravel in some instances. Disturbed surface soils were generally siltier, sandier, drier and stiffer than the undisturbed soils. Subsurface soils were generally poorly graded silty sand and sand.

The surface of bedrock in the earlier Lower Pond excavation was examined in the 1996 field effort. The bedrock was sandstone, tan to light tan in color and medium to coarse-grained. The sandstone was moderately well sorted and well cemented.

## 2.2 SBA Backfill Soil Properties

The properties of borrow soil from the SBA were evaluated in two successive investigations. In May of 1999, a preliminary geotechnical evaluation of the entire SBA area was done. The results of that evaluation are included herein as Appendix A. A subsequent evaluation of the soils of the western end of the SBA, from whence the soils for the FSDF fill will be drawn, was done in January of 2000. The evaluation included the collection of samples from a depth of 6 feet in five test pits. Each sample and an equal weight composite of the five samples were tested for the following:

- Grain size distribution (sieve and hydometer) by ASTM D-422;
- Atterberg limits by ASTM D-4318;
- USCS Classification by ASTM D-2487;
- Compaction curve by ASTM D-1557;
- Hydraulic conductivity at 90% of maximum density and at optimum water content by ASTM D-5084; and
- Capillary moisture characteristic by ASTM D-3152.

The field methods and results of the January 2000 field investigation are provided in the modeling report for the FSDF (IT, 2000). In Appendix A, a figure showing the test pit locations and the geotechnical laboratory reports of this latter report are provided.

Table 1 provides the results of the geotechnical tests of the five test pit samples and the composite sample, exclusive of the capillary moisture characteristic. The composite sample test results, when compared to the individual test pit sample results, appear to provide a reasonable set of aggregate properties. Based on these test results, the FSDF fill will be constructed of silty clay of low to moderate plasticity. The composite sample permeability is 5.0x10-6 cm/sec. Thus, the permeability of the placed fill will likely be much lower than that of the silty sand subsurface soils it replaces.

## 2.3 Backfill Configuration

The borrow soil from the SBA will be used to backfill the excavations at the Upper Pond, Lower Pond, and Western Area, and the excavation in Channel B. Thin fills over other areas of the FSDF will be placed to produce the approximate final grading shown in Figure 3. With this grading, surface water from south of the FSDF will be intercepted and routed around the area of the former Upper and Lower Ponds. Surface water from the FSDF will generally sheet flow east to northeast to the eastern rock contact, and then north out Channel B. Channel A will no longer receive flow from the FSDF.

Figure 4 shows an approximate north-south cross section through the Upper and Lower Ponds following filling. The elevation of the rock contact in this figure is estimated from limited existing data, and is thus only approximate. Undulations of several feet in the bedrock are anticipated.

# 3 INFILTRATION MONITORING OPTIONS

Various techniques exist for monitoring soil moisture movement through the vadose zone. These techniques may be divided into direct and indirect methods. Direct methods capture and measure the volume of moisture moving down through the soil column, or directly measure soil moisture content. Indirect methods infer soil moisture content changes by sensing a parameter which correlates to moisture content. The direct and indirect methods potentially useful for monitoring soil moisture movement in the FSDF backfill are described and evaluated in Appendix B.

The direct methods considered in Appendix B are soil sampling and gravimetric testing for moisture content, and the use of pan lysimeters. The drilling of boreholes, and the laboratory testing of the collected cores for moisture content is an inexpensive and accurate method of obtaining field moisture contents. The technique also provides calibration data for use with indirect measurement devices. The pan lysimeter (i.e., an impermeable pan which collects vertical infiltration) provides a direct measure of gravity-driven water movement through the fill under saturated or near saturated soil conditions. When soil is not near saturation and appreciable soil moisture tension is present, a pan lysimeter will not collect any water. Thus, indirect methods which can monitor unsaturated soil moisture content have also been considered.

The indirect techniques considered in Appendix B include tensiometers, the neutron moderation technique (i.e., nuclear soil moisture probe), and time domain reflectometry (TDR). These indirect techniques would all adequately measure moisture movement through the backfill. However, the neutron moderation technique is less appropriate due to its limitation in near surface soil (less than several feet in depth). The tensiometers are easy to install and inexpensive, but the maintenance of these instruments can be very labor-intensive as they would require constant recharging with water. In addition, tensiometers are not designed as long term monitoring devices, and would continually require replacement. TDR has gained regulatory acceptance for applications similar to this one. The TDR probes are inexpensive and can measure moisture content at shallow depth. The probes are also passive, have no moving parts, and should not wear out with age. The cost of the TDR pulse generator, analyzer, and datalogger is relatively high, but not when the cost is evaluated over the period of time it will be used at the FSDF. As the FSDF backfill will be low to moderate plasticity clay, a periodic check on the calibration of the probes would be prudent. TDR is judged to be an acceptable monitoring technique for the FSDF backfill.

Based on these considerations, pan lysimeters and TDR probes, supplemented with calibration data from coring and sample testing, are the moisture monitoring techniques to be used on the FSDF fill section.

# 4 INSTALLATION OF MONITORING INSTRUMENT

## 4.1 Overview of Monitoring Instrument Array

Soil moisture monitoring of the FSDF backfill will be accomplished using a combination of piezometers, pan lysimeters, and TDR probe clusters. Calibration data for the TDR probes are to be obtained by moisture content testing of soil cores collected near or during installation of the TDR probe clusters. The proposed location for instruments are shown in plan view in Figure 3. Figure 4 provides an approximate north-to-south cross section through the Lower Pond after backfill and instrument placement. The instrument locations are tentative, and will be refined once the FSDF excavation is complete, and the topography of the exposed bedrock surface known. It is intended that the deepest portion of the fill in the Upper Pond and Lower Pond areas receive instrumentation.

Four piezometers are proposed at the approximate locations shown in Figure 3. The piezometers will be placed in the native soils immediately south of the FSDF and will be screened to monitor moisture conditions at the soil/rock contact.

Two pan lysimeters are proposed. One will be placed in Lower Pond near the existing monitoring wells. The other is planned south of the first in the area of Upper Pond.

The TDR probes selected for use are two feet long and contain four vertically separate sensing points each. Thus a cluster of probes at each monitoring location is needed to provide vertical coverage from the bottom of the top soil layer to the rock contact for the depths of soil fill anticipated. Three clusters of three probes each are planned. One cluster will be placed immediately south of each of the lysimeters. The third cluster will be placed in the Western Area at the approximate position shown in Figure 3.

Discussions of the installation procedures for each of these instruments is provided in the subsections which follow. The installation and monitoring of instruments, and the collection of soil cores from the fill will be done in accordance with an addendum to the Health and Safety Plan for the IM specific to these operations.

## 4.2 Installation of Piezometers

Four piezometers will be drilled, logged, and installed under supervision of a field geologist or engineer to determine if lateral inflow occurs along the soil-bedrock contact.

The piezometers will be installed following completion of site excavation, and will be positioned in the natives soils immediately south of the excavation, but, if possible, north of the southern road. The piezometers will be constructed according to California well standards.

Borings will be advanced using hollow-stem auger to several inches into the sandstone bedrock. Soil samples will be taken during installation to allow for logging of the hole. The boring will be advanced to one foot into the sandstone bedrock. Cuttings and incidental water generated during drilling will be containerized and appropriately disposed. It is anticipated that the rock contact will be encountered at a depth of 5 to 7 feet.

Piezometer casing will be 2-inch diameter Schedule 40 PVC blank casing, with a two foot long factory-slotted screen with 0.010 inch-slots. Flush-threaded joints and a bottom slip cap will be used. Six to eight 1/4-inch holes will be drilled in the bottom cap, and the slip cap and bottom several inches of the slotted casing will be wrapped in non-woven filter fabric secured with a stainless steel hose clamp. This will allow the casing to completely drain when no water is present on the sandstone. The well casing will be placed in the bottom of the borehole and a Lonestar #2-12 sand filter pack will be placed from the bottom of the boring to 6 inches above the top of the screened interval. A 2-foot sanitary seal using 1/8 to 1/4-inch bentonite pellets will be poured into place above the sand filter. Pellets will be placed in 6-inch lifts and hydrated with potable water. After the bentonite seal hydrates for 1 hour prior, the annular grout seal will be placed to 1 foot below grade. After this grout sets, the upper foot of the borehole will be opened to 12-inches in diameter, and the well casing will be cut about 4 inches below grade and capped with an expanding well cover. The piezometer will be finished at the surface with a traffic-rated valve box set in concrete. The rim of the box will be set slightly above adjacent grade to minimize surface water entry into the box.

## 4.3 Installation of TDR Clusters

Moisture of the backfill soil will be monitored using three clusters of TDR probes. The brand of TDR equipment selected is the Moisture Point probes manufactured by Environmental Sensors, Inc. (ESI) of Victoria, British Columbia. The TDR probes will be read using a controller/datalogger unit mounted in a weather proof panel mounted at the location shown in Figure 3.

The ESI TDR probes function by measuring the propagation time of electromagnetic pulses sent along the dielectric body of the probes, and converting this response to a soil moisture content. Because the strength of the electromagnetic field diminishes exponentially with distance from the probe, the volume sensed by the TDR is essentially the first 1/2 inch of soil around the probe. Consequently, the contact between the soil and the probe must be very good.

The goal of the insertion process is to place the probe into the soil with no air gaps. To this end, a pilot rod is used to pre-form probe holes. The rod is first pressed into the soil by hand until it stands vertically without assistance. A slide hammer is next used to drive the rod to the required depth. An extraction jack is used to carefully withdraw the pilot rod. The probe is then carefully inserted in the pre-formed hole to the location desired.

The probes to be used are 2 feet in length, and contain four sense points each. As fill depths in the range of 5 to 7 feet is anticipated over much of the Upper and Lower Pond, three clusters of three 2-foot long probes will be installed at each cluster. If the soil profile is deeper than 6 feet, small vertical gaps between the probes will be planned to provide monitoring over the entire fill section. The two deep probes will be installed in pilot holes driven into the bottom of hand auger holes. The deepest probe will be placed with its tip touching the bedrock. The auger holes will be carefully backfilled with cuttings, with care being taken to protect the instrument coaxial cable.

Once the cable is within a foot of the surface, the cables from each of the probes will be threaded through PVC conduit to the instrument enclosure shown in Figure 3, and the conduit buried. The enclosure will be mounted on vertical steel channels mounted in a small concrete pad. The controller/datalogger will be installed in the weather-proof enclosure along with a power supply with top-mounted photocells. A modem and phone connection may be provided for remote access to data.

Technicians approved by the probe manufacturer will oversee probe installation, instrument configuration, and overall TDR system start up.

## 4.4 Pan Lysimeter

The two 10-foot square pan lysimeter will be installed at the approximate locations shown in Figure 3. The pans will be formed by single unseamed sheets of 30 mil, very low density polyethylene (VLDPE). Both sides of the VLDPE will be factory textured to reduce slippage. Because the average manufactured width of VLDPE is 14 feet, the 10-foot square pans will be installed without seaming.

At the location of the lysimeter, 12-inches of fill soil from the SBA will first be placed and graded (Figure 5). Twelve-inch berms, hand built of fill material, will form the sides of the pan. The pan of the lysimeter will have a minimum slope of 5%. At the lower end of the lysimeter pad, a shallow swale will be formed to receive 4-inch slotted PVC collection pipe. About 4 inches of 3/8-inch gravel will be placed over the VLDPE to convey infiltration toward the slotted PVC. A 4-ounce non-woven filter fabric will be placed over the gravel to prevent soil migration and eventual clogging of the gravel.

A slotted pipe at the base of the lysimeter will connect to a 12-inch PVC collection sump through a 4-inch PVC pipe (Figure 5). The bottom of the sump will be set 2 feet below the outlet of the collection pipe. Because 1/4-inch of water over a 10-foot square pan area yields about 15 gallons of water, the 10 gallons of storage capacity provided by this sump design is expected to be adequate for the anticipated weekly monitoring intervals planned for the wet season.

After installation of the pan and riser, backfilling will continue. Particular care will be taken in the placement of the first three lifts over the lysimeters, with a density test to confirm compliance with the compaction specification of the IMWP being taken in each of these lifts. Backfill over the lysimeter will conform to the lines and grades of the County-approved final grading plan. As the fill progresses upward, the 4-inch PVE riser from each of the PVC collection sumps will be maintained in a vertical position. The riser will be completed at the surface in the same manner as the piezometer (i.e., expandable well cover, and a traffic-rated valve box set in concrete).

# 5 TEST SECTION MONITORING

## 5.1 Schedule Overview

Monitoring will begin following the completion of instrument installation. This is currently anticipated to occur in the Fall of 2000. Monitoring will continue for 5 years or until the final corrective action for the FSDF is in place, whichever is sooner. The monitoring implementation schedule is discussed further in Section 6.0.

Monitoring of the lysimeters will be done by the controller/datalogger system on a quasi-continuous basis. The piezometers and lysimeters will be monitored monthly, except during the first wet season when these instruments will be monitored weekly. For this purpose, the wet season is defined as commencing with the first 1/4-inch rain and ending four weeks after the last 1/4-inch rain. This planned schedule presupposes that over the first wet season, little if any water is observed in the piezometers or from the lysimeters.

The method for monitoring each instrument is discussed in the subsections which follow.

## 5.2 Piezometers

The piezometers will be monitored first visually for the presence of water. This is done by uncapping the casing, and shining a light down the riser and noting any reflection off the water. If water is present, an electronic well sounder will be used to measure the depth of water in relation to the top of the riser. Observation of water, and, if present, the depth to water will be recorded in the monitoring record. After monitoring, each piezometer will be capped and locked.

## 5.3 Time Domain Reflectometry

The control/datalogger unit will be set to automatically measure moisture at each TDR probe once every four hours. Each probe contains four sensing points. Thus, for each scan of a probe, a record configured as follows will be stored to the datalogger memory:

*Record ID, Day, Hour/Minute, Probe Number, Moist 1, Moist 2, Moist 3, Moist 4*

Where:

*Record ID=A number which reflects the program location from which the record is written.*
*Day=Julian day from the start of the current year.*
*Probe Number=The unique ID code for the probe.*
*Moist 1...Moist 4=Soil moisture content at each of the four sense points.*

Data will be downloaded from the datalogger a minimum of once a month through the first wet season. Thereafter, the data will be downloaded quarterly. Data will be downloaded either with a laptop computer in the field, or remotely through a telephone data link.

## 5.4 Pan Lysimeter

Monitoring of the lysimeters will be done in parallel with the piezometers. Monitoring will be performed by uncapping the sump risers, and visually checking for water. If any is present, the water will be pumped out and its volume measured and recorded. Any collected lysimeter water will be handled in the same manner as groundwater removed from the FSDF area through the existing site wells.

# 6 REPORTS AND RECORD KEEPING

## 6.1 Recording Keeping

As monitoring of the piezometers and lysimeters is manual and periodic, records from these observations will be kept in a bound, water-resistant, field book. All entries will be made with indelible pen, with any errors being corrected by cross out and a new entry. For the piezometers, the date and time of each observation and water depth measurement will be recorded, along with the depth from top of case to water, or the notation of an absence of water. For the lysimeters, the date and time of each field check of a collection sump, and the volume emptied, or a notation that the sump was empty, will be recorded. Each entry should be initialed by the field technician performing the monitoring. Upon returning to the office, the field technician will copy each page of new entries, and keep these pages in a binder as a backup for the field book.

The TDR will be collected automatically by the controller/datalogger six times a day. After being downloaded, the data will be imported to a spreadsheet for later use in analysis and plotting. After each download and update of the spreadsheet, that data will be backed up on a "zip-disk" or CD.

When soil borings are advanced to obtain core for laboratory moisture content testing, this field effort will be documented in the same field book as used for the piezometer and lysimeter monitoring. In particular, the location of each soil boring relative to the TDR probes will be carefully measured and recorded. The depth of each sample, and its sample number will similarly be recorded.

## 6.2 Data Reduction

The lysimeter data will included a series of field observations of the volume of water, if any, removed from the lysimeter collection sump. Each observation will be converted to a volume per unit area of the lysimeter pan (e.g., gallons/sf), and to a weekly average of this quantity (e.g., gallons/sf/week) for the period between a data point and its immediate predecessor. For each lysimeter, a plot of average weekly infiltration per unit area (if any), and cumulative infiltration per unit area for the monitoring year will be produced and updated at least monthly. These plots will be compared to plots of daily precipitation and cumulative precipitation for the monitoring year. A tabular record for each lysimeter summarizing the date and time of each observation, the volume of liquid removed, the corresponding total and weekly average infiltration volume per unit area since the last observation, and the cumulative infiltration volume per unit area for that monitoring year will be maintained.

The observations of the presence and depth of water in the piezometers is intended to assess if perched groundwater is present atop the bedrock, and its depth if present. For each piezometer, a tabular summary of the time and date of each observation; the depth to water from the top of casing (TOC), if present; and the thickness of any saturated zone above the rock will be maintained. For each lysimeter, a bar chart of depth of saturated zone above the bedrock will be maintained for comparison to plots of daily precipitation and cumulative precipitation for the monitoring year.

TDR readings are converted to moisture content by the controller/datalogger system using a calibration derived by the supplier from geotechnical property information for the fill soil provided by Rocketdyne. Thus moisture content measurements for each TDR sensing point will be plotted as a function of time. Graphs of weekly average soil moisture content versus time for each sensing point of a TDR cluster will be presented on a common figure. In years where soil cores are taken to provide water content calibration points for the TDR probes, a tabular summary by sample of the location and depth of the sample, the laboratory moisture content value, and the TDR-measured moisture content from the nearest monitoring point will be produced.

## 6.3 Annual Report

The monitoring year will be from July 1 through June 30 of the following year. Within 60 days of the end of a monitoring year, an annual report for the monitoring program will be submitted that includes the following:

- Summary of the monitoring effort for the prior year, with any significant deviations from this planned highlighted.
- The field data reduced per the discussion of Section 6.2.
- Discussions regarding the presence/absence of detectable flow from the lysimeters and the presence/absence of free water on the bedrock in the piezometers.
- Qualitative comparison of the pattern of soil moisture content change detected by the TDR clusters and that predicted by the earlier modeling.

# 7 IMPLEMENTATION SCHEDULE

Implementation of the monitoring program will begin following completion of backfill placement and construction of the stormwater swale along the southern road. Monitoring system construction will include (1) installation of the piezometers; (2) installation of the pan lysimeter casing monuments; (3) pouring of a slab for mounting the TDR datalogger hardware; and (4) installation of the TDR probes, cables, and conduits. Once the TDR system, piezometers, and pan lysimeters are ready, monitoring will commence. To provide a check on the calibration of the TDR probes, a small diameter soil boring will be drilled and sampled adjacent to each TDR cluster. Soil samples collected from each boring will be tested gravimetrically for soil moisture content, and compared with the TDR probe readings.

Figure 6 shows the planned installation and start-up schedule for the monitoring elements. Assuming completion of FSDF backfilling in early August of 2000, monitoring will begin in mid-September.

## LIMITATIONS

The services described in this report were performed consistent with generally accepted professional consulting principles and practices. No other warranty, express or implied, is made. These services were performed consistent with our agreement with our client. This report is solely for the use and information of our client unless otherwise noted. Any reliance on this report by a third party is at such party's sole risk.

Opinions and recommendations contained in this report apply to conditions existing when services were performed and are intended only for the client, purposes, locations, time frames, and project parameters indicated. We are not responsible for the impacts of any changes in environmental standards, practices, or regulations subsequent to performance of services. We do not warrant the accuracy of information supplied by others, nor the use of segregated portions of this report.

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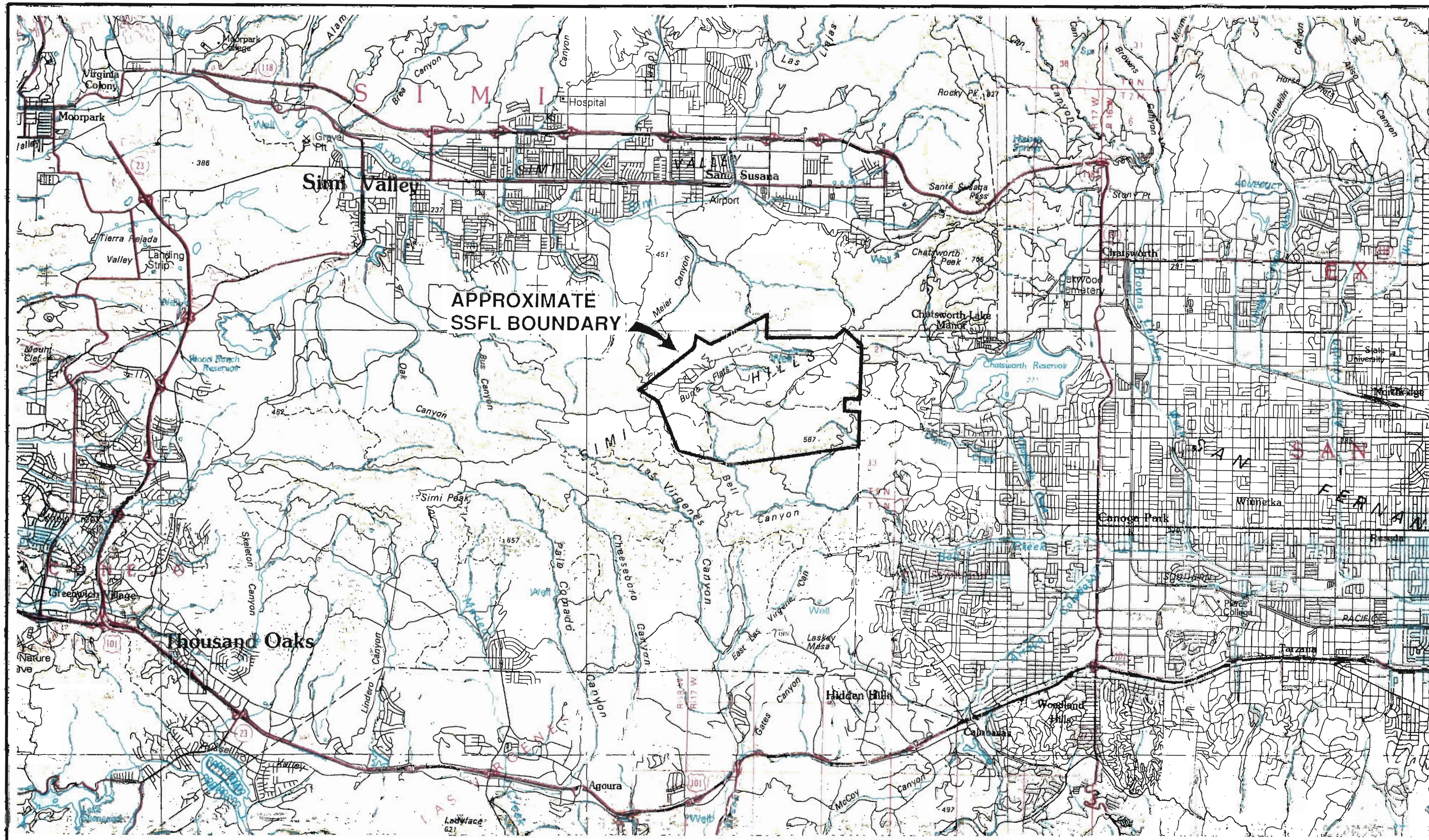
## Table 1
## Geotechnical Testing Results For January 2000 Investigation

| Sample Designation | Clay Fraction ASTM D 422 (% by wt.) | Plasticity Index ASTM D 4318 | Classification ASTM D 2487 | Maximum Dry Density ASTM D 1557 (pcf) | Optimum Moisture ASTM D 1557 (% by wt) | Hydraulic Conductivity ASTM D 5084 (cm/s) |
|---|---|---|---|---|---|---|
| TS-14 | 19 | 16 | CL | 112 | 15.5 | 6.3E-6 |
| TS-15 | 16 | 8 | CL | 112 | 16.5 | 6.1E-6 |
| TS-16 | 15 | 16 | CL | 119 | 12.0 | 1.4E-5 |
| TS-17 | 25 | 20 | CL | 117 | 14.0 | 4.7E-6 |
| TS-18 | 19 | 18 | CL | 111 | 16.0 | 3.7E-6 |
| Composite | 19 | 18 | CL | 116 | 15.0 | 5.0E-6 |




SCALE 1:100 000

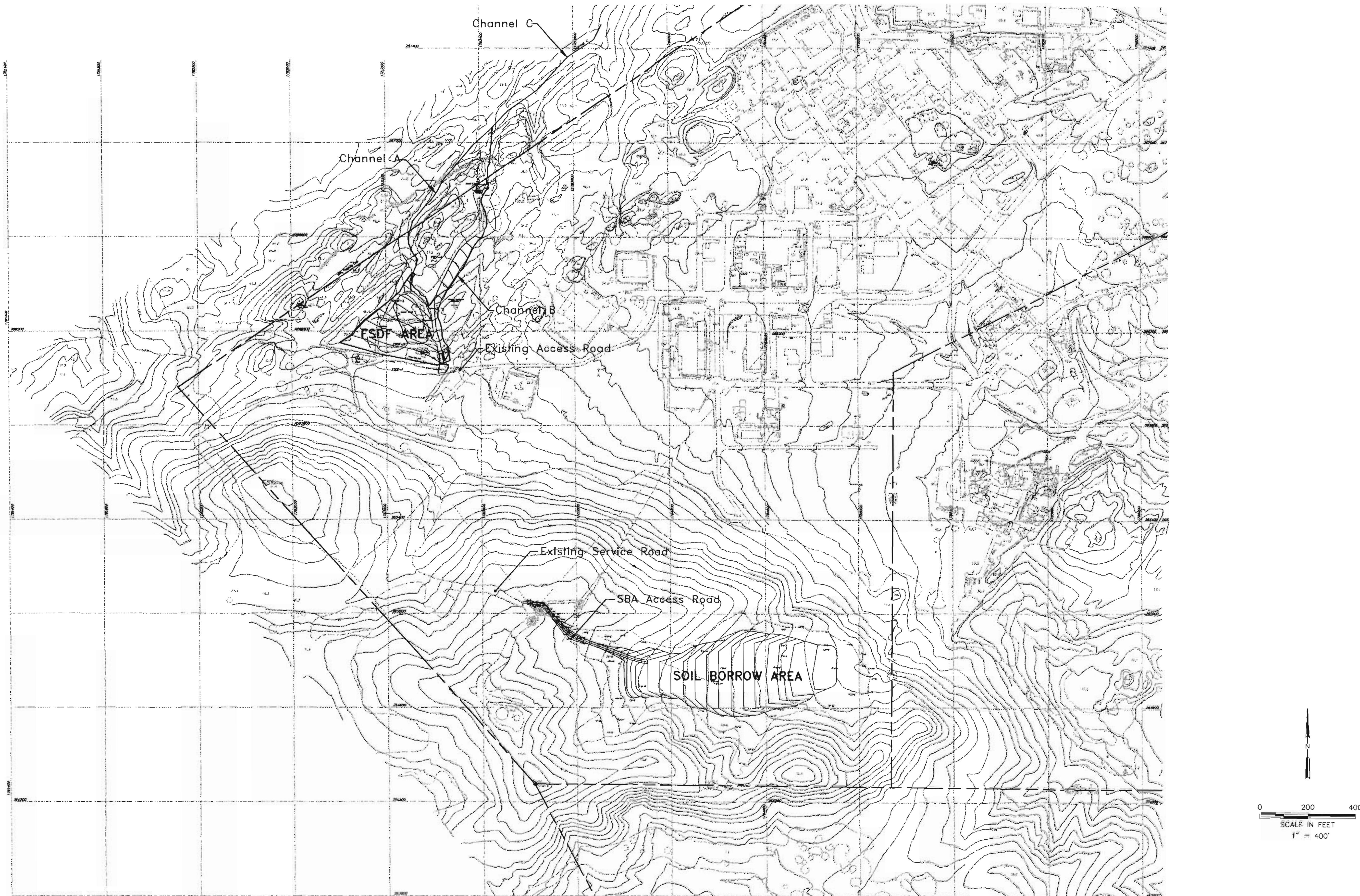
KILOMETERS 0 1 2 3 4 5 6 7 8
MILES 0 1 2 3 4 5

Reference: USGS 30x60 Minute Topographic Map
Los Angeles, California 1979

ICF KAISER
ENVIRONMENT & ENERGY GROUP

**Figure 1**
Rocketdyne
Santa Susana Field Laboratory (SSFL)
Site Location Map

| FILENAME: F:\ART\ROK-SRP1.DRW | DATE: 10.05.95 |
|---|---|




Note: Topographic base map compiled using photogrammetric methods by Sage Consultants, Inc., Camarillo, CA 93010.

| REV. | DESCRIPTION OF REVISION | RCE | APP. | DATE |
|---|---|---|---|---|
| D | | | | |
| C | | | | |
| B | | | | |
| A | | | | |

IT CORPORATION

DESIGNED ESA | DRAWN KLT | CHECKED JCM
PROJ. ENG. John McMillan | RECOMMENDED | APPROVED
REG. NO. | DATE

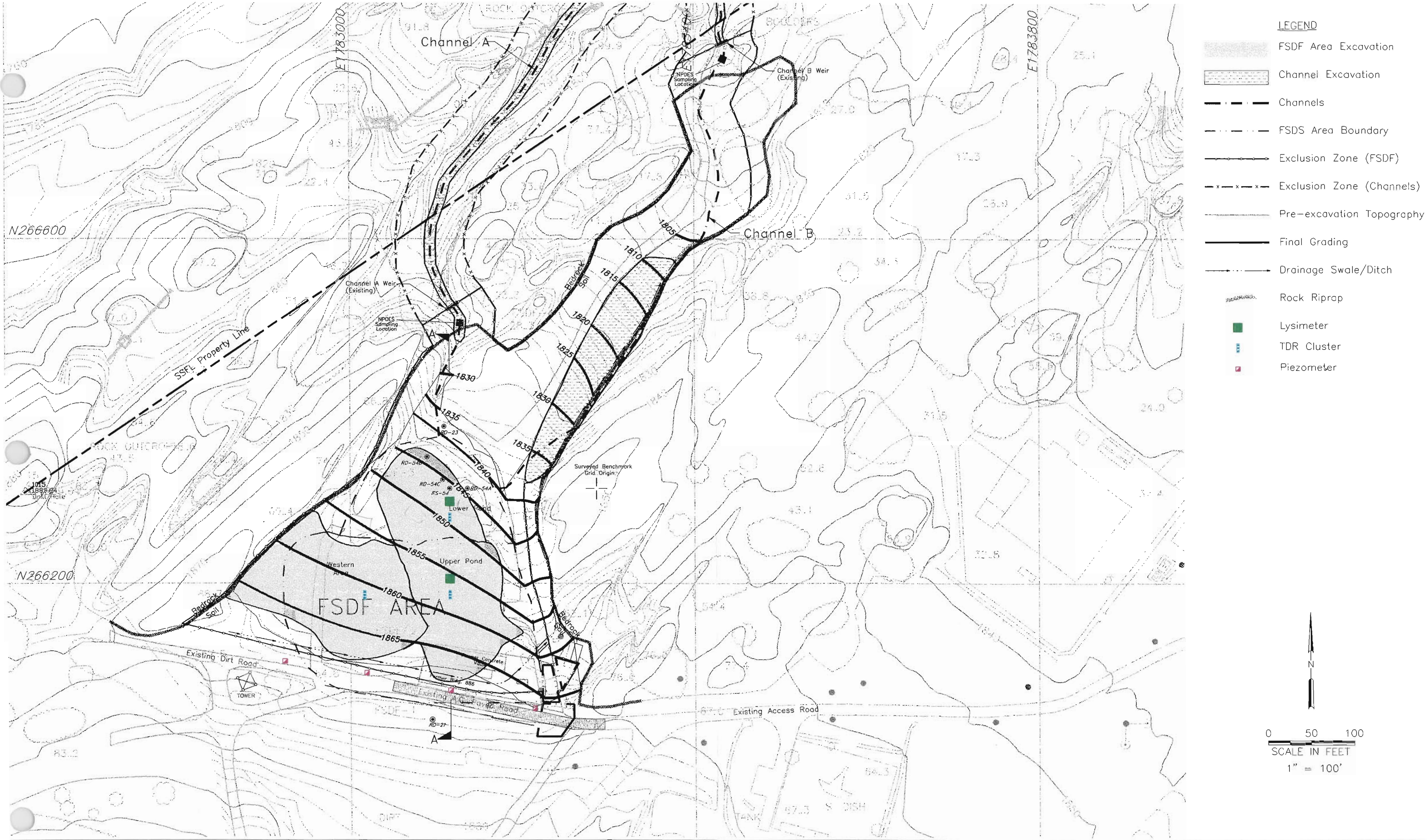
COUNTY OF VENTURA
PUBLIC WORKS AGENCY
DEVELOPMENT SERVICES

SPEC. NO.
PROJ. NO.

Rocketdyne
Santa Susana Field Laboratory

FSDF and SBA
Site Map

SHEET
OF
FIGURE NO. 2




| | | | |
|---|---|---|---|
| DESCRIPTION OF REVISION | RCE | APP. | DATE |

IT CORPORATION

DESIGNED FSA | DRAWN KLT | CHECKED JCM

PROJ. ENG. John McMillan | RECOMMENDED | APPROVED

REG. NO. | DATE

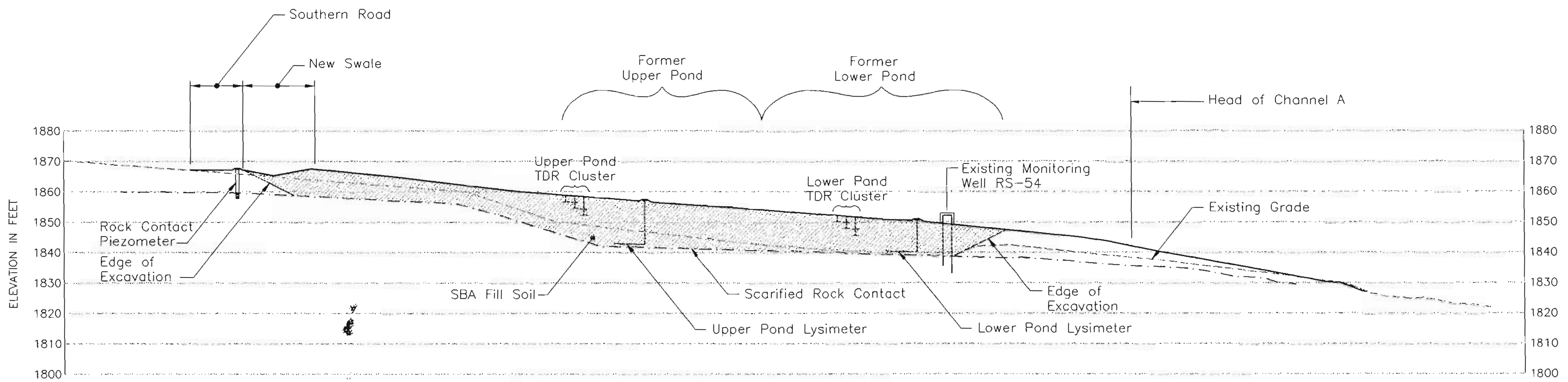
COUNTY OF VENTURA
PUBLIC WORKS AGENCY
DEVELOPMENT SERVICES

SPEC. NO. | PROJ. NO.

Rocketdyne
Santa Susana Field Laboratory

Approximate FSDF Final Grading and Instrument Locations

SHEET | OF | FIGURE NO. 3




SECTION A-A

0 20 40
SCALE IN FEET
1" = 40'

D
C
B
A
△ DESCRIPTION OF REVISION | RCE | APP | DATE

IT CORPORATION

DESIGNED ESA | DRAWN KLT | CHECKED JCM
PROJ. ENG. John McMillan | RECOMMENDED
REG. NO. | DATE | APPROVED

COUNTY OF VENTURA
PUBLIC WORKS AGENCY
DEVELOPMENT SERVICES

SPEC. NO.
PROJ. NO.

Rocketdyne
Santa Susana Field Laboratory

FSDF Area
Backfill Section

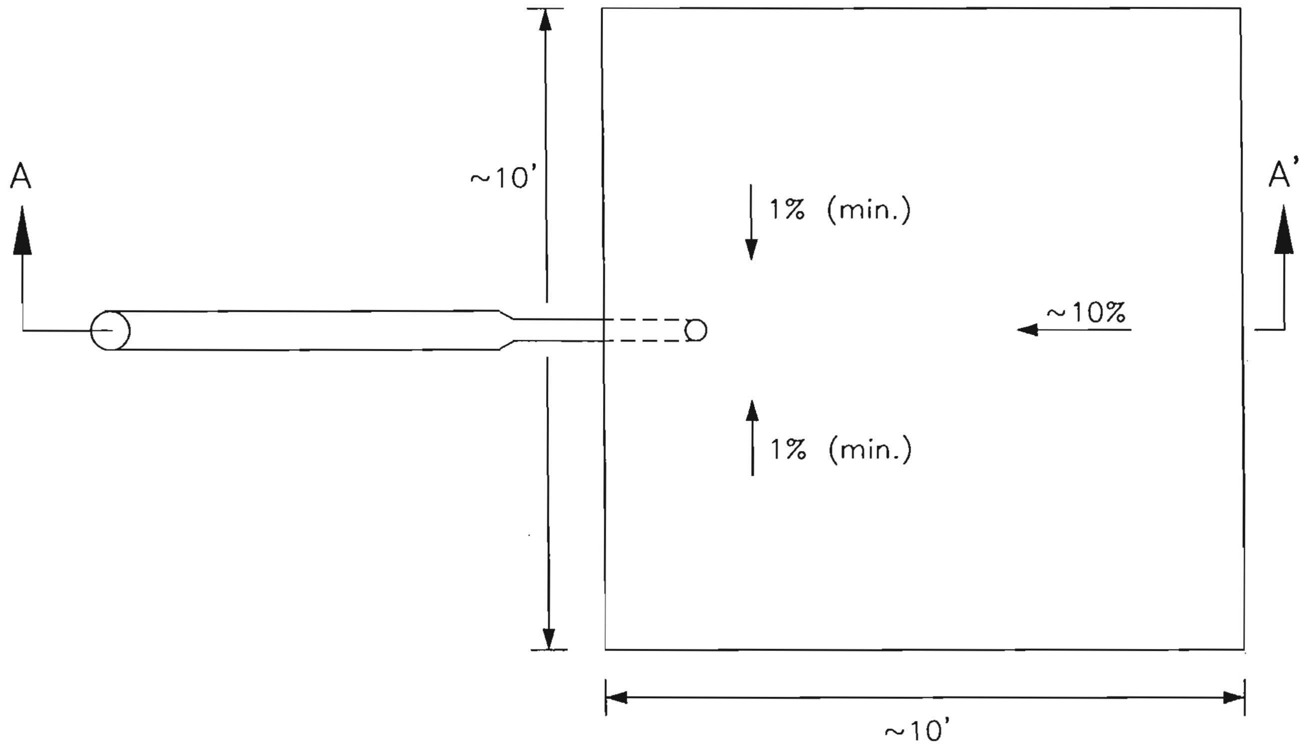
SHEET
OF
FIGURE NO.
4

PROJECT NUMBER 881344

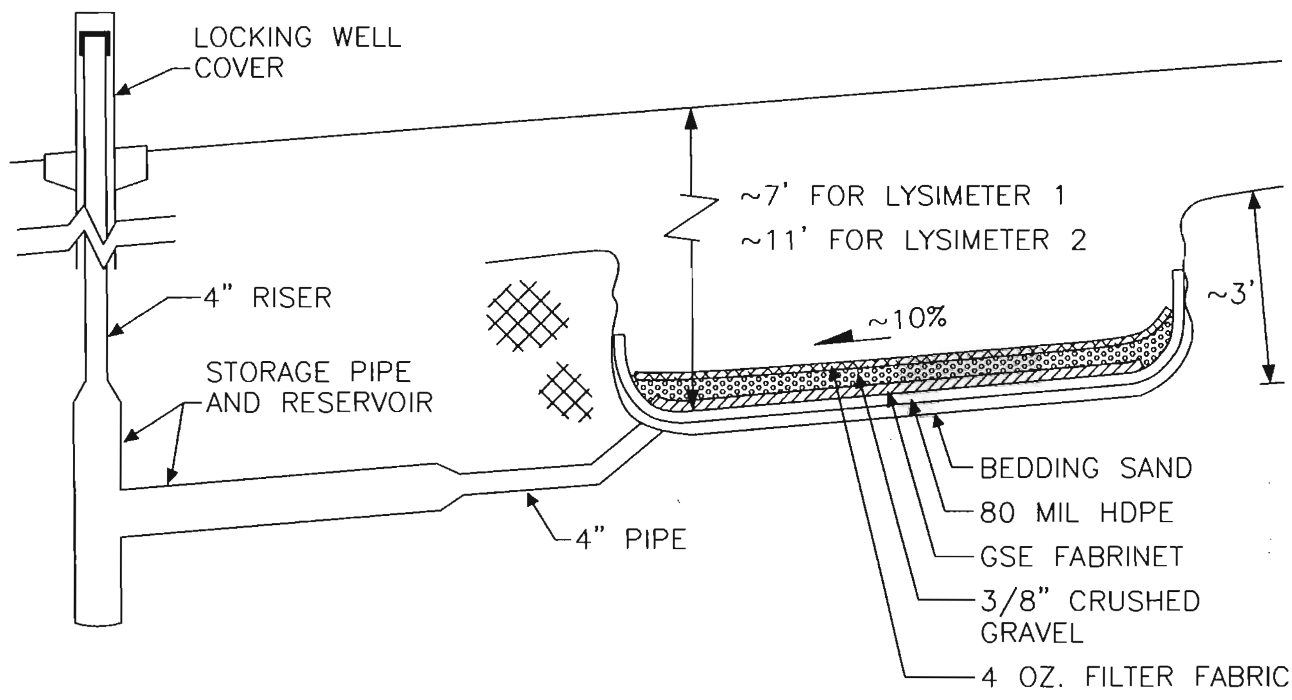
APPROVED BY -- --

CHECKED BY -- --

DRAWN BY L. Wahlgren 8-14-01




PLAN VIEW OF LYSIMETER (Approx. 1"=3')




SECTION A-A' OF LYSIMETER (Approx. 1"=3')

NOTE: PIPING AND RESERVOIR FABRICATED OF HDPE SDR 11 PIPE AND FITTINGS.

Shaw™
Shaw E & I, Inc.

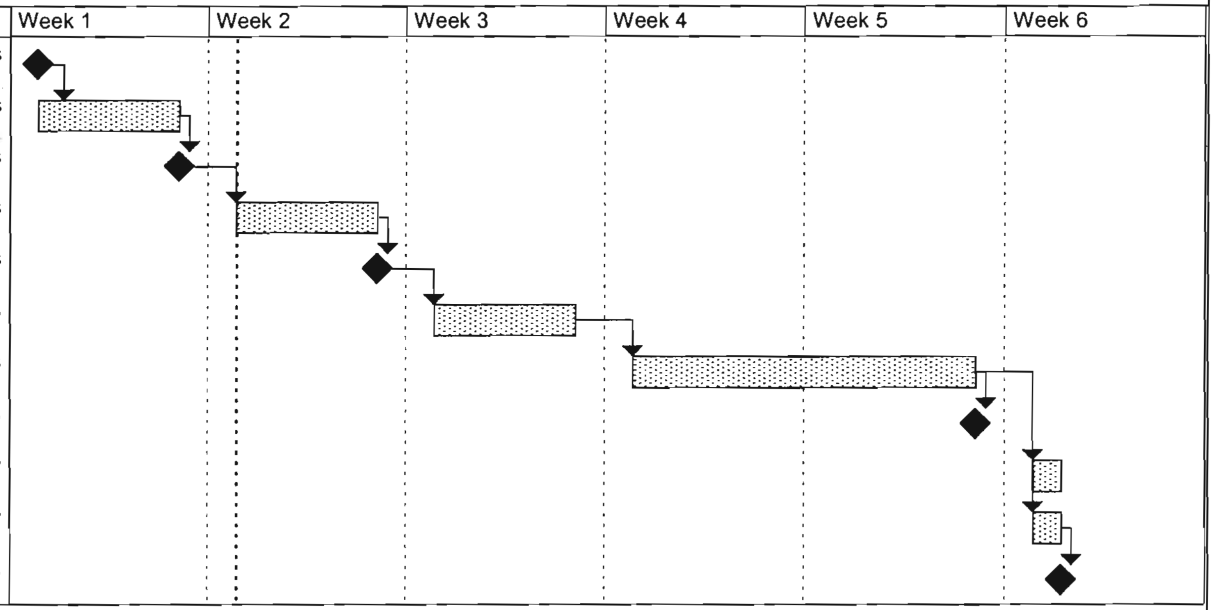
THE BOEING COMPANY
ROCKETDYNE PROPULSION AND POWER
SANTA SUSANA FIELD LABORATORY

Former Sodium Disposal Facility
INTERIM MEASURE

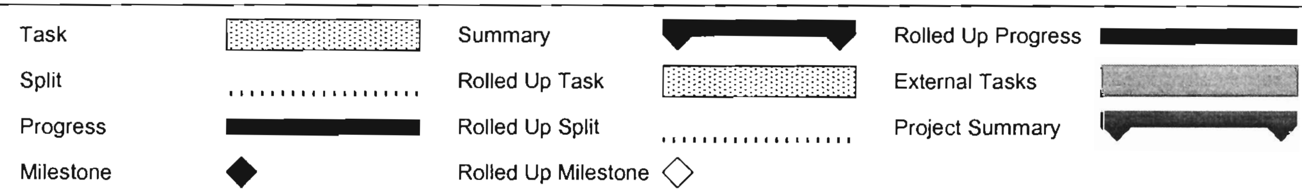
FIGURE 7
LYSIMETER DETAILS

# FIGURE 6
# IMPLEMENTATION SCHEDULE

| ID | Task Name | Duration |
|---|---|---|
| 1 | Completion of Fill Placement | 0 days |
| 2 | Construct TDR Pad and Lysimeter Monuments | 5 days |
| 3 | Lysimeter Complete | 0 days |
| 4 | Install Piezometers | 5 days |
| 5 | Piezometer Complete | 0 days |
| 6 | Install TDR Probes | 5 days |
| 7 | Install TDR Conduit and Datalogger | 10 days |
| 8 | TDR Complete | 0 days |
| 9 | Auger Calibration Holes | 1 day |
| 10 | Collect Baseline Data | 1 day |
| 11 | Begin Routine Monitoring | 0 days |




Project: rocketdyne
Date: Mon 4/3/00



# APPENDIX A

# GEOTECHNICAL DATA FOR THE SOIL BORROW AREA

# APPENDIX A-1

# PRELIMINARY GEOTECHNICAL EVALUATION OF MAY 1999

*Pacific Materials Laboratory, Inc.*

150-B Wood Road
P.O. Box 91
Camarillo, CA 93011
Phone: 482-9801

June 24, 1999
Lab No. 28592-3
File No. 99-7335-3

The IT Group
Attn: Mr. John McMillan
2101 Webster Street, Suite 1000
Oakland, CA 94612-3060

**SUBJECT:** **Preliminary Geotechnical Evaluation**
Onsite Borrow Site
Rocketdyne - Santa Susanna Field Laboratory

Dear Mr. McMillan:

Pursuant to your request and authorization, *Pacific Materials Laboratory, Inc.* has completed a preliminary geotechnical evaluation of onsite soils currently being considered for use as structural backfill materials for FSDF Area 4 at the Rocketdyne/Boeing Field Laboratory in the Santa Susanna area of Ventura County, CA. It is our understanding the borrow site under consideration is proposed as the primary source of import soil intended to structurally backfill the former sodium disposal site known as FSDF Area 4, which is to be remediated this fall. It is our further understanding the proposed borrow site will be used for future (*non-related*) projects which may continue for a period of four (4) to eight (8) additional years.

The focus of the current evaluation is to determine the geotechnical suitability of the (*onsite*) borrow site soil types for use as structural fill material. This was accomplished by a combination of exploratory test pits coupled with limited laboratory testing.

A total of thirteen (13) exploratory backhoe pits were excavated to depths of between 4.5'-18' below the present ground surface. Excavation was subcontracted to *Gary Buzza Backhoe Service*, Agoura Hills, CA. During excavation the pits were logged, bulk samples were obtained, tagged, packaged and transported to our laboratory for soils mechanics testing. Laboratory testing performed included moisture content determination, sieve and hydrometer analysis, maximum-density optimum moisture determination, direct shear testing and atterberg limits. Please find the following attachments included herein as an aid to the reader:

- ❑ **Appendix A:** Includes a sketch depicting the approximate borrow site limits and includes test pit locations.
- ❑ **Appendix B:** Includes the test pit logs Test Pit No. 1 through 13
- ❑ **Appendix C:** Includes laboratory test data on Enclosures C-1 and C-2, a test data summary sheet included as Enclosure *Summary*, and graphical interpretation of direct shear testing.

## SUMMARY OF FINDINGS/ RECOMMENDATIONS

1. The proposed borrow site appears to be underlain by variable depth of native (*colluvial*) soils classified by USCS Classification Methods (*ASTM D2487*) as silty clays. Expansion test data indicates the soil types encountered range from slightly to moderately expansive. The borrow site was found to contain a depth of from ~ 4.5' to >18' of soil above formational materials which is considered geotechnically suitable for use as structural fill. (*Please review the test pit logs and locations for soil depth information useful for estimating soil yardage*).

2. No free ground water was encountered during excavation of the test pits. The subsurface soils encountered ranged from damp to moist. No evidence of free ground water migration was observed.

3. The results of USCS soils classification tests (*ASTM D2487*) indicate all soils encountered within the borrow site excavation (*with the exception of the upper 6"-12"*) are geotechnically suitable for use in creation of structural fill(s).

4. All surface vegetation should be removed from the borrow site prior to the start of export grading. Careful attention should be taken to remove all root structures. It is anticipated to accomplish this the upper 6-12 inches of existing surface soils will require removal prior to reaching clean soils considered geotechnically suitable for use as structural fill. The upper 6"-12" of insitu soils should be stockpiled and used for revegetation of the borrow area near the completion of rough grading activity subject to suitability determination by the project landscaping consultant.

5. Temporary excavations without adjacent surcharge should not be excavated to a repose exceeding 0.5(H):1(V) up to a *maximum* height of 5'. Planned temporary excavations greater than 5' in height should be planned at a repose of 1(H):1(V) or flatter. No vertical excavations should be allowed.

6. Surface drainage should be directed away from the tops of all slopes via soil berms or engineered drainage devices as necessary to prevent erosion. Final grading of the borrow site should maintain positive drainage similar in nature to the existing, undisturbed conditions.

7. Final cut slopes should be planned to provide a repose of 2(H):1(V) or flatter.

8. All slopes should be planted with positive rooting vegetation at the completion of removals from the borrow site. If other than native field grasses and vegetation are employed, a uniform low volume, non-erosive irrigation system should also be provided and maintained to promote long term service.

9. All fill placement should be performed under the observation and testing of a California licensed geotechnical engineer.

The scope of this exploration does not include analysis of existing cut or fill slopes, proposed cut slopes, geologic structures, or associated geologic features such as faults, fractures, landslides, or potential geologic movement. This exploration was conducted in accordance with presently accepted soils engineering procedures consistent with the scope of *Pacific Materials Laboratory, Inc.* Geotechnical Proposal and Agreement dated 4-28-99, and no warranty or uniformity of soil conditions between test pit locations is implied.

The data findings and design recommendations incorporated herein are intended as an instrument of professional service. Pertaining to use of this document *Pacific Materials Laboratory, Inc.* authorizes use of this document, as needed, by the client, his professional representatives or consultants as necessary to further planning, development and construction of the specific project defined, and limited to, the subject of this report. This document is the exclusive property of *Pacific Materials Laboratory, Inc.*, and is not to be used in whole or part for any other use except as defined herein without prior written authorization by *Pacific Materials Laboratory, Inc.*

## CLOSURE

All building sites are subject to elements of risk wluch cannot be wholly identified and/or entirely eliminated. Furthermore, building sites in Southern California are subject to many different types of geotechnical hazard potentials including but not limited to the effects of water infiltration, erosion, inappropriate drainage, static total settlement, static differential settlement, expansive soil movement chemical alteration, seismic shaking, seismic-induced fault rupture, seismic-induced ground and slope deformation, seismic-induced settlement, liquefaction, hydroconsolidation, mud flow, and landsliding. Some, but not all the listed potential geotechnical hazards may have been evaluated within the scope of this report. Accordingly, the subject project may be at *risk* from some geotechnical hazard as of yet not evaluated. The scope of work performed in preparation of this report is consistent with work prescribed by the client and included within *Pacific Materials Laboratory, Inc.* cost estimate proposal and consistent with the agreement which was formally executed prior to the start of work on this report.

Acceptable long term performance is highly dependent on the property owner properly maintaining the site (*such as repair and maintenance of drainage facilities, slopes, etc.)* and by immediately correcting any and all deficiencies discovered throughout stewardship of the property. It is not possible to completely eliminate all hazards or inherent risks. Even with a thorough subsurface exploration and testing program, significant insitu geotechnical variability and latent defects between test locations may exist. Latent defects can be concealed by earth materials, deposition, geologic history and preexisting site improvements. Such defects, (*if any*), are beyond the scope of this evaluation. Accordingly, no warranty, expressed or implied, is made or intended in connection with findings, data or recommendations included in this report (*or by any other oral or written statement*) other than the services performed which were provided within the limits prescribed by and agreed to by the client. *Pacific Materials Laboratory, Inc.* warrants that the services performed in preparation of this report are consistent with the limits prescribed by the client and with generally accepted thoroughness and competence of the geotechnical and geological engineering profession.

This report is issued and made for the sole use and benefit of the client. *Pacific Materials Laboratory, Inc.* affirms that contents of this report remain applicable for a period of not greater than 12 months from the date of this report. Reports more than 12 months old require written supplemental updating by *Pacific Materials Laboratory, Inc.* to compliment prevailing plans, specifications and building codes.

This report concludes the current contracted agreement between *Pacific Materials Laboratory, Inc.* and the client. The recommendations contained herein are based upon the assumption that *Pacific Materials Laboratory, Inc.* will be requested to provide the necessary testing and observation services which are recommended during rough grading, fine grading and construction. Additional services and associated fees will be necessary to verify the actual soil conditions encountered and to affirm that the plans and construction are consistent with the intent of the recommendations contained herein.

A current Schedule of Fees should have already been provided to you prior to the commencement of current services. The Schedule of Fees will be the basis of all further invoices and will be fully itemized as a service to you. If you have not received a current Schedule of Fees it is incumbent on you to request one at your earliest convenience. If additional geotechnical services are performed by others, only the technical correctness of the actual tests performed can be attested to. Should a separate geotechnical firm assume this project, *Pacific Materials Laboratory, Inc.* will not be responsible for interpretations, opinions, conclusions nor recommendations made by others with regard to fill selection, fill placement, compaction, foundation, slab or hardscape support or any summary of findings, conclusion, recommendation or opinion presented in this report.

Thank you for allowing *Pacific Materials Laboratory, Inc.* to be of service. If we may be of further service regarding this or other geotechnical issues, please do not hesitate to call (805) 482-9801, Fax (805) 445-6551 or write.

Respectfully submitted,
PACIFIC MATERIALS LABORATORY, INC.

**Read L. Andersen,**
Staff Engineer

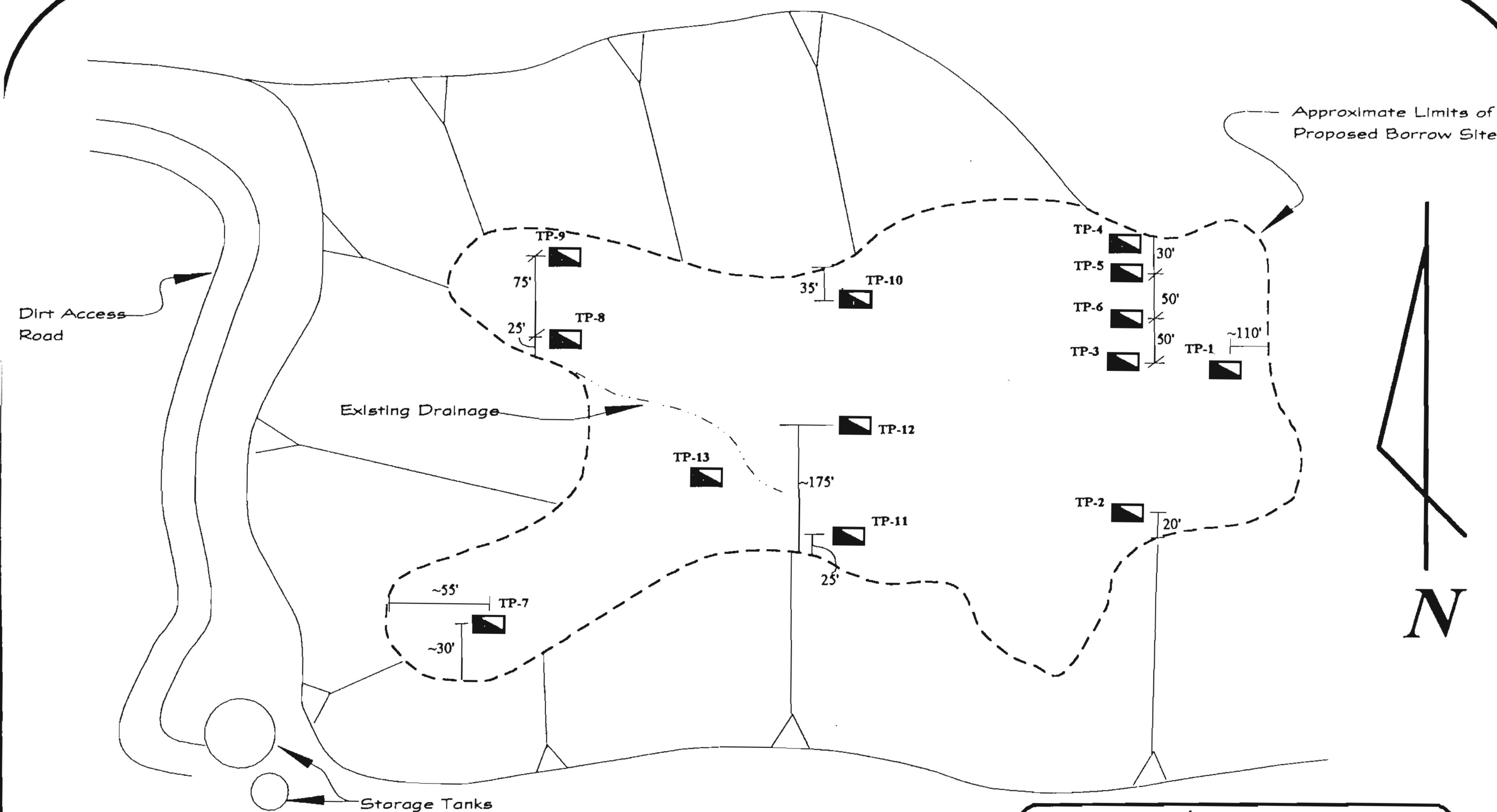
**Douglas C. Papay**, GE 664
Expiration Date 3-31-03

REGISTERED PROFESSIONAL ENGINEER
DOUGLAS C PAPAY
GE 664
Exp 3-31-03
GEOTECHNICAL
STATE OF CALIFORNIA

RLA:DCP:cmp
cc: Addressee (5)

Attachments:
Appendices A, B and C

# APPENDIX A




TP- ▬ - denotes test pit location

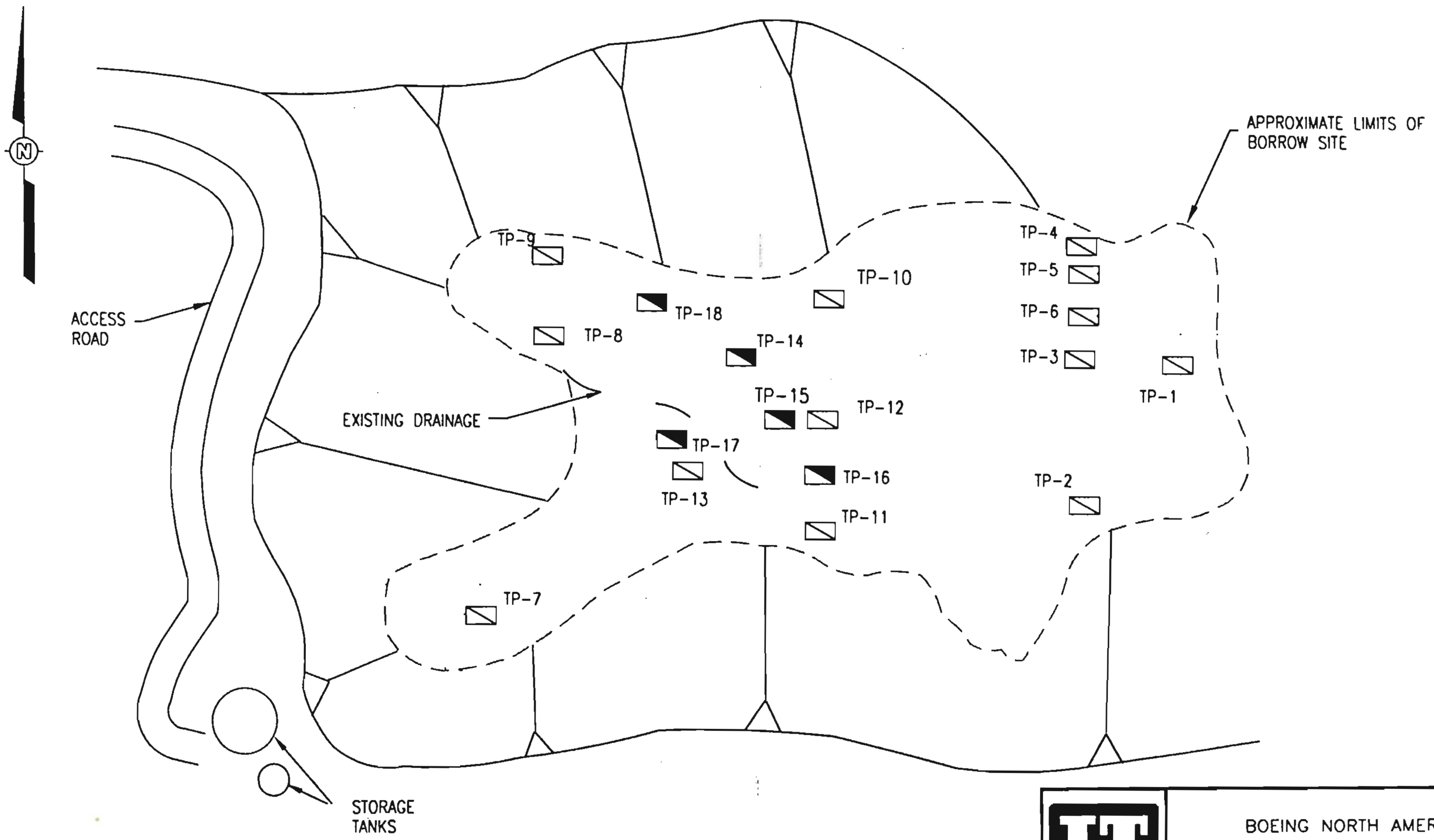
| Scale: None<br>By: RA | **ENCLOSURE - A**<br>**File No. 99-7335-3**<br>**Lab No. 28592-3** |
|---|---|

*Pacific Materials Laboratory, Inc.*

# APPENDIX A-2

# SUPPLEMENTAL GEOTECHNICAL INFORMATION FOR WESTERN SBA SOILS

| DRAWN BY | | CHECKED BY | | APPROVED BY | | DRAWING NUMBER | 881344-A1 |
|---|---|---|---|---|---|---|---|
| M. Schrage | 2-03-00 | HRF | 2/3/00 | HRF | 2/3/00 | | |




**EXPLANATION**

PREVIOUS TEST PIT STUDIES (See Appendix D)

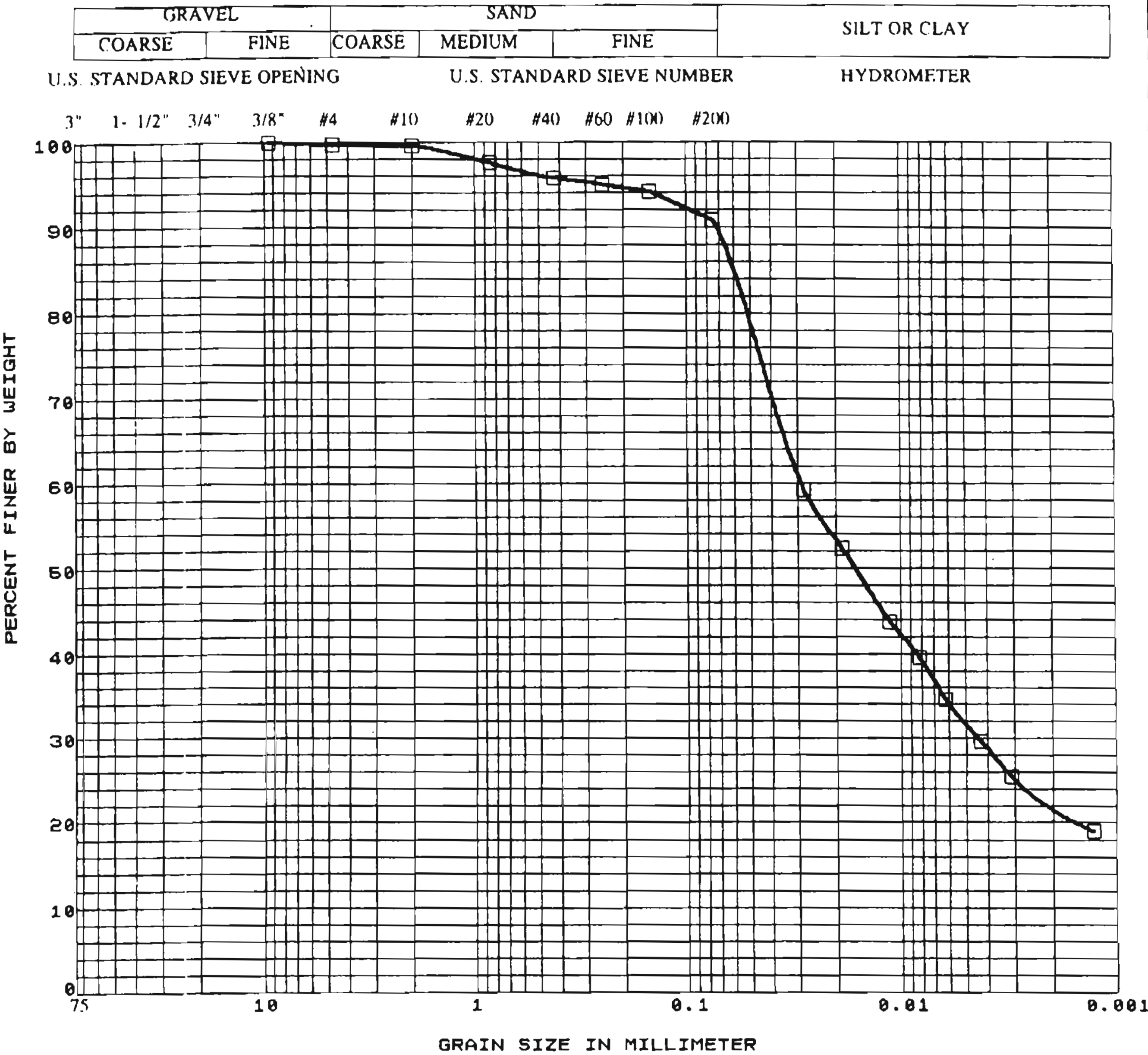
CURRENT TEST PIT STUDIES

IT CORPORATION

BOEING NORTH AMERICAN
ROCKEDYNE PROPULSION AND POWER
SANTA SUSANNA FIELD LABORATORY
SIMI VALLEY, CALIFORNIA

FIGURE 1

SOIL BORROW AREA
TEST PIT MAP
FSDF INTERIM MEASURE
SOIL EVALUATION MODELING REPORT



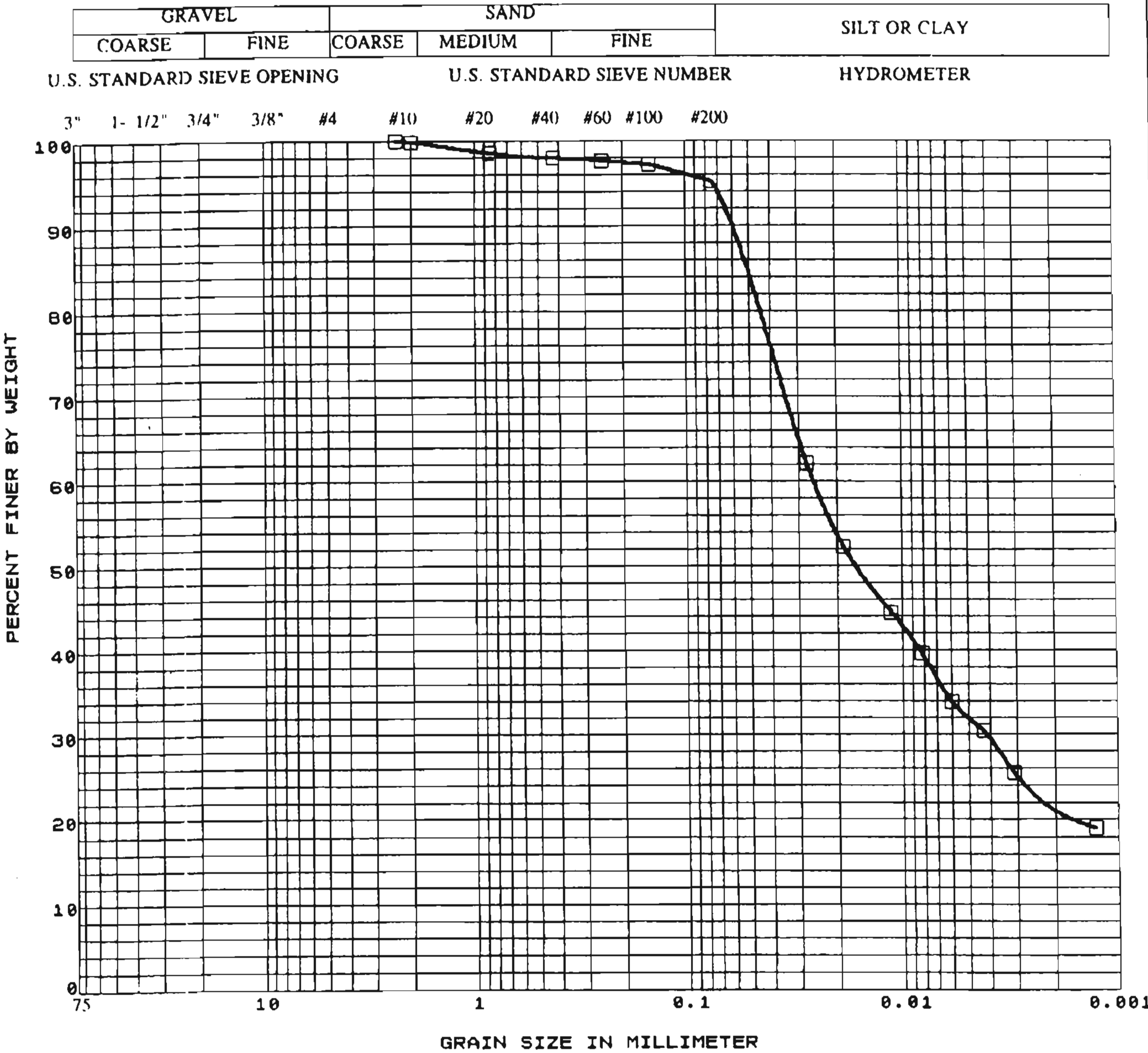

| SYMBOL | SAMPLE ID. | DEPTH (FT) | SAMPLE TYPE | SOIL TYPE | LIQUID LIMIT | PLASTI-CITY INDEX |
|---|---|---|---|---|---|---|
| □ | TP14 | N/A | BUCKET | CL | 37 | 16 |

| | |
|---|---|
| KEANTAN LABORATORIES | PROJECT NAME: FSDF BACKFILL |

# GRAIN SIZE DISTRIBUTION CURVE

1/00

FIGURE

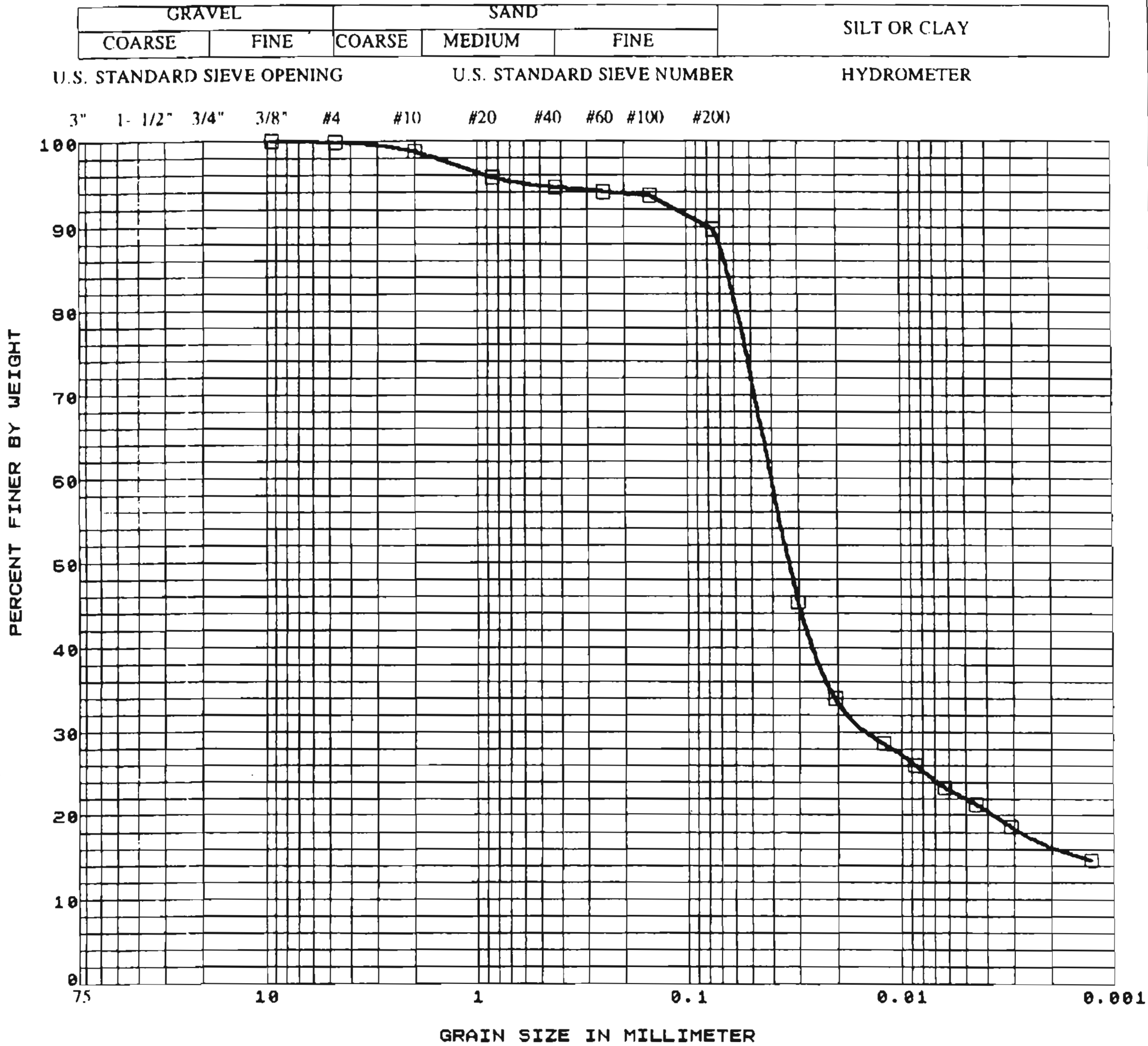



| SYMBOL | SAMPLE ID. | DEPTH (FT) | SAMPLE TYPE | SOIL TYPE | LIQUID LIMIT | PLASTI-CITY INDEX |
|---|---|---|---|---|---|---|
| □ | TP15 | N/A | BUCKET | CL | 37 | 16 |

| KEANTAN LABORATORIES | PROJECT NAME: FSDF BACKFILL |
|---|---|

# GRAIN SIZE DISTRIBUTION CURVE

1/00 FIGURE



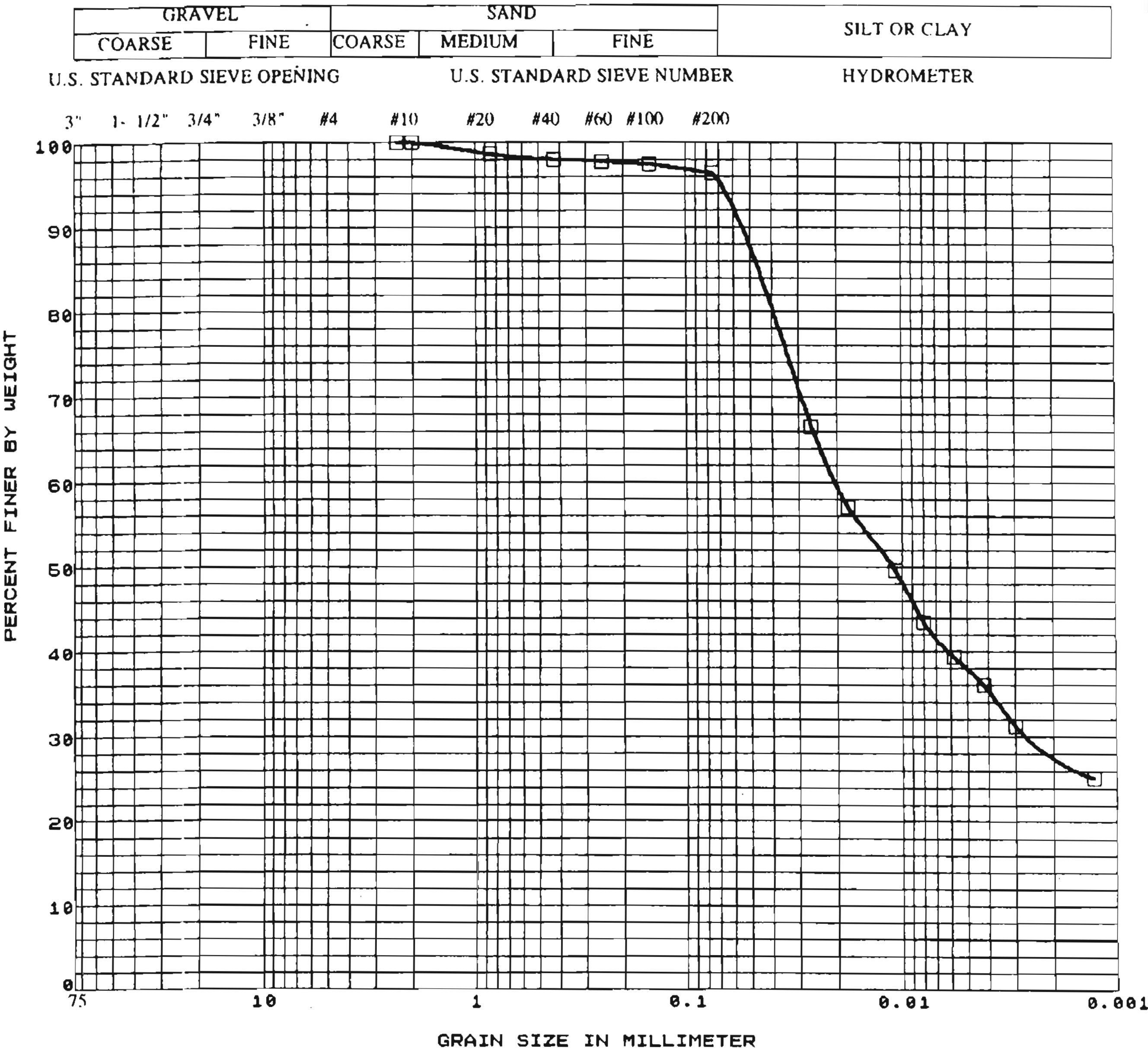

| SYMBOL | SAMPLE ID. | DEPTH (FT) | SAMPLE TYPE | SOIL TYPE | LIQUID LIMIT | PLASTI-CITY INDEX |
|---|---|---|---|---|---|---|
| □ | TP16 | N/A | BUCKET | CL | 26 | 8 |

| KEANTAN LABORATORIES | PROJECT NAME: FSDF BACKFILL |
|---|---|

# GRAIN SIZE DISTRIBUTION CURVE

1/00

FIGURE

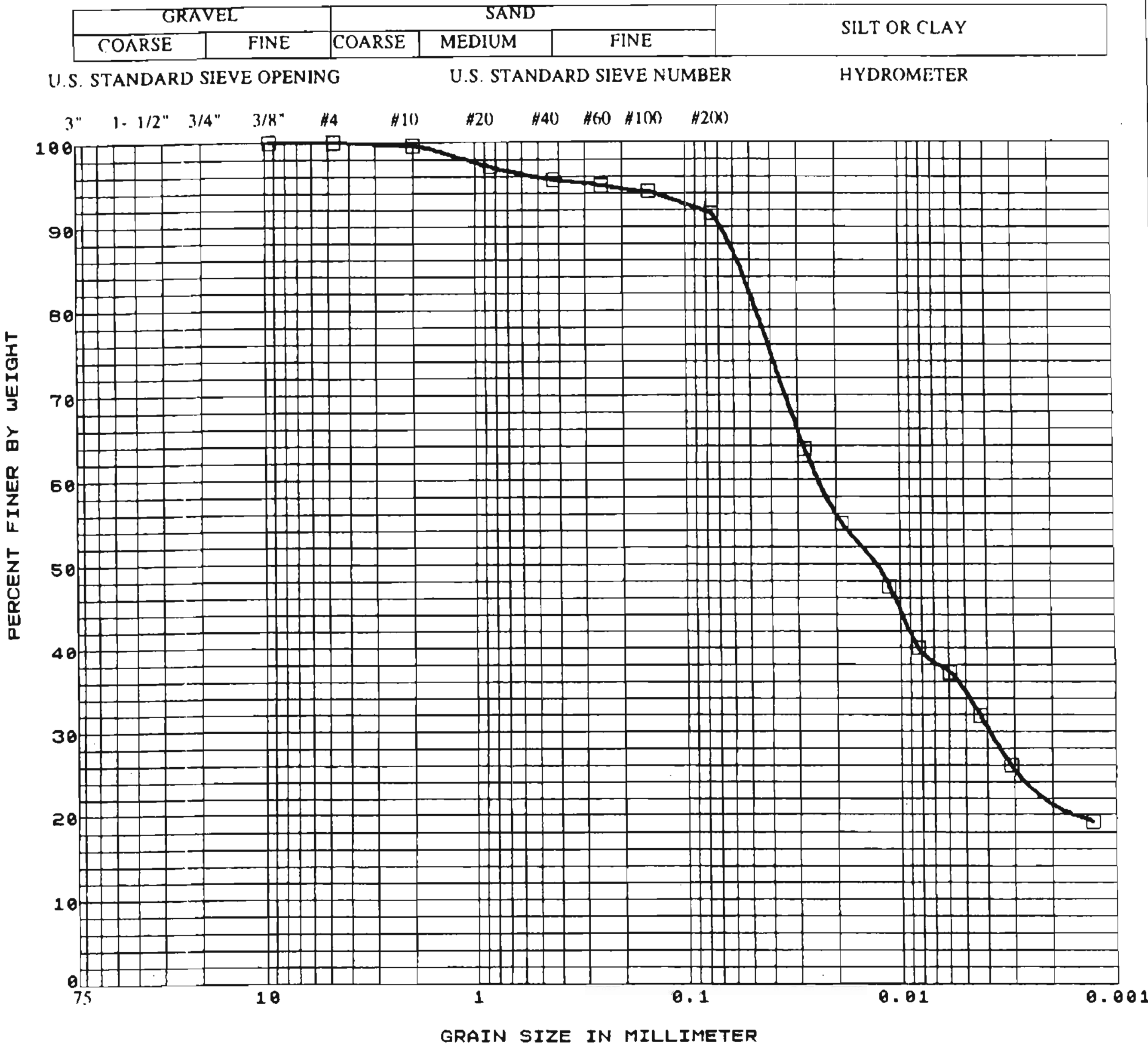



| SYMBOL | SAMPLE ID. | DEPTH (FT) | SAMPLE TYPE | SOIL TYPE | LIQUID LIMIT | PLASTICITY INDEX |
|---|---|---|---|---|---|---|
| □ | TP17 | N/A | BUCKET | CL | 38 | 20 |

| KEANTAN LABORATORIES | PROJECT NAME: FSDF BACKFILL |
|---|---|

**GRAIN SIZE DISTRIBUTION CURVE**

1/00 FIGURE



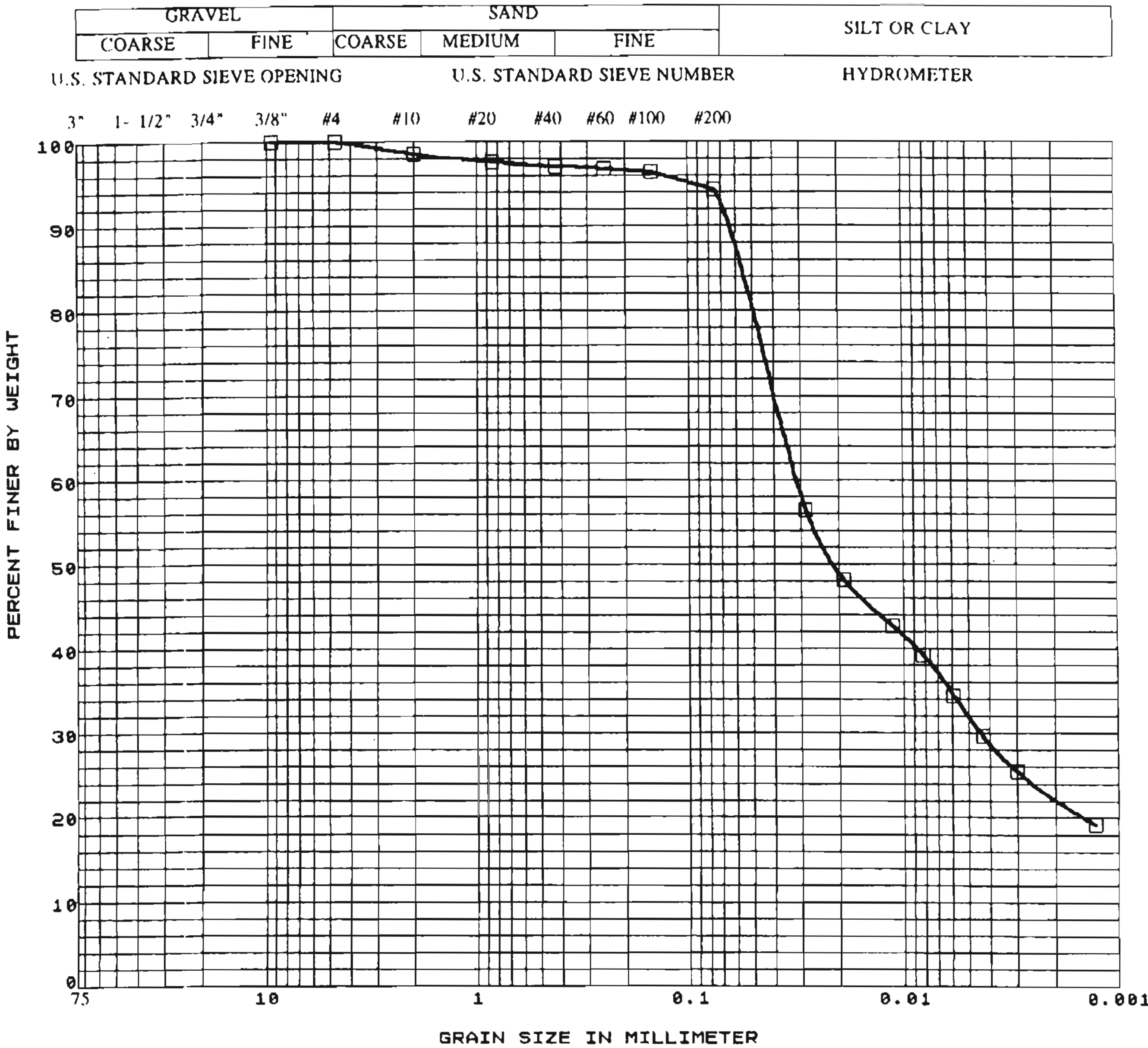

| SYMBOL | SAMPLE ID. | DEPTH (FT) | SAMPLE TYPE | SOIL TYPE | LIQUID LIMIT | PLASTICITY INDEX |
|---|---|---|---|---|---|---|
| □ | TP18 | N/A | BUCKET | CL | 40 | 18 |

| | |
|---|---|
| KEANTAN LABORATORIES | PROJECT NAME: FSDF BACKFILL |

# GRAIN SIZE DISTRIBUTION CURVE

1/00

FIGURE




| SYMBOL | SAMPLE ID. | DEPTH (FT) | SAMPLE TYPE | SOIL TYPE | LIQUID LIMIT | PLASTI-CITY INDEX |
|---|---|---|---|---|---|---|
| □ | COMPOSITE | N/A | BUCKET | CL | 37 | 18 |

| KEANTAN LABORATORIES | PROJECT NAME: FSDF BACKFILL |
|---|---|

# GRAIN SIZE DISTRIBUTION CURVE

1/00

FIGURE

**KEANTAN LABORATORIES**
720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

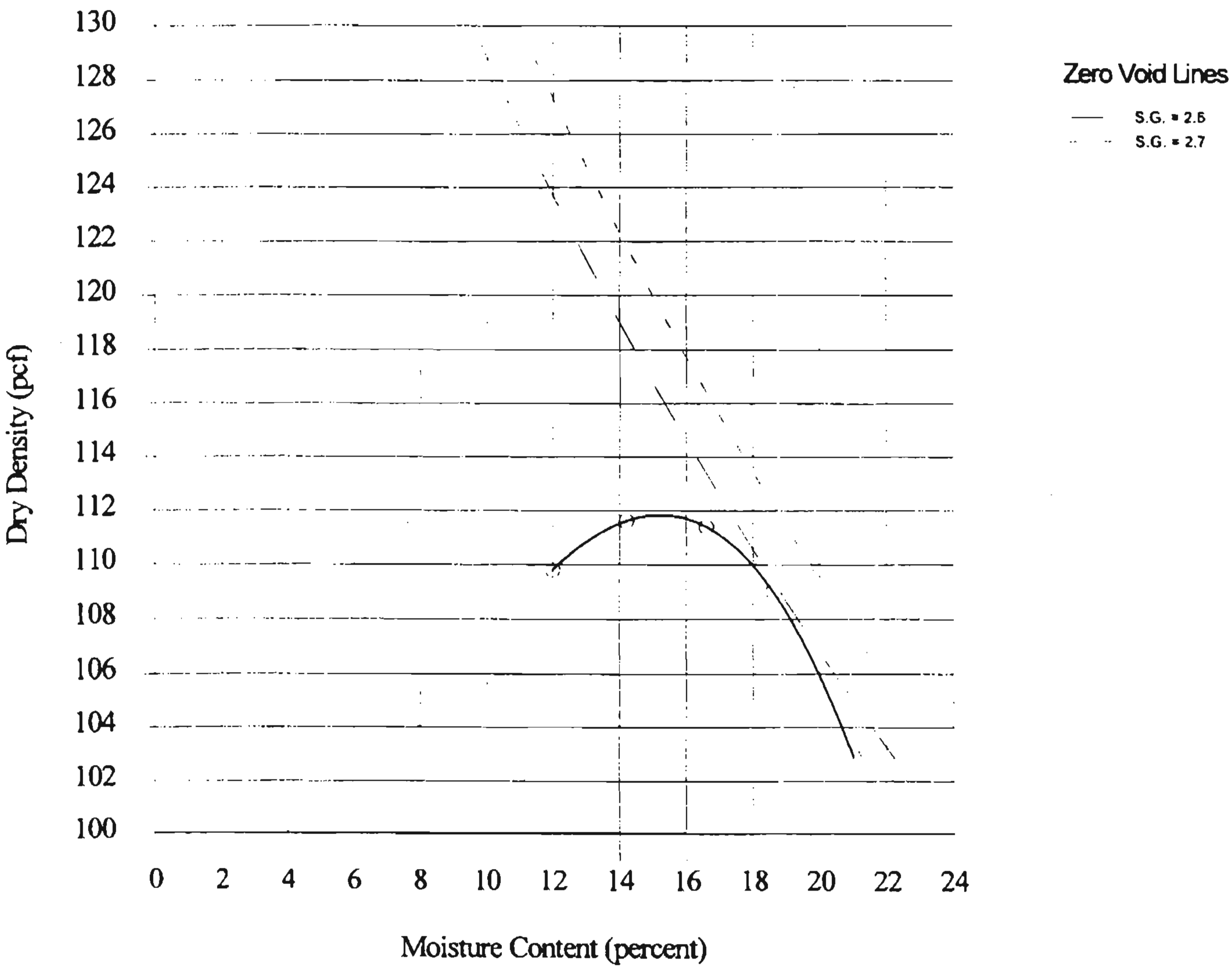
# Modified Compaction Test Results
## ASTM D 1557

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/80500000
DATE: JANUARY 2000
BORING NO.: N/A
SAMPLE NO.: TP-14

KTL NO.: 00-057-001
CLIENT: IT GROUP
DEPTH (ft):N/A
USCS CLASS.:CL

METHOD: A
DROP: 18 INCHES
NUMBER OF LAYERS: 5

RAM WEIGHT: 10 LBS
RAM TYPE: MANUAL
BLOWS/LAYER: 25




| Optimum Moisture Content, % | Maximum Dry Density, pcf |
|---|---|
| 15.5 | 112 |

FIGURE NO.

**KEANTAN LABORATORIES**
720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

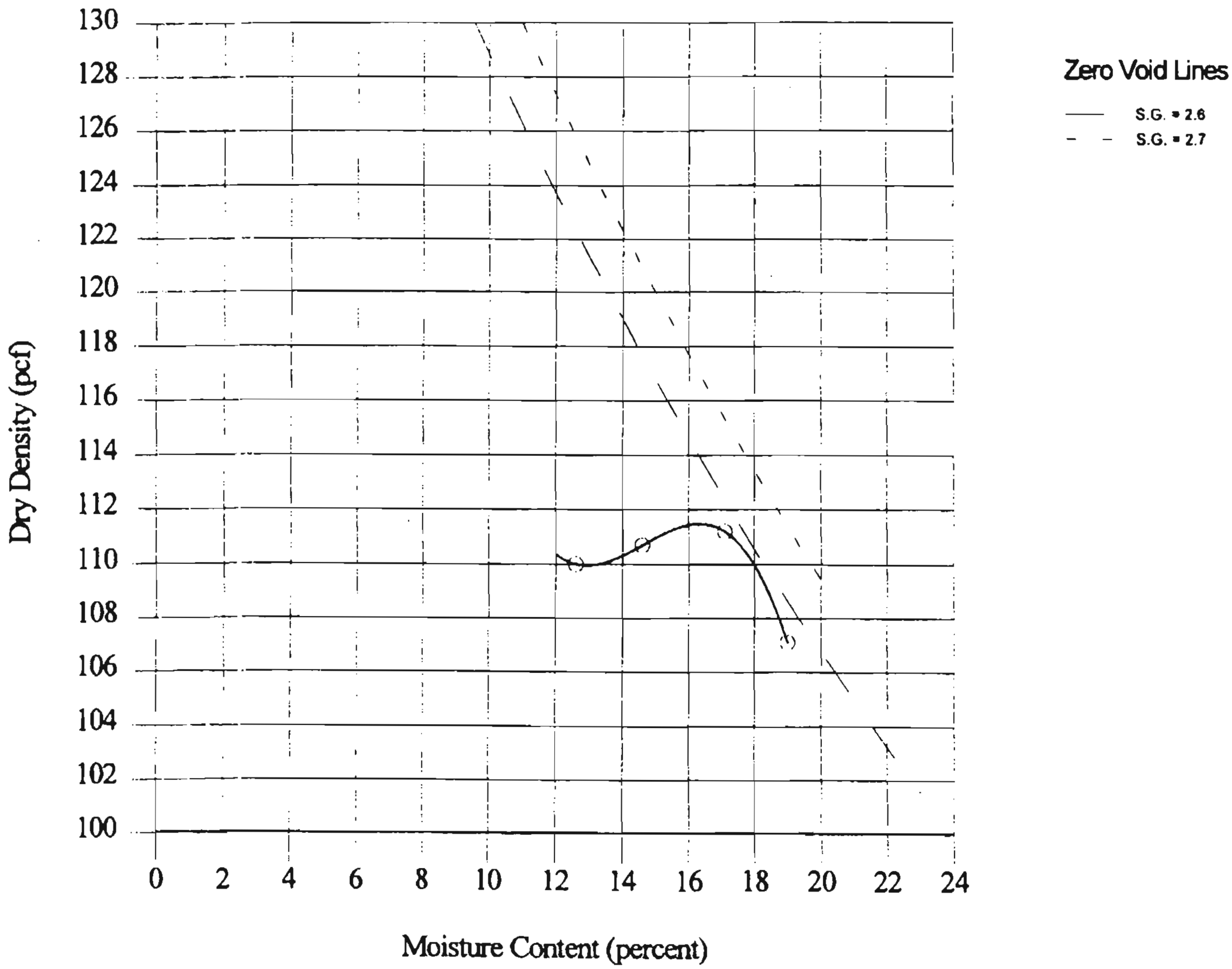
# Modified Compaction Test Results
# ASTM D 1557

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/80500000
DATE: JANUARY 2000
BORING NO.: N/A
SAMPLE NO.: TP-15

KTL NO.: 00-057-001
CLIENT: IT GROUP
DEPTH (ft):N/A
USCS CLASS.:CL

METHOD: A
DROP: 18 INCHES
NUMBER OF LAYERS: 5

RAM WEIGHT: 10 LBS
RAM TYPE: MANUAL
BLOWS/LAYER: 25




| Optimum Moisture Content, % | Maximum Dry Density, pcf |
|---|---|
| 16.5 | 112 |

FIGURE NO.

KEANTAN LABORATORIES
720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

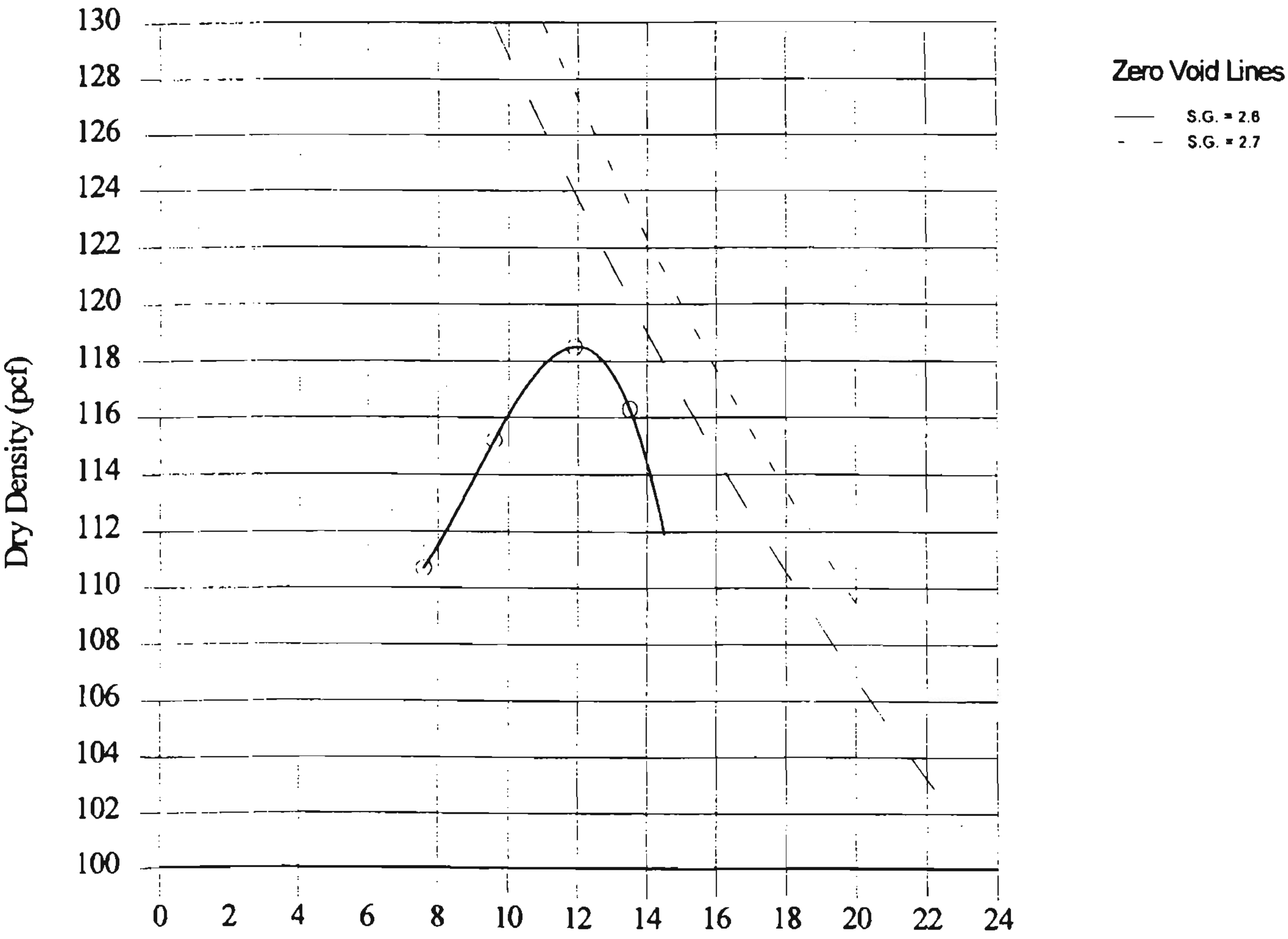
# Modified Compaction Test Results
# ASTM D 1557

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/80500000
DATE: JANUARY 2000
BORING NO.: N/A
SAMPLE NO.: TP-16

KTL NO.: 00-057-001
CLIENT: IT GROUP
DEPTH (ft):N/A
USCS CLASS.:CL

METHOD: A
DROP: 18 INCHES
NUMBER OF LAYERS: 5

RAM WEIGHT: 10 LBS
RAM TYPE: MANUAL
BLOWS/LAYER: 25




| Optimum Moisture Content, % | Maximum Dry Density, pcf |
|---|---|
| 12 | 119 |

FIGURE NO.

KEANTAN LABORATORIES
720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

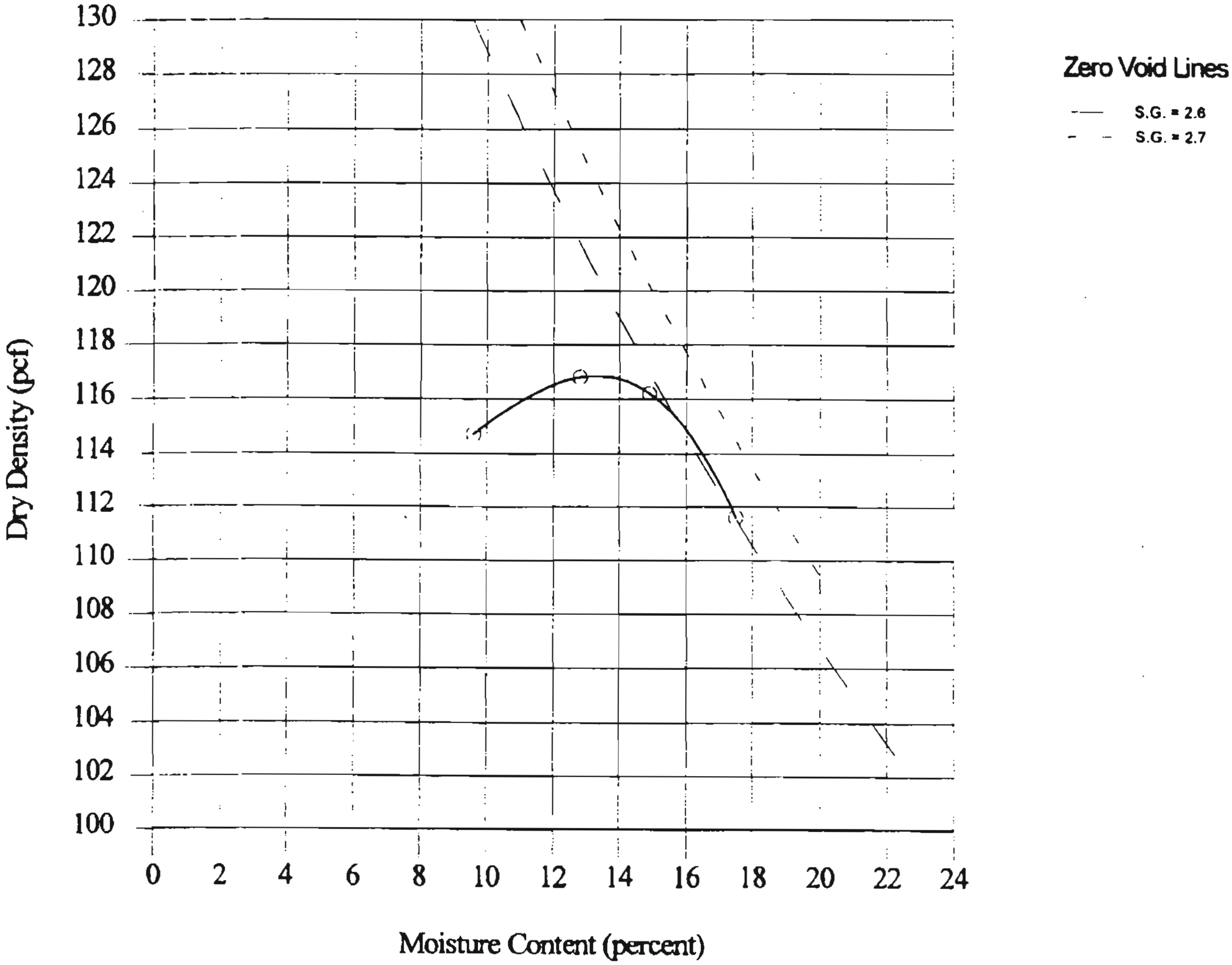
# Modified Compaction Test Results
## ASTM D 1557

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/80500000
DATE: JANUARY 2000
BORING NO.: N/A
SAMPLE NO.: TP-17

KTL NO.: 00-057-001
CLIENT: IT GROUP
DEPTH (ft):N/A
USCS CLASS.:CL

METHOD: A
DROP: 18 INCHES
NUMBER OF LAYERS: 5

RAM WEIGHT: 10 LBS
RAM TYPE: MANUAL
BLOWS/LAYER: 25




| Optimum Moisture Content, % | Maximum Dry Density, pcf |
|---|---|
| 14 | 117 |

FIGURE NO.

**KEANTAN LABORATORIES** 720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

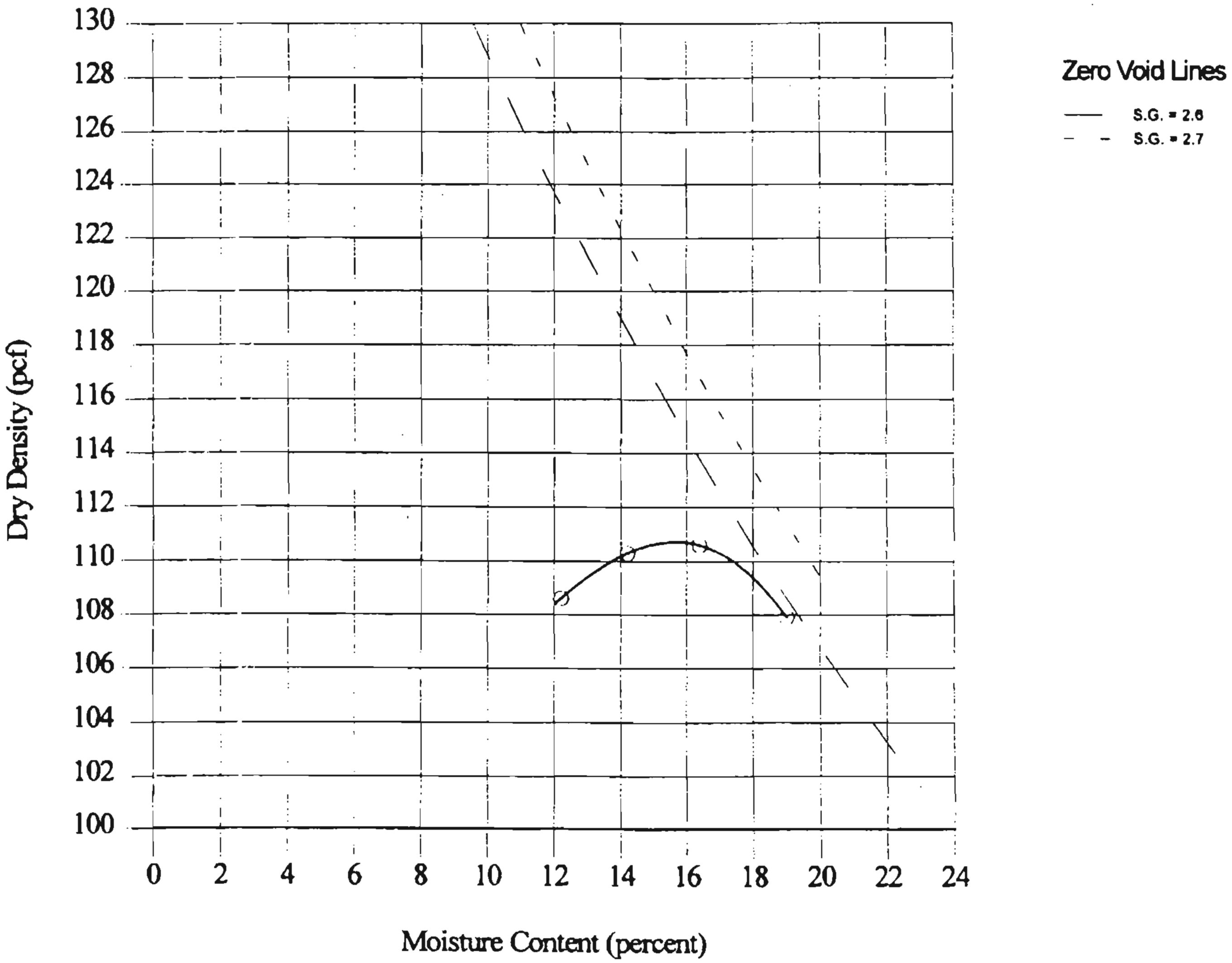
# Modified Compaction Test Results
## ASTM D 1557

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/80500000
DATE: JANUARY 2000
BORING NO.: N/A
SAMPLE NO.: TP-18

KTL NO.: 00-057-001
CLIENT: IT GROUP
DEPTH (ft):N/A
USCS CLASS.:CL

METHOD: A
DROP: 18 INCHES
NUMBER OF LAYERS: 5

RAM WEIGHT: 10 LBS
RAM TYPE: MANUAL
BLOWS/LAYER: 25




| Optimum Moisture Content, % | Maximum Dry Density, pcf |
|---|---|
| 16 | 111 |

FIGURE NO.

KEANTAN LABORATORIES
720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

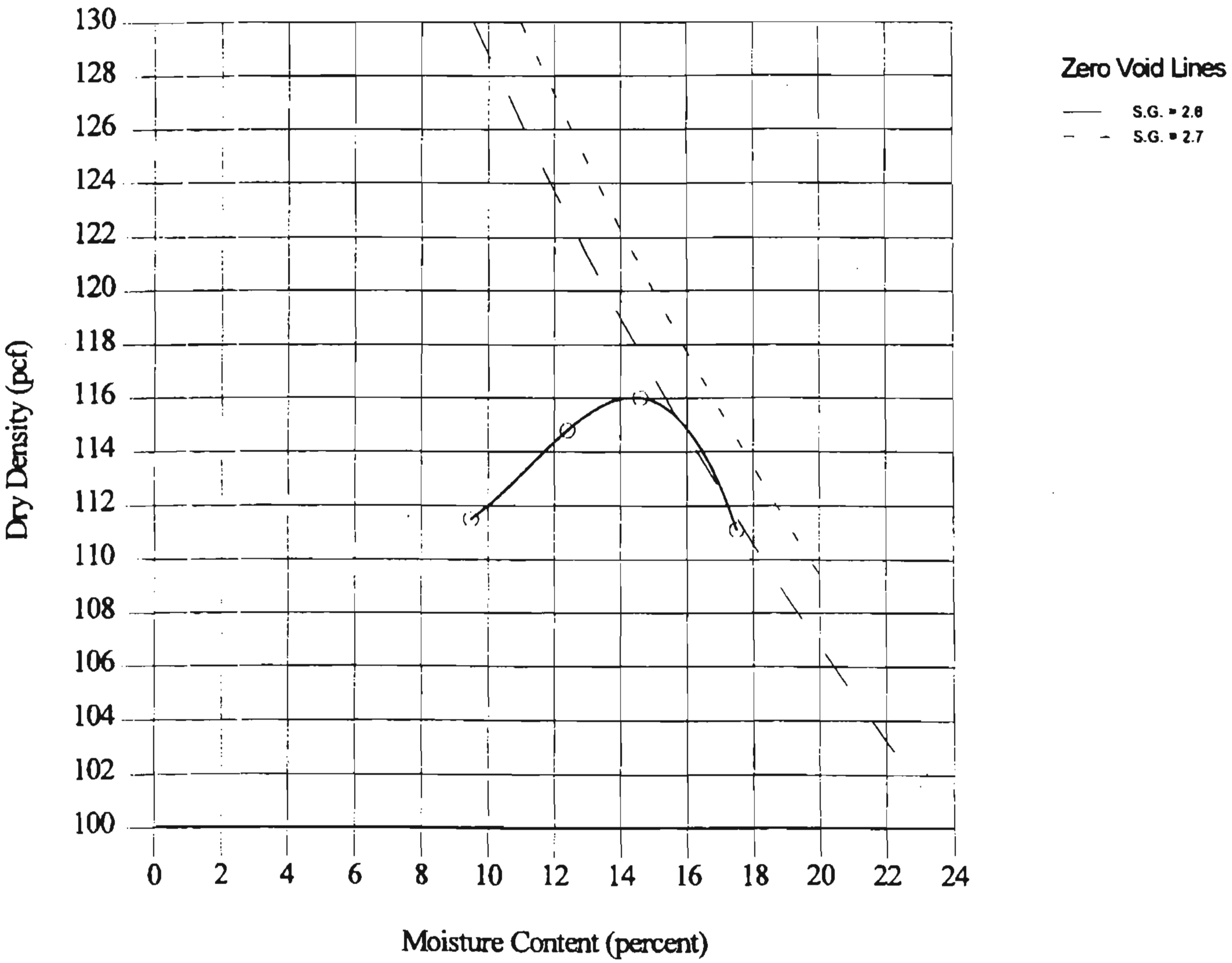
# Modified Compaction Test Results
## ASTM D 1557

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/80500000
DATE: JANUARY 2000
BORING NO.: N/A
SAMPLE NO.: COMPOSITE

KTL NO.: 00-057-001
CLIENT: IT GROUP
DEPTH (ft):N/A
USCS CLASS.:CL

METHOD: A
DROP: 18 INCHES
NUMBER OF LAYERS: 5

RAM WEIGHT: 10 LBS
RAM TYPE: MANUAL
BLOWS/LAYER: 25




| Optimum Moisture Content, % | Maximum Dry Density, pcf |
|---|---|
| 15 | 116 |

FIGURE NO.

**KEANTAN LABORATORIES** 720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

SUMMARY OF TRIAXIAL PERMEABILITY TEST RESULTS
ASTM D 5084

PROJECT NAME: FSDF BACKFILL | KTL NO.: 00-057-001

PROJECT NO.: 881344/80500000 | CLIENT: PACIFIC GEOSCIENCE

DATE: 1-18-00 | SUMMARIZED BY: K. Tan

| SAMPLE NO. | DEPTH (ft) | INITIAL MOISTURE (%) | FINAL MOISTURE (%) | DRY DENSITY (pcf) | EFFECTIVE STRESS (psi) | HYDRAULIC CONDUCTIVITY (cm/sec) |
|---|---|---|---|---|---|---|
| TP14 | N/A | 15.5 | 28.34 | 100.8 | 3 | 6.3E-06 |
| TP15 | N/A | 16.5 | 27.39 | 100.8 | 3 | 6.1E-06 |
| TP16 | N/A | 12.0 | 22.34 | 107.1 | 3 | 1.4E-05 |
| TP17 | N/A | 14.0 | 25.88 | 105.3 | 3 | 4.7E-06 |
| TP18 | N/A | 16.0 | 27.23 | 99.9 | 3 | 3.7E-06 |
| COMPOSITE | N/A | 15.0 | 24.61 | 104.4 | 3 | 5.0E-06 |

c:\My Documents\IT Corp\FSDF perm

**KEANTAN LABORATORIES**
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# Capillary-Moisture Relations
## ASTM D 3152

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/8050000
DATE: 1-18-00

KTL NO.: 00-058-001
CLIENT: IT CORPORATION

SAMPLE I.D.: COMPOSITE
DEPTH(FT): N/A

MOISTURE CONTENT: 15.0 PERCENT (BY WT.)
DRY DENSITY: 104.4 PCF

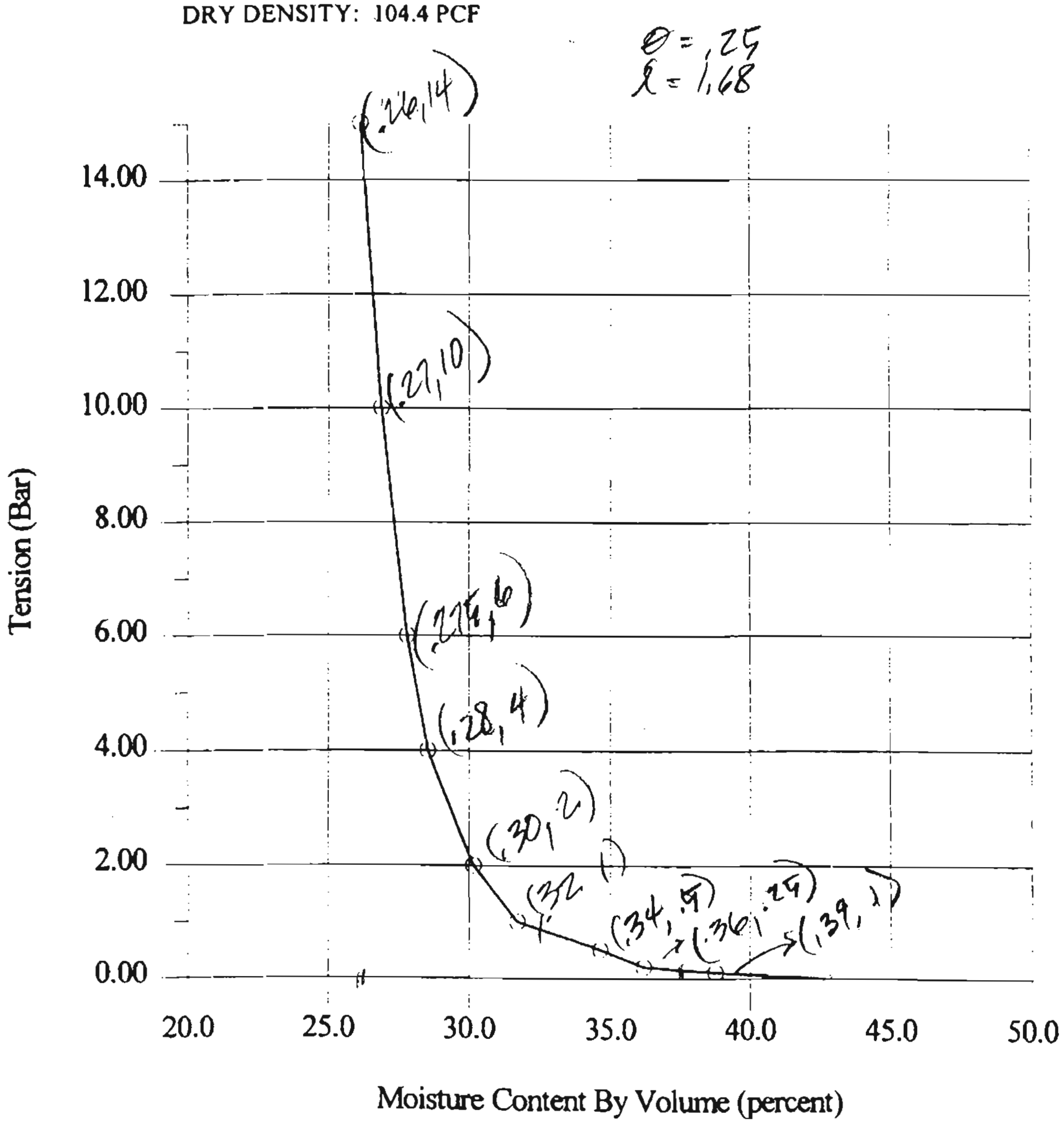


FIGURE NO.

**KEANTAN LABORATORIES**
720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

# Capillary-Moisture Relations
## ASTM D 3152

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/8050000
DATE: 1-18-00

KTL NO.: 00-058-001
CLIENT: IT CORPORATION

SAMPLE I.D.: TP-16
DEPTH(FT): N/A

MOISTURE CONTENT: 12.0 PERCENT (BY WT.)
DRY DENSITY: 107.1 PCF

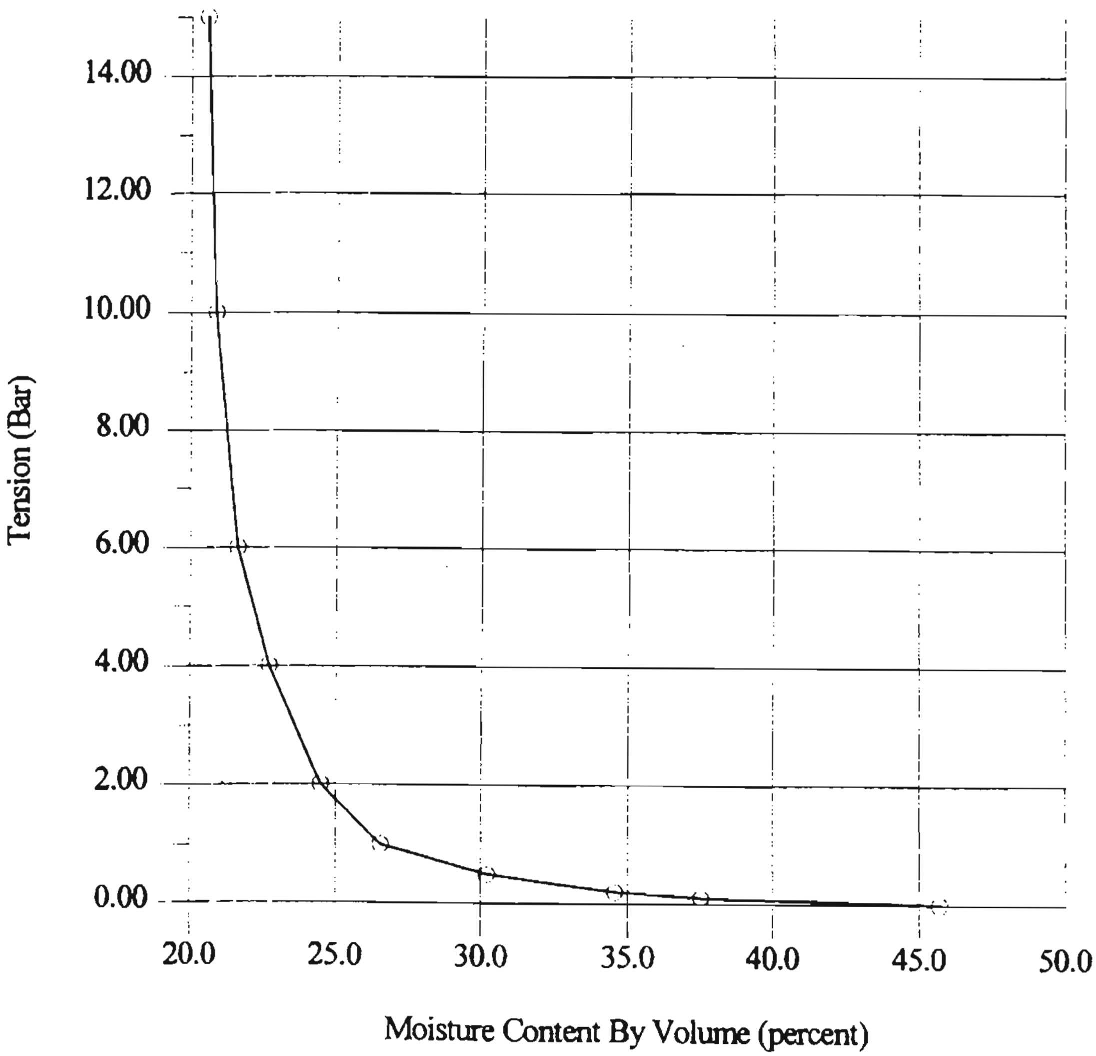


FIGURE NO.

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Tel.: (714) 535-7616 • Fax: (714) 535-7568

# Capillary-Moisture Relations
## ASTM D 3152

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/8050000
DATE: 1-18-00

KTL NO.: 00-058-001
CLIENT: IT CORPORATION

SAMPLE I.D.: TP-14
DEPTH(FT): N/A

MOISTURE CONTENT: 15.5 PERCENT (BY WT.)
DRY DENSITY: 100.8 PCF

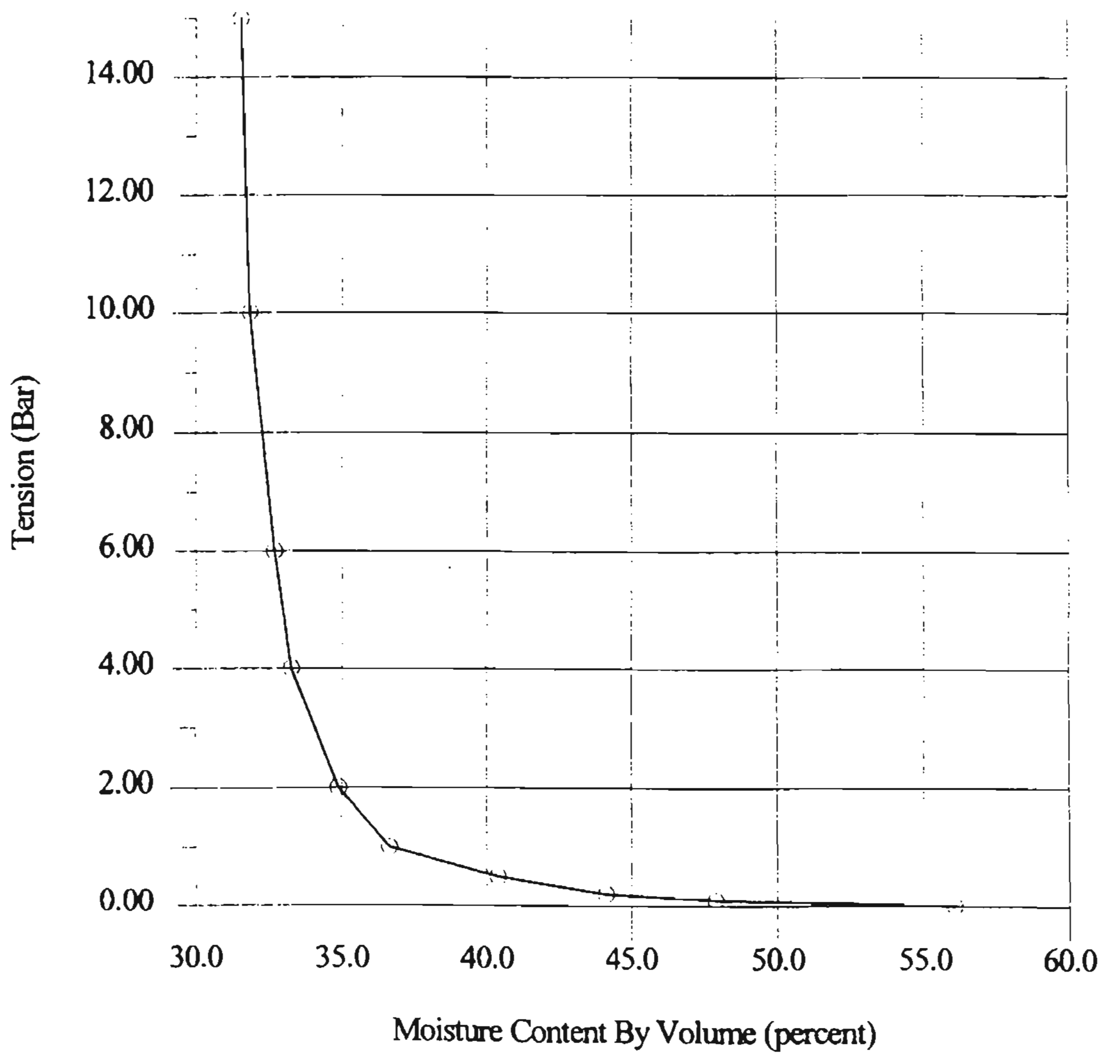



FIGURE NO.

**KEANTAN LABORATORIES**
720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

# Capillary-Moisture Relations
# ASTM D 3152

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/8050000
DATE: 1-18-00

KTL NO.: 00-058-001
CLIENT: IT CORPORATION

SAMPLE I.D.: TP-15
DEPTH(FT): N/A

MOISTURE CONTENT: 16.5 PERCENT (BY WT.)
DRY DENSITY: 100.8 PCF

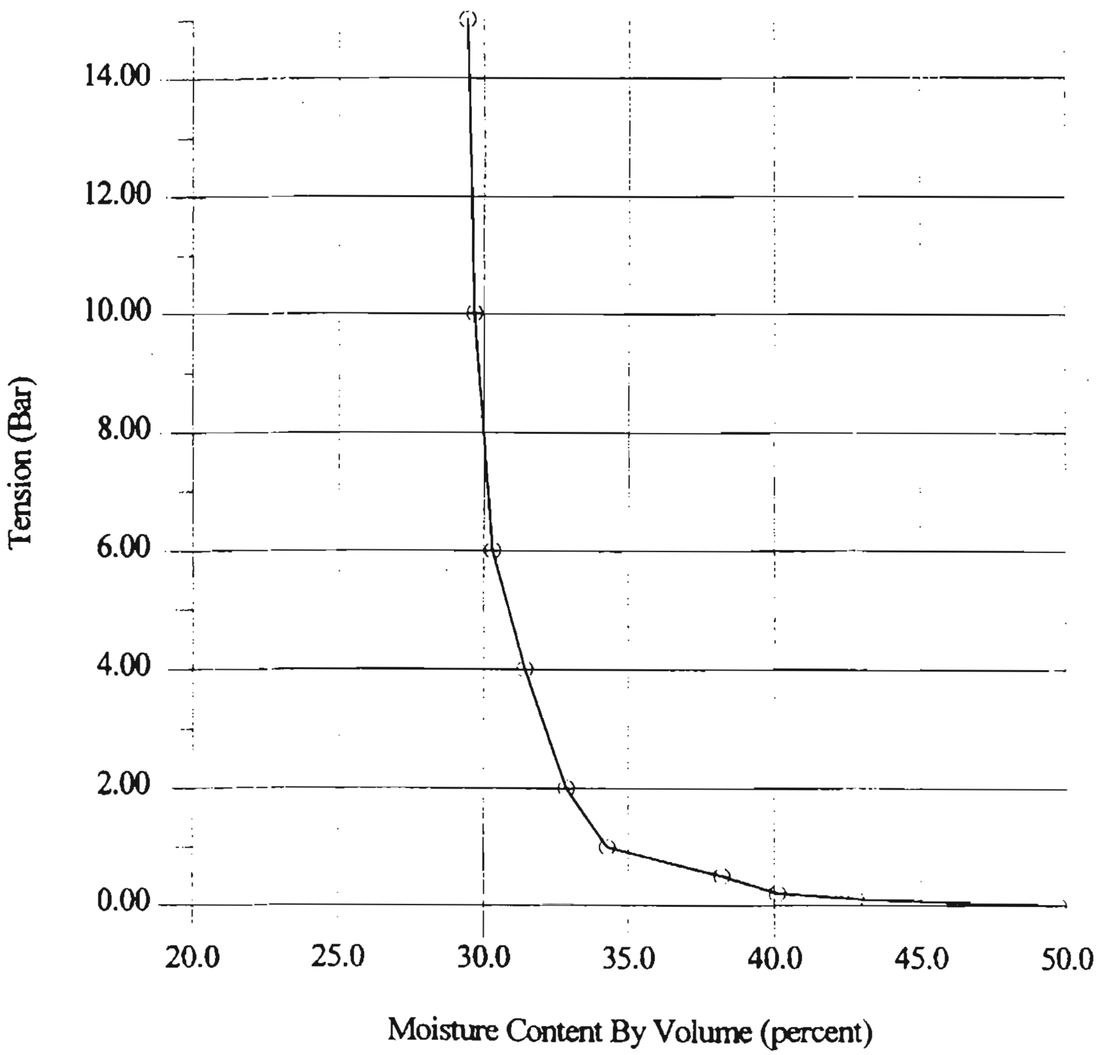



FIGURE NO.

**KEANTAN LABORATORIES**
720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

# Capillary-Moisture Relations
## ASTM D 3152

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/8050000
DATE: 1-18-00

KTL NO.: 00-058-001
CLIENT: IT CORPORATION

SAMPLE I.D.: TP-17
DEPTH(FT): N/A

MOISTURE CONTENT: 14.0 PERCENT (BY WT.)
DRY DENSITY: 105.3 PCF

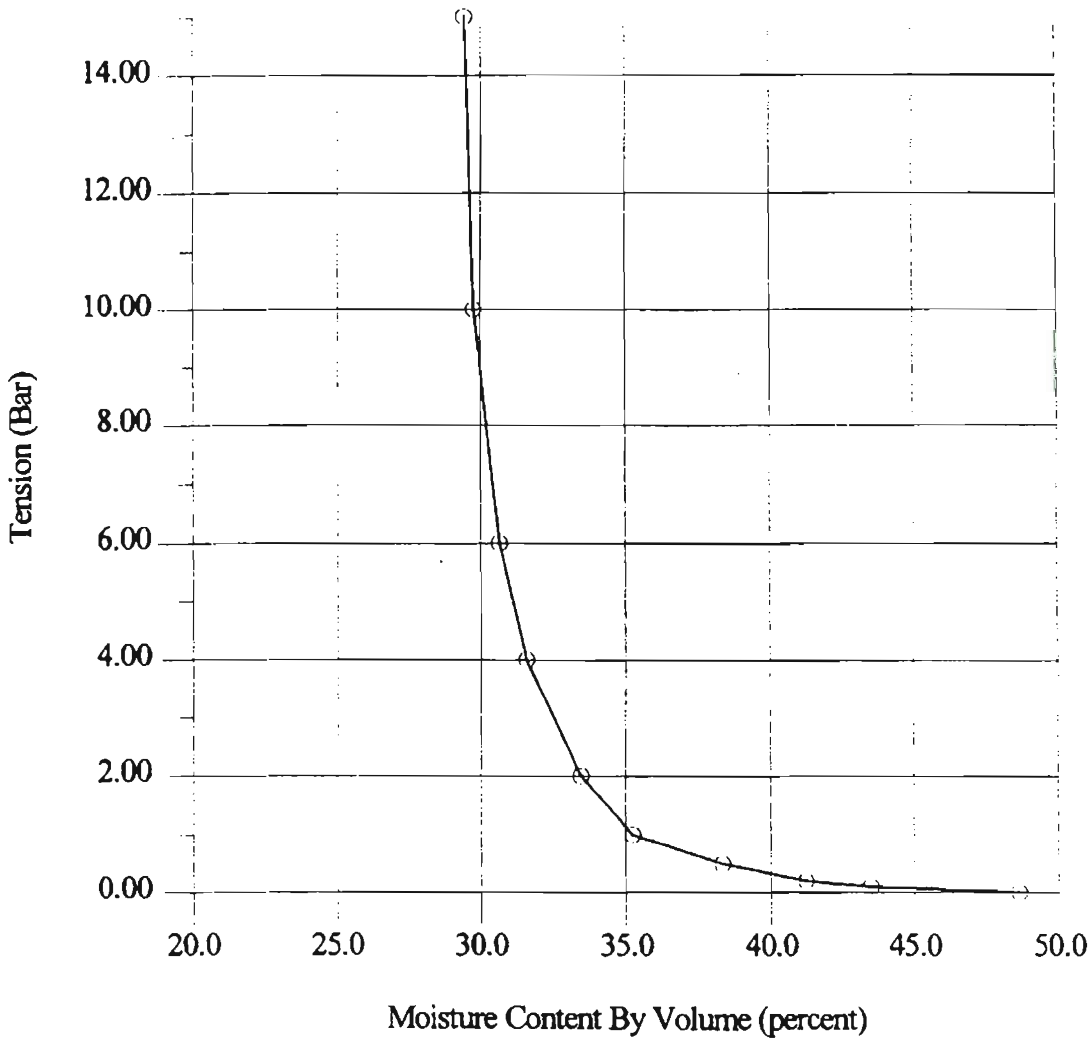



FIGURE NO.

**KEANTAN LABORATORIES**
720 North Valley Street, Suite B, Anaheim, CA 92801
Tel.: (714) 535-7616 • Fax: (714) 535-7568

# Capillary-Moisture Relations
## ASTM D 3152

PROJECT NAME: FSDF BACKFILL
PROJECT NO.: 881344/8050000
DATE: 1-18-00

KTL NO.: 00-058-001
CLIENT: IT CORPORATION

SAMPLE I.D.: TP-18
DEPTH(FT): N/A

MOISTURE CONTENT: 16.0 PERCENT (BY WT.)
DRY DENSITY: 99.9 PCF

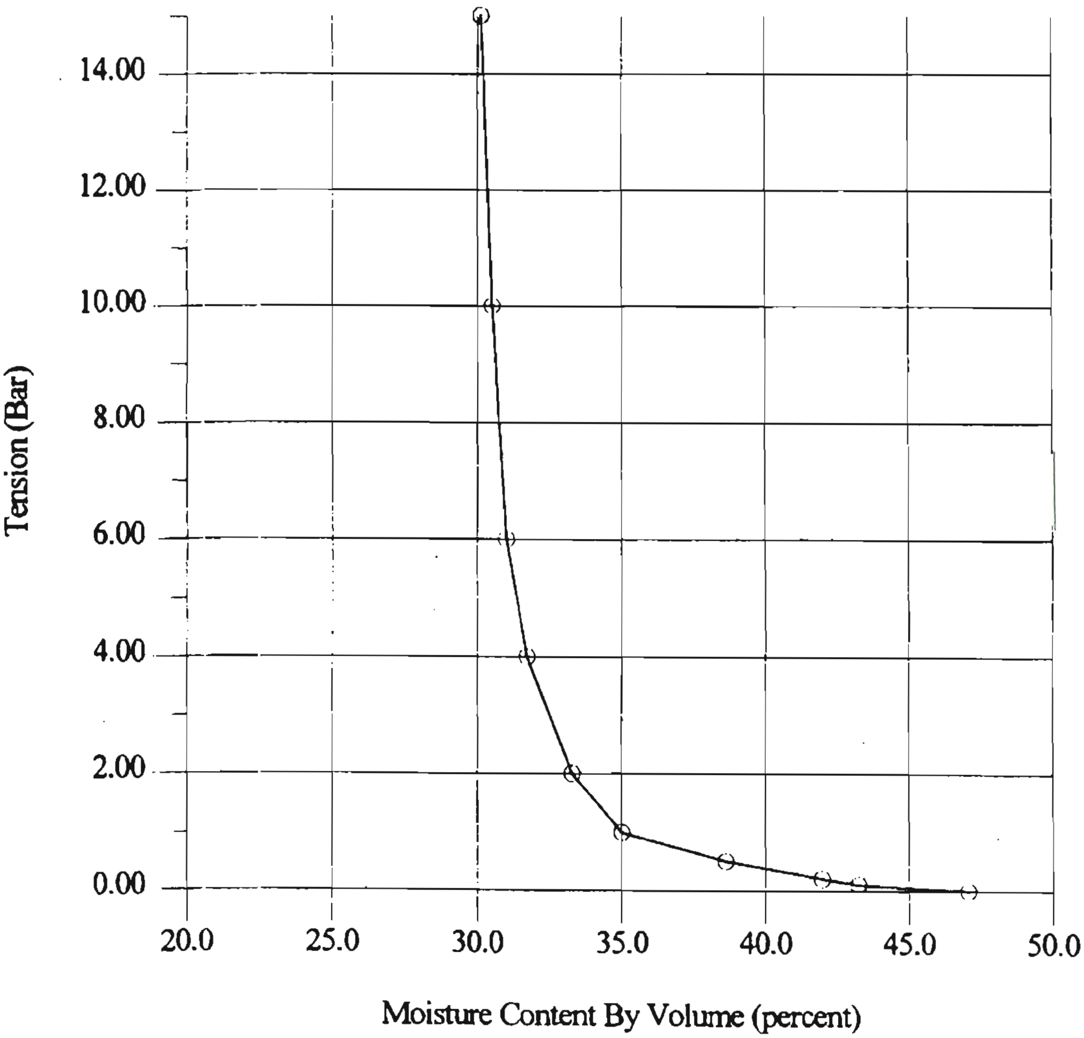



FIGURE NO.

# APPENDIX B

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 1**

| Blow Neq | Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | | ML-MH | Brown fine sandy clayey silt and silty clay, highly porous with minor rootlets, damp and loose |
| | | | | | | | Same, increasing in moisture content |
| | | | | 18.3 | | | |
| | | | | | | CL | Orange-brown silty clay and fine sand with minor siltstone gravels, moist and moderately loose |
| | | | | | 5 | | |
| | | | | | | CL | Reddish-brown silty clay, moist and moderately loose |
| | | | | 20.5 | | | |
| | | | | | | | Same, moist and moderately firm |
| | | | | 16.9 | 10 | | |
| | | | | 17.6 | | CL | Gray and orange-brown silty clay, moist and moderately firm |
| | | | | | | ML | **Bedrock:** Gray and green-brown fine sandy siltstone, fractured and tight |
| | | | | 9.9 | 15 | | |

**Total depth attempted = 15.5'**
**No freewater encountered**
**No sidewall caving**

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 2**

| Blow Neq | Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | | ML-MH | Orange-brown fine sandy clayey silt and clay, moist and moderately loose |
| | | | | 16.3 | | | |
| | | | | | | CL | Orange and red-brown sandy silty clay, moist and moderately loose |
| | | | | 20.5 | 5 | | |
| | | | | | | CL | Red-brown to orange-brown silty clay, moist and moderately firm below 6' |
| | | | | | | | Occasional siltstone gravels noted |
| | | | | 21.2 | | | |
| | | | | | | | Same as above |
| | | | | | 10 | | |
| | | | | | | ML-MH | Tan-brown fine sandy siltstone, moist and moderately firm below 13' |
| | | | | | | | Becoming firm @ 14' |

**Total depth attempted = 14'**
**No freewater encountered**
**No sidewall caving**

# LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 3**

| Blow Neq | Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | | ML-MH | Brown fine sandy silt and clay with minor rootlets, damp and loose |
| | | | | 16.3 | | | |
| | | | | | | | Same, increasing in moisture content |
| | | | | | | ML-MH | Orange-brown fine sandy clayey silt, moist and loose |
| | | | | 21.2 | 5 | CL | Brown and orange-brown silty clay, moist and moderately loose |
| | | | | | 10 | | |
| | | | | 18.3 | | | Same as above |
| | | | | 20.5 | | CL | Gray-brown and orange-brown silty clay, moist and moderately firm |
| | | | | 17.6 | 15 | | |
| | | | | | | CL | Orange-brown silty clay, moist and moderately firm |

Total depth attempted = 18.5'
No free water encountered
No sidewall caving

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 4**

| Blow Count Neq | Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | 13.0 | | ML-MH | Brown fine sandy silt and clay, damp and moderately loose |
| | | | | | | ML | **Weathered Bedrock:** Gray-brown siltstone with some sand and clay, moist and moderately loose |
| | | | | | | SM | **Relatively Fresh Bedrock:** Tan-brown silty sandstone, damp and firm |

**Total depth attempted = 4.5'**
**No freewater encountered**
**No sidewall caving**

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 5**

| Blow Neq | Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | | CL | Brown fine sandy silt and clay with minor rootlets, damp and loose |
| | | | | 14.9 | | | |
| | | | | | | CL | Orange-brown silty clay, moist and moderately loose |
| | | | | | 5 | ML-MH | **Weathered Bedrock:** Gray to tan-brown sandy to clayey siltstone, damp and moderately loose |
| | | | | | | SM | **Relatively Fresh Bedrock:** Tan-brown silty sandstone, damp and firm |

**Total depth attempted = 6.5'**
**No freewater encountered**
**No sidewall caving**

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 6**

| Blow Count Neq | Blow Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | 0–4 | ML-MH | Brown fine sandy clayey silt and clay, moist and moderately loose |
| | | | | 16.3 | | | |
| | | | | | 4–6.5 | CL | Gray to orange-brown silty clay, moist and moderately loose |
| | | | | | 6.5–9.4 | CL | Gray-brown silty clay, moist and moderately firm |
| | | | | | 9.4–10 | ML | **Weathered Bedrock:** Orange to yellow-brown fine sandy siltstone |

Depth scale: 5, 10

**Total depth attempted = 10'**
**No freewater encountered**
**No sidewall caving**

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 7**

| Blow Count Neq | Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | 0 | ML-MH | Orange-brown fine sandy clayey silt and clay with rootlets, moist and loose |
| | | | | | | CL | Orange-brown clayey silt and silty clay, moist and loose |
| | | | | 16.3 | 5 | | Same, moist and moderately loose |
| | | | | | | CL | Orange-brown silty clay, moist and moderately firm |
| | | | | | 10 | | Same as above, increasing in clay content and moisture content with depth |

**Total depth attempted = 14'**
**No freewater encountered**
**No sidewall caving**

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 8**

| Blow Neq | Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | 0 | ML-MH | Orange-brown fine sandy clayey silt and clay rootlets, moist and loose |
| | | | | | 2 | CL | Orange-brown clayey silt and silty clay, moist and moderately loose |
| | | | | 16.9 | 3 | | |
| | | | | | 5 | | |
| | | | | | 7 | CL | Orange-brown silty clay, moist and moderately firm |
| | | | | 11.7 | 8 | | |
| | | | | | 10 | | |
| | | | | | 11 | | Same as above, increasing in clay content and moisture content with depth |
| | | | | | 15 | | |

**Total depth attempted = 15'**
**No freewater encountered**
**No sidewall caving**

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 9**

| Blow Count Neq | Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | | ML | Orange-brown fine sandy silt and clay, moist and moderately loose |
| | | | | | | CL | **Weathered Bedrock:** Tan to orange-brown sandy siltstone and claystone, damp and moderately loose |
| | | | | 14.9 | 5 | | |
| | | | | | | | Same, becoming medium tight @ ~8.5' |

**Total depth attempted = 8.5'**
**No freewater encountered**
**No sidewall caving**

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 10**

| Blow Neq | Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | | ML | Orange-brown clayey silt with some clay and fine sand, moist and moderately loose |
| | | | | 14.3 | | | |
| | | | | | | | Same, moist and moderately loose |
| | | | | 14.9 | 5 | | |
| | | | | | | ML-MH | **Weathered Bedrock:** Orange to tan-brown sandy siltstone, moist and moderately loose |
| | | | | | 10 | | Same, moist and moderately firm |

**Total depth attempted = 12'**
**No freewater encountered**
**No sidewall caving**

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 11**

| Blow Neq | Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | 0–2 | CL | Brown fine sandy silt and clay with minor rootlets, moist and loose |
| | | | | 13.0 | 2–5.2 | CL | Orange-brown fine sandy silty clay, moist and moderatley loose |
| | | | | | 5.2–10 | CL | Orange-brown fine sandy silty clay, moist and moderately loose |

Total depth attempted = 10'
No freewater encountered
No sidewall caving

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 12**

| Blow Neq | Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | | CL | Brown fine sandy silt and clay, moist and loose |
| | | | | 15.6 | | | |
| | | | | | | | Same, moist and moderately loose |
| | | | | | 5 | CL | Tan to orange-brown silty clay, moist and moderately loose |
| | | | | | | CL | Orange-brown silty clay, moist and moderately firm |
| | | | | 19.0 | | | |
| | | | | | 10 | | Same, increasing in clay content |

**Total depth attempted = 14'**
**No freewater encountered**
**No sidewall caving**

## LOG OF TEST PIT

Excavated : 5-17-99
Logged by : RA
Equipment : Backhoe

**Test Pit No. 13**

| Blow Count Neq | Blow Count Nspt | Tube Type | Dry Density (pcf) | Moisture Content (%) | Depth (ft) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | | | | | CL | Brown clayey silt with some fine sand, moist and loose |
| | | | | | | CL | Brown to orange-brown silty clay, moist and moderately firm |
| | | | | | 5 | | |
| | | | | | 10 | | |
| | | | | | | | Same as above |

**Total depth attempted = 13'**
**No freewater encountered**
**No sidewall caving**

# APPENDIX C

# LABORATORY TEST DATA

## LABORATORY COMPACTION CHARACTERISTICS (ASTM D1557)

Maximum density optimum moisture data was determined in the laboratory from bulk soil samples using ASTM D1557 procedures. The test uses a 4 or 6 inch diameter mold of 1/30 or 1/56 cft. volume respectively. The soil is moistened to various degrees of saturation and compacted in 5-layers, using a 10-pound hammer falling 18-inches, and 25 or 56 blows per layer for 4 or 6 inch molds respectively. The test results are tabulated below.

| SOIL TYPE | ASTM METHOD | SOIL DESCRIPTION | MAXIMUM DRY DENSITY (lbs/cft) | OPTIMUM MOISTURE CONTENT (%) |
|---|---|---|---|---|
| 1 | A | Brown Sandy Silty Clay | 117.0 | 12.5 |
| 2 | A | Reddish Brown to Orange Brown Silty Clay | 120.0 | 13.0 |
| 3 | A | Orange-Brown Clayey Silt | 119.0 | 14.0 |
| 4 | A | Brown Fine Sandy Clayey Silt | 117.0 | 16.5 |
| 5 | A | Fine Sandy Silt Light Brown | 119.0 | 15.0 |

## EXPANSION INDEX TEST DATA (UBC Volume 3, Section 18-2)

An expansion index test was performed on representative near surface soil encountered. The expansion testing was performed in accordance with 1991 edition of the UBC Standards Test No.29-2. The test results are tabulated below.

| SOIL TYPE | MOISTURE CONTENT (%) | FINAL MOISTURE CONTENT (%) | DRY DENSITY (lbs/cft) | EXPANSION INDEX | EXPANSION[A] POTENTIAL |
|---|---|---|---|---|---|
| 1 | 13.6 | 23.4 | 97.6 | 18 | Very Low |
| 2 | 11.1 | 27.4 | 104.0 | 35 | Low |
| 3 | 13.0 | 27.4 | 99.2 | 67 | Medium |
| 4 | 13.6 | 30.7 | 98.0 | 34 | Low |

[A] Per UBC Table No. 18-1-B "Classification of Expansive Soils"

## MECHANICAL & HYDROMETER ANALYSES (ASTM D422)

MECHANICAL ANALYSIS (Values in Percent Passing)

| SIEVE SIZE | TP-3 @ 13.0' | TP-5 @ 1.5' | TP-7 @ 5.0' | TP-9 @ 8.0' | TP-12 @ 3.0' |
|---|---|---|---|---|---|
| No. 8 | ----- | ----- | ----- | ----- | ----- |
| No. 16 | ----- | 100 | 100 | ----- | ----- |
| No. 30 | 100 | 98 | 98 | 100 | 100 |
| No. 50 | 98 | 86 | 92 | 90 | 96 |
| No. 100 | 90 | 68 | 84 | 78 | 88 |
| No. 200 | 82 | 52 | 66 | 64 | 74 |

## HYDROMETER ANALYSES[A] (ASTM D422)

| LOCATION | % SAND | % SILT | % CLAY |
|---|---|---|---|
| TP-3 @ 13.0' | 16 | 40 | 46 |
| TP-5 @ 1.5' | 44 | 28 | 28 |
| TP-7 @ 5.0' | 30 | 42 | 28 |
| TP-9 @ 8.0' | 36 | 40 | 24 |
| TP-12 @ 3.0' | 28 | 38 | 34 |

[A] Hydrometer analysis modified to short method (1 hour), for determination of percentages of sand, silts and clay.

## ATTERBURG LIMITS - (ASTM D4318)

Classification ASTM D2487

| Boring: | TP-3 | TP-5 | TP-7 | TP-9 | TP-12 |
|---|---|---|---|---|---|
| Depth: | 13.0' | 1.5' | 5.0' | 8.0' | 3.0' |
| Soil: | Orange Brown Silty Clay | Dark Brown Silty Clay | Light Orange Brn. Silty Clay | Tan Brown Clayey Silt & Clay | Brown Sandy Silt and Clay |
| Soil Identification: | CL | CL | CL | CL | CL |
| Liquid Limit % : | 43 | 35 | 35 | 40 | 34 |
| Plastic Limit %: | 16 | 18 | 18 | 23 | 21 |
| Plasticity Index: | 27 | 17 | 17 | 17 | 13 |

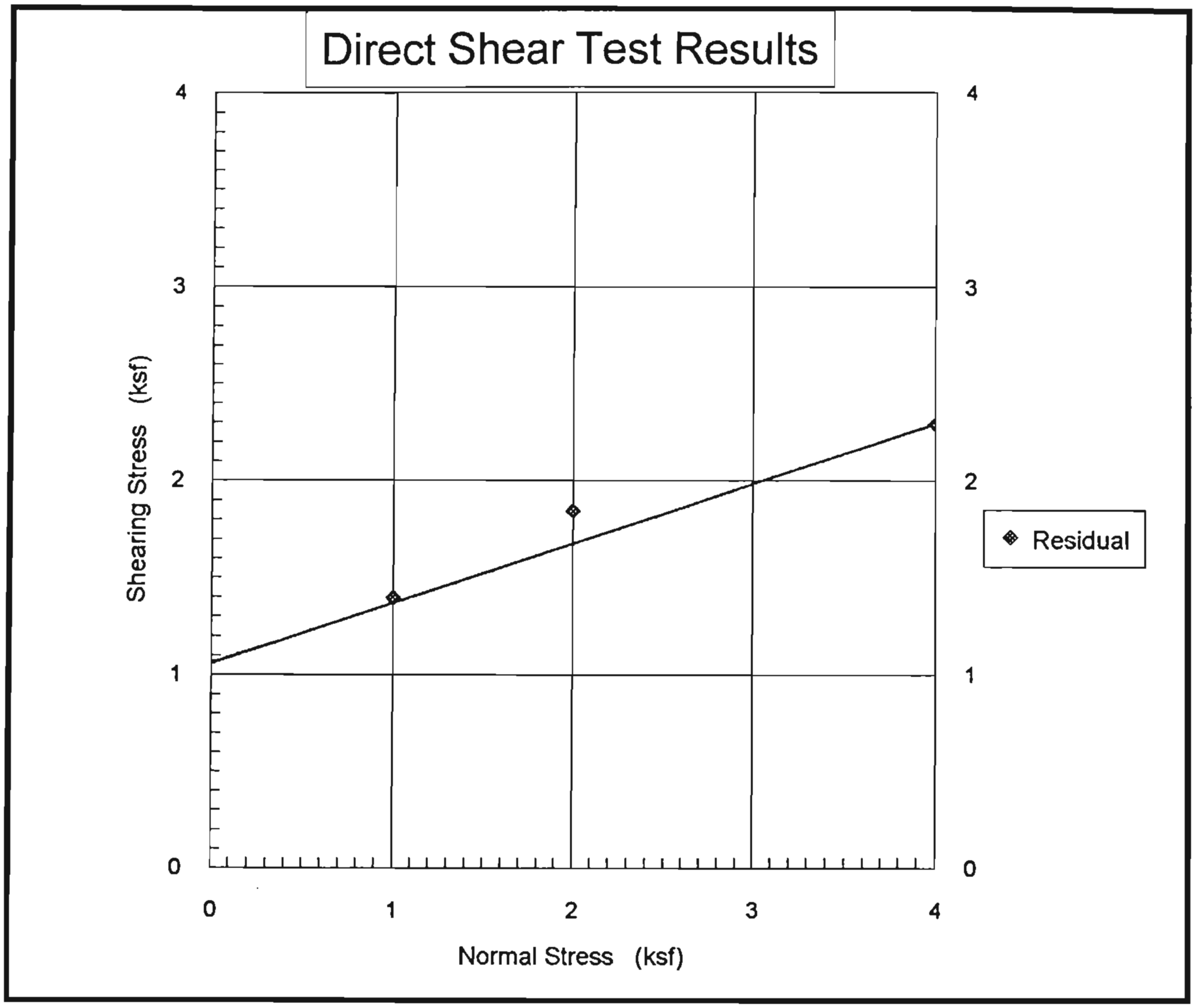
## DIRECT SHEAR DATA - (ASTM D3080)

Direct shear testing was performed on insitu specimens trimmed to 2.4" diameter x 1.5" high, placed under a normal confining load and saturated prior to testing. The reported parameters are peak or residual values. The results are presented graphically in Appendix C as SHEAR1 and SHEAR2.

## Rocketdyne Laboratory Test Summary

| | Soil | Description | Max | Exp Index | Hydrometer Analysis % Sand | % Silt | % Clay | Sieve % fines | Atterberg LL | PL | Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ST-1 | TP-5 @ 1.5' | Brown fine sandy clayey silt and clay | 117 pcf @ 12.5% | 18 | 44 | 28 | 28 | 52 | 35 | 18 | CL |
| ST-2 | TP-7 @ 5' | Orange brown silty clay | 120.0 pcf @ 13.0% | 35 | 30 | 42 | 28 | 66 | 38 | 18 | CL |
| ST-3 | TP-3 @ 13' | Gray-brown to orange-brown silty clay | 119.0 pcf @ 14.0% | 67 | 16 | 40 | 46 | 82 | 43 | 16 | CL |
| ST-4 | TP-12 @ 3' | Brown fine sandy silt and clay | 117.0 pcf @ 16.5% | 34 | 28 | 38 | 34 | 74 | 34 | 21 | CL |
| ST-5 | TP-9 @ 8' | Tan to orange-brown sandy to clayey siltstone (Weathered Bedrock) | 119.0 pcf @ 15.0% | NP | 36 | 40 | 24 | 64 | 40 | 23 | CL |

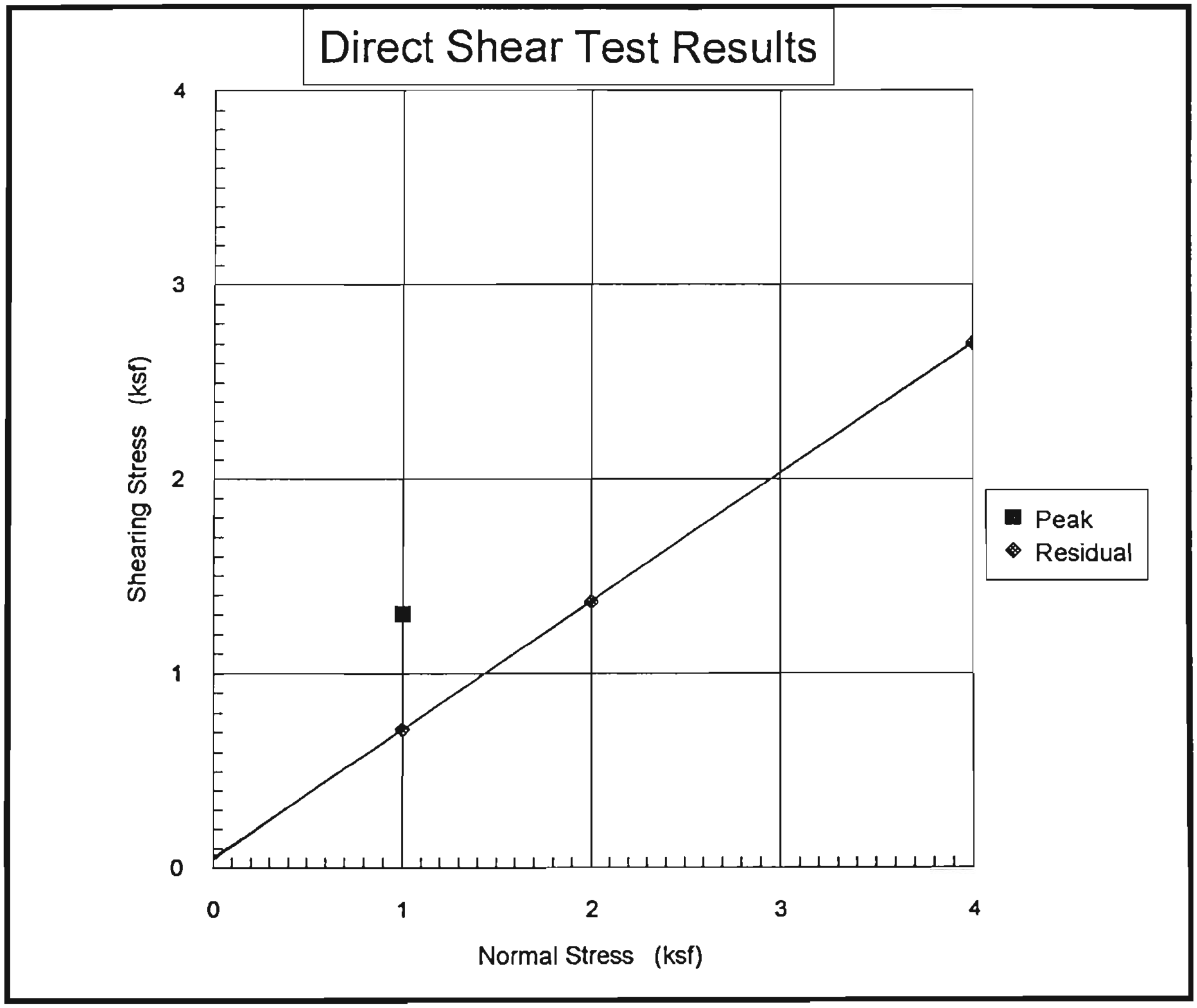
NP - not performed




**Sample Location:** TP-2 @ 8'
**Soil Description:** Red-brown to orange-brown silty clay

**Insitu Multiple Reverse Shear**

**Residual Values:**
Internal Angle of Friction = 17 degrees
Cohesion = 1080 psf




**Sample Location:** TP-6 @ 2'
**Soil Description:** Brown fine sandy clayey silt

**Insitu Multiple Reverse Shear**

**Residual Values:**
Internal Angle of Friction = 34 degrees
Cohesion = 45 psf

**Peak Values:**
Internal Angle of Friction = 34 degrees
Cohesion = 640 psf

# APPENDIX B

# INFILTRATION MONITORING OPTIONS

# APPENDIX B-INFILTRATION MONITORING OPTIONS

Various techniques exist for monitoring soil moisture movement through the vadose zone. These techniques may be divided into direct and indirect methods. Direct methods capture and measure the volume of moisture moving down through the soil column, or directly measure soil moisture content. Indirect methods infer soil moisture content changes by sensing a parameter which correlates to moisture content. The direct and indirect method potentially useful for monitoring soil moisture movement in the FSDF backfill are discussed in this appendix.

## B.1 Direct Monitoring Techniques

### B.1.1 Soil Sampling and Gravimetric Testing

The most direct method of measuring the soil moisture profile in the FSDF fill would be to drill and sample the fill, and perform laboratory soil moisture tests on the recovered samples. This technique is inexpensive, accurate, and repeatable. It is, however, a destructive test, and requires that attention be paid to the careful backfilling or grouting of the borehole.

### B.1.2 Pan Lysimeters

A direct monitoring technique well suited for use in the FSDF backfill is the pan lysimeter. The pan lysimeter utilizes an impermeable "pan" covered with a drain layer and buried in the fill to capture vertical infiltration. Figure 5 of the report text shows the configuration of a pan lysimeter as it would be configured for use at the FSDF. Pan lysimeters provide capture and a direct measurement of downward water flux through the soil column when free water is present, or the soil is at or near saturation. Alternately stated, water only enters pan lysimeters when soil suction is very low or absent.

Pan lysimeters are reliable, low maintenance, and easy to construct, but will collect no water in soil columns where soil conditions are not near saturation and appreciable soil moisture tension is present. Pan lysimeters can be used in combination with indirect techniques better suited to unsaturated flow monitoring to provide moisture movement information over a wide range of soil moisture conditions.

## B.2 Indirect Monitoring Techniques

Indirect techniques measure a property or condition of the soil which is related to water content. The methods discussed in this section include tensiometry, the neutron moderation technique, time domain reflectometry, and soil sampling and laboratory moisture testing.

### B.2.1 Tensiometers

Tensiometry involves the use of tensiometers to measure the metric potential of a soil. A tensiometer allows for direct hydraulic contact between the water in the soil and the water in the tensiometer through the use of a porous membrane (ceramic cup).

The tensiometer is filled with water and placed in the soil. If the soil is saturated, no water will leave the tensiometer. If the soil is not saturated, water will flow from the tensiometer to the soil until equilibrium is achieved. As the tensiometer is a sealed instrument, the water exiting creates a negative pressure inside the tensiometer. A pressure gauge attached to the tensiometer measure that pressure drop. The higher the water content, the less pressure drop will occur.

Tensiometry can, therefore, measure relative moisture content in the soil. When a moisture front moves through the soil, the soil tension will decrease. An array of tensiometer installed in various locations and various depths would measure the change in moisture content in the backfill.

The advantage of tensiometers is that they are inexpensive and easy to install. They are easy to monitor and there are no analytical costs. The disadvantages are they are hard to maintain, and are not very accurate. In addition, the most commonly used tensiometers, the jet-filled type, are very fragile and would require replacement over time.

### B.2.2 Neutron Moderation Technique

The neutron moderation technique is based on the neutron moderation process in which neutrons from a radioactive source will be slowed (or thermalized) by collision with surrounding atoms. Collision with hydrogen atoms creates, the most significant quantity of thermalized neutrons. These thermalized neutrons are absorbed by other atoms which release pulses of energy which are detected by the neutron probe. Therefore, the more hydrogen present in the soil, the higher the count on the neutron probe.

The most prevalent source of hydrogen in uncontaminated soil is generally water. If baseline conditions of the soil are known, then moisture content and moisture fronts can be determined from subsequent measurements.

The installation of the neutron probe access tubes are relatively simple. An auger hole is drilled either horizontally or vertically through the soil. Soil samples are retrieved at various depths for moisture content measurements. The PVC or steel access tube is installed in the hole and grouted. Baseline neutron probe measurements are taken at he same locations as the soil sample were taken, and neutron counts compared to soil moisture concentrations. This allows for future calculation of moisture content based on neutron counts.

Moisture movement through the backfill would be measured by installing an array of access tubes and taking neutron probe measurements at various depths in each tube. Any moisture front moving through the soil would be indicated by the increase in counts and could be correlated across the site.

The advantages of the neutron moderation technique include accuracy and consistency of measurements, and the compatibility of the technology with dataloggers. In addition, monitoring activities are easily performed. Disadvantages include the cost of the neutron probe and data logger, and limitations on the accuracy of the technique within several feet of the surface due to the influence of hydrogen in the air.

### B.2.3 Time Domain Reflectometry

Time domain reflectometry (TDR) is a soil moisture monitoring technique using electromagnetic wave guides or vertical probes installed in the subsurface. A signal generator sends a voltage pulses axially along the soil/probe interface. Higher moisture content in soil at the probe results in lower signal impedance. Less impedance means shorter pulse propagation times. The TDR pulse generator counts the propagation time, and mathematically derives the soil moisture content. The instrumentation adapts easily to automation (i.e., scanners and dataloggers). This in turn allows remote access to the data, and thus remote monitoring of the site.

Advantages to TDR are its common acceptance for similar applications (i.e., monitoring landfill caps) and its adaptability to automation. When used with a datalogger, TDR can provide a quasi-continuous record of soil moisture content at each monitoring point.

The disadvantage of TDR monitoring is its sensitivity to improper installation. Field experience has shown that air gaps along the probes resulting from improper insertion can create erroneous moisture readings. Even if probe installation results in good initial probe/soil contact, it is still possible for air gaps to form. In clay soils, soil shrinkage due to significant drying may over time allow for the formation of an air gap which in turn may cause the TDR results to drift or be unstable. Use of a complementary method of moisture content testing to provide a periodic check on the TDR results is thus advisable.

# APPENDIX C

# INSTRUMENT LITERATURE

# APPENDIX C

# INSTRUMENT LITERATURE

# User Instructions for Insertion of ESI's Profiling Probes using the AMS Slide Hammer

***These instructions must be followed for correct insertion/extraction of ESI's MoisturePoint® profiling probes.***

The correct installation procedure is to form a pilot hole using the pilot rod and then insert a MoisturePoint® profiling probe. Both operations require the slide hammer insertion/extraction system.

**Assembly / Insertion of Pilot Rod**

The pilot rod must be tightly screwed into the slide hammer. Once this has been done the insertion of the pilot rod can begin. (Continue to check that the pilot rod is tightly screwed to the slide hammer during the insertion/extraction. Failure to do this may place excessive force on the threaded area that may lead to damage to the threads.)

Insert the pilot rod only as far as needed for the length of probe being used. Care must be taken to ensure that the pilot rod is inserted as straight as possible. Failure to do so may cause damage to the probe either at insertion or extraction.

Insertion of the pilot rod is achieved by using a repetitive downward motion on the slide hammer until the pilot rod is inserted.

**Extraction of Pilot Rod**

Extraction of the pilot rod is achieved by using a repetitive upward motion on the slide hammer until the pilot rod is fully extracted.

Care must be taken to ensure that the extraction is done as straight as possible and that the hole is not enlarged during this process. Enlargement of the hole may result in air gaps forming between the probe and soil, potentially resulting in incorrect soil moisture readings.

**Probe Insertion**

Place the probe in the hole formed by the pilot rod and press as far as possible by hand. Then place the slide hammer, with the slide hammer adapter tightly screwed into the slide hammer, over the probe. Small, gentle strokes (6" strokes) of the slide hammer are essential for insertion of the probe. If too much impact force is applied to the probe, damage to the electronics of the probe may result.

***Do not use the dowel pins during the insertion process. These are only to be used for extraction of the probe***

# Moisture•Point™

**MP-917 Technical Brief 15**

# Insertion of Profiling Probes

**Ron McFarlane**

## Overview

To ensure reliable moisture data, it is important to ensure the proper installation of Moisture•Point™ profiling probes. The issues relating to the insertion of these probes are insertion technique, ease of insertion, depth of insertion, soil/probe contact, soil expansion-contraction ratios, alternate insertion methods, and the effects of soil compression due to probe insertion. These issues are discussed in this technical brief.

## Table of Contents

**Probe Extraction**

Align the hole in the slide hammer adapter with the hole at the top of the probe and insert the dowel pin. The pin must be flush with both sides of the slide hammer adapter. Once the pin is correctly inserted, ensure that the o-ring is contained in the milled grooved edges of the slide hammer adapter and covering the dowel pin. This step must be done to ensure that if a dowel pin should break, then any metal fragments will be contained inside the slide hammer adapter.

The slide hammer adapter must be tightly screwed into the slide hammer. Once this has been done the extraction of probe can begin. (Continue to check that the slide hammer adapter is tightly screwed to the slide hammer during the extraction process).

Small, gentle strokes (6" strokes) of the slide hammer are essential for extraction of the probe. If too much impact force is applied to the probe, damage to the electronics of the probe may result.

*Care must be taken when using and carrying the slide hammer as the bottom part of the slide may drop down, potentially causing injury. Steel toed work shoes are recommended to prevent possible injury to toes and feet. Eye and ear protection are recommended at all times when using the slide hammer. Care must also be taken to avoid getting fingers caught in slide mechanism.*

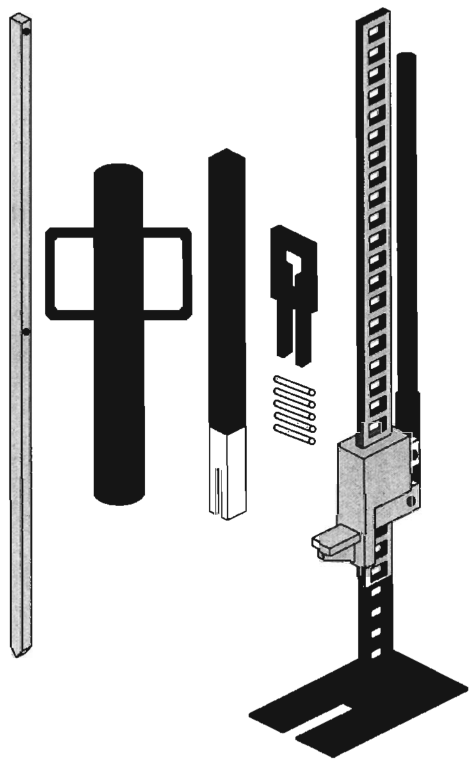
## Recommended Insertion Method

Insertion/extraction tools are mandatory in compact soils to ensure no damage occurs to probes in the insertion or extraction process. 500 pounds of lifting force is not uncommon to extract a multiple-segment profiling probe from compacted moist soil. In some cases the extraction force has exceeded 2000 pounds. If the probe is not smoothly inserted into the soil it may be damaged, or create pockets in the soil which may pool water and distort the data.

A TK-917 tool kit, including the storage crate and hearing protection, contains the following specialized components (from left to right):

- pilot rod
- probe driver
- extension shank
- coupling link and pin set
- extraction jack.

These items separately, and in combination, present personnel hazards if used improperly.



***Protective Equipment***

When in use the probe driver generates harmful levels of acoustic energy. Hearing protection with a Noise Reduction Rating of 20 decibels is provided with the TK-917 and it should always be worn. In addition, the driver user should wear work gloves (user provided), and keep both hands on the driver handles when driving pilot rods or probes.

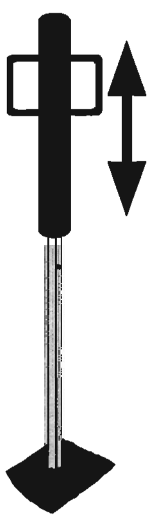
## *Pilot Rod*

The first operation required is preparation of a probe hole using a pilot rod, probe driver, and extension shank. Use of the pilot rod to pre-form probe holes insures that rocks and pebbles do not interfere with probe insertion. A pilot rod must be used to pre-form holes for all probes. It is generally not possible to directly insert a probe into the soil without damaging the probe or deforming the hole. First press the pilot rod into the soil by hand until it can maintain a vertical attitude without assistance. The pilot rod should be as near vertical as possible. This will insure that the rod does not follow subsurface discontinuities in soil layers as it is driven its full length into the soil by the driver.

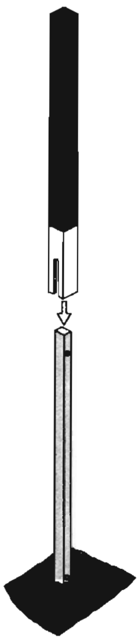

***Never use a hammer, or other unapproved driving tool to insert pilot rods or probes. Eye hazards from metal splinters are possible if hammers are used to drive pilot rods. Probes will be permanently damaged if driven with unapproved driving tools.***

## *Probe driver & Extension Shank*

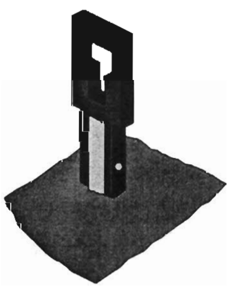

***To avoid hand injury DO NOT grasp the pilot rod, probe, or extension shank when using the driver. Severe hand injury is possible if these instructions are not followed.***



Slip the probe driver over the pilot rod until contact is made with the inside top surface. Keep hands and feet clear of the pilot rod during the driving operation. Keep both hands on the driver handles. Raise and drive downward with force in a smooth linear motion. Continue driving in the pilot rod until the bottom of the probe driver makes contact with the soil at the extreme end of the downward stroke.



Then remove the driver and place the extension shank over the end of the pilot rod. ***It is important to insure that the pilot rod is fully seated in the extension shank cavity.*** Slip the probe driver over the extension shank and continue driving in the pilot rod until the bottom of the extension shank is just making contact with the soil (Be sure to minimize the side to side wobbling of the pilot rod/extension shank while driving. This will prevent the pilot hole from being enlarged at the surface of the soil and creating an air gap between the probe and the soil). Driving the pilot rod to this depth ensures a hole of sufficient depth so that all segments of a probe will be in the soil. Remove the driver and extension shank from the pilot rod and tamp the soil around the rod so that it is roughly leveled for the extraction jack base plate.



## *Coupling Link & Steel Dowel Pin Set*

Attach the coupling link to the pilot rod using the hardened steel dowel pin provided. Insure that only the correct hardened steel dowel pins are used with the coupling link. Undersized dowel pins may eventually enlarge the holes in the pilot rod and probes, and underrated dowel pins may break under load. ***DO NOT use shear pins.*** Replacement pins are available from ESI.

## *Extraction Jack*

The jack assembly can present a foot or hand crush hazard if improperly used. Failure to heed the following cautions may result in probe damage, damage to the jack, or personal injury.

Before extracting a rod or probe make sure the jack is in a stable vertical position and the lift point is directly centered over the pilot rod or probe. When extracting a rod or probe, keep hands away from the moving parts in the jack's lifting mechanism. Always keep a firm grip on the steel handle of the jack, using both hands, when raising or lowering a loaded jack head.

**CAUTION**

***DO NOT grasp or stand on those parts of the jack painted RED when changing the position of the jack reversing latch***

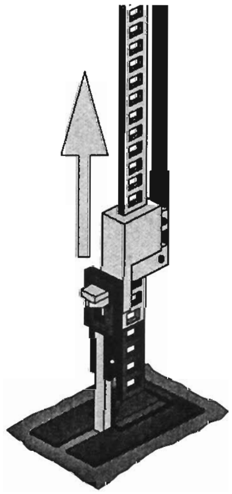
To prevent injury to hands and feet when lowering the jack head the jack user should proceed as follows:

- Lower the jack handle until it is perpendicular to the jack standard (upright post).
- Insure that hands and feet are clear of the jack areas painted **red**.
- Move the reversing latch to its lower position.

The jack must be loaded (45 kg. or more) to lower the jack head step-by-step. If the jack is upright and not loaded when the reversing latch is moved, the jack head will instantly return to its lowest point. This can result in personal injury if hands or feet are in contact with the red areas of the jack base plate.

Position the jack for use by placing the base plate such that the pilot rod is both fully inserted in the base plate slot and vertically parallel to the jack standard (vertical post). Make certain that the base plate is on firm level soil and the jack standard is vertical.

If the jack is not at its lowest position, lower the jack reversing latch. Once the jack is at its lowest position place the reversing latch in the up position until it locks.



With the coupling link attached to the pilot rod, slip the large opening over the jack head lifting nose and insure that the center of lift will be vertical and parallel to the jack standard.

Manually raise the jack head by grasping the lifting nose, pulling it up as far as possible. Then grasp the steel jack handle firmly and pump it up and down in a smooth motion. The pilot rod will be easily extracted. Depending on the holding strength and stability of the soil it may be necessary to relocate the coupling link in the middle of the pilot rod during extraction. A hole at the midpoint of the pilot rod has been provided for that purpose. The mid-length hole may be difficult to locate if it has become packed with soil. It may also be necessary to use the mid-length hole if the jack becomes unstable due to loose soil. It is important to extract the pilot rod in a smooth vertical motion to insure a well formed hole.

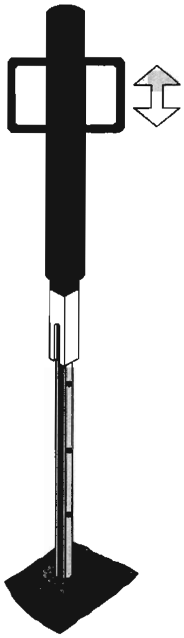
*Short Cut*

***If the soil is loose enough the pilot rod or probe may be extracted by hand. Following the driving operation, attach the coupling link. Grasp the coupling link through the large hole and take a squatting position over the pilot rod/probe. Pull upward smoothly and in one motion using the muscles of the legs and not the back. If any back strain is felt, discontinue manual pulling and use the Extraction jack.***

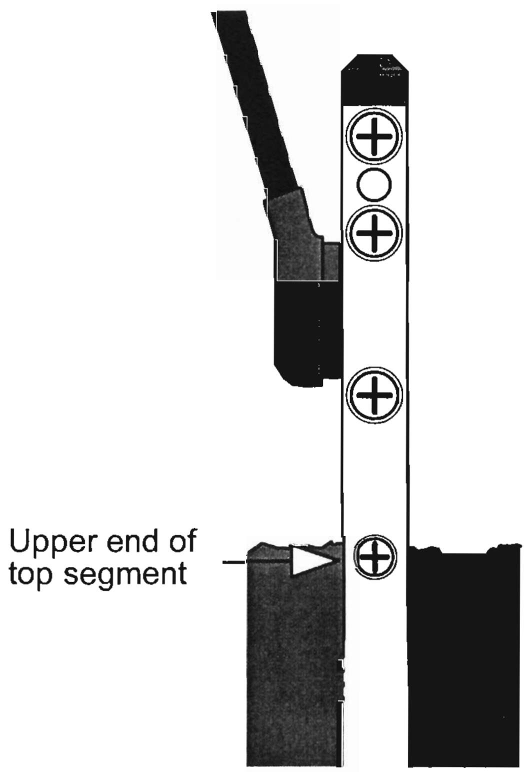
If the jack is overloaded and the safety shear pin breaks it can be temporarily replaced with a 5/16" SAE grade 2 bolt. Never, under any circumstances use a bolt of higher strength as a temporary safety shear pin. The temporary shear pin should be replaced as soon as possible with the manufacturers safety shear pin (Mfr. P/N SP-13). Once the pilot rod can be removed by hand pull it from the hole.

## *Probe Insertion*

Remove the jack and insert the probe as soon as possible. Any delay in inserting the probe into the pre-formed hole may allow moisture to swell the hole sides, or fill the hole with water.



Carefully insert the probe into the preformed hole, pressing it in by hand as far as possible before using any driving tools. If probe driving is necessary, always use the extension shank between the probe and the probe driver. **Never use the probe driver directly on the head of a probe.** Use short strokes of the probe driver to tap the probe into the soil until it is fully inserted. When driving probes with the probe driver the driving stroke must be limited to no more than 3-6 inches. Probes will be permanently damaged by excessive pounding. Insert the probe far enough into the soil so that the soil/air boundary passes through the screw marking the top of the uppermost segment (see diagram below). This ensures that the top segment is completely buried in the soil but not over buried. You can partially insert probes, however, since the moisture content for a segment is an average across the entire length of the segment, only segments completely within the soil will produce meaningful moisture readings.




***The probe extraction method is identical to that used to extract the pilot rod.***

## Problems Affecting Soil/Probe Contact

When a Moisture•Point™ profiling probe is interrogated by an MP-917 an electromagnetic field propagates out from the probe and into the soil. The effect the soil has on this field is the basis of operation of the Moisture•Point™ system. The electromagnetic field strength diminishes with the distance away from the probe in an exponential fashion. The net result of this changing field strength is that the soil right next to the probe has a much greater influence on the moisture reading than the soil further away from the probe. In practical terms, the volume of soil that affects 99% of the moisture reading is within approximately 1 cm of the side of the probe. The fact that most of the moisture reading is based on measurements taken from soil that is close to the probe requires that the contact between the soil and the probe be very good. This in turn, has a bearing on how, and into what type of soil, the probe is inserted.

The goal of the insertion process is to place the probe into the soil and have no air gaps between the probe and the soil. Air gaps can be caused by a number of processes. A cavity can be created near the probe when the pilot rod pushes rocks out of the way and soil doesn't completely fill the space previously occupied by the rock. While being tapped into the soil the pilot rod or probe can wobble back and forth, enlarging the pilot hole at the surface and for 15 to 20 cm below the surface. If inserted at an angle relative to the vertical, the pilot rod or probe will sag under the weight of the extension shank, enlarging one side of the hole at the surface and for several centimeters below the surface. Field experience has shown that air gap problems are avoided by following the recommended insertion method.

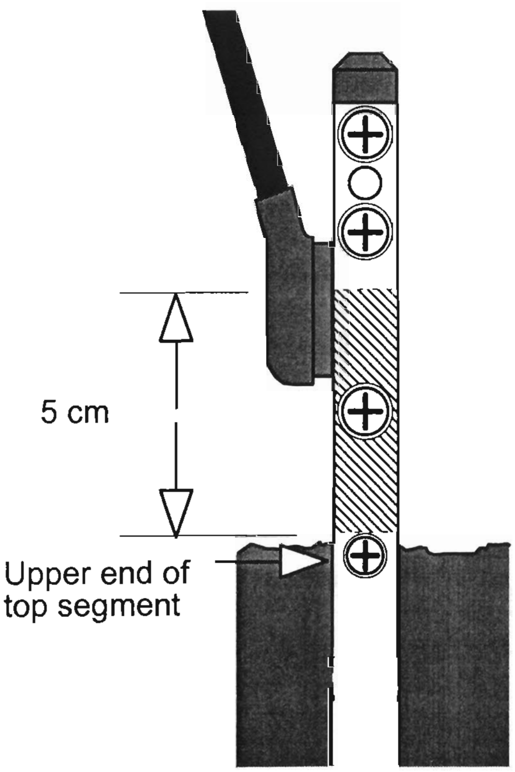
Even if the insertion process initially results in an installation with no air gaps it is still possible for air gaps to form. Certain types of clay soils will expand as they get moist and contract as they dry out (only some clay solid expand and contract; it depends on the type of clay). If the probe were inserted into this type of soil when it was moist and the then the soil subsequently dried out, air gaps will form as the soil shrinks away from the probe. Even inserting the probe into this type of soil when it is dry is no guarantee of good soil/probe contact. The expansion/contraction characteristics of the soil can exhibit significant hysteresis. After a few wetting/drying cycles the soil will not fit snugly around the probe giving rise to air gaps. This type of soil is often characterized by the appearance of moderate to severe surface cracks when the soil dries out.

Air gaps caused by enlargement of the pilot hole can be minimized by preventing the pilot rod/extension shank or probe/extension shank from wobbling back and forth during the insertion process. This caution is mentioned in the recommended insertion method documented above.

Air gaps caused by the motion of rocks during the formation of the pilot hole as required for the recommended insertion method may be unavoidable. If the soil contains a significant amount of rock, an alternative insertion method may be required to obtain reliable soil/probe contact. See below for a description of alternate insertion methods.

Air gaps caused by the soil expanding and contracting are more difficult to overcome. In an agricultural setting it may be possible to limit the variation of moisture content of the soil by periodic irrigation. Limiting the variation in moisture will limit the amount of expansion and contraction and thus reduce the chances that an air gap will form between the probe and the soil. If it is not possible to limit the variation in moisture level of the soil then a technique of filling the gaps may work. If, after a probe has been inserted into the soil for some time, the soil pulls away from the side of the probe, a slurry can be poured down the resulting crack to fill it. The slurry is made by mixing some of the soil from the immediate vicinity of the probe with water. The amount of water should be enough to make the slurry quite liquid. Some time after the slurry is poured down the crack it will dry out and shrink. This process will need to be repeated a number of times before the crack remains filled.

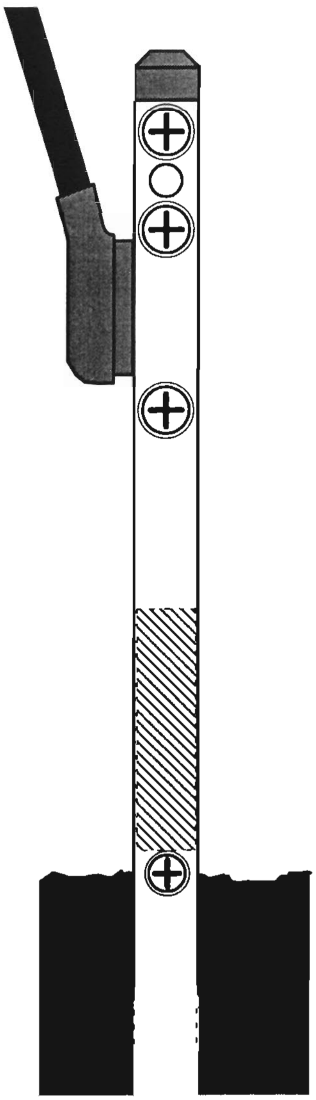
## Depth of Probe Insertion



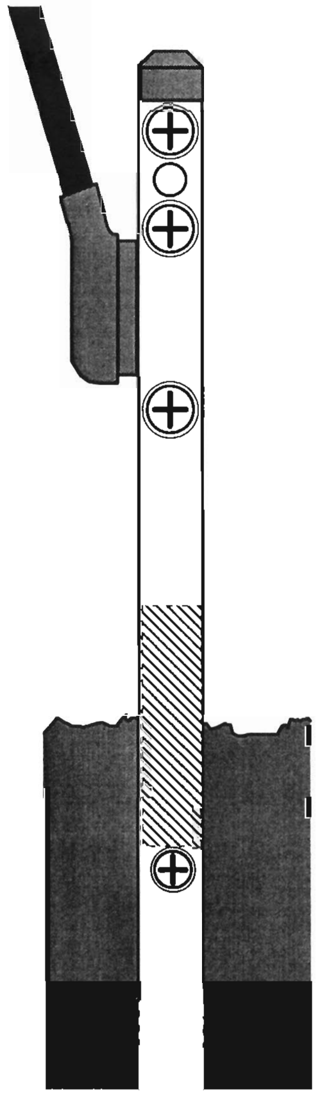

To obtain reliable moisture readings from the top segment of a profiling probe it is important to ensure that the probe is inserted to the proper depth. The soil/air boundary should be level with the upper screw of the top segment. There are two types of screws along the side of the probe. The sizes of these screw are 10-24 (large) and 6-32 (small). On all standard probes the uppermost 6-32 screw is the upper diode screw of the top segment.

The reason that care must be taken is that the soil/air boundary forms an impedance discontinuity. When the TDR signal reaches this discontinuity a reflection occurs. This reflection can interfere with the MP-917 data processing algorithm if the soil/air boundary lies anywhere within the hatched region above the upper screw of the top segment as shown in the figure to the left.

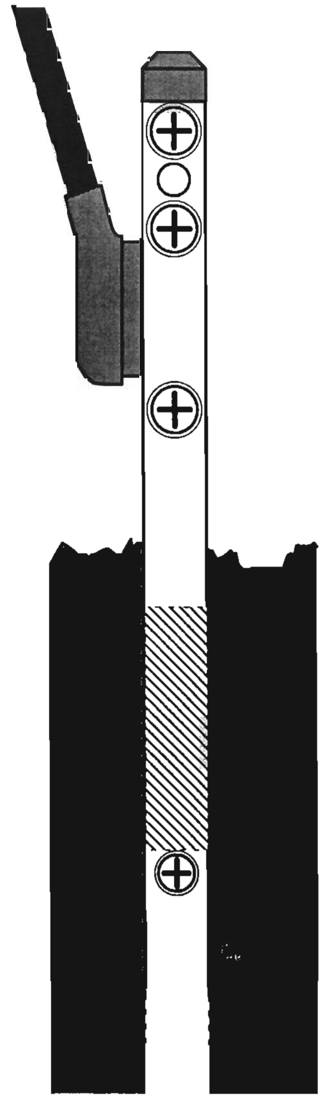
For standard profiling probes, inserting the probe so that the soil/air interface is more than 3.5 cm above the top screw of the upper segment means that the connector will be partially buried, and this is not recommended because of contamination problems with the connector. For some custom designed probes, the distance between the upper screw of the top segment and the connector can be as large as 30 cm, and for these probes it is possible to insert the probe so that the upper screw of the top segment is well below the soil/air boundary. In these instances the probe can be inserted as shown below.



GOOD



BAD



GOOD

## Ease of Probe Insertion

The proper functioning of a profiling probe dictates certain restrictions on the mechanical design of the probe. These restrictions limit the mechanical strength of the probe. The limited mechanical strength of the probe, in turn, limits the methods with which the probe can be inserted into the soil. The recommended method prohibits pounding directly on the top of the probe. Instead, use of the extension shank is required. This shank distributes the shock loading from the probe driver evenly around the top of the probe.

The ease with which a probe is inserted into the soil has a bearing on the reliability of the probe. As the soil becomes harder, more force is required to tap the probe into the soil. There comes a point where the force needed to insert the probe into the soil becomes so great that there is a large risk of damaging the probe during insertion. Two of locations in North America have been identified by users where the soil is so hard that following the recommended insertion method runs a significant risk of damaging the probes. When hard soil is encountered it is recommended that an alternative insertion method be used.

## Alternate Insertion Methods

### Giddings Rig

A Giddings rig is a hydraulic ram that is usually mounted on the back of a pickup truck. These rigs are normally used to collect core samples of soil by pushing a hollow tube into the soil and then extracting the tube containing the core sample. A Giddings rig may be used, instead of the TK-917, to insert profiling probes into the soil. The smooth, continuous motion of the Giddings rig produces peak mechanical forces on the probe that are far lower than the shock loads produced by the probe driver for a given soil condition. Because of the reduced loading on the probe, the use of a Giddings rig is preferred over the use of a TK-917.

A TK-117 is needed, instead of a TK-917, when a Giddings rig is used.. The TK-117 tool kit is a subset of the TK-917 consisting of a pilot rod, coupling link, and pin set. The user is responsible for acquiring an adapter that will attach to the driving end of the ram and allow the rig to push probes into the ground. This adapter must also couple with the coupling link in order to extract the probe/pilot rod.

When using a Giddings rig, it is still recommended that the pilot rod be used to make a pilot hole and that the profiling probe be inserted into this pilot hole.

### Augering Before Insertion

One method of reducing the forces experienced by the probe during insertion is to auger a hole before inserting the pilot rod. This process removes soil from the hole and reduces soil compression when the probe is inserted into the hole. The reduced compression, in turn, reduces the amount of work required to insert the probe into the soil. The reduced soil compression also reduces the changes in moisture behavior of the soil (see the section below Effects of Soil Compression Due to Probe Insertion).

This method requires a 1/2 inch diameter auger. The length of most commercially available augers is not sufficient to drill a 120 cm deep hole (required for a type A probe). Normally, an extension rod needs to be welded to the drive end of the auger to make it long enough. A battery powered hand drill is very useful for driving the auger during field operations.

Mount the auger (or more precisely, the extension rod welded to the driving end of the auger) in the chuck of the drill. Place the drilling end of the auger on the ground where the probe is to be inserted. Ensure that the auger/extension bar is vertical. Then start the drill and push down on the auger until it starts cutting into the soil. Let the auger drill to a depth of approximately 15 cm. While the auger is still spinning pull it out of the hole. This will clear the flutes of the auger of soil. Resume drilling with the auger, clearing the auger by pulling it out of the hole at least once for every addition 15 cm of depth drilled. As the hole gets deeper the auger may need to be cleared more often. Each time the auger is cleared, care must be taken to ensure that it remains vertical during the clearing motions. Once the hole is as deep as required, the auger may be extracted from the hole. The recommended insertion method should now be followed.

The auger method can also be used if it is desired to install the probes at an angle to the vertical. USDA-ARS scientists from the University of Nebraska have successfully employed this approach.

### Coring and Backfilling

If the ground is very hard or contains a large percentage of rocks, following the recommended insertion method could damage a profiling probe. In these cases it is recommended that a large hole be cored from the soil, the probe placed in the hole and the hole back filled.

There is a tradeoff associated with this method of inserting the probe. The advantage is that the probe is placed in the soil with the least amount of force and, therefore, the smallest risk of probe damage. The disadvantage of this insertion method is that the soil surrounding the probe is not the same as the soil into which the large hole was bored. The bulk density of the soil used for the backfill will be different that of the parent material. If the soil is heavily layered, the layers will be disturbed as well. The soil used for backfilling the hole will have different hydrological properties than the parent soil. The net effect is that the volumetric water content in the back fill soil will differ from that of the parent material under dynamic as well as equilibrium conditions.

The disadvantages can be reduced somewhat if care is taken to pack the backfill soil around the probe sufficiently. If the soil is heavily layered, taking care to pack the layers appropriately is beneficial. As beneficial as these measures are, they only reduce the effect of disturbing the soil. There will always be some soil disturbance and therefore the backfill soil will always have different hydrological properties. In making the decision to use this method to insert the probes, the disadvantage of disturbing the soil around the probe must be evaluated on a case by case basis, and weighed against the advantage of not damaging the probe during insertion.

## Effect of Soil Compression Due to Probe Insertion

When a probe is inserted into undisturbed soil, the probe displaces soil downward and sideways and in the process, compresses the soil near the probe. This compression can cause a small error in the moisture reading. The magnitude of this error will be greatest just after the probe insertion and will diminish as time passes. For best accuracy, it is desirable to wait about one week after insertion to allow the water content adjacent to the probe to reach equilibrium with the water content of the surrounding soil.

After equilibrium has been achieved, the ability to measure changes in the water content (resolution) and the ability to obtain repeatable data (repeatability) are unaffected by these compressions within the limits of the accuracy and resolution stated for moisture point profiling probes. One published calculation (Hook & Livingston, 1996) shows the TDR water content error due to changes in soil density to be small with respect to other instrument error sources.

For most agricultural applications the compression effects can be ignored. To date, there is little field evidence that compression is a problem even for sophisticated soil science applications. Furthermore, there is some field data to support the idea that spatial variability of water content in field applications can be as large as 0.15 $m^3/m^3$ . Therefore, in any field applications spatial variability is likely to cause errors much larger than those caused by compression. In any event, if compression effects are a concern to the user, the auger method of insertion may be employed to reduce these effects.

# Moisture•Point™

**MP-917 Technical Brief 17**

# Calibration of Profiling Probes

**G. D. (Joe) Young**

## Overview

The transmission line structure of the Moisture•Point profiling probes has a composite dielectric which affects the interpretation of propagation-time measurements obtained from these probes in soil. This dielectric structure, as well as soil characteristics and probe length, is taken into account in the MP-917's moisture calculation by including calibration parameters in the calculation. This Technical Brief shows how to determine the calibration parameters. An appendix gives a derivation of the moisture calculation formula.

## Table of Contents

## Description of Moisture Calculation

The MP-917 uses the following formula to relate propagation time measurements of a probe in moist soil to the soil's volumetric water content (see appendix A for derivation of this formula):

$$\theta_V = \frac{\left[\frac{T_{MC}}{T_{air}} - \frac{T_s}{T_{air}}\right]}{\sqrt{K_W} - 1}$$

Where:

$\theta_V$ is the volumetric water content of the soil ($m^3/m^3$),

$T_{MC}$ is the measured, corrected, round-trip propagation time along a segment when the probe is in the moist soil,

$T_{air}$ is the theoretical round-trip propagation time along that segment with air dielectric,

$T_s$ is the (measured, corrected) round-trip propagation time along that segment in completely dry soil,

$K_W$ is the relative dielectric constant of water. This factor varies with temperature: see appendix B.

The MP-917 determines the round-trip propagation time of a pulse along each segment in the probe in terms of counts of its internal delay generator. The calibration of the internal delay generator is performed at the factory using a Tektronix 1502 TDR cable tester which in turn is regularly compared with a length measurement on an air-dielectric transmission line. The Moisture•Point probe emulator provides a means to check the calibration of the MP-917 time base in the field (see Technical Brief on use of the probe emulator). This instrument time base calibration is not part of this description of the probe calibration, although it is obviously related to the overall system accuracy.

The round-trip time interval measured in counts is converted to the measured time, $T_M$, in nanoseconds (nsec) by multiplying the measurement by the MP-917 delay 0 calibration factor (see instrument defaults; this factor is typically 140 psec/count or 0.140 nsec/count). The MP-917 will display $T_M$ on its front-panel display when the TIME DELAY/MOISTURE switch is UP in the TIME DELAY position, or as the third line on the View•Point graphic display of the segment boundaries. This measured time is further corrected by the probe calibration factors $A$ and $B$ before applying the formula above to calculate $\theta_V$:

$$T_{MC} = \frac{T_M}{B} - A$$

The $A$ and $B$ terms are needed to adjust the measured times for the effect on the probe transmission line caused by its immersion in a dielectric which is partially filled with a fixed material, rather than its being uniformly filled with the soil to be measured. Probe calibration thus consists of a procedure to determine $A$ and $B$. Soil calibration for the moisture calculation above consists of determining $T_s/T_{air}$. The MP-917 stores $A$, $B$, $T_s/T_{air}$, and segment length values for each segment in non-volatile memory, and automatically includes the calculation of $T_{MC}$ in the moisture calculation.

The calibration coefficients are determined by placing the probe to be calibrated in conditions of known moisture for which the formula above applies, obtaining the MP-917 measurement of propagation time, and then calculating the coefficients. A volumetric moisture content of 0.000 $m^3/m^3$ is established by placing the probe in the centre of a volume of oven-dried sand which extends at least several cm in all directions from the probe's active segments. In this situation, the transmission line (probe) dielectric is a composite of the probe's encapsulation material and the dry sand. A volumetric moisture content of 1.000 $m^3/m^3$ is established by placing the probe in a water tank which has a similar minimum volume. In the water, the dielectric is a composite of the probe's encapsulation material and water. With measurements of the propagation time along a segment for each of the sand and water conditions, knowing the dielectric constants of the sand and of the water, correction factors $A$ and $B$ can be calculated to account for the effect of the dielectric constant of the probe encapsulation material.

When the probe is in dry sand, the appropriate $T_s/T_{air}$ is 1.762, and corresponds to a typical apparent dielectric constant of 3.105 for sand. Other soil types will have different apparent dielectric constants. An 'average' $T_s/T_{air}$ for agricultural soils is 1.55. See the Soil Calibration section below for a discussion of soil calibration.

When the probe is in water, the appropriate $T_s/T_{air}$ is 1.000 (see appendix A which gives the derivation of the volumetric moisture content formula).

## Calibration Procedure

To calibrate a probe segment, observe the round-trip propagation time $T_{M1}$ for the probe segment in water, and $T_{M0}$ when the probe segment is in dry sand. Then,

$$1.000 = \frac{\left[\dfrac{\dfrac{T_{M1}}{B} - A}{T_{air}} - 1\right]}{\sqrt{K_W} - 1}$$

$$0.000 = \frac{\left[\dfrac{\dfrac{T_{M0}}{B} - A}{T_{air}} - 1.762\right]}{\sqrt{K_W} - 1}$$

This pair of equations can be solved for $A$ and $B$ in terms of the two measurements:

$$A = \frac{T_{M0}}{B} - 1.762\,T_{air}$$

$$B = \frac{T_{M1} - T_{M0}}{T_{air}\left(\sqrt{K_W} - 1.762\right)}$$

The round-trip time, $T_{air}$ depends on the length of the segment, $L_{seg}$ as

$$T_{air} = \frac{2L_{seg}}{v_{air}}$$

and $v_{air} = 299.704$ mm/nsec is the velocity of an electromagnetic pulse in an air dielectric. Using lengths in mm and velocity in mm/nsec is convenient for times measured in nsec. Note that the determination of the coefficients $A$ and $B$ has a small temperature dependence because of the temperature dependence of the dielectric constant of water, so water temperature measurement and calculation of $K_W$ should be included in the calibration procedure

## Example Calibration

As a specific example of applyiing the procedure described above, consider calibrating a 15 cm segment and a 30 cm segment.

Place the probe in a box containing dry sand. The box should be about 20 cm by 20 cm in cross-section and long enough to contain the entire probe. Fill the box about half way with the dry sand and level the sand. place the probe on the leveled sand and cover it with the remaining sand, lightly packing the sand so that the probe is uniformly surrounded. Clear the sand away from the connector end of the probe so that the top few cm of the probe are in air--as the probe top will be when it is in normal use. The sloping sand surface should be at the centre of the screw head which locates the end of the segment nearest the connector. Obtain several time interval measurements for each of the segments of interest. Suppose for this example the average of several measurements is 1.7550 nsec for the 15 cm segment and 3.5418 nsec for the 30 cm segment.

Place the probe in a water tank. The tank should allow the probe to be suspended vertically with the cable in air but with the surface of the water at the centre of the screw head which locates the top end of the top segment. If the tank is made of a length of pipe, the diameter of the pipe should be at least 15 - 20 cm and care taken to ensure that the probe is in the centre of the tank all along its length. Suppose for this example the average of several measurements gives 6.0424 nsec for the 15 cm segment and 12.402 nsec for the 30 cm segment. Suppose the temperature of the water is 22 degrees C.

$$\sqrt{K_W} = 8.9234$$

For the 15 cm segment:

$$T_{air} = \frac{2L_{seg}}{v_{air}} = \frac{2 \cdot 150}{299.704} = 1.00098 \text{ nsec}$$

$$B = \frac{6.0424 - 1.7550}{1.00098(8.9234 - 1.762)} = 0.5980$$

$$A = \frac{1.7550}{.5981} - 1.762 \cdot 1.00098 = 1.1706$$

Similarly, using the 30 cm segment time measurements:

$$T_{air} = \frac{2L_{seg}}{v_{air}} = \frac{2 \cdot 300}{299.704} = 2.00198$$

$$B = \frac{12.402 - 3.5418}{2.00198(8.9234 - 1.762)} = 0.6180$$

$$A = \frac{3.5418}{0.6180} - 1.762 \cdot 2.00198 = 2.2036$$

## Soil Calibration

The soil calibration parameter in the moisture calculation formula (see Appendix A for derivation of moisture calculation formula) is the ratio $T_s/T_{air}$. To determine $T_s/T_{air}$, use the MP-917 to measure $T_s$, the propagation time along a segment when the probe is in completely dry soil, calculate $T_{air}$, the theoretical propagation time of an ideal-probe segment in air, and then calculate the ratio. A step-by-step description follows:

- Prepare a volume of the soil to be calibrated by completely drying the soil. Enough soil to completely surround the probe by several cm of soil is needed.

- Place the Moisture•Point probe in the dry soil, observe $T_M$ (nsec).

- Apply the probe calibration factors A and B to obtain $T_{MC}$, the round-trip propagation time of an ideal-probe segment in the dry soil using the formula:

$$T_{MC} = \frac{T_M}{B} - A$$

- Calculate the round-trip $T_{air}$:

$$T_{Lair} = \frac{2 \cdot L_{seg}}{c}\sqrt{K_{air}} = \frac{2 \cdot L_{seg}}{299.704}$$

  $L_{seg}$ is the length of the probe segment in mm.

- Form

$$\frac{T_{MC}}{T_{Lair}} = \frac{T_s}{T_{air}}$$

- Enter the parameter thus obtained in the probe calibration table for the probe in use for each segment which will be in contact with the soil so characterized, and verify that the calculated moisture reading displayed by the MP-917 is zero.

Accuracy of the time measurements can be improved by using the average value of several measurements, and by using a probe with a longer segment length.

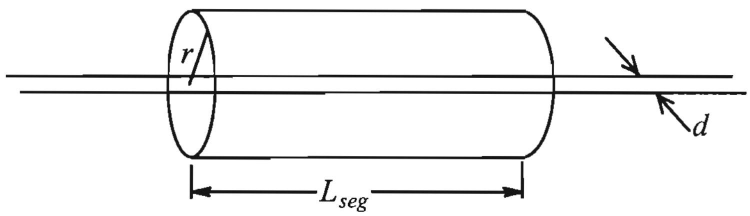
If the $T_s/T_{air}$ has been obtained by other experimental or theoretical means, or the apparent dielectric constant has been determined for the soil at zero volumetric moisture content, this value may be used as the calibration parameter instead of performing the measurements described above.

The MP-917 has a $T_s/T_{air}$ parameter associated with each segment of its profiling probes, so that a severely layered soil may be characterized by entering different $T_s/T_{air}$ values for each of the segments.

Experimental measurement of the correspondence between $\theta_V$ and $T_{MC}/T_{air}$ for several sandy loam soils are in reasonable agreement with the moisture calculation formula stated above with the equation slope determined by the theoretical, dielectric-mixing model of the soil (appendix A). However, the $\theta_V$ vs. $T_{MC}/T_{air}$ slope for individual soils may vary from the theoretical value of $1/[(K_W)^{1/2} -1]$ by several percent. The MP-917 stores the denominator (reciprocal of the slope) of the moisture calculation formula as an adjustable parameter, so that if the slope for a particular soil is determined by experiment (a process outside the scope of this Technical Brief) the new value can be entered for use in the moisture calculation.

## Appendix A. Derivation of Moisture Calculation Formula

Following the discussion in the paper "Errors in Converting Time Domain Reflectometry Measurements Of Propagation Velocity to Estimates of Soil Water Content" by W. R. Hook and N. J. Livingston, 1995, the soil to be measured is modelled as fine grains of mineral matter which has interstitial space, some of which is filled with water and the remainder with air. Accordingly, the model is valid for zero moisture and as moisture content increases until all of the air is displaced by water (soil saturation). To derive a relationship between volumetric moisture content and measured propagation time of an electromagnetic pulse travelling along a transmission line in this (soil) medium, consider a volume of the material enclosed within a cylinder of radius $r$, length $L_{seg}$ with the (ideal, two-rod) transmission-line probe on the axis.

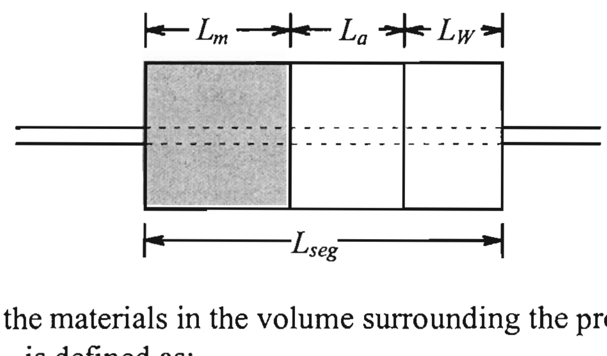



$$volume = L_{seg}\pi r^2$$

The propagation velocity of an electromagnetic wave along the transmission line segment is affected by the mineral/water/air mixture in this volume, where $r >> d$ is supposed to be large enough to completely contain the electromagnetic field of the wave following the transmission line. The *velocity factor*, $v_p$, of the wave is the ratio of the velocity in the dielectric medium to the velocity in a vacuum and is related to the relative dielectric constant, $K$, of the medium:

$$v_p = \frac{v_{dielectric}}{c} = \frac{1}{\sqrt{K}}$$

In the case of the soil volume surrounding the probe segment, the dielectric is made up of three components--the mineral material, the water, and air. To determine the propagation time for the wave along the length $L_{seg}$, assume these three media occupy distinct volumes, $L_m\pi r^2$, $L_a\pi r^2$, $L_W\pi r^2$:




With this partition of the materials in the volume surrounding the probe, the volumetric water content of the soil in this volume, $\theta_V$, is defined as:

$$\theta_V = \frac{L_W\pi r^2}{L_{seg}\pi r^2} = \frac{L_W}{L_{seg}}$$

Also, define the time required for an electromagnetic wave to travel the length of the segment when the whole segment is in air alone $T_{Lair}$:

$$T_{Lair} = \frac{L_{seg}}{c}\sqrt{K_{air}}$$

The time required for an electromagnetic wave to travel the length of the probe segment when the segment is surrounded by the volume of soil is the sum of the times taken to traverse each separated component:

$$T_L = \frac{L_m}{c}\sqrt{K_m} + \frac{L_a}{c}\sqrt{K_{air}} + \frac{L_W}{c}\sqrt{K_W}$$

Form the ratio of the propagation time in soil to the propagation time in air:

$$\frac{T_L}{T_{Lair}} = \frac{L_m\sqrt{K_m}}{L_{seg}\sqrt{K_{air}}} + \frac{L_a}{L_{seg}} + \frac{L_W\sqrt{K_W}}{L_{seg}\sqrt{K_{air}}}$$

Then, substitute the definition of the volumetric water content, $\theta_V$, into the third term and eliminate $L_a$ from the second term by observing that $L_a = L_{seg} - L_m - L_W$

$$\frac{T_L}{T_{Lair}} = \frac{L_m\sqrt{K_m}}{L_{seg}\sqrt{K_{air}}} + \frac{L_{seg} - L_m - L_W}{L_{seg}} + \theta_V\frac{\sqrt{K_W}}{\sqrt{K_{air}}}$$

$$\frac{T_L}{T_{Lair}} = \frac{L_m}{L_{seg}}\left[\frac{\sqrt{K_m}}{\sqrt{K_{air}}} - 1\right] + 1 + \theta_V\left[\frac{\sqrt{K_W}}{\sqrt{K_{air}}} - 1\right]$$

Considering this equation for the case when the water content is zero, the last term vanishes, leaving an expression for the ratio of the propagation time across the segment in dry soil to the propagation time across the segment in air:

$$\left[\frac{T_L}{T_{Lair}}\right]_{\theta_V=0} = \frac{L_m}{L_{seg}}\left[\frac{\sqrt{K_m}}{\sqrt{K_{air}}} - 1\right] + 1 = \sqrt{K_s} = \frac{T_s}{T_{air}}$$

As indicated, this quantity is equal to the square root of the apparent dielectric constant, $K_s$, of the dry soil. It is a soil characteristic, calibration coefficient for each segment. For consistency with the paper referenced, the notation used for this soil characteristic is $T_s/T_{air}$. Substituting this definition of $T_s/T_{air}$ into the equation above and dropping the subscript $L$ which has been carried through the algebra until now to keep clear that the total length of the segment is meant, gives the moisture calculation formula used by the MP-917:

$$\frac{T}{T_{air}} = \frac{T_s}{T_{air}} + \theta_V\left[\frac{\sqrt{K_W}}{\sqrt{K_{air}}} - 1\right]$$

$$\theta_V = \frac{\left[\frac{T}{T_{air}} - \frac{T_s}{T_{air}}\right]}{\frac{\sqrt{K_W}}{\sqrt{K_{air}}} - 1}$$

Notice that for the case where the volume surrounding the probe segment is entirely filled with water (no soil, no air or $L_m = 0$, $L_a = 0$ )

$$\left[\frac{T_L}{T_{Lair}}\right]_{L_m=0} = 1 + \theta_V \left[\frac{\sqrt{K_W}}{\sqrt{K_{air}}} - 1\right]$$

and then carrying out the same two steps as just above results in the expression

$$\theta_V = \frac{\left[\frac{T}{T_{air}} - 1\right]}{\frac{\sqrt{K_W}}{\sqrt{K_{air}}} - 1}$$

That is, when the probe is placed in water for calibration, the 'moisture' calculation formula must have $T_s/T_{air}$ replaced by 1.

Finally, notice that the MP-917 moisture calculation provides for the possibility that the probe transmission line may be partially embedded in a fixed material in addition to the soil so that the time measured by the MP-917, $T_M$, may differ from $T$, but the difference is compensated for with the probe calibration coefficients $A$ and $B$. The compensation is indicated in the moisture calculation formula by using $T_{MC}$ for the measured time. Also, in the denominator of the MP-917 moisture calculation, it is assumed that the relative dielectric constant of air is indistinguishable from 1.000.

## Appendix B. Constants Used in Moisture Calculation

The CRC Handbook of Chemistry and Physics First Student Edition, 1988 gives the following values :

The velocity of light in a vacuum, $c$, is $2.99792458 \cdot 10^8$ m/sec

The dielectric constant of air, $K_{air}$, is 1.00059

Consequently, $v_{air} = \frac{c}{\sqrt{K_{air}}} = 299.704058$ mm/nsec

The dielectric constant of water is given by

$$K_W = 78.54\left[1 - 4.579 \cdot 10^{-3}(t-25) + 1.19 \cdot 10^{-5}(t-25)^2 - 2.8 \cdot 10^{-8}(t-25)^3\right]$$

Evaluating this expression for some temperatures of interest gives the following table:

| $t$ (°C) | $K_W$ | $\sqrt{K_W}$ | $t$ (°C) | $K_W$ | $\sqrt{K_W}$ |
|---|---|---|---|---|---|
| 5 | 86.1241 | 9.2803 | 21 | 79.9936 | 8.9439 |
| 6 | 85.7255 | 9.2588 | 22 | 79.6274 | 8.9234 |
| 7 | 85.3291 | 9.2374 | 23 | 79.2630 | 8.9030 |
| 8 | 84.9347 | 9.2160 | 24 | 78.9006 | 8.8826 |
| 9 | 84.5424 | 9.1947 | 25 | 78.5400 | 8.8623 |
| 10 | 84.1522 | 9.1735 | 26 | 78.1813 | 8.8420 |
| 11 | 83.7641 | 9.1523 | 27 | 77.8245 | 8.8218 |
| 12 | 83.3780 | 9.1312 | 28 | 77.4694 | 8.8017 |
| 13 | 82.9940 | 9.1101 | 29 | 77.1163 | 8.7816 |
| 14 | 82.6120 | 9.0891 | 30 | 76.7649 | 8.7616 |
| 15 | 82.2320 | 9.0682 | 31 | 76.4154 | 8.7416 |
| 16 | 81.8540 | 9.0473 | 32 | 76.0676 | 8.7217 |
| 17 | 81.4780 | 9.0265 | 33 | 75.7216 | 8.7018 |
| 18 | 81.1040 | 9.0058 | 34 | 75.3774 | 8.6820 |
| 19 | 80.7319 | 8.9851 | 35 | 75.0349 | 8.6623 |
| 20 | 80.3618 | 8.9645 | | | |

## Appendix C. Setting the Calibration Coefficients in the MP-917

The following description is highly-abbreviated, to serve as a checklist reminder of the steps to follow for setting MP-917 probe calibration parameters. If this description is too brief, please refer to the MP-917 manual sections on using View•Point software with the MP-917.

- Connect the MP-917 to PC via POWER/COMM cable
- Start the View•Point program, wait for 'downloading...' to complete, see blank graphic display with the command menu along the bottom. If this screen does not appear, refer to the View•Point manual sections describing how to establish communincation between the MP-917 and View•Point.
- Choose F9 (DEFAULTS). A 'main defaults' text menu is displayed. Use arrow keys to move up and down among menu choices, hit the ENTER key to select a highlighted choice.
- Select 'Modify Current Probe Calibration Defaults'
- Select the probe type you are calibrating
- Use arrow keys to move down the parameter selections for this probe type to the segment to be set, then enter the $T_s/T_{air}$, Length, $A$, and $B$ values for that segment. Repeat as necessary for all of the segments in the selected probe. View•Point enforces limits on the range of values which may be entered for each of the parameters. If an attempted entry is invalid, the parameter will remain unchanged.
- Select 'exit from...' (HOME key) to back out of each of the menus to return to the graphic screen.

When the main defaults menu is exited, the newly-entered parameters are sent to the MP-917 and View•Point briefly displays a message stating how many new parameters have been uploaded. This number should agree with your recollection of how many parameters were entered.

The new parameters are in effect immediately. The values will be retained by the MP-917 in non-volatile memory until they are changed again.

The set of all probe calibration parameters which were just uploaded is also retained on the computer as a text file called LAST.PRB. This file is created automatically by View•Point. Another file called FACTORY.PRB holds the probe calibration coefficients which were originally present in the MP-917 when it was shipped. Either of these files or other files with different sets of probe calibration coefficients may be loaded into View•Point and then into the MP-917 using other menu selections in the 'defaults' menus. The data format for the coefficients in these files is different from that used by View•Point's prompting entry screens to accommodate the integer-only storage format in the MP-917. As well, the file is not divided up into probe-type sections, but is just a list of all the probe calibration factors from probe type 0 through the largest probe number supported. A way to use these files to manage several sets of calibration coefficients would be to enter the coefficients as described above to take advantage of View•Point's validity checking, then after exiting View•Point, rename LAST.PRB to a meaningful name that reminds which probe calibration factors are contained in the file.

**Moisture•Point**[TM]

**MP-917 Product Brief 19**

# The MP-917 in Multiplexed Datalogging Systems

**G. D. Young**

## Table of Contents

## Notice:

Every effort has been made to ensure that the information provided in this product brief is correct, and will be useful for those incorporating ESI Environmental Sensors Inc Moisture•Point™ equipment into larger moisture logging systems. However, ESI will not be responsible for the consequences of errors or ommissions in the provided information, nor for ensuring the correct operation of systems based on this information.

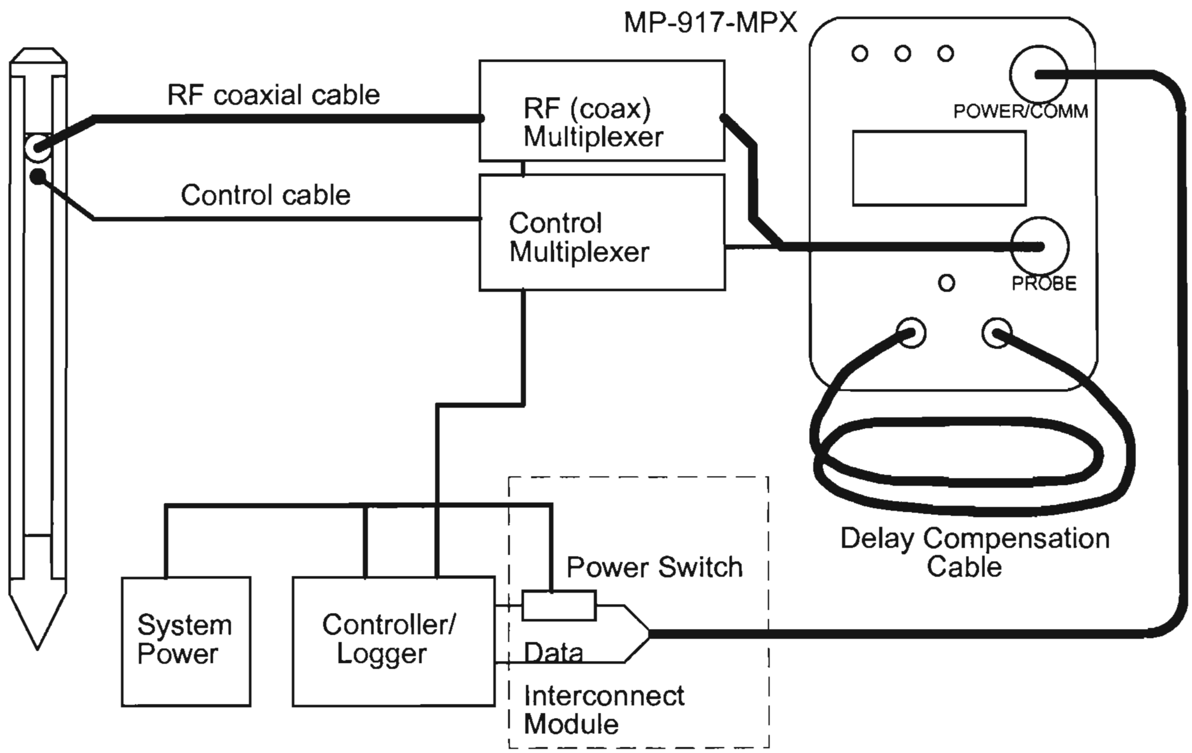
## Overview

The MP-917 includes hardware and firmware features which enable its operation as a component of larger instrumentation systems. In particular, the MP-917 power may be switched on and off by external equipment, and the operating mode 6 may be selected. When the MP-917 operates in mode 6, the normal, front-panel-controlled pacing of its operation is suspended. Instead, applying power causes the MP-917 to immediately take a set of measurements, send the measurement results to the serial output, and then halt in a reduced-power mode awaiting power-down.

Furthermore, a factory-configured MP-917-MPX provides for adding an external, passive, delay-compensation cable which allows using long cables between the MP-917 and the soil-moisture probe. The extended-length probe cable may be up to 100 metres long provided soil conditions are suitable and the cable is suitable.

These features of the MP-917 enable it to act as a sensor with RS232 serial data output in control and datalogging systems, to use long cables to connect to the Moisture•Point probes, and to be used in systems which include a probe multiplexing capability.

## Basic System Configuration



# Mode 6 Operation

Operating the MP-917 instrument in mode 6 allows an external controller to initiate, monitor, and record soil moisture measurements. Probe measurements are started by turning the instrument on. A special pin on the POWER/COMM connector bypasses the front panel **ON/OFF** switch, allowing a switched external power supply to turn the instrument on and off. Measurement data from the MP-917 is transmitted serially via the POWER/COMM connector at RS-232 levels in ordinary text format. Each probe scan is reported on a single line. This section describes the format of data from the MP-917, and how to externally control the power to the MP-917.

In mode 6, when the MP-917 is turned on it immediately transmits the instrument ID, the ID of the currently connected probe, and the number of segments in the probe (determined by the probe type). Then a probe measurement is started, and serial output pauses during the measurement operation. Once the measurement is completed, the moisture results for each segment (top segment (segment 1) first, to bottom segment last) are transmitted, and finally a carriage return line feed line terminator is transmitted. At this point the instrument halts. To start the next measurement, the instrument must be turned off and then on again.

To set up an MP-917 to run correctly in mode 6, the following parameters must be changed:

1. Set the message level to 3.
2. Set the correct baud rate for the datalogger serial input.
3. Set the operating mode to 6

1. Message Level

The instrument's message level controls how much detail about the measurement process is displayed when the MP-917 sends data to the serial port. When the instrument is running with the View•Point software, more information is required to plot the waveforms on the graphics screen, but this waveform information is not required when running in mode 6, and you should set the message level so that only the final results are displayed. The correct message level for mode 6 operation is 3. This level will restrict the output from the instrument to the instrument ID (12 hex digits), the probe ID (12 hex digits), the number of segments in the current probe type, followed by the readings for each segment. The readings may be either calculated moisture values or raw time-interval values, depending on the position of the **TIME DELAY/MOISTURE** front panel switch (but see note below). Segment information is displayed from the top of the probe first (segment 1) to the bottom of the probe last. All data is comma delimited. An example of a typical probe scan for a five segment probe appears below:

\# of segments — segment 2 moisture reading

```
00000050DC1B,00000050DCE4,5,+0.494,+0.453,+0.502,+0.457,+0.424
```

Instrument ID — Probe ID — segment 1 moisture reading — segment 5 moisture reading

The message level can be changed using the **Modify Instrument Defaults** menu with the View•Point program (refer to the software manual for instructions on changing the instrument defaults). The message level parameter is on line 9 of the second page of instrument parameters. Change this parameter to 3. Alternatively, the message level can be changed using a terminal connected to the instrument via the POWER/COMM cable. Terminal settings are 9600 baud, no parity, 8 data bits and 1 stop bit. Change the

| Value | Baud Rate |
|---|---|
| 0 | 9600 |
| 1 | 4800 |
| 2 | 2400 |
| 3 | 1200 |
| 4 | 600 |
| 5 | 300 |
| 6 | 150 |
| 7 | 75 |

instrument to MODE 0 (refer to Operators Manual for instuctions). Once in mode 0, there should be some response to key presses at the terminal. Type the following command at the MPT> prompt to change the message level to 3.

MPT> **MSGL 3**

2. Baud rate setting for Mode 6 operation:

You should ensure that the instrument will use the correct baud rate for your application. The MP-917 instrument defaults to 9600 baud in all modes except for mode 6. In mode 6 you can set the baud rate to the rates listed in the table.

The baud rate can be changed using the **Modify Instrument Defaults** option with the View•Point software (refer to the software manual for instructions on changing the instrument defaults). The baud rate parameter is on line 8 of the third page of instrument parameters. Change this parameter to the desired setting. Alternatively, the baud rate can be changed using a terminal connected to the instrument via the POWER/COMM connector (see section 1 above for instructions on connecting a terminal to the MP-917). Use the **BAUD** command at the MPT> prompt to change to the desired baud rate. ***The new baud rate becomes effective only after the instrument has been turned off and then back on.***

For example, to operate at 1200 baud when the instrument is in MODE 6 issue the following command:

MPT> **BAUD 3**

3. Selecting Mode 6

Finally, change the operating mode of the instrument to 6 by issuing the following command:

MPT> **MODE 6**

Alternatively, the MP-917 mode may be selected using the front-panel switches: Switch the MP-917 power OFF. Hold down the **MODE** button and switch power ON. Operate the **MODE** button until 6 appears in the 2nd digit position in the display. Select that mode by pushing the **MEASURE/DISPLAY** button. The MP-917 will begin a measurement sequence on entry to mode 6, but you need not wait for it to complete before turning power OFF. (For earlier firmware, mode selection uses TIME DELAY/MOISTURE switch--see note at end of section 4 below)

Mode 6 operation is automatic. Every time the instrument is powered on it takes one complete probe scan, transmits the results, and then stops. The instrument must be powered off and then on again to take another measurement. When controlled from an external supply, the instrument **ON/OFF** front panel switch should be in the **OFF** position (down).

4. Time delay output in mode 6:

If it is desired to log time delay values measured by the MP-917 instead of the calculated moisture, then the **TIME DELAY/MOISTURE** front panel switch should be placed in the **TIME DELAY** position. The data format is shown in the following example. It is the same as in the moisture example above, except that the readings for each segment will be the measured propagation time intervals in nanoseconds for the segment.

# of segments
segment 2 time reading

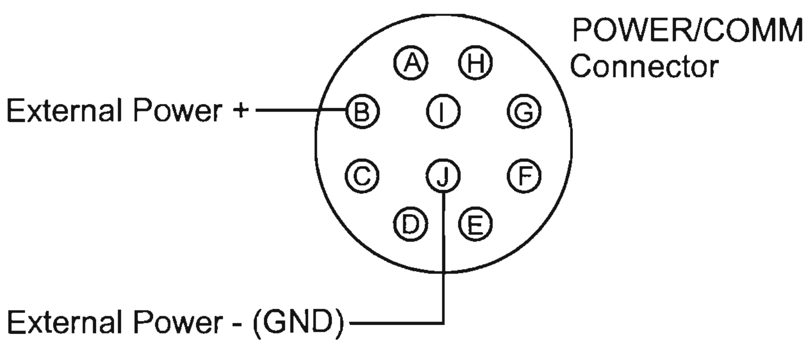
`00000050DC1B,00000050DCE4,5,+4.010,+3.993,+8.042,+7.995,+7.965`

Instrument ID
Probe ID
segment 1 time reading
segment 5 time reading

Note: Instruments with firmware version 1.26 or earlier (purchased before June 1995, s/n 50102-015 or earlier, without subsequent upgrade) must have the **TIME DELAY/MOISTURE** toggle switch in the **MOISTURE** position (down). If this toggle switch is in the up position (to allow mode selection) the MP-917 will enter Mode Select State on power up and the **MEASURE/DISPLAY** button must be pressed before the instrument will initiate a probe scan, defeating the mode 6 operation. Therefore, time delay logging is unavailable in the earlier firmware versions.

5. Powering the MP-917 Under External Control:

To turn the instrument on under computer control, power must be supplied to the POWER/COMM connector. The applied power must be in the range 10-14VDC, 3 to 2A peak load, approximately 0.5A average during measurement. Connect the positive power lead to pin B of the POWER/COMM connector. Connect the negative (ground) power lead to pin J:




**WARNING: The power supply used must be a regulated, low impedance source. DO NOT USE SUPPLIES WITH CURRENT LIMITING ENABLED. Exceeding 17VDC will damage the MP-917 power supply board.**

Switch the instrument off and make sure that the **TIME DELAY/MOISTURE** switch has been returned to the correct position. Operation in mode 6 is automatic. As soon as power is supplied, the instrument reports the instrument ID, the probe ID, and the number of segments in the probe. It then starts a probe scan and when it is completely finished, the instrument transmits all segment moisture readings followed by a carriage return line feed. When operating with external switched power, be sure the MP-917 front panel **ON/OFF** switch is left in the **OFF** position.

## Interconnect Module

As shown on the basic system block diagram, there are several signals which must pass between the MP-917 via the POWER/COMM connector and the external system. To facilitate these interconnections a module is available which receives the POWER/COMM signals on a DB-15 connector and allows for wire terminal connection to the rest of the system. The features of this interconnect module are:

- A solid-state relay to convert logic-level ON/OFF signal to switch power to the MP-917.
- A DB-9 connector to allow RS-232 communication between other equipment and the MP-917.
- Level translation of the serial output to 0..5V logic levels.
- Provision for probe-type selection logic levels into the MP-917 including a low-current 5V regulator.

  Probe-type selection permits a mix of probe types connected to the system. The probe type selection mechanism operates either by looking up the selection saved in MP-917 defaults memory (only one type of probe is used in the system), or by reading the binary value applied to 4 probe-select inputs on the POWER/COMM connector. The 4-bit binary value corresponds to the probe-type number.

## Basic System Example - **MP-917 is a 'sensor' added to a CR10 data acquisition system**

The block diagram for this basic configuration follows that shown in the Overview section above, and is illustrated in more detail in Figure 1.

Features

- ♦ All of the usual CR10 capabilities. For example:
  - weather station, soil temperature, water flow monitoring, extensive sensor-interface capability
  - control of other equipment (such as multiplexers)
  - at-site data storage, serial RS232 communication to DCP, data telemetry
  - custom program development for data collection, processing, and storage
- ♦ Flexible expansion of storage capacity, sensors, communications
- ♦ Moisture•Point MP-917 with profiling probes measure soil moisture profiles to 1.2 M depth

Minimum suggested Equipment for basic system

- CR10X or earlier CR10 with library special PROM to give instructions P15 and P109
  The CR10X has 128K memory, with optional expansion to 1 or 2 Mbyte. Earlier CR10s can have external memory expansion with Storage Modules.
- CR10KD portable keyboard/display for CR10 field operation/setup
- SC32A CR10 to RS-232 interface adapter
- PS12LA rechargeable gel-cell battery supply with AC float charger
- PC208 software
- two AM416 relay multiplexers for control signals
- SDMX50 coax cable multiplexer.

- MP-917-MPX, includes mpx power/comm cable, standard type A mpx probe, delay compensation port, delay compensation cable, Moisture•Point interconnection module, MP-917-CABPRBM cable and other miscellaneous hardware.
- Probe cables, specify length. All cables must be the same length.
- Delay compensation cable - approximately twice probe cable length (see calculation of length section)
- Specify MPX-head probes, probe-head cover boxes

- Enclosure

Additional MP-917 probes Options - larger multiplex configurations

- Specify additional, equal-length probe cables, one per probe.
- Larger enclosure--enclosure needs to be about 30" high, 12" deep, and about 15" per pair of multiplexers wide as a minimum, larger if surplus cable is to be stored, or extra equipment is specified.
- Specify SDMCD16AC if more than 2 AM416's required (see table below)

Single-diode probe multiplex configuration

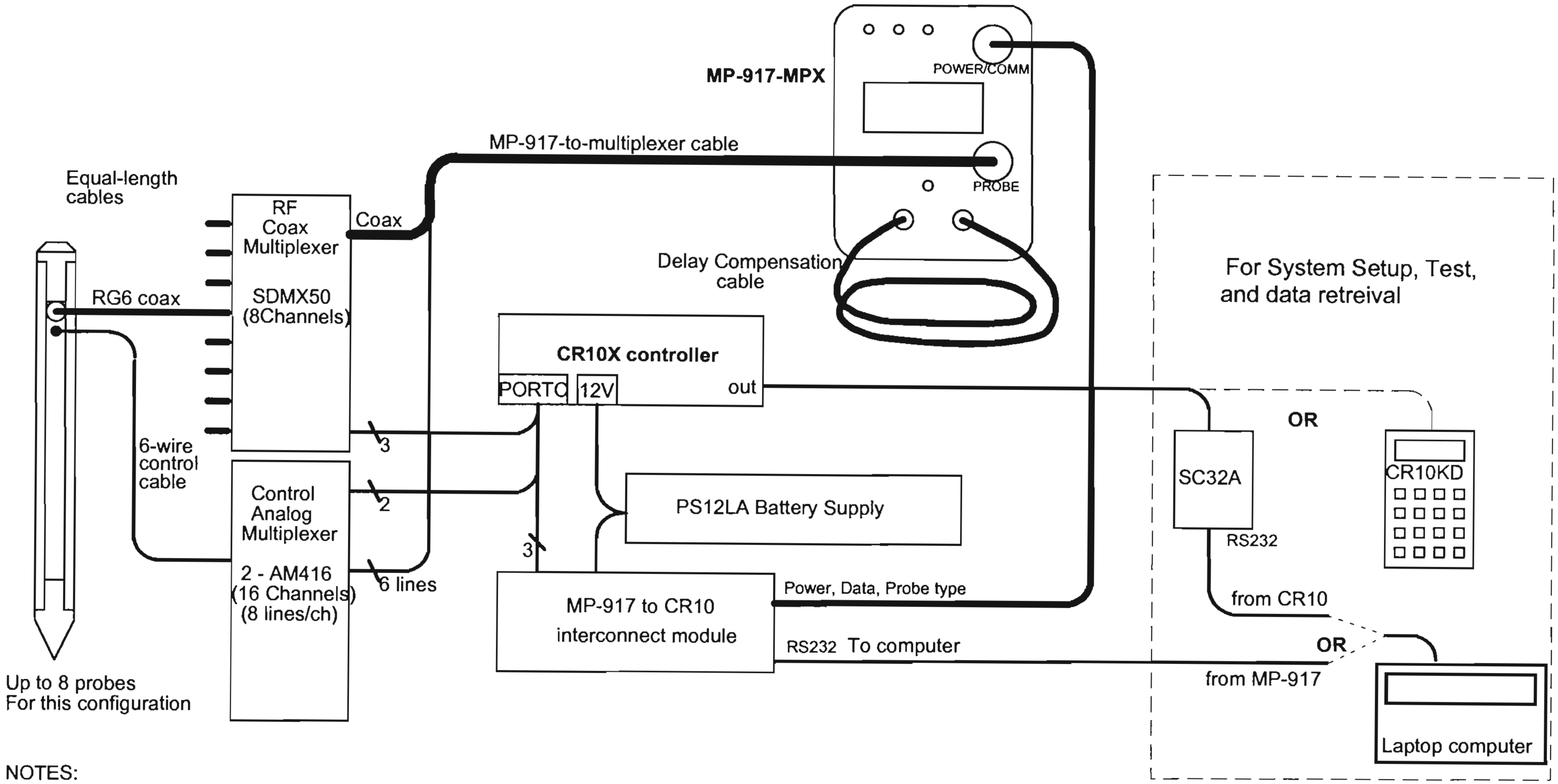
When there will be only single-diode probes in the system, the control signal relay multiplexer can be omitted and instead the one control signal may be combined with the coaxial cable at the multiplexer as shown in Figure 2.

SDMX-50/AM416 Selection Table

The following table indicates the number of SDMX-50 RF multiplexer and AM416 analog multiplexers required to multiplex different combinations of probes. The requirement depends on the number of probes in the system, and the number of segments per probe. The first number in a table cell is the number of SDMX50 RF mulitplexers required. The second number is the number of AM416 analog multiplexers required. The heavily outlined table cells show when the SDM-CD16A port expander is required to control all of the AM416 analog multiplexers. For example, to multiplex 15 five segment profiling probes requires 2 SDMX-50 RF multiplexers and 2 AM416 anaolog multiplexers. The SDM-CD16A port expander is not required.

| | # of segments/probe | | |
|---|---|---|---|
| # probes | 1* | 2-3 | 4-7 |
| up to 8 | 1 RF/0 AM | 1 RF/1 AM | 1 RF/2 AM |
| up to 15 | 2 RF/0 AM | 2 RF/1 AM | 2 RF/2 AM |
| up to 22 | 3 RF/0 AM | 3 RF/2 AM | 3 RF/4 AM |
| up to 29 | 4 RF/0 AM | 4 RF/2 AM | 4 RF/4 AM |
| up to 35 | 5 RF/0 AM | 5 RF/3 AM | 5 RF/6 AM |

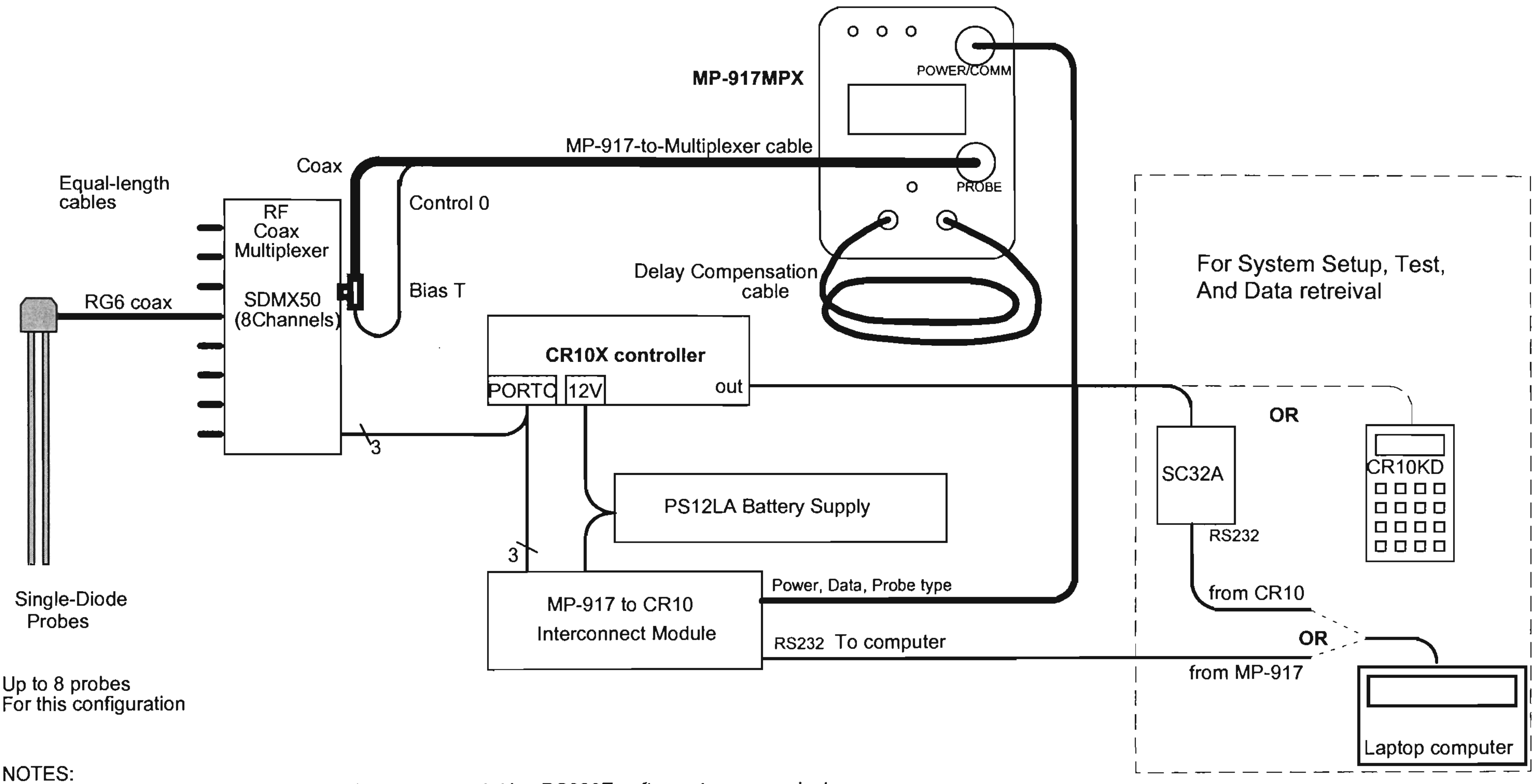
* Bias-T interface required.




NOTES:

1. Add one SDMX50 to expand to 15 probes
2. More than 15 probes adds AM416 pairs and more SDMX50s, up to eight. Over 15 probes requires SDMCD16A because more CR10 control ports (C1, C2, ..., C8) are needed.
3. System power from 12V DC; 3A peak, 0.5A average when measuring.
4. Use PC208E software to communicate with CR10X
5. Use ViewPoint to communicate with MP-917.
6. Computer is not required except for setup and data retrieval.
7. Delay compensation cable approx. 2 X probe cable length

## Figure 1. Profiling Probe Multiplex and Datalogging System




NOTES:
1. Add one SDMX50 to expand to 15 probes
   Additional SDMX50 as needed.
2. Single-diode probes DO NOT use AM416
   analog multiplexers for the control lines.
3. System power from 12V DC; 3A peak,
   0.5A average when measuring.
4. Use PC208E software to communicate
   with CR10X
5. Use ViewPoint to communicate with
   MP-917.
6. Computer is not required except for setup
   and data retrieval.
7. Delay compensation cable approx. 2 X probe cable length

## Figure 2. Single-Diode Probe Multiplex and Datalogging System

## Add-ons to the basic system

To enhance the basic system capabilities specify the following equipment in addition to the basic system

Power System Options

- Solar Panel battery recharging
- External source of 12V DC, 0.75 A. average, 3A peak MP-917/CR10 operating. About 10 mA. continuous depending upon other sensors. Delete PS12LA from basic list.

Storage Module Options (for older CR10).

- SM192 - about 3 months hourly data from one 5-seg probe
- SM768 - about 3 months 4/day data from 20 5-seg probes

CR10X includes 128K memory, approx. equivalent to CR10 with SM192

- 1Meg Flash expansion - about 4 months 4/day data from 20 5-seg probes
- 2Meg Flash expansion - about 8 months 4/day data from 20 5-seg probes

Adds:

- ♦ Extra on-site storage capability OR ability to collect data from multiple sites by carrying storage module from site to site.
- ♦ Automatic CR10 program re-load on power-up (included in all CR10X)

Communication Options for any CR10 installation

- Telephone modem

Adds:

- ♦ Dial-up telephone access for data download, remote control

- Cellular telephone modem plus suitable antenna

Adds:

- ♦ Dial-up access wherever cell site is available

- Radio modem, antenna at each site
- Radio modem at base station

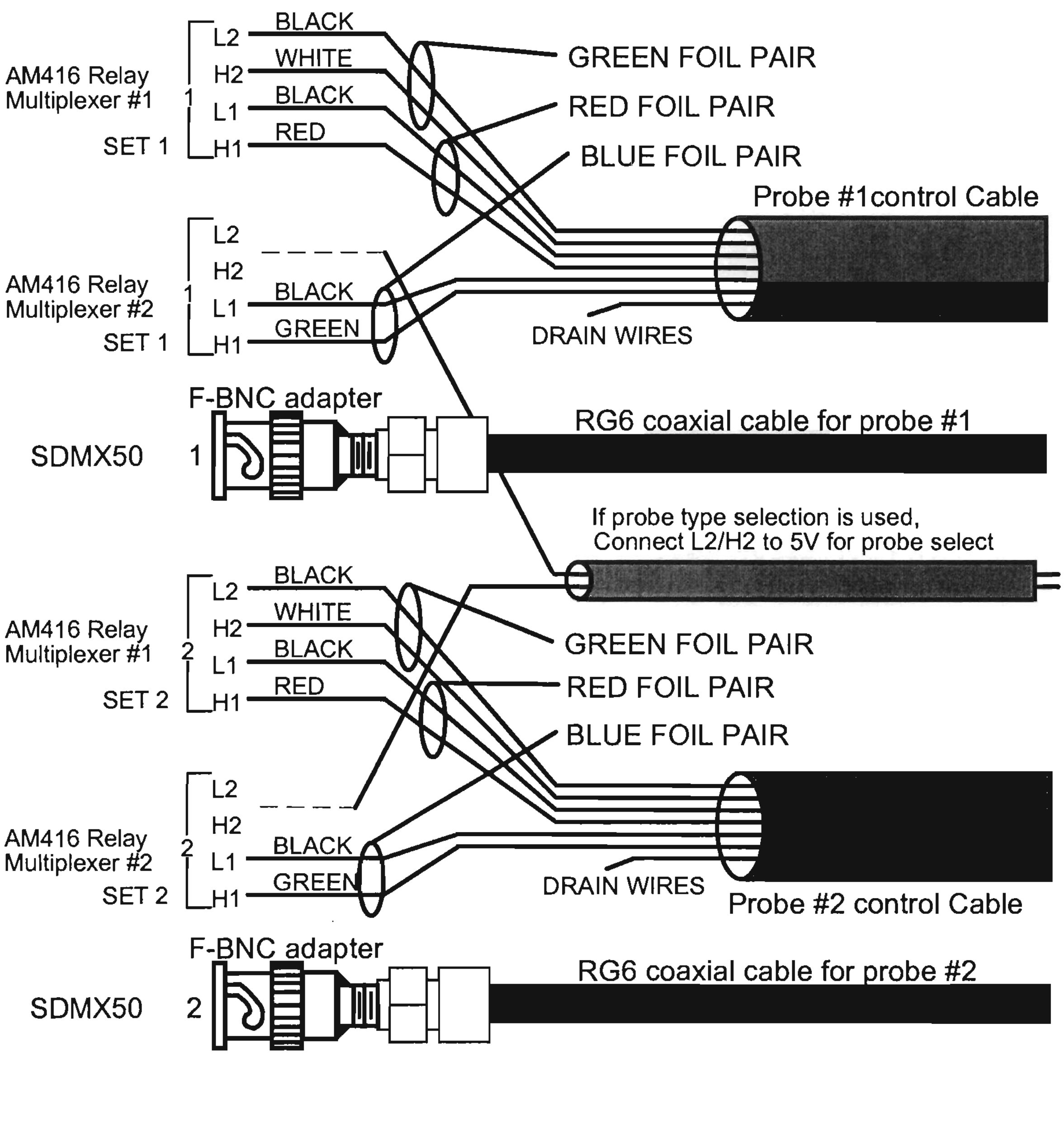
Adds:

- ♦ Data communications network of stations
- ♦ Remote site access

## Probe cable to multiplexer wiring

| Wire Pair | Wire Colour | Name | AM416 Relay Mux'er Connection |
|---|---|---|---|
| RED | BLACK | ±1 | AM416 #1 L1 |
| FOIL | RED | ±0 | AM416 #1 H1 |
| GREEN | BLACK | ±3 | AM416 #1 L2 |
| FOIL | WHITE | ±2 | AM416 #1 H2 |
| BLUE | BLACK | GND | AM416 #2 L1 |
| FOIL | GREEN | ID | AM416 #2 H1 |
| | DRAIN WIRES | SPARE | no connection |

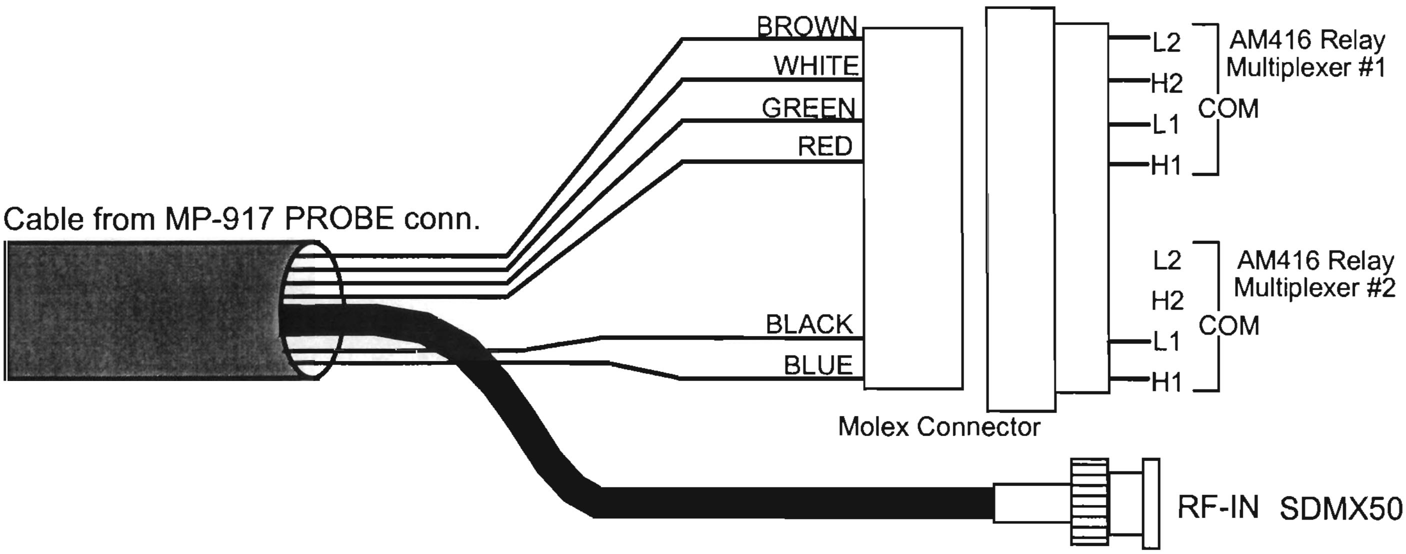
The red and green foil pairs must connect to AM416 Relay Multiplexer #1 (or #3). The blue foil pair wires must connect to AM416 Relay Multiplexer #2 (or #4). Connect all wires from one probe cable to the same SET on each relay multiplexer. The drain wires do not need to be connected.

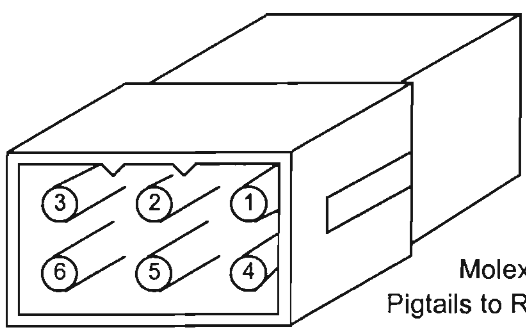


## MP-917 to multiplexer cable connections

| Wire Colour | Name | Molex Connector Pin Number | AM416 Relay Mux'er Connection |
|---|---|---|---|
| RED | ±0 | 1 | AM416 #1 COM-H1 |
| GREEN | ±1 | 2 | AM416 #1 COM-L1 |
| WHITE | ±2 | 3 | AM416 #1 COM-H2 |
| BROWN | ±3 | 4 | AM416 #1 COM-L2 |
| BLUE | ID | 5 | AM416 #2 COM-H1 |
| BLACK | GND | 6 | AM416 #2 COM-L1 |

Connect the red, green, white and brown wires to the COM bank on the AM416 Relay multiplexer #1. Connect the blue and black wires to the COM bank on the AM416 Relay multiplexer #2.



Molex housing with pins.
Pigtails to Relay Mux Common

## Miscellaneous

The equipment lists for various configurations outlined above assume that the CR10 will be dedicated to operating the MP-917 and its probe multiplexers. If other sensors are to be connected as well, there will likely be additional equipment required (especially port expansion).

When the probes are 5-segment or fewer, two lines are available on the AM416 channels which may be used for bringing another sensor at each probe site (temperature say) in with the selected probe, *OR* the lines may be used to select different MP-917 probe types, *OR* the lines may be used to multiplex 7-segment probes. (NOT 'all of the above'!--that would take additional AM416's)

For multiplexed, single-diode probes, the system is simplified because the AM416's may be omitted. One bias T is required to combine the control signal with the coax. See the revised block diagram--Figure 2--for this configuration.

Calculation of length of delay compensation cable

Cable runs to the probes generally must be all the same length and use the same type of low-loss coax so that the effect of delay over the long cables may be removed from the MP-917 measurement by adding one approximately double-length, same-type coax cable to the delay-compensation inputs. Assuming same-type, low-loss, coaxial cable is used for the probe cables and for the delay compensation, the delay compensation cable length is calculated as:

(length of cable from MP-917 front panel PROBE connector to the probe head, minus 2 metres) X 2.

Note that the length to the probe includes the length of the MP-917-CABPRBM and inter-multiplexer connections, if any. The reason for subtracting the 2 meters from the length to compensate is that the MP-917 has already provided internal compensation for a standard 2 metre probe cable. The multiplication by two accounts for the fact that the delay to remove is the round-trip travel time to the probe.

## Example CR10 Program Structure

**Table 2, 1/second rate**

At moisture sampling time:

Initialize:
- probe count
- multiplexer channel selection

Advance Multiplexer to next channel
Measure and Record Moisture (subroutine)
Check for completion of all probes

Finish:
- Place muliplexers in low-power state

End of moisture sampling

**Table 3, Subroutines**

Measure and Record Moisture:

Zero input locations for this probe
Turn on MP-917
Handle ID's (skip by waiting)
Wait for data on serial input
Turn OFF MP-917
Record Data.

End of Measure and Record Moisture

## Example CR10 Program

```
;{CR10}
;Program: MPADLPB - CR10 Multiplexer/MP-917 control
;         Illustrative example for product brief
;
;         For 1 to 8 probes, each probe 1 to 5 segments
;         No change to program needed for mixed probe types
;
;(c) 1997 ESI Environmental Sensors Inc.
;
; created: Feb 27, 1996
; revised:
;
;
;
;Flag Usage: none
;
;
;Input Channel Usage: 1 - current probe number
;                     2..6 - current segment data
;
;Excitation Channel Usage: none
;
;
;Control Port Usage: C1..C3 SDMX50 addressing
;                    C4, C5 AM416 control
;                    C6, C7 MP-917 serial data input
;                    C8 MP-917 power control
;
;  Note: SDMX50 assumed to be selected at address 00
;
;
;Pulse Input Channel Usage: none
;
;
;Output Array Definitions: One line per probe. Format:
;
;  recordID,day,hr/min,probe_nr,rdg1,rdg2,rdg3,rdg4,rdg5
;
;
;


*Table 1 Program
  01: 0.0       Execution Interval (seconds)

; Table 1 usually used for meteorological sensors where continuous
; sampling and averaging is required.
```

```
*Table 2 Program
  02: 1.0       Execution Interval (seconds)


;If time for moisture measurement, complete scan of all probes
;This example starts at top of each hour
;
1:  If time is (P92)
 1: 0000     Minutes (Seconds --) into a
 2: 60       Interval (same units as above)
 3: 30       Then Do
;
;
;Initialize:
;
;             zero the probe number counter
    2:  Z=F (P30)
     1: 0.0000   F
     2: 00       Exponent of 10
     3: 1        Z Loc [ probe_nr  ]
;
;             reset and enable analog multiplexer AM416
    3:  Do (P86)
     1: 55       Set Port 5 Low

    4:  Do (P86)
     1: 45       Set Port 5 High
;
;
;
;Loop over n<=8 probes
;
    5:  Beginning of Loop (P87)
     1: 0000     Delay
     2: 8        Loop Count
;       This count determines the number of probes scanned

        6:  Z=Z+1 (P32)
         1: 1        Z Loc [ probe_nr  ]

;    clock AM416's
;
        7:  Do (P86)
         1: 74       Pulse Port 4

;Note that P109 in a loop auto-increments channel no.
;
        8:  SDMX50 Channel Select (P109)
         1: 00       ADDRESS
         2: 1        SDMX50 Channel

        9:  Do (P86)
         1: 1        Call Subroutine 1

    10:  End (P95)
;    End loop over probes
;
;
;Finish:
;          Enter low-power state for AM416
;
```

```
    11:  Do (P86)
     1: 55       Set Port 5 Low
;
;
;
12:  End (P95)
; End of if time section



*Table 3 Subroutines
;
;Subroutine 1 operates the MP-917, records segment data

1:  Beginning of Subroutine (P85)
 1: 01       Subroutine 1
;
;
;Zero the input locations each time so unused channels
;are stored in log as zero
;
    2:  Beginning of Loop (P87)
     1: 0000     Delay
     2: 5        Loop Count

        3:  Z=F (P30)
         1: 0.0000   F
         2: 00       Exponent of 10
         3: 2     -- Z Loc [ seg_1     ]

    4:  End (P95)
;          of input clearing loop
;
;Turn on the MP-917
;
    5:  Do (P86)
     1: 48       Set Port 8 High
;
;Wait (20 seconds) until ID's are sent, measurement is
;complete. This time may require adjusting. Want most
;of waiting time in this loop so table 1 can interrupt
;
    6:  Beginning of Loop (P87)
     1: 1        Delay
     2: 20       Loop Count

7:  End (P95)
;       of waiting loop
;
;Read serial data from MP-917
;
8:  Port Serial I/O (Special) (P15)
 1: 1        Reps
 2: 1        ASCII/RS-232, 1200 Baud
 3: 0000     Wait for Clear to Send
 4: 6        First Control Port
 5: 2        Output Loc [ seg_1     ]
 6: 0000     No. of Locs to Send
 7: 13       Termination Character
 8: 100      Maximum Characters
 9: 9500     CTS/Input Wait
```

```
10: 2        Loc [ seg_1     ]
11: 1        Mult
12: 0.0000   Offset
;
;Turn OFF MP-917, wait power-down settling

9:  Do (P86)
 1: 58        Set Port 8 Low

10:  Beginning of Loop (P87)
 1: 1         Delay
 2: 2         Loop Count

11:  End (P95)
;        of power-down wait loop
;
;Record data to final storage with time tag
;
12:  Do (P86)
 1: 10        Set Output Flag High

13:  Real Time (P77)
 1: 110       Day,Hour/Minute

14:  Sample (P70)
 1: 1         Reps
 2: 1         Loc [ probe_nr  ]

15:  Sample (P70)
 1: 5         Reps
 2: 2         Loc [ seg_1     ]

16:  End (P95)
;End Subroutine 1
;
;
End Program
```

## Data format from example program

Each probe measured will result in one data record in the output storage. The format for the data is:

`Record ID, day, hour/min, probe_nr, rdg1, rdg2, rdg3, rdg4, rdg5`

Where:

`Record ID` is a number which reflects the program location from which the record is written
`day` is the julian day from the start of the current year
`probe_nr` is the number of the multiplexer input channel
`rdg1..rdg5` are the measurement results from the MP-917 (either moisture or time interval)

Storage required for each such record is 9 locations. Consequently, for example, a 128K CR10X could store approximately 6600 records assuming no other data is recorded (approx. 60,000 locations divided by 9 per record).

## Likely changes to program

Place instructions for other sensors in Table 1. This placement allows for the sensors which may require regular-interval reading (so that averages, or other statistics can be calculated) to interrupt the wait timing loops in table 2. If the program executes the P15 instruction to wait for serial input from the MP-917 it cannot be interrupted and thus there would be large time gaps in the statistics of the other sensors in the system.

Instruction 1 in Table 2, If time is...this instruction determines the sample rate for the moisture sensors.

Instruction 5 in Table 2, Loop...parameter 2 may be reduced for fewer than 8 probes connected.

Instruction 6 in Table 3, Loop...This instruction determines how long to wait after turning on the MP-917, before entering the uninterruptible P15 to wait for the serial data. The second parameter determines the time in seconds to wait. The minimum value should be 2 seconds to skip over the ID output (which is ignored in this example program). The maximum value may need to be determined experimentally since it will depend on the power-on wait parameter set in the MP-917 (10 seconds is standard), the type of probes connected, and the type of soil the measurements are taken in. A typical 5-segment probe in normal soils takes 30 to 45 seconds. A single-segment probe may take 10 to 15 seconds. The value of the wait shown in the listing is for a 20 second wait.

## Possible Problems

| Symptom | Cause |
|---|---|
| The MP-917 turns on briefly, then off before any measurement. | Battery voltage < 11.5V (approximately) |
| The MP-917 turns on, starts measurement but power off before complete. | Message level set < 3 |
| The MP-917 turns on, stays idle, no data, timeout errors (-6999) in data log. | Mode not set to 6 |
| Timeout errors (-6999) in data log | No data from MP-917. Baud rate set incorrectly. Wait loop before P15 set incorrectly |
| MP-917 always ON | Front panel switch ON, should be OFF |
| Probe type selection doesn't work (giving errors in stored probe values) | Probe type selection parameter set to MEMORY instead of being set to PLUG. |
| Errors in one or more of stored readings | Errors from MP-917 measurement--probe defective, installation poor, or in difficult soil conditions |

# APPENDIX C

# HEALTH AND SAFETY PLAN ADDENDUM

**PENDING**